

Appendix A
Approach to Baseline

Incorporation of New Drill Centres into the White Rose EEM Program

Selection of Station Locations

Sampling and statistical analyses of Environmental Effects Monitoring (EEM) data at White Rose occurs at micro- and macro-scales within the nearfield and farfield regions to address zones of influence (ZOI). The nearfield is that region described by the immediate influence of the drill centres. The farfield region is the area further out along transects outside the nearfield area. As such, the design includes a survey grid centered on the FPSO and a second series of stations centered on the location of drill centres.

Husky Energy's approach to sampling drill centre areas in the nearfield has been to sample six stations located 1 km from the proposed location of new drill centres. This approach accommodates a 1.5-km movement of drill centres should the proposed location change. The approach was employed during initial baseline collection in 2000 (Husky Energy 2001) and for sampling around the potential new drill centre at the NN and South White Rose Extension (SWR-X) drill centres in 2004 (Figure 1). With slight variation, this approach was used again in 2006 for the proposed West Alpha and West Bravo drill centres (Figure 1). Once the location of new drill centres is finalized, three or four of the nearest drill centre stations are retained¹ depending on projected drilling intensity, and one new station is added 300 m from the drill centre in the following sampling year if drilling has occurred at that drill centre. For instance, stations N4, C5 and S5 were added after baseline sampling around the Northern, Central and Southern drill centres (see Figure 1). Drill centre stations are only re-sampled if drilling has occurred at the drill centre between baseline sampling and the next sampling cycle.

In 2007, baseline stations were sampled around the North Amethyst drill centre (Figure 1). However, since the final location of that drill centre was known, stations were added 300 m east, 500 m south, 750 m west and 1000 m north of the drill centre to provide good spatial coverage and a reasonable number of stations in close proximity to the drill centre².

For other new drill centres, if the exact location is determined, the approach used for North Amethyst will be used to collect baseline data, otherwise, the precautionary approach of sampling six stations around a proposed location will be employed.

Also, should a drill centre be located outside or near the edge of the survey grid, then additional stations may be required in addition to the drill centre stations (as was done for West Alpha and West Bravo). The decision to add transect or inter-transect stations will be made on a case-by-case basis since addressing the varied possibilities beforehand is not feasible.

¹ If six stations are sampled at equal distances from a point and the location of that point changes, then some of these six stations will be located closer to the final location.

² Note also that since 2007 was not an EEM year, EEM stations 14 and 16 were also sampled to provide some indication of any large inter-annual variation.

Data Analysis

For any EEM sampling year, two sets of analyses are performed:

- analyses of data from that sample year, and
- multi-year analyses

Analyses for a single sample year consist of assessment of correlations among sediment quality variables and relationships with distances from active drill centres. Baseline and EEM data for the North Amethyst drill centre can easily be incorporated into these analyses, as were baseline data for stations around the proposed NN, SWR-X, West Alpha and West Bravo drill centres in past programs (see Figure 1). In any sample year, the ZOI can be estimated using regressions of physical, chemical and biological (Y) on distance from the nearest active drill centre (X).

Multi-year analyses consist of:

- Repeated Measures (RM) regression analyses of distance and depth effects, and
- comparison of relationships between biological responses and drill mud tracers ($>C_{10}-C_{21}$ HC) among years

RM regression analyses in past programs were restricted to the set of EEM stations re-sampled every year. Stations around the North Amethyst drill centre sampled in 2007 and around other proposed drill centres cannot be included in RM regression analyses as conducted in the past. However, targeted RM regression analyses of nearfield effects could be conducted on a subset of stations surrounding the North Amethyst or any other “new” drill centre.

In the past, exposure-response relationships with biological variables (responses) as Y and $>C_{10}-C_{21}$ hydrocarbon concentrations as X have been effective in terms of removing the effects of differences in drilling intensity among drill centres and some small directional effects, and assessing generalized effects of all drill centres combined. That approach can potentially use all stations from each sample year and can be extended to include distance as an alternative X variable and more formal comparisons of exposure-response relationships and ZOI among years (a meta-analytical approach).

As new sample years, drill centres and sample stations are added, data analyses for the EEM program potentially become more complex. However, sample sizes also increase so that any reasonable analyses should be robust and powerful. It also becomes feasible to use summary values (e.g., ZOI) as Y values in comparisons among years (trend or meta-analyses).

Appendix B

Minutes from White Rose Advisory Group Meeting and Table of Concordance of Discussions

WRAG Meeting Minutes • July 22, 2003
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White Rose Advisory Group Meeting Minutes July 22, 2003

A meeting was held July 22, 2003 with the White Rose Advisory Group (WRAG) to discuss the draft EEM program. In attendance were:

- Dr. Elisabeth DeBlois, Senior Scientist, Jacques Whitford
- Leslie Grattan, Environmental Planning and Management Projects, Newfoundland and Labrador Department of Environment
- Dr. Roger Green, Statistician, University of Western Ontario
- Dr. Doug Holdway, Ecotoxicologist, University of Ontario Institute of Technology
- Mary Catherine O'Brien, Lawyer; Manager at Tors Cove Fisheries Ltd.
- Dr. Mike Paine, Statistician, Pain, Ledge and Associates
- Dr. Paul Snelgrove, Benthic Ecologist, Memorial University
- Dave Taylor, Environmental Coordinator, Husky Energy
- Ellen Tracy, Jacques Whitford
- Dr. Len Zedel, Memorial University

Dave Taylor, representing Husky Energy, provided an overview of the White Rose Project and Elisabeth DeBlois, representing the EEM design team, presented an overview of the draft EEM program.

Issues discussed during the meeting included:

Sediment and Water Quality Components

Use of 18-km stations as controls

The WRAG felt that the 18-km stations would be adequate Reference Areas and did not support sampling at either the Northwest Reference Area or the South Southeast Reference Area. There was discussion about adding more distant stations (e.g., 16 km). There was consensus that replication within stations beyond what is currently proposed (one replicate for benthic invertebrates and no replicates for other variables) was not needed. It was noted that if 18-km stations are used as controls, then a full suite of samples (sediment, conductivity-temperature-density (CTD) and water samples – but see Water Quality below) need to be collected at these stations. Using all four 18-km stations or selecting two stations most comparable to near-field stations was not discussed. The possibility of mapping sediment types using geophysical data collected by Husky Energy was discussed as a possible means of identifying suitable Reference Areas.

Near-field Station location

The WRAG recommended adding stations closer to drill centres. Ideally, new stations would be located within 500 m (e.g., 250 m and 500 m) from drill centres.

Number of stations overall and power

The power of the sediment/water sampling grid was discussed. An assessment of the statistical power and robustness of the proposed design had been provided as appendix material in the draft report and will be updated if new stations are added.

Barium/Aluminum

The analysis proposed by Geoff Veinott of DFO was discussed. It was agreed that the method currently used is superior to that proposed by DFO if baseline data are available. However, it was felt that using this analysis method in addition to the current method would not constitute a large effort. Therefore, provision of these analyses as appendix material was suggested.

Use of isotopes to track the drill cuttings zone of influence

It was felt that naturally occurring isotopes could be used to track drill cuttings. However, it was mentioned that hydrocarbons have proved to be very effective tracers in other EEM programs on the Grand Banks.

Water Quality

The usefulness of the water quality monitoring program was questioned. It was generally felt that some ground-truthing of predictions made on the distribution of the produced water plume was required. The installation of up to four permanent CTD moorings around the floating production, storage and offloading (FPSO) facility in order to track currents and better predict the potential location of the plume was discussed. The availability and utility of current data currently collected for drilling needs to be investigated. The use of remote sensing imagery (aerial or satellite) to map the thermal signature (surface only) of the plume was discussed. An adaptive survey strategy for water, based on best available knowledge of plume location, was proposed. It was not clear if the WRAG proposed these changes instead of the proposed program or if it felt that additional samples should be collected. Other than installation of permanent moorings, the frequency of more targeted water collections was not discussed.

Monitoring Hypothesis

It was recommended that both the sediment and water monitoring hypotheses be modified to include “effects” of direction as well as distance.

Commercial Fish Component

Use of American plaice as a sentinel species

Given the mobility of this species, it was felt that American plaice is more suited to regional monitoring and may not be suitable to assess project-specific effects.

Use of sand lance as a sentinel species

Given the information that the WRAG had at hand, there was general agreement that sand lance could be a better fish sentinel. It was felt that more information was required on the habits of sand lance to evaluate this species further. It was pointed out that work has been done on Alaskan sand lance; this could be used as a starting point.

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Usefulness of MFO

The WRAG saw MFO as a useful index of short-term exposure – with the caveat that several confounding factors, including reproductive activity and metals contamination, can inhibit MFO. The use of a series of health indicators for fish combined with a weight of evidence approach, as is currently proposed, was supported.

BAPH on crab

BAPH analyses on crab was proposed. The feasibility of performing these kinds of analyses locally needs to be explored. Potential logistic constraints (liquid nitrogen requirements) in sample collection and preservation need to be examined.

Reference Area

The group seemed to favour use of one or more 18-km stations as a Reference Area instead of the Northwest Reference Area. However, the group also felt that intermediate locations (for instance 10 km) should also be sampled, at least for crab and perhaps also for fish. The number of intermediate stations was not discussed. The point was made by the design team that fish availability can constrain sampling location.

Crab sampling

It was felt that crab could be sampled with pots rather than with a dragger and that fishers could be hired to carry out sampling. The logistics and safety of this needs to be examined in light of 1) requirements for liquid nitrogen and 2) sensitivity of analyses on tissue metals and hydrocarbons and risk of sample contamination on vessels not specifically designed for scientific sampling.

Caged fish

The use of caged fish to determined effects was discussed, but it was then agreed that laboratory experiments with dilutions of either drill cuttings or produced water would provide similar information.

Sample size and sample composites

It was felt that sample sizes for fish and crab were low. The design team did not recommend increased sampling of American plaice given the state of the resource. Larger sample sizes for crab, and potentially sand lance, may be feasible. Compositing of samples for taste analysis was approved. Compositing of samples for tissue chemistry was questioned. Archiving tissue samples from individual fish for later analysis if health indices indicate potential effects was supported. However, it was noted that sufficient tissue would likely not be available from liver. Liver volume for American plaice is currently too small to allow individual analysis. This problem would be magnified if sand lance are used instead of American plaice as a sentinel species.

Timing of sampling

Sampling of crab and fish needs to exclude the reproductive period because MFO and BAPH analysis will be affected by reproductive state. Sampling more than once a year for fish/crab was discussed. However, it was pointed out that all tests proposed for

tissue, with the exception of MFO and BAPH, measure cumulative exposure. Therefore, sampling more frequently would not necessarily provide additional information.

Report format

A list of acronyms at the beginning of the report was recommended.

Various features on figures should be identified with different symbols.

The word “grab” should be replaced with box-core.

The last column in Table 2.3 is in error and should be corrected.

Document requests were made for: [note: these have been forwarded to WRAG members]

Produced water and drill cuttings modeling report

Baseline design document

White Rose Advisory Group Meeting Minutes September 8, 2003

A second meeting was held September 8, 2002 with the White Rose Advisory Group (WRAG) to discuss the draft EEM program. In attendance were:

- Dr. Elisabeth DeBlois, Associate Scientist (Oil and Gas), Jacques Whitford
- Leslie Grattan, Environmental Planning and Management Projects, Newfoundland and Labrador Department of Environment
- Dr. Roger Green, Statistician, University of Western Ontario
- Dr. Doug Holdway, Ecotoxicologist, University of Ontario Institute of Technology
- Mary Catherine O'Brien, Lawyer; Manager at Tors Cove Fisheries Ltd.
- Dr. Mike Paine, Statistician, Pain, Ledge and Associates
- Dr. Paul Snelgrove, Benthic Ecologist, Memorial University
- Dave Taylor, Environmental Coordinator, Husky Energy
- Ellen Tracy, Jacques Whitford

Issues requiring further clarification since the July 22, 2003 meeting were discussed.

The Advisory agreed that the four 18-km stations should be used as reference stations and that the reference stations used during baseline collections should be dropped. Sampling at reference stations should include sediment physical, chemical and biological (benthic invertebrate) characteristics; crab leg tissue sampling; American plaice liver and fillet sampling. A water column profile (including temperature, salinity, chlorophyll) will also be performed at these, and all, stations.

Use of geophysical data collected by Husky Energy to select reference stations was discussed. Mike Paine reported that, from baseline collections, there was variability among the 18-km stations and between the 18-km stations and remaining stations. However, this variability was very low and no greater than what would be expected through distance effects alone (stations that are further apart are more different than stations closer together).

Installation of one or two permanent moorings within 1 km of the proposed location of the FPSO to measure temperature, salinity and chlorophyll was discussed. The advisory group supported this approach. The use of semi-permeable membrane devices (SPMDs) to measure hydrocarbon accumulation was discussed, as was the use of dye tracers. More information will be collected on these methods and presented to the Advisory. A discussion will be held with Len Zedel when he returns to get feedback on benefits of two versus one fixed mooring. The Advisory did not feel that the use of bottom sensors to measure drill cuttings discharge at drill centres was warranted. If sediment hydrocarbon and barium concentrations do not provide sufficient information on the spread and concentration of drill cuttings (particularly as hydrocarbons degrade), then the use of isotopes could be explored.

The Advisory group agreed that the proposed water sampling program, where water samples are collected at fixed depths at some sediment stations once a year, or once every two years, should not be executed. All were in agreement that this type of sampling provides little information. Instead, the advisory favoured mapping the produced water plume using available technologies and setting up a sampling grid based on the known location of the plume. The advisory recommended that Husky Energy review its water quality monitoring program a year before release of produced water to afford sufficient time for collection of some baseline data. It was recommended that these fixed moorings be installed one year before release of produced water. Len Zedel will be consulted on fixed moorings.

The use of sand lance instead or in addition to American plaice as a monitoring species was rejected. There is very little known about sand lance. It is classified as a semi-pelagic species that leaves its burrow at night to feed on plankton. There is no information on horizontal movement of this species. It may or may not return to its day location after feeding.

If was felt that the use of additional health indices (metabolites in bile or haemolymph, MFO) on crab/American plaice was not warranted if contamination could be detected using current methodologies. If current methodologies fail to detect contamination, then other indices may be considered.

The use of larger samples sizes for crab was discussed. Mike Paine suggested that three to five tissue composites per site was sufficient to assess contamination. Roger Green felt that three composites was too few. The use of crab pots for sampling crab was rejected because crab can be obtained from trawls carried out to obtain American plaice. It was proposed that all crab and American plaice in any given trawl be composited into one sample for metals and hydrocarbon analysis. This would allow some assessment of among trawl variability. Availability of crab and American plaice will determine if this is feasible.

White Rose Advisory Group Meeting Minutes October 27, 2003

A third meeting was held October 27, 2003 with the White Rose Advisory Group (WRAG) to discuss the draft EEM program. In attendance were:

- Dr. Elisabeth DeBlois, Associate Scientist (Oil and Gas), Jacques Whitford
- Leslie Grattan, Environmental Planning and Management Projects, Newfoundland and Labrador Department of Environment
- Dr. Roger Green, Statistician, University of Western Ontario
- Dr. Doug Holdway, Ecotoxicologist, University of Ontario Institute of Technology
- Mary Catherine O'Brien, Lawyer; Manager at Tors Cove Fisheries Ltd.
- Dr. Mike Paine, Statistician, Paine, Ledge and Associates
- Dr. Paul Snelgrove, Benthic Ecologist, Memorial University
- Dave Taylor, Environmental Coordinator, Husky Energy
- Ellen Tracy, Jacques Whitford
- Dr. Len Zedel, Oceanographer, Memorial University

Comments received during consultations with the public and members of the regulatory community were discussed, as were any remaining EEM design issues.

Paul Snelgrove recommended that only the first few centimetres (2 cm) of sediment obtained from box-cores be processed for hydrocarbon, metals and particle size analysis. This recommendation was approved by the WRAG.

Discussion was held on benthic infauna identification. Infauna are currently identified to the lowest taxonomic level possible and raw data are/will be reported in EEM program reports. There will be clear mention of benthic infauna raw data appendices in both the body of the main report and in Tables of Contents.

Discussion was also held on whether analysis of data for lower taxonomic levels would improve ability to detect effect. Some WRAG and design team members felt analysis of data for these lower levels would introduce noise rather than improve analysis. It was agreed that a within-year comparison of lower (in most cases, species) versus higher (in most cases, family) would be of value. There was discussion on potential sources of research funding to undertake such work.

Paul Snelgrove asked for information on how WRAG comments would be integrated into material submitted to regulatory bodies. Dave Taylor responded that meeting minutes and resolutions would be submitted as part of the EEM design document.

Minor statistical issues were discussed by Mike Paine, Paul Snelgrove and Roger Green. Of these, only one follow up issue emerged. Roger Green is to supply Mike Paine with references on use of root-root transform in MDS. However, given that the analysis is NMDS rather than MDS, it is not clear that this follow-up item is still relevant.

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Given the MDS/NMDS confusion, it was again recommended that any acronyms used in EEM design and report documents be clearly defined at the front of documents.

Comments received from the public and the regulatory community were then discussed.

A general discussion was held on effects of seismic, vessels and development drilling noise on seabirds and marine mammals. Dave Taylor provided some information on Husky Energy commitments with respect to these issues. However, Elisabeth DeBlois pointed out that noise effects on seabirds and marine mammals, as well as effects monitoring requirements in the event of an accidental event were issues that Husky Energy deals with outside of a standard development drilling and operational EEM program. It was recognized by all that these issues are of concern to the public.

Regulator comments on station location were discussed. It was agreed that three new sediment stations located 250 to 300 m from Glory Holes (one around each Glory Hole) should be added. Dave Taylor stated that dredge spoils were dumped immediately outside Glory Holes for two of the three Glory Holes. It was recommended that stations be located outside the immediate influence of Glory Holes. Some clarification from the WRAG is required on weather this means “off” dredge spoils. Safety constraints were acknowledged and it was recognized that these stations would not necessarily be accessible during each EEM year. It was recommended that these stations be sampled as often as possible.

Discussion was held on sampling the dredge spoil pile from the central Glory Hole (located some kms to the South). Dave Taylor stated that some clarification from DFO was required before such sampling would be undertaken. The WRAG also felt that the stations already located in the immediate vicinity of these dredge spoils might provide some indication of dredge spoil effects.

The water quality monitoring program was discussed at length. It was recommended that two moorings be placed as close as possible to the point of discharge for produced water one year before release of produced water. Instruments to be installed on these moorings would include CTDs and SPMDs. Additional instrumentation could include a fluorometer for oil detection (if instrument sensitivity is sufficient) and “some instrument” to measure concentration of radioactive tracers. Elisabeth DeBlois will check on the fluorometer sensitivity. Dave Taylor will check on radioactive tracers and instrumentation for these types of measurement. Dave Taylor will also discuss use of additional sensors with Ken Lee at the Department of Fisheries and Oceans. It was agreed that data from these moorings would be supplemented by Husky Energy measurements of current velocity/direction. It was recommended that sensors be located as close to the surface as possible and no deeper than 10 m.

With respect to measurement frequency, it was recommended that measurements be collected at least every hour but ideally every five minutes. It was also recommended that the instruments be serviced four times per year and that four set of sensors be purchased. Sensors would be “swapped” at each servicing.

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Measurement of other variables such as chlorophyll *a* and phytoplankton community composition was discussed. However, it was stated that the objective of collecting this mooring data was to verify produced water modelling predictions and that these other measurements would not offer substantial improvement over what was proposed above.

Design options for the commercial fish survey were also discussed at length. More elaborate power analyses were discussed. Mike Paine specified that this exercise would be of little value without specification of effects size to be detected. Various concepts and exercises were discussed, including assessment of Maximum Acceptable Effects Levels (MAEL) for each EEM variable and setting $\alpha = \beta$ in an assessment of relative power. The difference between statistical significance and biological significance was discussed. A consensus was eventually reached: it was recognized that the use of four Reference Areas instead of one is an improvement over other program; that other programs have sufficient power to detect small statistical differences and that these small differences have not had biological relevance; that a weight-of-evidence approach is used for EEM programs. Therefore any one test should not be looked upon as conclusive without supporting evidence from other tests; that as many fish/composites as is reasonable within a one to three day time window should be collected and processed for body burden; that an assessment of power should be performed on EEM results once these data have been collected and if no statistical differences are noted. Some clarification from the WRAG is required on whether as many fish as is reasonable should also be collected for Health Indices, and on whether more than one composite per trawl should be obtained for body burden. The original EEM design document recommended compositing all fish within any given trawl when possible.

WRAG Comments on Environmental Effects Monitoring Program

Table of Concordance

WRAG Discussion Item	Final WRAG Recommendation	Husky Position	Action Item
Sediment Quality Component			
The WRAG felt that the 18-km stations would be adequate Reference Areas and did not support sampling at either the Northwest or South Southeast Reference Areas.	Use 18-km stations as Reference	Agreed	Use 18-km stations as Reference
There was discussion on adding more distant stations, but it was pointed out that near field stations are the most important stations given anticipated distribution of drill cutting.	This discussion item was dropped		No action
There was consensus that replication within stations beyond what is currently proposed (one replicate for benthic invertebrates and no replicates for other variables) was not needed	No additional replication required	Agreed	No action
The possibility of using geophysical data collected by Husky to identify reference stations was considered. However, it was noted that the sediment and benthic invertebrate profiles of 18-km stations was no more different from stations closer to the development than what would be expected from distance effects alone.	This discussion item was dropped		No action
It was recommended that three new stations, one around each drill centre, be located within 250 to 300 m of drill centres and that these	Add a station within 250 to 300m around each drill centre (a total of three stations)	Agreed	Add a station within 250 to 300m around each drill centre (a total of three stations)

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WRAG Discussion Item	Final WRAG Recommendation	Husky Position	Action Item
stations be sampled as often as feasible taking safety into account. The WRAG also considered regulator comments on carrying out transects between current drill centre stations and drill centres but favoured the addition of one station around each station.			
Number of stations overall and statistical power were discussed. A power analysis had been provided.	This discussion item was dropped		No action
The analysis proposed by Geoff Veinott of DFO was discussed. It was agreed that the method currently used is superior to that proposed by DFO if baseline data are available. However, it was felt that using this analysis method in addition to the current method would not constitute a large effort.	Provide these analyses as an Appendix to the EEM report.	Agreed	Provide these analyses as an Appendix to the EEM report.
Use of isotopes to track the drill cuttings zone of influence was discussed. However, it was mentioned that hydrocarbons have proved effective tracers in other EEM programs on the Grand Banks.	This discussion item was dropped		No action.
It was recommended that monitoring hypotheses on sediment (and water) be modified to include effects of direction as well as distance.	Include effects of direction as well as distance.	Agreed, for those hypotheses that retain a distance component (see Water Quality below).	Include effects of direction as well as distance in Sediment Quality Hypothesis. (Husky has modified the Water Quality hypothesis to reflect new work proposed by the WRAG (see below)).

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WRAG Discussion Item	Final WRAG Recommendation	Husky Position	Action Item
<p>It was recommended that only the first few centimeters (2 cm) of sediment obtained from box-cores be processed for hydrocarbons, metals and particles size analysis.</p>	<p>Sample only first 2 sediment of box-cores for hydrocarbon, metals and particle size analysis.</p>	<p>Husky feels that, since other EEM programs on the Grand Banks have and continue to sample the top 7.5 cm for these analyses, that this change would not allow comparison between projects. The current sampling depth has enable detection of contamination in other projects. However, Husky is prepared to make additional core samples (collected opportunistically) available to WRAG members for determination of depth stratification of project contaminants, if these WRAG members are interested in pursuing this issue.</p>	<p>Make additional core samples (collected opportunistically) available to WRAG members for determination of depth stratification of project contaminants, if WRAG members are interested in pursuing this issue.</p>
<p>Discussion was held on whether analysis of benthic invertebrate data for lower taxonomic levels would improve ability to detect effect. Some WRAG and design team members felt analysis of data for these lower levels would introduce noise rather than improve analysis. It was agreed that a within-year comparison of lower (in most cases, species) versus higher (in most cases, family) level would be of value. There was discussion on potential sources of funding to undertake such work.</p>	<p>None</p>		<p>No action</p>
<p>Water Quality Component</p>			
<p>The usefulness of the water quality monitoring program was questioned. It was generally felt that some</p>	<p>Install two moorings near the point of discharge one year before release of produced water. Review water quality</p>	<p>Agreed.</p>	<p>Install two moorings near the point of discharge one year before release of</p>

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WRAG Discussion Item	Final WRAG Recommendation	Husky Position	Action Item
<p>ground-truthing of predictions made on the distribution of produced water was required. The installation of two moorings near the point of discharge measuring temperature and hydrocarbons, at a minimum, was recommended. It was also recommended that these moorings be in place one year before release of produced water. Once predictions on distribution of produced water were validated, it was further recommended that Husky review it's water quality program to see if additional steps were required. Further detail on discussions on water quality can be obtained from meeting minutes.</p>	<p>program in light of findings from mooring data.</p>		<p>produced water. Review water quality program in light of findings from mooring data.</p>
<p>Commercial Fish Component</p>			
<p>Given the mobility of American plaice, it was felt that this species was more suited for a regional monitoring exercise.</p>	<p>None</p>		<p>No action</p>
<p>The use of sand lance as a potential monitoring species was proposed. Husky reviewed available information on sand lance and this species was found not to be suitable. Sand lance is a semi-pelagic species that leaves it burrow at night to feed on plankton. It is not known if it returns to its day location after feeding.</p>	<p>None</p>		<p>No action</p>

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WRAG Discussion Item	Final WRAG Recommendation	Husky Position	Action Item
It was agreed that any one health indicator for fish should not be examined in isolation but that a weight-of-evidence approach should continue to be used.	None		No action
BAPH analyses on crab were considered, as were bile and haemolymph metabolites analyses. It was felt that use of additional health indices on crab or plaice was not warranted if contamination could be detected using current methodologies. If current methodologies fail to detect contamination, then other indices may be considered.	None		No action
It was agreed that commercial fish should be sampled in the vicinity of 18-km sediment stations (i.e. four Reference Areas) and that the Northwest Reference Area should be dropped.	Sample commercial fish in the vicinity of 18-km sediment stations and drop Northeast Reference Area.	Agreed	Sample commercial fish in the vicinity of 18-km sediment stations (four Reference Areas) and drop Northwest Reference Area.
The use of crab pots to sample crab was proposed while the WRAG was considering dropping American plaice as a monitoring species. However, since American is retained as a monitoring species, both crab and plaice can be obtained concurrently in trawl samples.	None		No action.
There was discussion of adding Reference Areas at intermediate locations (e.g. 10 km).	This discussion item was dropped		No action.

WRAG Discussion Item	Final WRAG Recommendation	Husky Position	Action Item
There was discussion on using caged fish but it was agreed that laboratory experiments with dilutions of either drill cuttings or produced water could provide this type of information.	None.		No action.
It was noted that sampling of American plaice should exclude the reproductive period as much as is feasible because this will affect MFO results.	Sample outside the reproductive period as much as is feasible.	Sampling is carried out in late June/early July at the tail end the American plaice reproductive period. This is latest date that can be sampled given sample processing time, vessel availability and the need to collect samples concurrent with both the Hibernia and Terra Nova EEMs – in late June/Early July.	No action.
Compositing American plaice tissue for chemistry analysis was questioned	It was recommended that tissue from individual fish be archived for later analysis if health indicators showed an effect. However, it was also recognized that liver volume is often not sufficient to allow analysis on individuals.		Archive American plaice fillet tissue for analysis of individual fish if health indices show an effect. Archive liver tissue when possible.
The use of larger sample size for crab was discussed and a call was made for the statisticians in the group to address this issue. Sample sizes for crab and American plaice body burden analysis were discussed at length. Sample size for health indices was also discussed.	Obtain as many composites as are reasonable within a one to three-day sampling window. Carry out a power analysis on results if no statistical differences are noted.	Targeting 50 fish in the Study Area and 30 fish in each of the Reference Areas; and targeting 100 kgs of crab in the Study Area and 30 kgs in each of the Reference Areas is an increase over previous amounts (collected in two to three days) and would therefore seem reasonable. Five composites for the Study Area and three composites in each of the Reference Areas are total increase of 7 composites, and would seem reasonable.	Target 50 fish in the Study Area and 30 fish in each of the Reference Areas; and target 100 kgs of crab in the Study Area and 30 kgs in each of the Reference Areas. Five composites for the Study Area and three composites for each of the Reference Areas will be processed for body burden for both crab and American plaice. All

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WRAG Discussion Item	Final WRAG Recommendation	Husky Position	Action Item
			American plaice will be processed for health indices. Power analyses will be performed on results if no statistical differences are noted.
Report			
	It was recommended that raw data be appended to EEM reports and that mention of these appendices be made clear in text.	Agreed	Raw data will be appended and mention of these appendices will be made clear in text.
	It was recommended that a list of acronyms be provided at the front of the report.	Agreed	A list of acronyms will be provided at the front of the report.
	It was recommended that features on figures be identified with different symbols as well as different colours	Agreed	This will be done as much as is feasible.

Appendix C
Consultation Report

**WHITE ROSE ENVIRONMENTAL
EFFECTS MONITORING DESIGN
CONSULTATION REPORT**

NOVEMBER 2003

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without the express written consent of Husky Energy.*

PROJECT NO. NFS09193-0003

**WHITE ROSE ENVIRONMENTAL
EFFECTS MONITORING DESIGN**

CONSULTATION REPORT

PREPARED FOR:

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NOVEMBER 2003

TABLE OF CONTENTS

	Page No.
1.0 INTRODUCTION.....	1
2.0 PUBLIC INFORMATION SESSION.....	1
2.1 Public Notification	1
2.2 Session Materials	1
2.3 The Session	2
3.0 MEETING WITH GOVERNMENT AGENCIES	2
4.0 ISSUES AND CONCERNS.....	2
4.1 Public Consultation Issues and Concerns	3
4.1.1 Noise	3
4.1.2 Effects Monitoring Requirements of an Accidental Discharge	3
4.2 Regulator Consultation Issues and Concerns.....	3
4.2.1 Station Locations	3
4.2.2 Water Monitoring	3
4.2.3 Subsea Infrastructure	4
4.2.4 Sand Lance.....	4
4.2.5 Future Activities	4
5.0 REFERENCES.....	4

LIST OF APPENDICES

Appendix A	Newspaper Advertisement
Appendix B	Display Panels
Appendix C	Exit Questionnaire
Appendix D	Regulatory Consultation Participant List

1.0 INTRODUCTION

Husky Energy Inc. (Husky) presented its draft EEM design to the general public and to the C-NOPB and members of other government agencies. Results of these meetings are summarized in this document for discussion with the WRAG.

2.0 PUBLIC INFORMATION SESSION

The public information session was held in St. John's at the Fluvarium on October 16, 2003 from 3:00 p.m. to 9:00 p.m. The purpose of the session was to inform the general public about the proposed EEM program and related activities, and provide an opportunity for all interested parties to request information and state their views. The session was open to all members of the public interested in the project.

2.1 Public Notification

The public information session was advertised in *The Telegram* on October 11, 14, 15 and 16 (Appendix A). The newspaper announcement described the subject of the session and stated the date, location and time of the events. The announcement also included a contact address, telephone number and fax number, and requested the public to forward any comments or concerns that they had about the project. Husky (Ken Dyer) also participated in a radio interview on CBC Radio One, aired on the evening of October 15, 2003.

2.2 Session Materials

The session featured a series of display panels (Appendix B), an information brochure replicating the display panels, and an exit questionnaire (Appendix C). The displays and brochure were used to provide information about the project, and input was obtained through use of comment sheet and discussions between Husky and Jacques Whitford representatives and session attendees.

The display panels highlighted the proposed EEM program, zones of influence, environmental features and the environmental assessment. The information brochure contained 8.5 in. by 11 in. black and white bound copies of the individual display panels and was provided to session participants. The exit questionnaire was developed as a means to obtain public input about the project and participants were invited to fill one out as they exited the session.

Information on the EEM program was displayed with materials on the White Rose oilfield project, including copies of the White Rose oilfield Comprehensive Study (Husky Oil 2000), Decision 2001.01 (C-NOPB 2001) and the drill cuttings deposition and produced water dispersion modelling report (Hodgins and Hodgins 2000), which were available for participant review, and the revised Offshore Waste Treatment Guidelines (NEB et al. 2002), which was available for participant use.

2.3 The Session

The public information session provided an opportunity for participants to speak directly with Husky representatives and the consultant team involved in designing the EEM program. Husky representatives present were Ken Dyer and Dave Taylor. Members of the consultant team present were Dr. Elisabeth DeBlois and Ellen Tracy of Jacques Whitford. Jacques Whitford representatives organized the session, prepared the displays, information brochure and exit questionnaire on the EEM program and handled logistics for the session.

Sixteen people participated in the public information session. Five exit questionnaires were completed at the session, and at least two participants took an exit questionnaire with them. No additional written submissions or mailed questionnaires have been received to date.

Issues and concerns raised during the public information session are summarized in Section 4.0.

3.0 MEETING WITH GOVERNMENT AGENCIES

A meeting was held at the Fluvarium on October 20, 2003, from 2:00 p.m. to 3:30 p.m. Participants includes representatives from the C-NOPB, Department of Fisheries and Oceans (DFO), Environment Canada and the Newfoundland and Labrador Department of Mines and Energy (see Appendix D for a list of participants). Representatives from the Newfoundland and Labrador Department of Fisheries and Aquaculture (NL DFA) and the Newfoundland and Labrador Department of Environment (NLDOE) were also invited but did not attend. The session was held to inform the agencies about the proposed EEM program and to discuss issues and concerns. Issues and concerns identified during the meeting with government agencies are addressed in Section 4.0.

4.0 ISSUES AND CONCERNS

Few issues and concerns were raised during the public information session (Section 2.3). In general, the participants were pleased with the information presented (they thought it was comprehensive) and were impressed with the proposed EEM program (one participant was impressed with the openness and transparency of the Husky organization); no major concerns were identified. The bulk of the issues and concerns were raised during the meeting with government agencies (Section 3.0). These are summarized in the following sections.

4.1 Public Consultation Issues and Concerns

4.1.1 Noise

There was concern expressed regarding noise levels within the air and water and its potential effects on seabirds and marine mammals and a question as to how such noise pollution levels will be investigated.

4.1.2 Effects Monitoring Requirements of an Accidental Discharge

It was noted that no information was provided on EEM monitoring requirements subsequent to an accidental event/discharge of oily (hydrocarbon) water. Husky responded that it has submitted a draft document addressing an oil spill EEM program to C-NOPB for review and comment. It was suggested by the participant that the appropriate Accidental Discharge EEM design be incorporated into the emergency oil spill response plans and approved more than six months before production drilling starts (i.e., by June 2004 at the latest).

4.2 Regulator Consultation Issues and Concerns

4.2.1 Station Locations

Two separate issues were raised concerning station location. Once related to moving the reference (or 'control') stations to the four existing 18-km stations and whether or not experience at Terra Nova (which has control stations located 20 km from the centre of the project) indicated that this distance was sufficient. The design team responded that, based on the experience at Terra Nova and elsewhere in the world, 18 km should be sufficient.

The second station location issue related to distance from drill centres. The regulators were more concerned with having stations closer to the drill centres than having corresponding baseline stations. The design team pointed out that the WRAG also had concerns with station locations near drill centres. However, rather than move the baseline stations, it was suggested that Husky conduct additional transects as close as feasible to the drill centre to collect information on the near-field deposition of drill cuttings and its potential effects on the benthos. These transects would not be collected during every EEM years but would be additional to the 'standard' program.

4.2.2 Water Monitoring

The participants seemed to acknowledge that sampling once per year using the original design proposed to the WRAG would provide little valuable information. The participants seemed to accept the utility of placing a moored current/CTD meter in the immediate vicinity of the production platform to collect continuous long-term data that could provide useful information on seasonal and between year trends.

One of the participants questioned whether or not the water quality monitoring program was a gradient design and if the null hypothesis for water quality was still valid. The design team responded that the null hypothesis, which implicitly calls for a gradient design, would be address shortly before release of produced water. It was also confirmed that there is no real vertical component to the plume, except immediately upon release. In addition, another participant pointed out that the EEM program's emphasis is on biological effects and specifically fish health, which will provide some indicators on water quality.

4.2.3 Subsea Infrastructure

The C-NOPB pointed out that the current location of subsea infrastructure is unknown and needs to be taken into account before deletion of baseline stations, especially as relates to the northern drill centre. It would appear that station number 37, which has been retained in the current EEM design, could be lost due to the potential location of flowlines from the more southern drill centres. If this is the case, then an alternative station should be sampled around this drill centre.

4.2.4 Sand Lance

The participants wanted to know the rationale for not using sand lance as a monitoring species. The design team responded that there is too little known about sand lance to make it an effective monitoring species. One participant added that sand lance are much shorter lived than American plaice and are not of commercial value. It was also added that American plaice is currently used as a monitoring species in both the Hibernia and Terra Nova EEMs. The design team voiced some concern about sampling American plaice given the state of this resource in the project area. Participants felt the resource was recovering, although slowly.

4.2.5 Future Activities

Husky indicated that based on the delineation well drilling Husky has recently conducted, the potential exists that Husky could excavate a fourth drill centre 5 km south of the southern glory hole. Husky acknowledged that if this happens, there would be modifications to the EEM design to accommodate the new drill centre. In addition, Husky acknowledged that the fourth drill centre could have an impact on the southeast and southwest reference stations.

5.0 REFERENCES

C-NOPB (Canada-Newfoundland Offshore Petroleum Board). 2001. *Decision 2001.01: Application for Approval – White Rose Canada-Newfoundland Benefits Plan and White Rose Development Plan*. St. John's, NL. iii + 185 pp.

Hodgins, D.O. and S.L.M. Hodgins. 2000. *Modelled Predictions of Well Cuttings Deposition and Produced Water Dispersion for the Proposed White Rose Development*. Part Two Document by Seaconsult Marine Research Ltd. for Husky Oil Operations Limited. 45 pp.

Husky Oil Operations Limited. 2000. *White Rose Oilfield Comprehensive Study - Part One: Environmental Impact Statement*. Submitted to the Canada-Newfoundland Offshore Petroleum Board, St. John's, NL.

NEB, C-NOPB and C-NSOPB (National Energy Board, Canada-Newfoundland Offshore Petroleum Board and Canada-Nova Scotia Offshore Petroleum Board). 2002. *Offshore Waste Treatment Guidelines*.

Appendix A
Newspaper Advertisement

PUBLIC NOTICE

An Open House

to consult with the public on the

**Environmental Effects Monitoring Program Design
for the White Rose Project**

will be held at

The Fluvarium
St. John's, NL
October 16, 2003
3:00 pm to 9:00 pm

In accordance with commitments made by Husky Energy and Decision 2001.01 issued by the Canada-Newfoundland Offshore Petroleum Board, Husky Energy is presently developing an Environmental Effects Monitoring Program (EEM). The purpose of the program is to determine if the project's effects on the environment correspond with those predicted in the Development Application. Husky is committed to providing interested stakeholders with the opportunity to comment on the design of this EEM program. Accordingly, Husky is seeking input from interested stakeholders on the EEM design. This Open House will make available information on the EEM design and will offer an opportunity for interested stakeholders to state their views and ideas concerning the EEM design.

For further information about the meeting or to submit comments, please contact:

Ken Dyer
Health, Safety, Environment and Quality Manager
Husky Energy Inc.
Suite 801, Scotia Centre
235 Water Street
St. John's, NL A1C 1B6

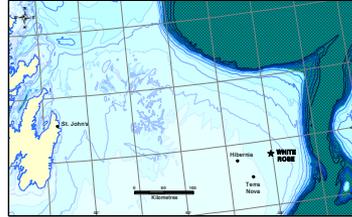
Telephone: (709) 724-3900
Fax: (709) 724-3915
E-mail: ken.dyer@huskyenergy.ca



Appendix B
Display Panels

Significant Milestones White Rose Project

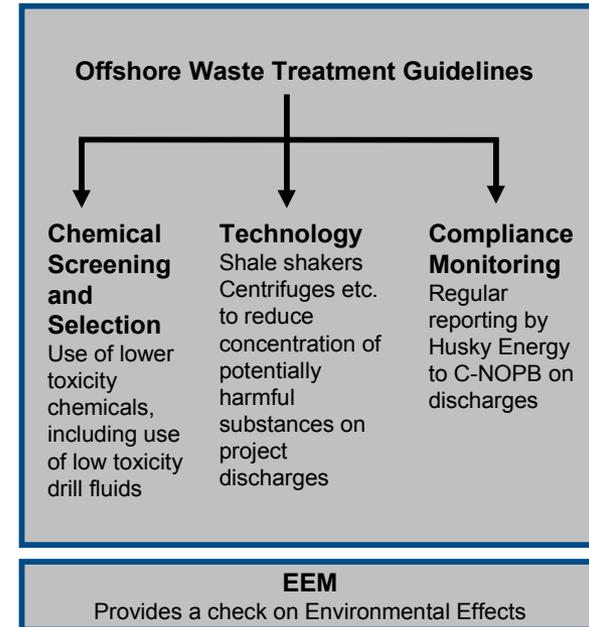
1984 - White Rose OilField Discovered



1984-1988	Exploration drilling
1999 and 2000	Delineation drilling
November 1999	Concept selection
October 2000	Husky submits Comprehensive Study
January 2001	Husky submits Development Application
June 2001	Comprehensive Study released from federal assessment process
July 2001	Public Hearings
September 2001	White Rose Public Hearings recommends approval of project with recommendations
November 2001	C-NOPB Decision Report recommending approval with Conditions, including the development of an Environmental Protection Plan
December 2001	Regulatory approval
March 2002	Project sanction
Q3 2002	Fabrication commences
Oct. 16, 2003	Public Information Sessions on EEM Design
December 2003	EEM Design submitted to C-NOPB
Q3 2003	Drilling scheduled to commence
Q4 2005/Q1 2006	First oil

Environmental Protection Planning

Husky Energy is preparing Environmental Protection Plans (EPPs) for all phases of the White Rose project. EPPs include series of elements that ensure compliance with regulatory guidelines and meet Husky Energy's environmental stewardship commitments. The design and implementation of an Environmental Effects Monitoring (EEM) Program constitutes an integral part of Husky Energy's environmental planning process.



Elements of Husky Energy's EPP

Safety & Environmental Protection Commitments

Husky Energy, as operator of the White Rose project, is committed to adhering to standards in its “Health, Safety and Environmental (HS&E) Loss Control Management and Performance Standards”, which will assist in meeting the following objectives:

- keep employees (Husky and contractor(s)) free from harm
- ensure that project facilities and operations are run in a manner that demonstrates Husky’s commitment to HS&E stewardship to it employees, neighbours, regulators and the general public
- manage the effects of Husky’s operations on the environment and the liabilities associated with those effects
- ensure clarity of expectations and appropriate consistency in the company’s HS&E loss control program
- ensure the project complies with government legislation, target levels of safety, corporate policy and applicable standards pertaining to the protection of employees, the environment and the public



Marystown FPSO Wharf



Glory Hole Excavation Vessel

Purpose Of This Open House

The purpose of this open house is to discuss the draft approach for the White Rose EEM program with the interested public. Please feel free to ask questions and provide comments throughout the open house. We provide a hand-out of this poster presentation and a copy of Offshore Waste Treatment Guidelines for your use. We would also appreciate receiving your comments in writing on the questionnaire provided.

**White Rose Project
Environmental Effects Monitoring Program**

Husky Energy is interested in learning of any concerns that you may have about the proposed environmental effects monitoring (EEM) program for the White Rose Project. We would appreciate it if you could take a few minutes to answer the following questions. The information that you provide will be used to assist Husky Energy in designing the EEM program.

1. What is your overall impression of the proposed EEM program for the White Rose Project?

2. Do you have any concerns about the EEM program design? Yes No
If yes, what are they?

What steps do you think Husky Energy could take to address your concerns?

... See Reverse

Public Feedback Questionnaire
(please ask for details)

White Rose EEM Design Team

Husky Design Team

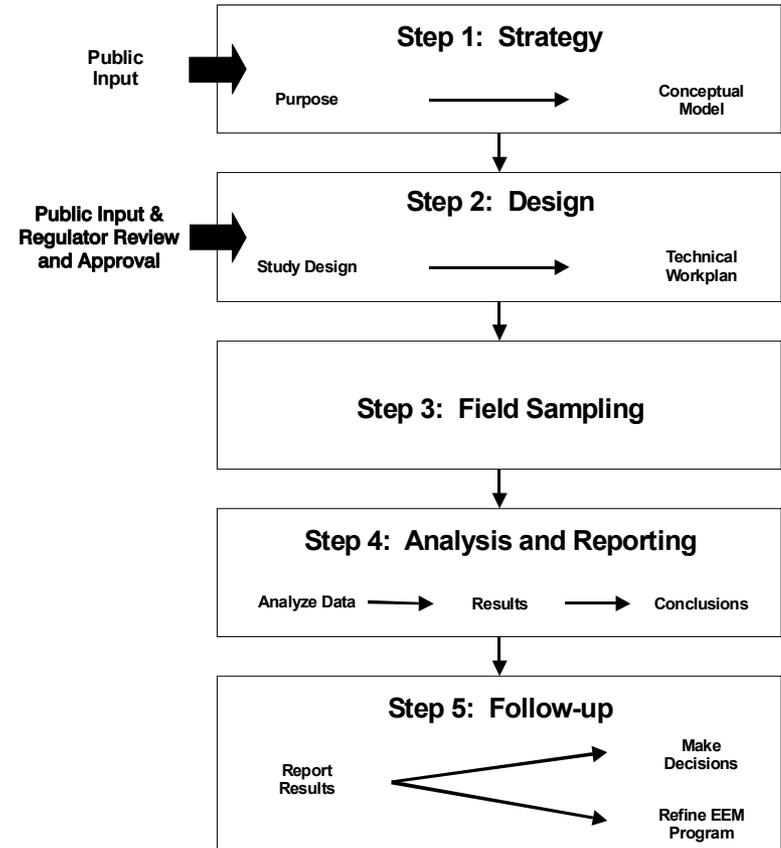
Ken Dyer, Husky Energy
 Dave Taylor, Husky Energy
 Dr. Elisabeth DeBlois, Jacques Whitford
 Dr. Mike Paine, Paine, Ledge and Associates
 Ellen Tracy, Jacques Whitford

Leslie Grattan, Dept. Environment
 Dr. Roger Green, University Waterloo
 Dr. Doug Holdway, U. Ontario Institute of Technology
 Mary C. O'Brien, Manager Tors Cove Fisheries Ltd.
 Dr. Paul Snelgrove, Memorial University
 Dr. Len Zedel, Memorial University

White Rose Advisory Group (WRAG)

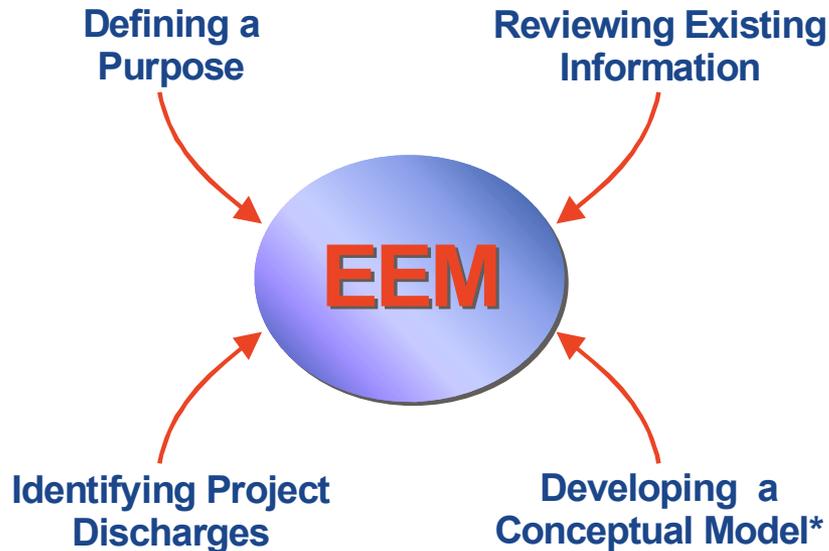
The White Rose Advisory Group provides expert advice and feedback to the Husky Team during the design phase of the EEM program

Steps In EEM Design Process



Step1: EEM Strategy

What Is Important



* Conceptual Model will include identification of resources at risk and establishment of sampling boundaries in space and time.

Purpose of EEM

Purpose

The purpose of an EEM is to determine and quantify project-related change in the marine environment and to help evaluate the effectiveness of mitigation measures.

Specific Objectives are:

- determine the zone of influence of project contaminants
- test effects predictions made in the EIS
- provide an alert to unexpected effects
- provide a scientifically defensible analysis and interpretation of data
- provide information to Husky Energy and regulators to evaluate the need for modification of operations practices
- be cost-effective, making optimal use of personnel, technology and equipment
- communicate results to the public

Review of Existing Information

Baseline information, which is collected before site development, was collected in 2000 and 2002. Three studies were completed:



Sediment Quality Study

- chemical and physical characteristics
- toxicity
- benthic community

Water Quality Study

- chemical and physical characteristics
- chlorophyll



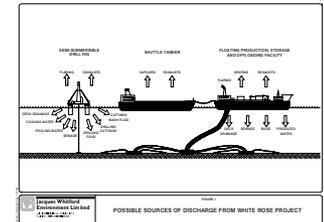
Commercial Fish Study

- taint
- metals and hydrocarbon body burden
- health indices

This provides information on the White Rose site prior to development for comparison with data that will be collected during drilling and production. This information allows evaluation of approaches for designing and conducting the EEM program.

Project Discharges

The two primary discharges are liquids and solids, as indicated in Figure 1.



Liquid discharges may include the following:

Produced water

- water associated with oil and gas reservoirs that is produced along with oil and gas
- there is very little water in the producing formations at White Rose; therefore, most of the produced water will be sea water injected to enhance recovery
- produced water will be passed through a treatment system to reduce its oil content to meet or exceed compliance with *Offshore Waste Treatment Guidelines*

Sewage

- treated to meet or exceed compliance with *Offshore Waste Treatment Guidelines*

Cooling water

- chlorinated sea water used as a coolant treated to meet or exceed compliance with *Offshore Waste Treatment Guidelines*

Bilge Water and Deck Drainage

- treated to meet or exceed compliance with *Offshore Waste Treatment Guidelines*

Solid discharges may include the following:

Water-based and synthetic-based drilling muds

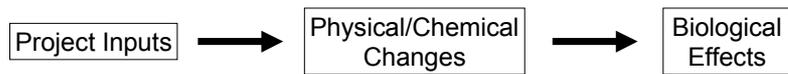
- discharged in compliance with *Offshore Waste Treatment Guidelines*

Drill cuttings

- discharged following treatment to meet or exceed compliance with *Offshore Waste Treatment Guidelines*

Conceptual Model

A conceptual model is based on predicted causes-and-effects. The basic conceptual model is shown below. Physical/chemical change provides an early warning of potential for biological effects, while biological effects indicate what has already occurred. The EEM is intended to provide early warning of effects.



Project-related inputs may include:

- trace hydrocarbons in liquids or solids
- trace metals in liquids or solids
- particulate matter

Physical and chemical changes may result from project inputs. These changes may include:

- chemical changes to the water column and sediment resulting from discharges
- physical changes to the water column and sediment resulting from discharge of particulates

Biological effects of concern are undesirable effects to marine resources

Identifying Marine Resources

Marine resources that share the environment at White Rose include:

- commercial fish species
- seabirds and marine mammals

These were identified as valued environmental components (VECs) in the White Rose Development Application Environmental Impact Statement.

Indicators of the physical environment of these marine resources include:

- sediment quality
- water quality

Monitoring water quality and sediment quality will provide information on possible indirect effects to marine resources, particularly commercial fish species.



Atlantic puffin



Humpback whale

Defining Boundaries: Timing and Study Area

Timing

- the EEM Program will be conducted throughout the duration of drilling and production
- it is proposed that the EEM program be conducted annually for the first 3 years of project operations, after which the frequency of the program will be reviewed

Study area

- the study area is determined by the distribution of project-related discharges to the marine environment
- the predicted distribution and concentration of drill cuttings and produced water is expected to diminish rapidly with distance from each drill centre, as indicated in the Figures 2 and Figure 3
- the proposed EEM study area is shown in Figure 4. The study area extends well beyond the predicted limit of distribution of drilling muds, cuttings and produced water



Zone of Influence for Drill Cuttings

The zone of influence for project discharges is the area where higher concentrations of project discharges are expected and where most of the biological effects from the project might be expected. Based on predictions made in the White Rose EIS, the zone of influence for project discharges is not expected to extend beyond 5 km from source of discharge.

Drill cuttings deposition decreases to 0.01 mm at roughly 5 km from source. Levels in the range of 10 to 100 mm are expected only in the area immediately surrounding the drill centres.

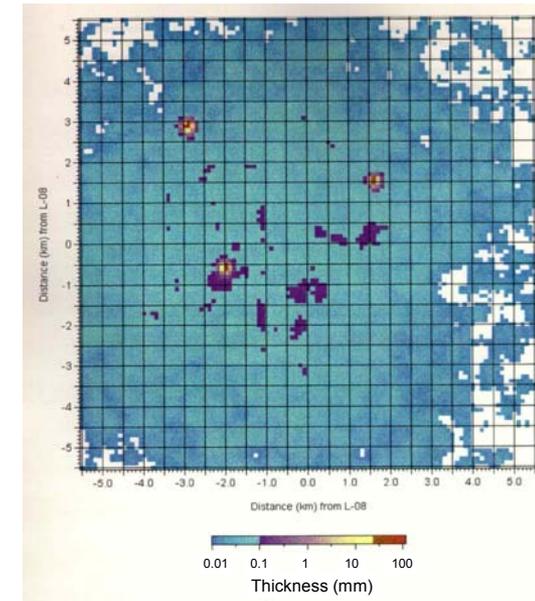


Figure 2. Predicted Distribution of Drill Cuttings Around Drill Centres

Zone of Influence for Produced Water

Produced water is expected to decrease to a low of 0.13 mg/L at roughly 3 km from source.

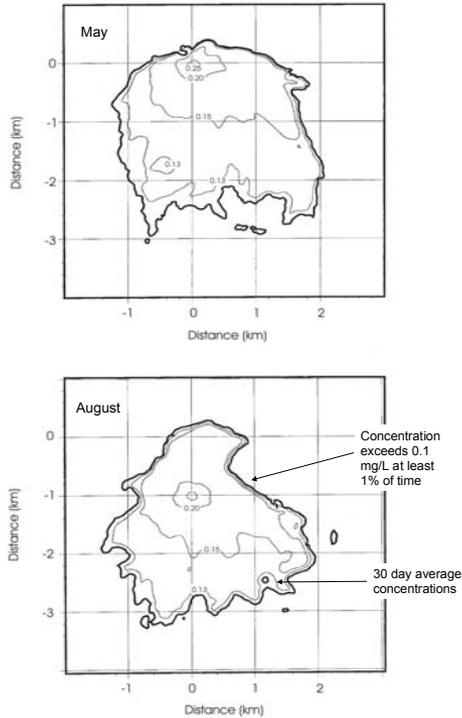


Figure 3. Predicted Distribution of Produced Water at Point of Discharge

Study Area

The proposed study area would cover 650 km² and would extend to a maximum of 18 km of the proposed location of the FPSO. This area covers the expected zone of influence of drill cuttings and produced water, as well as areas outside the expected zone of influence.

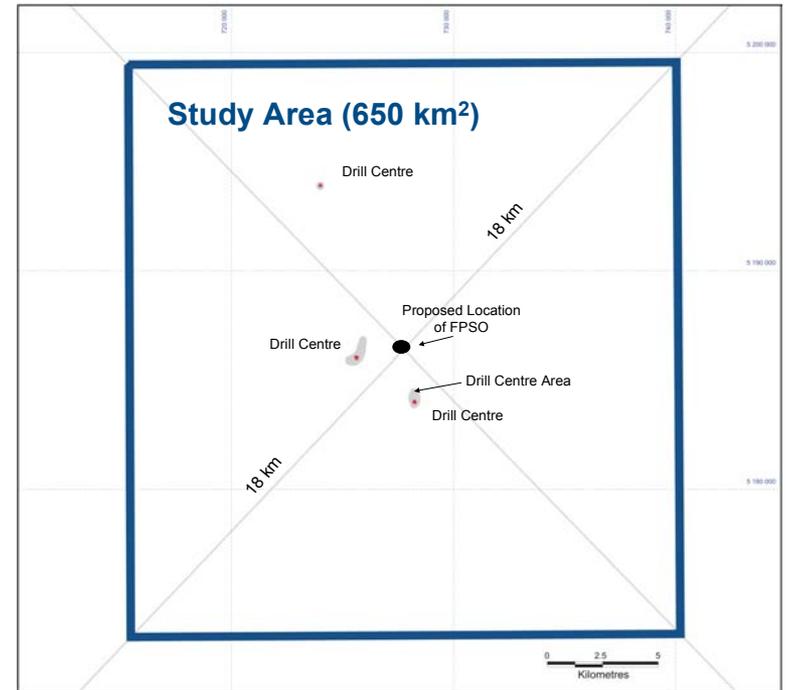


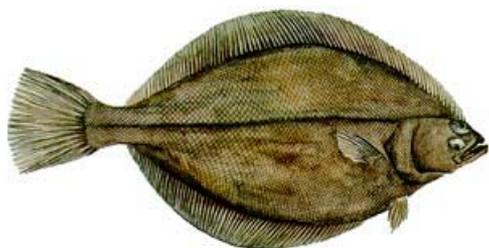
Figure 4. Proposed Study Area

Step 2: EEM Design

What is Involved?

EEM design involves the following:

- selecting monitoring variables
- choosing a statistical design
- developing a sampling design
- developing a workplan



American Plaice
Hippoglossoides platessoides



Snow Crab
Chionoecetes opilio

Monitoring Variables

Monitoring variables are aspects of the marine environment that are used to determine if adverse effects may occur or have occurred.

Monitoring variables being considered for the EEM program include the following:

Sediment Quality

- chemical characteristics: hydrocarbon and metal concentrations
- physical characteristics: particle size analysis
- toxicity: lethal and sublethal effects on organisms
- benthic communities: species presence and abundance in sediment

Sediment analyses will determine if there is deterioration of sediment quality within the project area and whether there is a relationship with distance from source of discharge.

Water Quality

- chemical characteristics: hydrocarbon and metal concentrations
- physical characteristics: temperature, salinity, dissolved oxygen, pH
- chlorophyll concentrations

Water analyses will determine if there is deterioration of water quality within the project area and whether there is a relationship with distance from source of discharge.



Monitoring Variables (Cont.)

Commercial Fish Species

- taint
 - presence of a flavour or odour in organisms which, when captured or harvested, is not typical of the flavour or odour of the organisms themselves

Taint testing will determine if taint has occurred within the project area compared with control areas.

- body burden
 - hydrocarbon and metal concentrations in tissues to indicate uptake by the organism from the marine environment

Body burden is a measure of bioavailability (i.e., uptake) and may provide an early warning of potential taint.

- health
 - tissue analysis for abnormalities
 - enzyme indicators of exposure to pollutants or stress
 - population measures such as age, size, reproduction

Health indicator analysis will determine if there is a deterioration in commercial fish health within the project area compared to control areas.

Seabirds and Marine Mammals

- seabird landings on and collisions with project operations
- marine mammal and seabird incidence in the project area

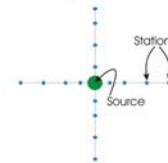
Observations on seabirds and marine mammals will provide information on the interaction of seabirds and marine mammals with project operations.

Statistical Design

Statistical design involves selecting an appropriate statistical analysis model to answer specific questions about project effects. Once a statistical design is chosen, sampling stations are selected to meet the requirements of the design.

The statistical design being proposed for sediment sampling is **Attenuation by Distance**, which is based on the relationship between monitoring variables and spatial distances. Stations are located at varying distances from source, as shown in Figure 5. Analyses then aim to determine if there is a change in monitoring variables with distance from source. Figure 5, below, provides an example where hydrocarbon levels are higher closer to source and decrease with distance.

Spatial Layout of Stations



Results

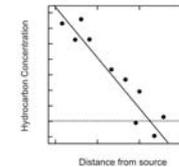


Figure 5. Example of spatial layout of stations and data analysis in an attenuation by distance design

An **Adaptive Attenuation by Distance** design is proposed for water monitoring. The release of produced water at White Rose is not expected until 2008. Until release of produced water, and in preparation for produced water monitoring, a fixed mooring will be installed at White Rose to monitoring water current patterns and verify model predictions made during the EIS.

Statistical Design (Cont.)

For commercial fish species, a **Control-Impact** design is proposed to determine if there are differences in biological variables, such as taint or body burden, between samples collected within the study area and samples collected in control areas.

Figure 6, below, provides an example of the spatial lay-out of stations in a Control-Impact model. Analyses examine differences in average levels of a response variable between study and control areas. In the example provided, fish liver cadmium levels are higher in the control area than in the study area.

Spatial Layout of Stations

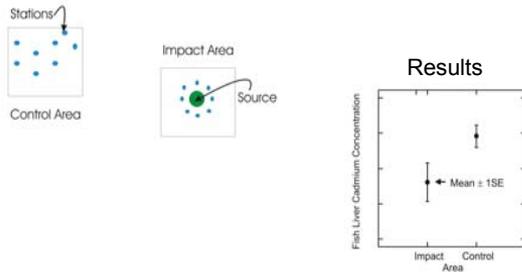


Figure 6. Example of spatial layout of stations and data analysis in an control-impact design

Statistical Design (Cont.)

Station locations for sediment and sampling areas for commercial fish trawling are determined by the chosen statistical design and by the predicted zone of influence of project discharges. Proposed sampling locations are provided below.

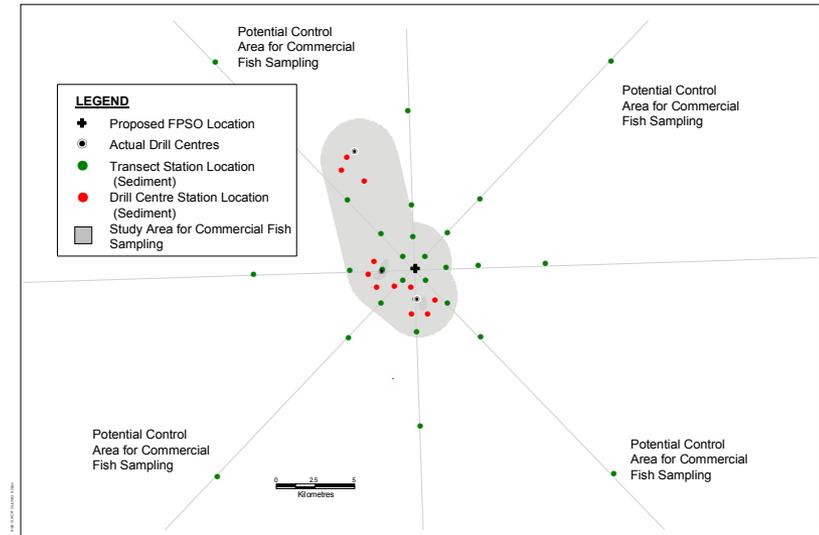


Figure 7 Proposed Station Location and Sampling Areas for the White Rose EEM

Workplan

The workplan provides technical direction on how to implement the design. The EEM program will be conducted throughout the duration of drilling and production. Workplan options to be considered include:

Sediment Quality

- sample stations within the proposed EEM study area using a box corer
- analyze samples for:
 - 1) particle size, hydrocarbons and metals
 - 2) toxicity, using standard tests to determine if there are lethal or sublethal effects to test organisms
 - 3) benthic community status, in terms of which species are present and their abundance
- sample once per EEM cycle



Sediment Box Corer

Water Quality

- until release of produced water at White Rose, install a fixed mooring near the proposed location of the FPSO with instruments to record speed and direction of currents, temperature, salinity, dissolved oxygen, pH and chlorophyll
- also measure hydrocarbon and metal concentrations at fixed time intervals at this mooring

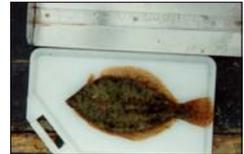


Water Current Meter

Workplan

Commercial Fish Species

- collect snow crab and American plaice samples within the proposed EEM study area and at control sites
- analyze samples for taint, body burden and health (may include tissue analysis, enzyme analysis and population measures)
- sample once per EEM cycle



American plaice

Seabirds and Marine Mammals

- monitor seabird and marine mammal incidence from project platforms and vessels using platform weather observers trained and experienced in making these observations
- develop action plan for recovering and releasing birds following collisions with project platforms
- develop monitoring program for seabirds and marine mammals in the case of a large spill



Herring Gull

Step 3: Field Sampling

After developing the technical workplan, the EEM program may be implemented using the following steps:

Sampling platforms: vessels must be chosen that will allow for effective collection, transportation and storage of samples.

Sampling schedule: must consider project activities, availability of sampling platforms and weather.

Documentation:

- **Cruise Plan:** provides detailed information on sampling locations, roles and responsibilities of field crew and logistical details (including schedule, reporting requirements, communications)
- **Field Manual:** provides details on technical operations for sample collection, quality assurance/quality control plan (measures in place to ensure sample integrity and legal defensibility) and standard operating procedures (sample collection, records, equipment operation)

Sample Collection: samples are typically collected on two separate cruises:

- Sediment Collection Cruise
- Commercial Fish Sample Collection Cruise

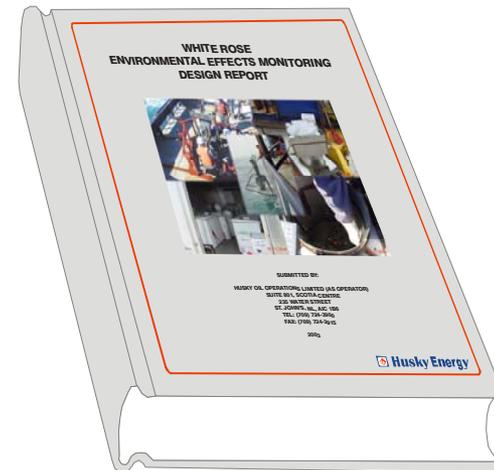


Cruise Report: provides chronology of the activities associated with the sample collection cruises. This report is submitted to C-NOPB.

Step 4: Analysis And Reporting

This includes analysis of the data, reporting of the results and developing a set of conclusions. Statistical analyses will be chosen to allow testing of specific hypotheses for monitoring variables and to meet the statistical design.

A report will be written for each EEM cycle and will provide data summaries, methods of analysis, results and conclusions. This report will be submitted to the C-NOPB and other regulatory agencies for review and approval. The report will be made available to the public through the White Rose Project Website. EEM results will then be used to assess if program refinements are required.



Appendix C
Exit Questionnaire

White Rose Project Environmental Effects Monitoring Program

Husky Energy is interested in learning of any concerns that you may have about the proposed environmental effects monitoring (EEM) program for the White Rose Project. We would appreciate it if you could take a few minutes to answer the following questions. The information that you provide will be used to assist Husky Energy in designing the EEM program.

1. What is your overall impression of the proposed EEM program for the White Rose Project?

2. Do you have any concerns about the EEM program design? Yes No
If yes, what are they?

3. What steps do you think Husky Energy could take to address your concerns?

... See Reverse

4. Which of the following best describes your feelings about the proposed EEM program?

- Very Satisfied
- Satisfied
- Neither Satisfied nor Dissatisfied
- Dissatisfied
- Very Dissatisfied

5. Additional comments:

**Thank you for taking the time to give us your input.
We appreciate your assistance.**

Name: _____

Affiliation: _____

Address: _____

Telephone: _____ **Fax:** _____

Please leave your completed questionnaire or any other written comments at the reception desk or forward to:

Contact person

Address: Ken Dyer
Phone: (709) 724-3900
Fax: (709) 724-3915
E-mail: ken.dyer@huskyenergy.ca

Appendix D
Statistical Analysis

The original text submitted in the 2004 Design Document (Husky Energy 2004) is provided in Section 1. Modifications made since the original submission are noted in Section 2. Past EEM reports (Husky Energy 2005, 2006, 2007) provide more details on the statistical analyses conducted.

1 Original Submission (2004)

1.1 Sediment Quality

1.1.1 Primary Analysis

1.1.1.1 Single Sample Year

Analyses for single EEM sample years will be similar to those used for the baseline survey and in the Terra Nova EEM program. Basic analyses will consist of calculation of summary statistics (minima, maxima, means, standard deviation, etc.) over all sample stations, distance regressions, and correlations within and among SQT components. Other analyses will occasionally be conducted to refine methods.

For the baseline survey, three X variables were used for regression analysis of SQT or Y variables:

- distance from the centre of the development (i.e., from the original proposed floating production, storage and offloading (FPSO) facility location);
- direction from the centre (expressed as \cos and $\sin \theta$, with θ the angle relative to due north); and
- depth (which increases to the east).

The baseline analysis used distances and directions from a single “source”, the proposed FPSO location. In the EEM program, direction variables will probably be unnecessary. If distances from each of the three drill centres are used as X variables, directional effects can be inferred from the magnitude of effects from each source (=triangulation). If directional effects are limited, a single X variable (distance from the nearest drill centre, or the nearest of the southeast and southwest drill centres may be adequate. Depth will be included in regression analyses because there were some significant baseline depth effects.

Distance regressions describe the magnitude and spatial extent of contamination or effects. The regressions can be used to predict Y values at any distance or location, and compare those values to reference values or standards (e.g., sediment quality criteria or effects concentrations). Similarly, inverse prediction (prediction of X from Y) can be used to determine distances at which reference values, standards, or other Y values occur or are exceeded.

Correlational analyses of SQT data focus on relationships within and especially among components (i.e., chemical and physical characteristics, toxicity, benthic infaunal communities). The primary objective is to determine if contamination (or physical alterations) and biological

effects are correlated (=stress- or dose-response relationships). Correlations within SQT components are used to assess if there are generalized patterns or “syndromes” of contamination or effects, and to develop summary measures for each component (i.e., correlations are expected within each component, especially when contamination and effects occur).

In the White Rose baseline report, Spearman non-parametric rank correlations (r_s) were used to calculate bivariate correlations between variables within SQT components. Using r_s is a universal approach that avoids any need to make transformations, and non-parametric methods can be as powerful as parametric methods with larger sample sizes (i.e., $n > 10$). Kendall's non-parametric Coefficient of Concordance (W) can be used to calculate the overall or multiple correlation among $v > 2$ variables.

In the White Rose baseline report, relationships among SQT components were examined using a multivariate approach suggested by Green et al. (1993), and used by Chapman et al. (1996) for an SQT study of sewage discharge effects. Briefly, matrices of multivariate pair-wise distances between stations were calculated for each SQT component, then correlations among those distance matrices tested. Green et al. (1993) discuss other approaches for analyzing SQT data.

1.1.1.2 Multiple Sample Years

Repeated Measures (RM) distance regressions will be used to analyze data from multiple years. RM regressions are the same as single-year regressions, except that Y is some combination of values from multiple years. For example, after the first EEM sample year, Y could be the EEM value minus the baseline value (or vice versa) or the before-after (BA) difference. Significant regressions of BA on distance from active drill centres would indicate that distance gradients changed after drilling started, which is usually evidence of contamination or effects. RM designs and analyses are most effective when there are strong carry-over effects, or persistent differences among stations over time unrelated to distance (or other X variables of interest).

For comparisons of EEM values to before or baseline values, using the before values as an additional X variable in multiple regression will always be more powerful than differencing (i.e., subtracting or dividing by baseline values) (Cohen 1988; Everitt 1994). Treating the before and after values as multiple Y values in multivariate regression will also be more powerful than differencing. These two alternatives effectively use different weights for the before and after values to maximize the relationship between BA and distance, whereas differencing weights before and after values equally. However, the standard RM model and approach, which is based on differencing, is more flexible, more informative, and preferred when there are greater than two years and several comparisons of interest.

Correlations among SQT variables over multiple years can also be examined. If natural changes over time are small, data from all years can be pooled and analyses conducted as for single years, but with much larger sample sizes. This approach can be effective for collapsing more complex RM distance regressions when contamination is not a simple function of distance from drill centres, or when the timing or intensity of drilling activity varies among drill centres or years. If natural changes over years are larger, correlations can be compared among years. Carry-over

effects can be accommodated by subtracting or dividing by baseline values, or more generally, by analyzing differences or other combinations of values over multiple years.

1.1.2 Secondary Analysis

At the request of regulators, aluminum normalization will also be used to assess barium concentrations in sediments. Concentrations of barium in uncontaminated marine sediments will usually be positively correlated with concentrations of other metals, as they were in the baseline survey. Thus, “expected” barium concentrations in the absence of contamination from water-based drilling muds (WBM) can be predicted from concentrations of other metals that are largely unaffected by drilling. Aluminum is typically used as a predictor, because it occurs naturally at high concentrations in marine sediments, and is not a major constituent of drilling muds.

The first step is to develop a baseline barium-aluminum regression. Barium concentrations in EEM years are then compared to values predicted by aluminum concentrations in the same sediments, using the baseline regression. Higher-than-predicted barium concentrations would be considered evidence of contamination from WBM. If distance gradients for barium contamination were of interest, observed minus predicted barium concentrations could be regressed on distance.

Aluminum normalization is a potential alternative to repeated measures (RM) approaches, in which baseline barium concentrations, rather than aluminum concentrations, are used as predictors of EEM barium concentrations. Aluminum normalization will be most effective when:

- carry-over effects are weak, and baseline barium concentrations are poor predictors of EEM barium concentrations; and/or
- baseline barium concentrations are unavailable (e.g., for the three near-field EEM stations not sampled in baseline).

Otherwise, RM approaches, which are effectively “baseline normalization”, are preferred, because they can be applied to analysis of many other sediment quality variables.

1.2 Commercial Fish

Analyses of commercial fish data from single years will include:

- calculation of summary statistics for each Area;
- comparison of American plaice and snow crab body burdens among Areas in ANOVA;
- comparison of taste results between Study and Reference Areas in ANOVA or t tests;
- comparison of American plaice health indicators among Areas in ANOVA; and
- comparison of American plaice and snow crab biological characteristics (e.g., sex ratios, size, age) among Areas, and among trawls or composites within Areas.

With four Reference Areas, two comparisons or contrasts are of primary interest:

- Among References, and
- Study Area versus References.

Given the size of the Study Area, comparisons between the northern and southern portion of the Study Area are also of interest and can be performed given sample sizes and distribution of collection sites proposed in this document.

Differences among Reference Areas represent natural large-scale spatial differences. Differences between the northern and southern portion of the Study Area could represent natural differences or differences in the extent or magnitude of project effects. One would conclude that the differences were natural if they were similar to differences among the Reference Areas. The difference between the Study Area and the overall or grand Reference mean is a measure of potential effects, and is also known as the Control-Impact or CI difference. The three contrasts can be tested in most statistical packages (e.g., SYSTAT, SPSS) following an ANOVA. Alternatively, the four Reference Areas can first be compared in an ANOVA, and the northern and southern portion of the Study Area can be compared in a *t* test. The four References would then be pooled as a single “Area” for comparison to the Study Area. That is the approach that would be used for analysis of frequencies (e.g., sex ratios or incidences of abnormalities) in log-likelihood or *G* tests (similar to χ^2 tests; Sokal and Rohlf 1981; Paine 1998).

The tests described above use composites or individual American plaice or snow crab within Areas as replicates, and assume that there is no added natural large-scale variance among Reference Areas or between the northern and southern portion of the Study Area. If there are differences among the Reference Areas, Areas are the appropriate replicates for testing the Study versus Reference contrast. Comparisons among Areas would then be made in nested ANOVA, with Areas as replicates within “Reference” and “Study” groups, and composites or individual American plaice or snow crab (i.e., subsamples) as replicates within groups. The northern and southern portion of the Study Area would be treated as separate groups if differences between them were greater than differences among the References. Replication (i.e., >1 Area) is not required within the Study group, provided that there are multiple References. Winer (1971) suggests that variance among Areas within groups can be pooled with the variance among subsamples (i.e., subsamples rather than Areas can be used as replicates for testing the Study versus Reference contrast) when $p > 0.20$ for the Among References test or contrast. When differences among References are larger, or significant at lower p ($p < 0.20$ and especially < 0.05), the magnitude and potential causes of those natural differences may be more relevant than the statistical significance of the Study versus Reference contrast, however tested.

In the White Rose EEM program, American plaice and snow crab size and other biological characteristics could be compared among trawls or composites within Areas, as well as among Areas. Nested ANOVA, with Area and Trawls within Areas as terms or sources of variance, could be used for analysis of size, for example. The objective of these analyses would be to estimate smaller-scale variance among trawls, and the legitimacy of protocols or procedures used for pooling or compositing American plaice or snow crab within Areas. Variance among trawls or composites within Areas is not expected to be large for mobile fish or shellfish, but that assumption should be tested whenever possible.

In EEM programs, it is usually preferable to sample the same Areas both before and after project activity (e.g., drilling) occurs. With a single Reference Area and a single Study Area, this is a Before-After Control-Impact (BACI) design (Green 1979). The test for effects is then a test for a change in the CI (Study versus Reference) difference between before and after years, with the before or baseline CI difference providing an estimate of natural variance among Areas. In the baseline survey, differences in body burdens and American plaice health indicators between the Northwest Reference and the Study Area fish were measured, but:

- sediment chemistry and benthic invertebrate communities differed significantly between the two Areas;
- sample sizes for body burden analyses were limited for American plaice; and
- Reference snow crab were sampled two years after Study Area snow crab.

Ideally, the four 28 km References as well as the Study Area would have been sampled in the baseline survey. However, it was not known in 2000 (the baseline sampling year) that the Northwest Reference Area was not comparable to the Study Area. The baseline Study Area sampled also did not extend as far as the new NN and SS drill centres (see Appendix A). The multiple-reference design effectively replaces the baseline estimate of natural variance between Areas with an estimate (the Among References contrast) made each EEM or after year. As EEM data accumulate, changes in the Study versus Reference contrast or difference with intensification and then cessation of drilling activity may be of interest, and can be assessed in two-way ANOVA with Year and Area as factors.

In the Terra Nova EEM, there have been few or no consistent differences in American plaice health between the Study and Reference Areas, so quantitative comparisons among years have not been warranted or conducted. Body burdens have been compared over both time (Years) and space (Areas).

2 Modifications Since Original Submission

Appendix A describes analyses proposed to specifically address the addition of the North Amethyst drill centre in the 2008 and subsequent EEM programs. The modifications described below are those made from 2004 to 2006.

2.1 Sediment Quality

2.1.1 Primary Analysis

2.1.1.1 Single Sample Year

Distance regressions are calculated for each EEM year. The first step is to calculate rank-rank regressions for all sediment quality variables. Depth and distance from each drill centre are used as X variables. The rank-rank regressions are a useful screening tool, and generally suitable and robust for most variables. Parametric log-log regressions are then calculated for variables showing the strongest relationships with distance in the rank-rank regressions. In these

regressions, distance from the nearest drill centre is used as X , since that has proven to be an effective single distance variable. When appropriate, “hockey-stick” models are used to define threshold distances where Y variable values reach Reference or background levels. The threshold distances define Zones of Influence or Effects.

Spearman rank correlations (r_s) are calculated between variables within SQT components. The emphasis on analyses of relationships among components has shifted from the general multivariate analyses conducted in the baseline report (Husky Energy 2001) to more specific analyses of concentration-response relationships between benthic invertebrate community variables and $>C_{10}-C_{21}$ HCs, a tracer of synthetic-based drill muds (SBMs). Rank-rank, log-log and hockey-stick regressions are used for the concentration-response relationships.

2.1.1.2 Multiple Sample Years

RM regression analyses with depth and distance from each drill centre as X variables are used to assess differences among years. The van Belle test (van Belle and Hughes 1984) is used to compare selected correlations (r_s) among years, and test the common correlation over all years when there are no differences among years (Husky Energy 2006, 2007).

2.1.2 Secondary Analysis

Normalizing barium to aluminum was assessed in the 2004 and 2005 reports (Husky Energy 2005 and 2006), with a recommendation in the 2005 report that the analysis be dropped . Aluminum normalization has not been used since then. Further details are provided in Husky Energy 2005.

2.2 Commercial Fish

Within each year, crab and plaice biological and body burden variables are analyzed in nested ANOVA, as described in Section 1.2. Analysis of frequencies is conducted using log-likelihood (*G*) tests as described in Section 1.3, except that Fisher's Exact Test is used to compare the Study Area versus pooled Reference Areas. Pooling References is usually necessary for many of the health indicators because frequencies of abnormalities are low.

A Repeated Measures (RM) ANOVA is used for analyses of multiple years, which are restricted to crab and plaice body burdens. The Reference Areas are the replicates that are re-sampled over time, and the analysis is conducted using annual Area means (i.e., there is no replication within Areas) (see Husky 2007 for more details).

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Appendix E
Statistical Power and Robustness

The original text submitted in the 2004 Design Document (Husky Energy 2004) is provided unaltered in Section 1; some figures and tables have been edited or corrected. Section 2 provides an update, based on EEM monitoring experience and results from 2004 to 2006 (Husky Energy 2005, 2006, 2007).

1 Original Submission (2004)

1.1 Overview

Statistical power (P) is the probability that an effect of a specified size (=target effect size (ES)) will be detected in samples if it exists in the real world. Real-world or population effects can only be estimated from samples; their precise values are never known. Because of sampling error or uncertainty, real-world effects may go statistically undetected (=Type II error, with probability β (or $1-P$)). Target ES must be specified to calculate P ; it is incorrect to assume that power refers to the probability of detecting any non-zero effect (i.e., $ES \neq 0$). Small effects will always occur and go undetected in samples. For example, release of one hydrocarbon molecule is an effect that would never be detected.

An effect in samples may be statistically significant when the target ES does not exist in the real world (=Type I error). The probability of a Type I error is α , with α typically set at 0.05 (or 5 percent) (i.e., results are not considered statistically significant unless $p \leq 0.05$). The probability that the target ES, if it does not occur, will not be statistically significant is then $1-\alpha$.

Combinations of real-world ES and results of statistical tests conducted on samples, and their probabilities, are summarized in Table 1. In environmental monitoring programs, the objective should be to minimize both Type I and Type II errors. Type I errors are potentially damaging to proponents (e.g., industry, dischargers), if they have to pay for unnecessary clean-up or remediation. Type II errors are potentially damaging to the environment, if large effects go undetected. Minimizing both Type I and Type II errors maximizes the probability of making correct conclusions about real world effects (Table 1).

Table 1 Outcomes and Their Probabilities for Sample Estimates of Real-World Effects

Sample results	Real-world	
	ES < target ES	ES ≥ target ES
Observed ES not significant	Correct (probability = $1-\alpha$)	Type II error (probability = $1-P = \beta$)
Observed ES significant	Type I error (probability = α)	Correct (probability = P)
NOTE: ES=Effect Size		

P increases with increasing sample size (n), increasing ES (i.e., larger effects are easier to detect), increasing α , and decreasing error variance (i.e., variance unrelated to the effect of

interest). Because α is usually fixed at 5 percent (or 0.05), power analyses usually focus on examining various combinations of n , P , or ES. Beyond $n=10$, variance and sample size are inversely related. Reducing variance by a factor of two, for example, provides the same increase in power as doubling sample size, and is usually considerably less costly and more practical. The emphasis should be on developing better sampling designs, field and laboratory procedures, and statistical analyses that reduce error variances and better estimate real-world effects, rather than on increasing n .

Robustness is also important. Robust results are informative, reliable, repeatable, and potentially applicable to other situations or scenarios (=generality). There is often a trade-off between power for a specific purpose or ES, and information and generality. For example, a basic Control-Impact (CI) design comparing the Study Area to a single Reference may be powerful enough to detect relatively small CI differences (=ES), but only between those two Areas. A regression design with the same overall sample size would provide a poorer estimate and test of that specific CI difference, but would add information on effects at intermediate exposure levels. Similarly, a multiple-reference design would provide a weaker test of the difference between the Study Area and a specific or single Reference, but additional tests or estimates of natural variance among multiple References, and a more robust comparison of the Study Area to Reference Areas in general.

1.2 Sediment Quality Survey

For the sediment quality survey regression and correlation analyses, ES can be expressed as correlations, with ρ representing real-world correlations estimated by observed or sample correlations (or r (or non-parametric equivalents)). ρ^2 is the proportion of variance in Y attributable to variance in X . $1-\rho^2$ is the error variance as a proportion of the total variance in Y .

From a practical or operational perspective, reducing error variance is equivalent to increasing ρ . Real-world effects (or ρ) do not depend on sampling designs, technical methods or data analyses, but those factors affect sample estimates of real-world effects. Suppose that sample or observed $r=0.3$ for Method 1 (e.g., for some design, field method or statistical analysis) and 0.5 for Method 2. Method 2 is more powerful, although both methods estimate the same real-world effect (or ρ). Method 2 may provide a better “picture” or model of reality than Method 1, because it:

- uses a more appropriate statistical model (e.g., an X variable that explains more variance in Y);
- eliminates or reduces some sampling variance (e.g., due to field or laboratory practice) that does not exist in the real world; or
- explains or removes some real natural variance (i.e., some portion of $1-\rho^2$) attributable to factors other than X variables of interest.

1.2.1 Bivariate Regression and Correlation in a Single Year

The relationship between detectable ES or ρ and sample size for $P=95$ percent and $\alpha=0.05$ (or 5 percent) (i.e., with $\alpha=\beta=5$ percent) (left plot), and the relationship between P and n for selected ρ (right plot), are provided in Figure 1. Increasing sample size provides ever-diminishing returns, in terms of reducing detectable ES or increasing P , as illustrated in Figure 1. The curves are asymptotic, with the greatest gains in power (steepest slopes) achieved at small sample sizes.

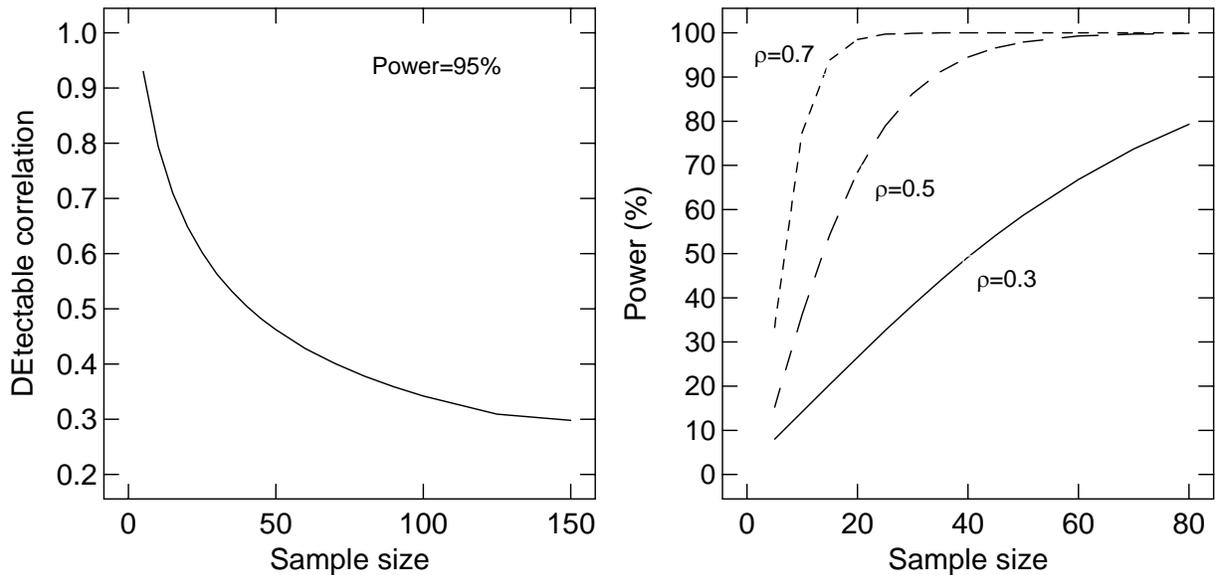


Figure 1 Statistical Power for Analysis of Distance Gradients and Other Correlations (ρ)

With $n \geq 48$ (as for baseline collection and the proposed EEM design), there is a high probability ($P > 99$ percent) that $\rho=0.7$ ($\rho^2 \approx 0.5$) will be detected. In the White Rose baseline survey, r for natural distance gradients and relationships between SQT components were generally < 0.7 . Even at contaminated sites, correlations among SQT components may be < 0.7 (e.g., Green et al. 1993; Green and Montagna 1996).

Prohibitively large sample sizes ($n \geq 80$ stations) would be required to provide a ≥ 80 percent probability of detecting lower ES such as $\rho=0.3$ (Figure 1). With $n \geq 48$, the probability of detecting $\rho=0.3$ is approximately 50 percent (Figure 1, right plot). Correlations of this strength, with X accounting for < 10 percent of the variance in Y , have little predictive or explanatory power, and may be lower than many r for natural distance gradients and correlations among SQT variables.

For any given n , the power of regression or correlation analysis also increases as the variance or range of X values increases. Increasing the variance of X effectively reduces $1-\rho^2$, or explains more of the variance in Y than a narrower range of X values. For example, the observed or sample r based on X values ranging between 1 and 10 is likely to be greater than r based only on X values between 5 and 6. For that reason, stations representing extreme values of X (e.g., distance) may be more “valuable” than stations representing intermediate values. That was the rationale for adding the three near-field stations 250 m of drill centres, which represent extreme

or low distance values (=worst case). The addition of four far-field stations at 28 km also increases power.

1.2.2 Multiple Regression

With multiple X variables in distance regressions, the power curves in Figure 1 shift to the right, because adding variables reduces error degrees of freedom and effective sample size. However, if the effects of the different X variables on Y are relatively independent, error variances will be reduced relative to bivariate regression. ρ or ρ^2 effectively increases, and power may increase for any n . In the White Rose EEM program, including depth in distance regressions should reduce error variances and increase power for analyses of some SQT variables.

1.2.3 Multiple Years

The power curves in Figure 1 also apply to Repeated Measures (RM) regression for multiple years, with Y some combination of single-year values. The power of RM analyses depends on the particular time combination of interest. Power usually increases as the number of years included in the comparison increases. Power will be greater for tests on means than for tests on differences. Power will also be greater for more balanced comparisons (e.g., two EEM or after years versus two other EEM years, as opposed to the mean of all four years versus a single baseline year).

For the first EEM year, regressions of after (EEM) minus before (baseline) values (=before-after (BA) differences) on distance will be of primary interest (see Appendix D). Sample size remains the same as for a single year, because there will be one BA difference for each of the 37 stations sampled in baseline (i.e., $n=37$ not 74). Detectable ES or P for any ES also remain the same. However, those ES represent ρ between BA differences, not single-year values, and X . Baseline, or natural distance gradients, have been removed, so ρ or sample r for BA are better or “purer” measures of effects than single-year correlations. There is less risk that natural correlations for BA (presumably approximately 0) will be misinterpreted as effects (i.e., reliability and robustness increase).

A correlation of differences is also a difference in correlations, although correlations are not strictly additive. Given that:

- natural correlations for BA regressions should be approximately 0; and
- the suggested target ES of $\rho=0.5$ for single years was based on the assumption that natural correlations within years were non-zero.

Target ES should be reduced for BA regressions (e.g., to $\rho=0.3$). Real-world ρ will be lower for BA distance gradients, because BA ρ will be roughly equivalent to EEM ρ minus baseline ρ , at least for ρ between 0.3 and 0.7. However, sample size for BA regressions remains $n=35$, providing insufficient power to detect lower ρ . The variance of a difference between two variables (e.g., before and after) is also the sum of the variance of those two variables, if the

variables are *independent* or uncorrelated. Assuming before and after variances are similar, error variances for BA regressions would be double error variances for a single year. Similar considerations apply to a difference between two *independent* correlations. The error variance of the difference is double the error variance of a single correlation once the correlation(s) have been transformed to a quantity known as z (Sokal and Rohlf 1981). Thus, for any target ES, BA regressions would have less power (higher detectable ES) than single-year regressions, yet target (and real-world) ES would usually be smaller.

The above scenario is a worst case that will never be realized in the White Rose EEM. The key word is *independent*. If the two variables used to calculate a difference are independent, the data should be treated as if a different set of stations were sampled in each year (=re-randomization). Distance gradients or slopes could be compared between years in an ANCOVA, or distance correlations could be compared between years using the test described in Sokal and Rohlf (1981, pp. 587-591). Sample sizes would double, which would at least offset the doubling of error variances.

If there are carry-over effects, or persistent differences among stations unrelated to distance, RM and related approaches should be used. The variance of a difference decreases as the correlation between the two variables used to calculate the difference increases (i.e., as the variables become increasingly less independent).

Results of regression analyses of barium concentrations from the Terra Nova baseline (before) and first EEM (after) years for 33 stations sampled in both years are provided in Table 2. Barium is a major constituent of water-based drilling muds (WBM) used at Terra Nova. The distance measure used was distance from the nearest of four drill centres. Barium concentrations and distance were log-transformed for all analyses.

First, there was a significant baseline barium gradient, with barium decreasing with increasing distance, as there was in the White Rose EEM survey. That distance gradient increased in strength in the EEM year, potential evidence of barium contamination from use of WBM. Error variances were similar in both years. If before and after years are treated as independent, and distance slopes compared in ANCOVA, the difference in distance slopes between years is not significant ($p=0.33$) despite $n=66$. The same p can be obtained by comparing correlations for the two years. The correlation between BA and distance was -0.24, estimated by back-transforming the difference in z between the two years.

Table 2 Example Analyses of Terra Nova Baseline (before) and First EEM Year (after) Barium Concentrations

Model	Error df	Error variance (× 1000)	Distance gradient (r)	p
Before	31	11.9	-0.426	0.013
After	31	10.4	-0.606	<0.001
ANCOVA	62	NA	-0.24 ¹	0.333
BA versus distance	31	7.1	-0.298	0.093
Before as X	30	5.7	-0.479 ²	0.006

Multivariate	30	NA	-0.608 ³	<0.001
<p>NOTES: The first two analyses test within-year concentrations gradients; the last four test for changes in gradients between years. BA = before-after difference in barium concentrations. Barium concentrations and distance log-transformed for all analyses. n=33 stations sampled in both years. NA = Not Applicable (error variance comparable to other analyses difficult to estimate).</p> <p>¹—estimates assume natural BA gradient (<i>r</i>) would be 0. ²—partial correlation between after and distance, with effects of before removed. ³—based on 10:1 after:before weighting.</p> <p>Source: Petro-Canada 2002.</p>				

Carry-over effects were highly significant for barium in this example ($p < 0.001$). The correlation between residuals from distance regressions (i.e., with distance effects removed) for the two years was $r = 0.69$. That r is one of the highest natural correlations observed in the Terra Nova EEM program (except for other carry-over effects and correlations). Consequently, the error variance for a regression of BA differences on distance was lower than the error variances within each year. The sample estimate (r) of the real-world distance gradient or correlation (ρ) was -0.298, somewhat higher than the estimate based on assuming before and after values were independent. Thus, power was increased by reducing error variance and increasing the estimate of ρ . The correlation between BA and distance was not statistically significant ($0.05 < p < 10$), but would be if distances from the two drill centres active at the time were used as X (arguably a more logical model).

When before, or baseline barium concentrations, were used as an additional X variable in multiple regression, p for regression of EEM, or after values on distance, was highly significant ($p = 0.006$; Table 2). Error variance was reduced to approximately half the error variance in either year. The sample estimate of the partial correlation between EEM values and distance (i.e., with the effects of baseline values or carry-over effects removed) was -0.479.

When before and after values were used as multiple Y variables in multivariate regression, results indicated that the change in distance gradients was significant at $p < 0.001$ (Table 2). This analysis suggested that a 10:1 before:after weighting maximized the relationship between the BA difference and distance. Based on that weighting, the correlation between weighted BA and distance increased to -0.61 (similar to r for the EEM year only, which is a 10:0 after:before weighting). The multivariate approach will usually be more powerful and appropriate than other RM alternatives only when $t = 2$ times or years (Green 1993; Tabachnick and Fidell 1989). With $t > 2$ times, multivariate analysis rapidly loses power, and becomes a “fishing expedition” exploring all possible time combinations.

The analyses in Table 2 required less than two hours to conduct, but the RM design and analyses had more power than would re-randomization designs and analyses based on much larger and more costly sample sizes. This is an admittedly extreme example; differences among methods for

analyses, and between RM and re-randomization design, would be smaller for other SQT variables with weaker carry-over effects. However, RM designs and analyses would still be superior to re-randomization designs and analyses for most, if not all, SQT variables.

1.2.4 Multivariate Correlation and Other Methods

Multivariate approaches will usually be more robust and powerful than examining bivariate correlations among SQT variables. For example, Principal Components Analysis (PCA) was used in the baseline survey to derive a single summary measure (effectively a weighted average) of concentrations of 10 frequently detected metals in sediments. Even at uncontaminated sites, metal concentrations will usually be strongly positively correlated. Using a summary measure such as the first Principal Component (PC1) that reflects those correlations increases:

- power (error variances are lower for a weighted mean than for a single variable or metal); and
- generality (i.e., robustness) and efficiency (conclusions based on metal PC1 can be generalized to all metals, without conducting analyses on 10 different variables or metals).

Kendall's Coefficient of Concordance (W), a multivariate correlation, is less powerful than Spearman's rank correlation (r_s) for analysis of correlations between two variables. However, for multiple related variables, W can be more powerful than r_s (depending on how one wants to adjust p or α for analyzing multiple bivariate correlations). A single value of W is also easier to interpret and present than a matrix of bivariate or pair-wise correlations. Paine (1998) showed that testing W among SQT components (chemistry, toxicity, benthic infaunal communities) was as powerful as more complex multivariate approaches suggested by Green et al. (1993) for some sample Vancouver harbour SQT data. The overall status for the 13 stations could be simply expressed by averaging ranks for the three SQT components (or ranking those averages from 1 to 13).

1.3 Commercial Fish

The commercial fish survey data will be analyzed in ANOVA comparing Areas and sometimes Years, or equivalent procedures for analyzing frequencies (e.g., sex ratios or incidence of abnormalities). As noted in Appendix D, two comparisons or contrasts are of primary interest:

- Among References; and
- Study versus Reference.

The power of tests of these two contrasts is considered below. Discussion considers sample sizes of up to five composites for body burden in the Study Area (which would apply to comparison of either the northern or southern portion of the Study Area to Reference Areas) and sample sizes of up to 50 fish for health indices in the Study Area. Planned sample sizes to 10 composites for body burden and 60 fish for health analysis, overall, for the Study Area provide higher power

than that reported below. The power of taste tests is not considered, since that is largely determined by protocols.

For power analysis of fish health indicators and tissue chemistry (body burdens), ES can be standardized by dividing them by the SD within Areas. The Study versus Reference contrast or difference (=CI difference) would be the Study Area mean minus the grand mean of the Reference Area means, divided by the within-Area SD. Overall variance or differences among the four Reference Areas can be expressed using f , a common power index for ANOVA (Cohen 1988). f is the SD among the Reference Area means, divided by the within-Area SD. f can be considered the roughly comparable to the CI difference, since it is the “average” difference between any single Reference Area and the grand mean of the Reference means. General points made for sediment quality for power of analysis of ρ also apply to the CI difference and f , since both can be converted to correlations or ρ (Cohen 1988).

1.3.1 Body Burdens (Tissue Chemistry)

Detectable f and CI differences (=ES) for power (P) of 50 and 95 percent are given in Table 3 for various multiple-reference designs. The ES for $P=50$ percent are also minimum significant differences (MSD), or the smallest observed differences that would be statistically significant at $p \leq 0.05$. The f provided are for an ANOVA comparing the References only (i.e., with the Study Area excluded). Detectable f would be slightly lower if the Among References contrast were tested using the error and error df from an ANOVA comparing all Areas, but power for that contrast is difficult to calculate except by simulation. Detectable CI apply to a test of the Study versus Reference contrast using the error and error df from an ANOVA comparing all Areas.

Table 3 Detectable Effect Sizes (ES) for Analyses of Commercial Fish and Shellfish Body Burdens

Design	No. Ref. Areas	n_R	n_S	Total sample size	Detectable Effect Size (SD units)			
					Among References (f)		Study versus Reference (CI difference)	
					Power=50%	Power=95%	Power=50%	Power=95%
1	4	2	3	11	1.36	2.53	1.49	2.75
2	4	2	4	12	1.36	2.53	1.33	2.46
3	4	2	5	13	1.36	2.53	1.22	2.26
4	4	3	3	15	0.88	1.55	1.37	2.52
5	4	3	4	16	0.88	1.55	1.22	2.24
6	4	3	5	17	0.88	1.55	1.11	2.06
7	3	2	3	9	1.54	3.01	1.61	2.99
8	3	2	4	10	1.54	3.01	1.44	2.67
9	3	2	5	11	1.54	3.01	1.33	2.46
10	3	3	3	12	0.96	1.74	1.45	2.68
11	3	3	4	13	0.96	1.74	1.29	2.39
12	3	3	5	14	0.96	1.74	1.19	2.19
CI	1	5	5	10	Not Applicable		1.41	2.62

NOTES: n_R =no. composites per Reference Area; n_S =no. composites in Study Area
 SD=SD within Areas
 Effect sizes from original submission based on tables in Cohen (1988) were updated using G*Power 3.0.10 (Faul et al. 2007)

In Table 3, ES are provided for designs with Reference sample sizes (n_R) of two or three composites per Area, and Study Area sample sizes (n_S) of three to five composites. ES are provided for three as well as four References, to account for the possibility that one Reference may not provide adequate numbers of American plaice or snow crab, or may not be physically or biologically similar to other Areas (i.e., excluded from analyses). Detectable CI differences are also provided for a basic CI design comparing the Study Area to a single Reference, with $n=5$ composites within each Area. These are the sample sizes used in the Terra Nova EEM CI design.

Detectable f for the comparison among References decrease substantially when n_R increases from two to three (Table 3). With only two composites per Area, detectable f are not much smaller than detectable CI differences. Therefore, the CI difference or Study versus Reference contrast could be statistically significant when differences among References that are not much smaller are not statistically significant. With three composites per Reference Area, detectable f are much smaller than detectable CI differences.

The Study Area sample size (n_S) has no effect on the power of the test of the Among References contrast, except to slightly increase error df from an ANOVA comparing all Areas. Therefore, the “optimal” Study Area sample size for a test of the Among References contrast is 0. However, for a test of the CI difference or Study versus Reference contrast, the optimal allocation is to use approximately equal numbers of Reference and Study Area samples (i.e., $\sum n_R \approx n_S$ or $n_S \approx rn_R$ where r is the number of Reference Areas). Once $\sum n_R \geq n_S$, increasing Reference sample sizes is

not as cost-effective as increasing Study Area sample sizes. For example, Design 4 in Table 3, with three composites per Area and a total of 15 composites, is less powerful for a test of the CI difference than Design 3, with two composites within each Reference Area, five composites within the Study Area, and a total of 13 composites. However, Design 4 provides a much more powerful test of the Among References contrast.

Given that there is a conflict between optimal sampling allocations for the two contrasts of interest, and no *a priori* reason to consider one contrast more important than the other, Design 6 in Table 3, with $n_R=3$ composites in each Reference Area and $n_S=5$ composites in the Study Area, is a reasonable compromise for the White Rose EEM program. That design provides more power for a test of the CI difference than the basic or more traditional CI design with a single Reference, and a more powerful test of natural differences among References than any design with only two composites per Reference Area (Table 3). Sample sizes for Design 6 should be regarded as target sample sizes, since failure to achieve them in every Area should still provide a reasonably powerful test of both spatial contrasts of interest. Larger sample sizes would provide more power, but, assuming that 10 American plaice or snow crab are required per composite, would probably be unachievable or unacceptable in terms of sampling mortality.

If differences among References are large (i.e., $p \leq 0.20$ and especially ≤ 0.05 for the Among References contrast), the one versus many *t* test or a nested ANOVA is appropriate for testing the CI difference or Study versus Reference contrasts (Appendix D). Sample sizes would then be the number of Reference Areas. With only three or four Reference Areas, those tests have little power. The CI or Study versus Reference difference would usually not be statistically significant unless the Study Area mean were outside the range of Reference means, and much larger than the MSD or detectable differences for $P=0.5$ in Table 3. The number of Reference Areas would have to be increased to increase power, which might not be feasible. When there are large differences among multiple references, the statistical significance of the Study versus Reference contrast, however tested, may be of minor interest. Important questions should be:

1. Are one or more Reference Areas inappropriate for comparison to the other Reference Areas and the Study Area?
2. Are Study versus Reference or CI differences (i.e., potential effects), regardless of statistical significance, trivial relative to naturally occurring differences among apparently similar Reference Areas?

When data from multiple (i.e., *t*) EEM years are analyzed in two-way ANOVA with Year and Area as factors, effective sample sizes for tests of consistent spatial differences (e.g., Among References; Study versus Reference) increase by a factor of approximately *t*. In other words, years are an additional form of replication. However, changes in spatial differences or contrasts, particularly the CI difference, over time may be of more interest. These are tests of Year \times Area interactions, and like any tests of differences, will have less power than tests of main effects (Year or Area).

1.3.2 Fish Health Indicators

Detectable ES or f among References and CI differences are provided in Table 4. Designs are the same as those in Table 3 for body burden analysis, with sample sizes multiplied by 10, assuming that 10 American plaice would be required per composite. The ES in Table 4 also apply to analysis of any variable (e.g., size) measured on individual snow crab. Satisfying minimal or recommended sample sizes for body burden analysis should provide more than adequate power for most analyses of fish health indicators and other variables measured on individual American plaice or snow crab. Even if that were not true, further increases in sample sizes would not substantially increase power. With sample sizes of 20 to 50 American plaice or snow crab per Area, and four or five Areas, power curves for f or the CI difference converted to ρ would be towards the right half of the two plots in Figure 1.

Table 4 Detectable Effect Sizes (ES) for Analyses of Commercial Fish Health Indicators

Design	No. Ref. Areas	n_R	n_S	Total sample size	Detectable Effect Size (SD units)			
					Among References (f)		Study versus Reference (CI difference)	
					Power=50 %	Power=95%	Power=50%	Power=95 %
1	4	20	30	110	0.275	0.475	0.423	0.779
2	4	20	40	120	0.275	0.475	0.383	0.704
3	4	20	50	130	0.275	0.475	0.356	0.655
4	4	30	30	150	0.223	0.385	0.403	0.741
5	4	30	40	160	0.223	0.385	0.360	0.662
6	4	30	50	170	0.223	0.385	0.332	0.610
7	3	20	30	90	0.295	0.521	0.443	0.815
8	3	20	40	100	0.295	0.521	0.404	0.743
9	3	20	50	110	0.295	0.521	0.379	0.696
10	3	30	30	120	0.239	0.422	0.417	0.766
11	3	30	40	130	0.239	0.422	0.375	0.690
12	3	30	50	140	0.239	0.422	0.348	0.640
CI	1	50	50	100	Not Applicable		0.396	0.728

NOTES: n_R =no. fish per Reference Area; n_S =no. fish in Study Area
 SD=SD within Areas
 Effect sizes from original submission based on tables in Cohen (1988) were updated using G*Power 3.0.10 (Faul et al. 2007)

All designs in Table 4 provide sufficient power to detect relatively small differences (i.e., $f < 0.3$) among four or three Reference Areas, and reasonable power to detect CI differences. For example, Design 8, with a total of 100 American plaice and a sampling allocation of approximately $\Sigma n_R = n_S$, provides almost as much power for a test of the CI difference as a basic single-reference CI design with the same number of American plaice, *plus* a powerful test of differences among References. Design 6, recommended for body burden analysis, provides a

more powerful test of the CI difference than the single-reference CI design, even if target sample sizes cannot be achieved in every Area (e.g., as in Designs 12 or 5).

As for analysis of body burdens, the one versus many *t* test using Reference Areas as replicates will have less power for a test of the Study versus Reference contrast than tests using individual fish or shellfish within Areas as replicates. The CI difference is unlikely to be significant unless the Study Area mean lies outside the range of Reference means. However, with $n_R \approx 30$ fish within the Reference Areas, the range of Reference means may be narrow when the Among References contrast is significant at $p \leq 0.20$ or even $p \leq 0.05$. For example, the Among References contrast would be significant at $p = 0.05$ if f or the SD among Reference means were 0.20 to 0.25 times the SD within Areas (see values for $P = 0.5$ in Table 4). That would represent a range of Reference means 0.4 to 0.8 times the within-Area SD, since the range is typically two to three times f (Cohen 1988). If the Study Area mean was within that range, one could legitimately question whether any effects were environmentally significant, even if the Study versus Reference or CI difference were statistically significant.

2 Updates to Original Submission

The updates provided below consider whether general statements or conclusions about power and robustness in the original submission were supported by results of EEM from 2004 to 2006. In some cases, issues discussed at length in the original submission were addressed, and in other cases, new issues have emerged based on unexpected results or modifications of the sampling design and statistical analyses conducted.

2.1 Sediment Quality Survey

2.1.1 Bivariate Regression and Correlation in A Single Year

Figure 1 (Section 1.2.1) was updated using values from G*Power 3.0.10 (Faul et al. 2007), which are more accurate than the values in the original submission from Cohen (1988). The updated values represent negligible changes and do not alter any of the statements and conclusions in Section 1.2.1.

Forty-four stations (44) were sampled in every EEM year¹; 49 stations will be sampled regularly as of 2008 with the addition of the North Amethyst drill centre stations. Twelve (12) additional stations were sampled around the proposed NN and SS drill centres in 2004 and 15 additional stations were sampled around the proposed West Alpha and Bravo drill centres in 2006 to provide baseline data if drilling commenced at the proposed drill centre. Station additions increase the power of bivariate regression and correlation analyses. However, the increases in power are minimal (see Section 1.2.1 and Figure 1).

¹ Up to 2008, there were 45 EEM stations, but station S5 could not be sampled in 2005 because of its proximity to a drill rig anchor.

2.1.2 Multiple Regression

In analyses of EEM data, including depth as an X variable in multiple regressions significantly reduced error variance and increased power for detection of distance and other effects for some variables, especially benthic invertebrate community variables. The depth relationships have been consistent over time.

For the 2005 and 2006 EEM programs, threshold (“hockey stick”) regressions were used to define distances or $>C_{10}-C_{21}$ HC concentrations at which background levels were reached (=thresholds). Hockey stick models are non-linear rather than multiple regressions, but similar considerations apply to both. Hockey stick regressions estimate a third parameter (threshold X), in addition to the intercepts and slopes from bivariate regression. Hockey stick regressions have significantly reduced error variances and provided a better description of distance or concentration-response relationships for some variables. The hockey stick regressions are most effective (i.e., powerful and robust) when bivariate relationships are strong (i.e., $r > 0.5$ and especially $r > 0.7$), but have limited power and robustness for weaker bivariate relationships (which may still be statistically significant). From a design perspective, intermediate values of X (e.g., distance) are more important for hockey stick and other curvilinear models than for bivariate linear models, because the intermediate stations define the threshold. Thus, sampling additional stations around proposed drill centres in 2004 and 2006 increased the power and robustness of hockey stick models in those years, because those stations represented intermediate distances from other drill centres (Husky Energy 2007).

2.1.3 Multiple Years

Carry-over effects, or persistent differences among stations unrelated to distance from drill centres, have been significant for sediment quality variables, especially benthic invertebrate community variables, in Repeated Measures (RM) regression models. Thus, the RM approach (i.e., re-sampling the same stations over time) is effective (Section 1.2.3). With one baseline and three EEM years to date, and 37 stations sampled every year and 44 stations sampled every EEM year to 2006, sample sizes are large and the RM regressions are very powerful.

The van Belle test (van Belle and Hughes 1984) was used to examine correlations (Spearman r_s) between benthic invertebrate community variables versus depth and sediment physical and chemical characteristics. The test “blocks” by year (i.e., calculates correlations within each year), then compares those correlations among years. If correlations do not differ among years, the mean correlation over all years is tested. Tests of mean correlations will be more powerful than tests of correlations with all years pooled when there are differences among years common to all or most stations; blocking by year removes those differences. Tests of mean correlations over multiple years are very powerful; effective sample sizes for the Husky Energy EEM program would be greater than those in Figure 1 (Section 1.2.1). Tests of differences in correlations among years are less powerful.

2.1.4 Multivariate Correlation and Other Methods

Principal Components Analysis (PCA) is routinely used to provide summary measures of metal concentrations in sediment (and tissue). Non-Metric Multidimensional Scaling (NMDS) (Clarke 1993), which could be considered a non-parametric analogue of PCA, is used to derive summary measures for benthic invertebrate communities. As noted in Section 1.2.4, these multivariate techniques and summary measures increase power and robustness; they also simplify analysis and presentation.

2.2 Commercial Fish

Snow crab and American plaice are the commercial fish species monitored in the EEM program. For both tissue chemistry (body burden) and fish health analyses, the original submission adopted the conservative approach of assuming that target sample sizes of 10 Study Area body burden composites and 60 fish for health analysis might not be achieved every year, and that all four Reference Areas might not be suitable for comparison to the Study Area. A conservative approach was justified for the original submission; the proposed EEM sample sizes and sampling scale within the Study Area were more extensive than in baseline sampling (2000), and the four Reference Areas had not previously been sampled. In other words, there was no evidence from baseline sampling that target sample sizes, however desirable, were feasible. However, target sample sizes were generally achieved in subsequent EEM years and all four Reference Areas were generally suitable. Therefore, the major focus below is on the power and robustness of analyses for sample sizes that have actually been achieved in EEM years.

2.2.1 Body Burdens (Tissue Chemistry)

Target sample sizes for crab and body burden analyses have been $n_S=10$ composites from the Study Area and $n_R=3$ composites from each of the four Reference Areas (i.e., Design 6 in Table 3, Section 1.3.1, but with 10 rather than 5 Study Area composites). Those targets have been met, except that one or two, rather than three, crab claw composites within one Reference Area were analyzed in crab claws in 2004 and 2005 because few crab were collected. Lipid content was also not measured on some claw composites because of limited sample volume.

Detectable effect sizes (ES) for comparisons of smaller Study Area sample sizes ($n_S=3$ to 5) to the Reference Areas are provided in Table 3 (Section 1.3.1). Table 3 has been updated using values from G*Power 3.0.10 (Faul et al. 2007); the changes have negligible effects on ES and do not alter the statements or conclusions in Section 1.3.1. Detectable ES for the Study Area versus Reference contrast with Study Area sample sizes doubled to $n_S=6$ to 10 (i.e., more realistic and achievable sample sizes) are provided in Table 5. Design 6, which represents target and generally achieved sample sizes, is shaded. Designs 5 and 12 are also shaded and represent realistic scenarios for crab claw composites with a few less Reference or Study Area composites than in Design 6. The other designs represent more conservative scenarios, provided for comparison to Design 6 and also for general comparison of the smaller Study Area sample sizes in Table 3 (Section 1.3.1) to the larger Study Area sample sizes in Table 5.

As expected, tests of the Study versus Reference contrast are more powerful (i.e., detectable ES are reduced by approximately 0.5 SD units) with Study Area sample sizes doubled. Increasing

Study Area sample size also creates more balanced or equal sample sizes for Study versus Reference Area totals, which will also increase power and robustness. Detectable ES for the Study versus Reference Area contrast for larger ($n_S=6$ to 10 composites) versus smaller ($n_S=3$ to 5 composites) are plotted in Figure 2. The designs are ordered from smallest ES (most powerful) to largest ES (least powerful) based on larger sample sizes of 6 to 10 Study Area composites. Design 6, the design used, is the most powerful design. Designs 5 and 12, which reflect the effects of minor reductions in the number of Reference or Study Area composites (e.g., as for crab claws), still provide powerful designs relative to other more conservative designs.

Table 5 Detectable Effect Sizes (ES) for Analyses of Plaice and Crab Body Burdens with 6 to 10 Study Area Composites

Design	No. Ref. Areas	n_R	n_S	Total sample size	Detectable Effect Size (SD Units)	
					Study versus Reference (CI difference)	
					Power=50%	Power=95%
1	4	2	6	14	1.15	2.13
2	4	2	8	16	1.05	1.94
3	4	2	10	18	0.99	1.82
4	4	3	6	18	1.04	1.92
5	4	3	8	20	0.95	1.74
6	4	3	10	22	0.88	1.62
7	3	2	6	12	1.25	2.32
8	3	2	8	14	1.15	2.13
9	3	2	10	16	1.09	2.00
10	3	3	6	15	1.12	2.06
11	3	3	8	17	1.02	1.88
12	3	3	10	19	0.95	1.76
CI	1	5	5	10	1.41	2.62

NOTES: n_R =no. composites per Reference Area; n_S =no. composites in Study Area
 SD=SD within Areas
 —target (and generally achieved) sample sizes (Design 6) plus scenarios with a few less Reference or Study Area composites (Designs 5 and 12)
 Effect sizes for tests of differences Among References are as in Table 3

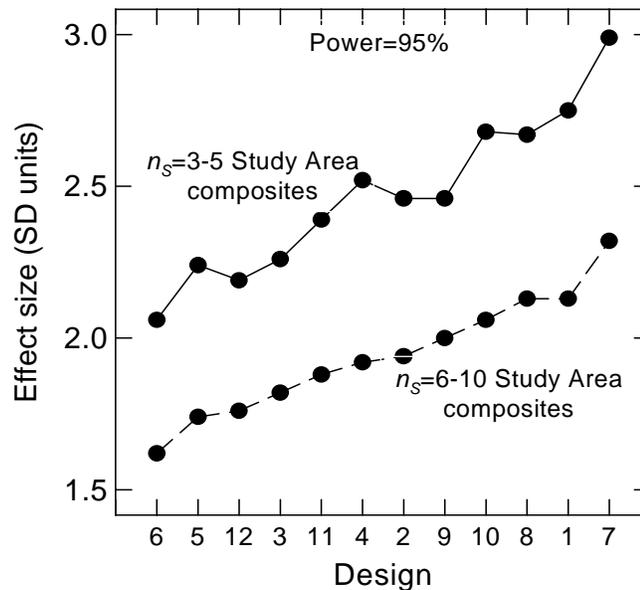


Figure 2. Detectable Effect Sizes for Comparisons of Body Burdens Between the Study versus Reference Areas.

Differences among Reference Areas have been significant at $p \leq 0.25$ and sometimes much lower p for some variables. In those cases, the Study versus Reference contrast is tested using the variance among Reference Areas as the error term. As discussed in Section 1.3.1, those tests have limited power with only four Reference Areas, and Study versus Reference contrasts were rarely significant at $p \leq 0.05$. To address that issue, comparisons have been made over multiple years using a Repeated Measures (RM ANOVA) (Husky Energy 2007). The Reference Areas are the replicates re-sampled over time, and annual Reference Area means are the values analyzed. With multiple years and larger sample sizes, the RM ANOVA will provide powerful tests of the mean Study versus Reference contrast over all years, and can also be used to test for changes over time, including trends, for that contrast (=increased flexibility).

Correlations among body burden variables, and between those variables and biological variables, have also been analyzed. With $n \geq 20$ composites, those correlation analyses should be reasonably powerful (see Section 1.2.1 and Figure 1); increasing the number of composites (i.e., increasing catches) is impractical. The power and robustness of correlation analyses could be increased by using van Belle tests to analyze correlations over multiple years.

2.2.2 Fish Health Indicators

Target sample size for fish health indicators have been 60 fish in the Study Area and 30 fish in each of the Reference Areas.

Detectable ES for comparisons of smaller Study Area sample sizes (i.e., $n_S=30$ to 50 fish) to Reference Areas in Table 4 (Section 1.3.2) were updated using G*Power; the changes were negligible for these large sample sizes. As for body burden analyses, doubling Study Area sample sizes to $n_S=60$ to 100 increases power (reduces detectable ES) for the Study versus Reference contrasts, and results in more balanced sample sizes, especially for Design 4 (the design used) (Table 6; Figure 3). The reductions in detectable ES (approximately 0.1 SD units) for the large fish health sample sizes are much smaller than reductions for the smaller body burden sample sizes (approximately 0.5 SD units), illustrating the general principle that increases in sample size are most effective for smaller sample sizes.

The discussion above and in Section 1.3.2 assumed that all fish within Areas would be pooled for analysis of health indicators, which is true for assessments of haematology, and liver and gill histopathology. However, analyses of mixed function oxygenase (MFO) activity, an important health indicator, are conducted separately on each sex (female, male) \times maturity stage (immature, mature) because MFO levels differ naturally among sexes and maturity stages. As a result, sample sizes within sex-maturity classes are lower than $n_R=30$ fish per Reference Area and $n_S=60$ in the Study Area, reducing power for analysis of MFO activity.

Table 6 Detectable Effect Sizes (ES) for Analyses of Commercial Fish Health Indicators with 60 to 100 Study Area Fish

Design	No. Ref. Areas	n_R	n_S	Total sample size	Detectable Effect Size (SD Units)	
					Study versus Reference (CI difference)	
					Power=50%	Power=95%
1	4	20	60	140	0.337	0.620
2	4	20	80	160	0.312	0.573
3	4	20	100	180	0.296	0.544
4	4	30	60	180	0.312	0.573
5	4	30	80	200	0.284	0.523
6	4	30	100	220	0.267	0.490
7	3	20	60	120	0.361	0.664
8	3	20	80	140	0.337	0.620
9	3	20	100	160	0.322	0.592
10	3	30	60	150	0.329	0.605
11	3	30	80	170	0.303	0.557
12	3	30	100	190	0.286	0.526
CI	1	50	50	100	0.396	0.728

NOTES: n_R =no. fish per Reference Area; n_S =no. fish in Study Area
 SD=SD within Areas
 — current target sample sizes per Area
 Effect sizes for tests of differences Among References are as in Table 3

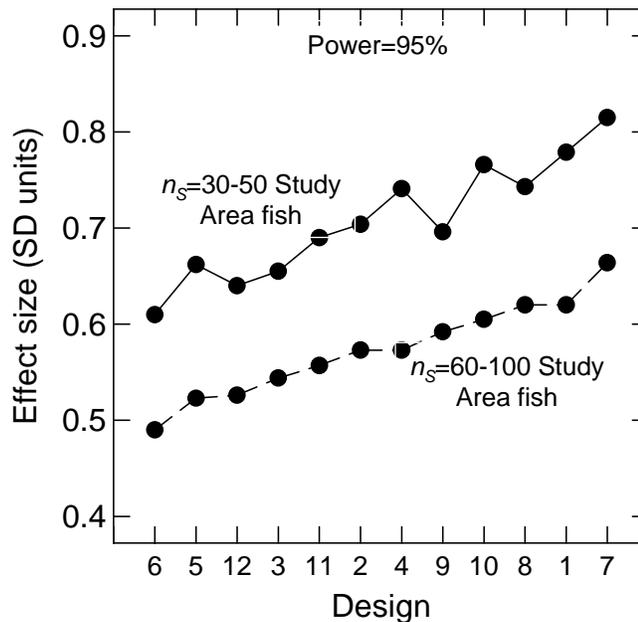


Figure 3. Detectable Effect Sizes for Comparisons of Fish Health Indicators Between the Study versus Reference Areas.

Mature females are the most abundant sex-maturity class, and the most important biologically. Numbers range from 10 to 20 per Reference Area, and 20 to 40 in the Study Area. Figure 4 provides detectable effect sizes for among References and Study versus reference contrasts for $n_R=10-50$ fish per Reference Area. Study Area sample sizes (n_S) are double Reference Area sample sizes (i.e., $n_S=2n_R$). Power is not substantially reduced (i.e., detectable ES are not much larger) for $n_R=20$ versus 30 fish per Reference Area, and increasing sample size beyond $n_R=30$ provides limited gains. However, the difference in detectable ES between $n_R=10$ versus $n_R=20$ is larger than the difference between $n_R=20$ versus $n_R=50$. Therefore, power can be limited for analyses of MFO activity, even for the dominant mature females. Note, however, that when sample sizes are low for mature females, sample sizes will increase for one or more of the other sex-maturity classes (usually immature females), which will increase the power of tests for those classes and the robustness of any comparisons among classes.

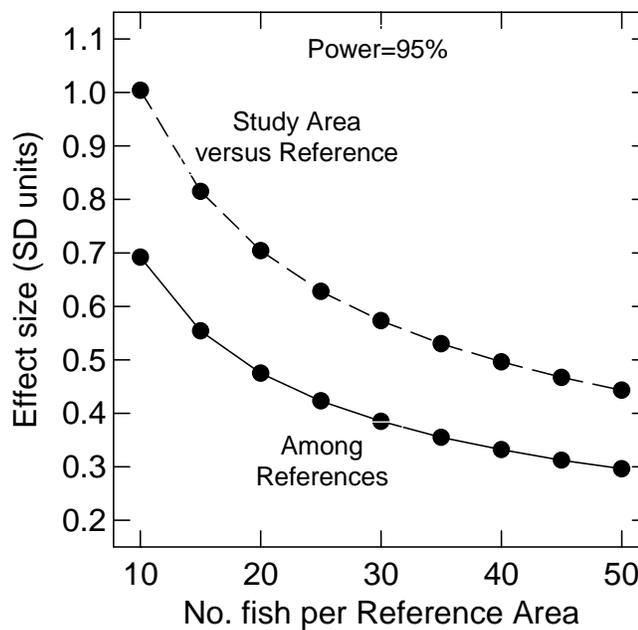


Figure 4. Detectable Effect Sizes for Among References and Study versus Reference Contrasts for $n_R=10-50$ Fish per Reference Area. Note: Study Area Sample Sizes (n_S) Are Double Reference Area Sample Sizes (i.e., $n_S=2n_R$).

Power and robustness of comparisons of frequencies of liver and gill abnormalities between Study versus Reference Areas was not considered in the Section 1.3.2 of the original submission, since these indicators had not been statistically analyzed in baseline. Gross abnormalities have rarely been observed, and frequencies of the more subtle liver and gill abnormalities are usually low (often 0% or near 0%) in all Areas. As a result, analyses are generally restricted to comparisons of Study fish versus pooled Reference Area fish using Fisher’s Exact Test; comparisons among Reference Areas using G (maximum-likelihood; similar to χ^2) tests are rarely made and would not be robust with the low frequencies of most abnormalities.

Detectable ES expressed as numbers and % of affected fish for Fisher’s Exact Test are provided in Table 7 for Reference Area frequencies of 0, 5 and 10%. Except for frequencies of biliary

parasite infections (which are not abnormalities), Reference Area frequencies of affected fish are almost always $\leq 10\%$. Table 7 indicates that when Reference Area frequencies of affected fish are lower than 10% (e.g., 5%), current sample sizes of 60 Study Area fish and 120 Reference Area fish provide high power for detection of Study Area frequencies of 20-30%. Comparisons of Study versus Reference Areas are even more powerful as Reference Area frequencies approach or reach 0, providing high power for detecting Study Area frequencies approaching 10%, despite the low number of fish affected (i.e., <10). Conversely, at higher Reference Area frequencies at or near 10%, only relatively high Study Area frequencies (i.e., $>30\%$) can be detected with confidence.

Table 7 Detectable Effect Sizes (ES) for Analyses of % and Number of Commercial Fish Affected by “Abnormalities”

Tails	Reference Area (<i>n</i> =120 fish)		Study Area (<i>n</i> =60 fish)			
			Power=50%		Power=95%	
	%	No. fish	%	No. fish	%	No. fish
Two	0	0	5	3	12	7
	5	9	15	9	27	16
	10	18	22	13	35	21
One	0	0	5	3	12	7
	5	9	13	8	23	14
	10	18	20	12	32	19

NOTE: Calculations assume that frequencies of affected fish are greater in the Study Area than in the Reference Area

Two-tail tests are appropriate for frequencies of biliary parasite infections, since higher incidences do not necessarily represent negative effects. However, one-tail tests for elevated frequencies in the Study Area (usually considered negative effects) may be more appropriate for other variables, and would increase power. However, as Table 7 shows, increases in power (i.e., reduction in detectable ES) for one- versus two-tail tests are small.

3 References

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Appendix F
GPS Coordinates of EEM Sediment Stations and Distance to Drill Centers

Station	Easting UTM (NAD83)	Northing UTM (NAD83)	Distance (km) from Drill Centres				
			N	C	S	NA	Nearest
1	728436.36	5187144.12	8.08	3.03	3.15	7.52	3.03
2	729823.51	5188621.85	7.86	4.95	4.88	9.49	4.88
3	731868.72	5190785.92	8.46	7.86	7.69	12.42	7.69
4	746787.66	5206806.03	26.19	29.67	29.39	34.22	26.19
5	729768.87	5186492.52	9.39	4.17	2.92	7.72	2.92
6	731767.00	5186568.85	10.68	6.17	4.36	9.17	4.36
7	737768.87	5186492.52	15.63	12.15	9.84	14.21	9.84
8	728457.98	5185685.16	9.35	2.85	1.70	6.28	1.70
9	729839.69	5184237.92	11.29	4.57	1.61	6.20	1.61
10	731906.33	5182066.52	14.23	7.41	4.14	7.20	4.14
11	740224.61	5173383.12	26.16	19.30	16.00	16.93	16.00
12	747030.49	5166232.75	36.00	29.14	25.85	26.37	25.85
13	727834.64	5184425.08	10.22	2.72	0.59	4.89	0.59
14	727912.97	5182365.06	12.18	4.30	1.67	3.55	1.67
15	728146.12	5176433.04	17.95	9.90	7.57	5.24	5.24
16	727072.34	5185666.32	8.79	1.49	2.04	5.59	1.49
17	725699.77	5184198.36	9.85	1.81	2.56	3.76	1.81
18	723666.28	5182025.45	11.88	4.44	4.99	1.93	1.93
19	708735.67	5166017.32	31.79	26.17	26.54	21.70	21.70
20	725772.67	5186341.88	7.76	0.37	3.41	5.88	0.37
21	723752.16	5186266.73	7.64	1.89	5.04	5.85	1.89
22	717740.00	5186034.47	10.05	7.89	10.71	9.01	7.89
23	727073.01	5187136.89	7.43	1.84	3.35	6.97	1.84
24	725683.95	5188599.44	5.56	2.60	5.27	8.11	2.60
25	723613.62	5190743.51	3.18	5.15	8.18	10.30	3.18
26	715355.48	5199436.03	10.27	16.91	20.11	21.17	10.27
27	708497.81	5206585.08	20.03	26.77	30.00	30.78	20.03
28	727684.94	5188396.60	6.62	3.16	4.43	8.36	3.16
29	727609.01	5190410.09	5.02	4.83	6.44	10.25	4.83
30	727450.25	5194601.93	3.52	8.79	10.63	14.31	3.52
31	727366.46	5196401.29	4.19	10.54	12.43	16.07	4.19
C1	726525.21	5185301.72	8.96	1.14	2.16	5.05	1.14
C2	725418.95	5185196.55	8.82	0.83	3.07	4.70	0.83
C3	724888.01	5186034.29	7.92	0.74	3.93	5.51	0.74
C4	725255.13	5186847.85	7.16	0.92	4.13	6.33	0.92
C5	725953.32	5186002.68	8.26	0.30	3.01	5.43	0.30
N1	724873.45	5191902.53	2.18	5.95	8.59	11.38	2.18
N2	723224.27	5192630.34	1.49	7.05	9.99	12.22	1.49
N3	723583.34	5193429.31	0.63	7.70	10.52	12.97	0.63
N4	723995.37	5194198.06	0.30	8.35	11.04	13.70	0.30
NA1	725162.00	5180525.00	13.43	5.50	4.65	0.29	0.29
NA2	724862.00	5180025.00	13.90	6.03	5.22	0.50	0.50
NA3	724112.00	5180525.00	13.38	5.69	5.40	0.76	0.76
NA4	724862.00	5181524.00	12.41	4.55	4.20	1.00	1.00
S1	728606.12	5183516.99	11.36	3.88	0.60	4.78	0.60
S2	727607.40	5183482.58	11.02	3.21	0.83	4.03	0.83
S3	727548.74	5185213.97	9.38	2.08	1.40	5.40	1.40
S4	729080.22	5184401.12	10.77	3.81	0.92	5.72	0.92
S5	727935.31	5183994.08	10.62	3.04	0.32	4.65	0.32

Appendix G
Quality Assurance / Quality Control

Quality Assurance/Quality Control

Quality assurance (QA) can be defined as a "set of operating principles that, if strictly followed during sample collection and analysis, will produce data of known and defensible quality whose analytical accuracy can be stated with a high level of accuracy" (APHA 1992). QA is comprised of two separate but interrelated activities: quality control and quality assessment (NRC 1990).

Quality control (QC) will ensure that the data collected will be of adequate quality. QC activities will include standardized protocols for sample collection and processing. The goals of QC are to ensure that: sampling, processing and analysis techniques are consistent; data are comparable with similar data collected elsewhere; and study results can be reproduced (NRC 1990). The following are specific QA/QC methods that will be instituted for the White Rose EEM Program.

Sample Station Location

Accurate positioning is essential to ensuring that stations can be plotted and reoccupied with a high degree of certainty. All locations will be fixed by Differential Geographical Positioning Systems (DGPS). All personnel using such devices will be trained in their proper use, care and limitations.

Sample Handling

- All stages of sampling handling will be carefully documented to ensure sample handling requirements are sustained to minimize against errors in collection, shipping and analyses of the samples.
- SOPs will be used to ensure all field personnel activities are conducted in the same manner regardless of the actual person conducting the activity.
- Sample programs will maintain integrity of sample from time of collection to data reporting. Chain of custody procedures ensure all the possession and handling of samples can be traced from collection to final disposition.
- Sample labels will be waterproof and securely fastened and contain the following information:
 - sample identification (identifier),
 - preservation technique,
 - date/time of collection,
 - location (depth and by identifier),
 - collectors ID, and
 - sample analysis required.
- Chain of custody forms will be filled out with information from the sample label and will accompany every sample shipped to a laboratory or consultant for analysis with each person who has custody signing off to ensure sample traceability.

- Shipment manifests will accompany every sample shipped to a laboratory or consultant for analysis with the consigner and consignee signing off on the shipment.

Sample Shipment

- All samples will be shipped in such a manner to ensure that the samples are received at the appropriate destination (labs) within an acceptable holding time.
- Shipping containers will be in good shape and capable of handling rough treatment.
- Samples will be tightly packed:
 - dividers will separate glass; and
 - empty spaces will be filled so jars are secure.
 - leak-proof containers will be used wherever appropriate.
 - sample request form and/or chain of custody forms will accompany all samples.

A chain of custody form will be filled out for each shipment. The original chain of custody will be placed inside shipping container in such a manner that it is protected and than can serve as a sample request form.

- A copy of the chain of custody form will be retained by shipper.
- Shipping containers will be sent by a courier who will provide a delivery slip.
 - This will serve as a backup to the chain of custody.
 - This will confirm that the laboratory received the samples.
- All shipping charges will be prepaid to avoid rejection of shipment by consigner.

Laboratory Analysis

- The laboratory will provide proof of membership (in good standing) in CAEAL or be an recognized expert (benthic analysis) upon request.
- The laboratory will have an acceptable quality assurance/quality control program in place.
- The laboratory will have in place a corporate Safety and Environmental Protection Policies and Procedures.
- The laboratory will be suitably equipped to meet the analytical requirements for the analyses undertaken.
- The laboratory will assign a specific staff member who will be responsible for the project and will act as liaison person with the client in terms of delivery of results, quality control of results and overall activities of the laboratory. This person will be responsible for
 - sample reception,
 - maintenance of chain of custody,
 - maintenance of sample tracking logs,
 - distribution of samples for laboratory analyses,
 - subcontracting samples to other facilities,
 - supervision of labelling, log keeping, data reduction, and data transcription, and

- storage and security of all samples, data and documents.
- The laboratory will provide all necessary forms and documentation required for sample submission.
- The laboratory will notify the client of inconsistencies between labels and sample request forms (Chain of Custody Forms).
- Prior to initiation of testing, all parameters will be confirmed with the client.
- Data transfer will be submitted by faxed results and by hard copy in mail and electronically.
- The client will not pay for samples that must be reanalyzed due to laboratory error.
- Originals of the following documents will be sent to the client
 - chain of custody forms,
 - data report sheets, and
 - QA/QC control records and reports.

Analytical Laboratory

- The laboratory will be required to analyze samples on a 10 percent replicate basis or one replicate per batch, whichever is more frequent.
- Where available, Certified Reference Material (CRMs) will be run along side each batch of samples.
- The laboratory will provide appropriate QA/QC reports or data for each set of samples analyzed.
- The reported data will include results of laboratory duplicates, reference samples, method blanks, and spike recovery. The laboratory will provide validation of these QA/QC data to demonstrate their acceptability.

Toxicological Laboratory

- The toxicity results will be provided within two weeks of test conclusion. A full report will include bench data and related reference toxicant data. These assays will be conducted as per procedures outlined in Environment Canada (1992a; 1992b; 1992c).
- Where available, reference toxicants will be run along side each batch of samples.
- The laboratory will provide full references for all methods used.

Benthic Invertebrate Analysis Laboratory

Data Management

Data management involves a number of systematic processes and protocols that are designed to provide a framework for providing quality environmental data with a high degree of credibility. The major components for a data management system used for environmental programs will include or consider items such as:

- data documentation (computer programs, and statistical, normalization and error control procedures);
- data recording (laboratory reports, field notebooks, field maps and auxiliary data records);
- data custody and transfer (chain of custody records, QA/QC procedures for authorizing changes to data, QA/QC documentation of transfer formats, data recording forms, and data verification and validation);
- data validation (data identification, transmittal errors, flagged or rejected data, data comparability, and data review and evaluation);
- data verification (sample results reported and checked for transmission errors, sample labels verified, cross-referencing field data sheets and laboratory results, data review, flagging and screening);
- data presentation (tables, graphs and figures); and
- data storage (digital format and hard copy).

Appendix H

Sediment Chemistry Methods Summaries

METHOD SUMMARY

Title: Volatile Petroleum Hydrocarbons in Soil/Sediment

SOP #: 9110/9210

Reference: Atlantic PIRI Guidelines for Laboratories, Draft 1.0, 1999

Effective Date: January 17, 1996

Revision Date: June, 2000

1. Scope and Application

This method is designed for the extraction and analysis of volatile petroleum hydrocarbons, including benzene, toluene, ethylbenzene, o-xylene, m-xylene, p-xylene (BTEX), and gasoline range organics (C6-C10) in soils and sediments. The reporting limit is 0.025 mg/kg for benzene, toluene and ethyl benzene, 0.05 mg/kg for total xylenes, and 2.5 mg/kg for gasoline. Low level benzene and ethylbenzene reporting limits are 0.005 mg/kg, and 0.01 mg/kg respectively.

This method is used in conjunction with SOP # 9015, "Total Extractable Hydrocarbons (>C10 – <C32) in Soil" to quantify Total Petroleum Hydrocarbons (C6 – <C32) in a sample.

2. Summary of Method

A 10 gram portion of wet soil or sediment is extracted by shaking with methanol. An aliquot of the methanol extract is diluted into water and analyzed by purge and trap-gas chromatography/mass spectrometry (GC/MS) or headspace-gas chromatography with flame-ionization and photo-ionization detection (GC-FID-PID). A surrogate standard (isobutyl benzene) is added to the sample to monitor instrument performance.

The instrumentation is calibrated weekly with multi-component standards of known concentration. Calibration accuracy is verified with independent reference standards of BTEX and gasoline. The day-to-day stability of the calibration is confirmed by analyzing calibration check solutions with each batch of samples. Components in the samples are identified using retention time criteria, and/or through verification of mass spectral fit. After detection, the individual peaks are integrated and quantified. The wet weight concentrations are converted to a dry weight basis using the moisture content of the sample obtained by gravimetric analysis.

3. Quality Assurance

A method blank, spiked blanks (BTEX and gasoline), matrix spike (gasoline-spiked onto a soil sample), and a replicate sample are analyzed with each batch of twenty samples. The spiked blank QC results are control charted and must meet specific acceptance criteria before sample results are released.

METHOD SUMMARY

Title: Mercury in Soils and Sediments

SOP #: 3420

Reference: USEPA Method 245.5

Effective Date: March, 1999

1. Scope and Application

This method is designed for the digestion and analysis of total mercury in soil and sediment samples as referenced in EPA Method 245.5. The EQL for this procedure is 0.01 mg/kg based on an initial soil dry weight of 0.3 grams.

2. Summary of Method

Approximately 0.3 grams of air dried and sieved sample is accurately measured for analysis. Sulphuric acid and nitric acid are added to the samples. The samples are then digested @ 95 °C. After cooling, an excess of potassium permanganate is added to ensure that the mercury remains in an oxidized state. Excess potassium permanganate is destroyed with hydroxylamine hydrochloride. All prepared solutions are analyzed for mercury by CVAAS with a Leeman PS200 Mercury Analyzer. The solutions are mixed with stannous chloride which reduces the mercury to its atomic state. The mercury vapour is pumped into the gas/liquid separator where it is removed from solution using nitrogen. The vapour is then swept into the absorption cell. The instrument signal (absorbance) is proportional to the concentration of mercury in the sample. Digested standards are used for daily calibration, and additional standards are used to monitor instrument drift.

3. Quality Assurance

Reagent blanks, duplicates, reference materials and method spikes are prepared and analyzed in the same manner as mentioned above for the samples. One reagent blank, one duplicate, one spike and one reference material (MESS-2) is analyzed for every 20 samples with a minimum of one per batch. A total QC effort of 10% should be maintained.

METHOD SUMMARY

Title: Low Level Extractable Hydrocarbons (>C₁₀-C₃₂) in Sediment

SOP #: 9016

Reference: Atlantic PIRI Guidelines for Laboratories, Draft 1.0, 1999

Effective Date: May 2001

Revision Date: March 25, 2002

1. Scope and Application

This method is designed for the extraction and analysis of petroleum hydrocarbons, including diesel range organics (>C₁₀-C₂₁) and lubricating oils (>C₂₁-C₃₂) in sediments. The reporting limits are as follows: Diesel Range (>C₁₀-C₂₁) – 0.25 mg/kg; Lubricating Oil Range (>C₂₁-C₃₂) – 0.25 mg/kg.

2. Summary of Method

A 10 gram portion of wet sediment is weighed out and spiked with two surrogate compounds (isobutylbenzene and n-dotriacontane). These compounds represent a range of volatilities and are used to monitor the efficiency of the sample preparation. The sample is extracted by vigorous shaking with 50:50 (v/v) Acetone: hexane. The extract is partitioned with the addition of water, and non-petrogenic compounds are removed from the resulting hexane extract using silica gel. The extract is then concentrated and analyzed by capillary column gas chromatography with split/splitless injection and flame ionization detection (GC-FID).

Characterization and quantitation of the sample components are obtained by comparing instrumental responses with those of prepared multi-component standards. Calibration accuracy is verified by analyzing independent reference standards. The day-to-day stability of the calibration is confirmed by analyzing calibration check solutions with each batch of samples. The wet weight concentrations are converted to a dry weight basis using the moisture content of the sample obtained by gravimetric analysis.

3. Quality Assurance

Sample duplicates, process spikes, matrix spikes, and method blanks are prepared and analyzed with each batch of 40 samples. Process and matrix spikes are fortified with known concentrations of transformer oil.

METHOD SUMMARY

Title: Low Level Total Extractable Hydrocarbons (>C₁₀-C₃₂) in Soil and Sediment

SOP #: 9028

Reference: Atlantic PIRI Guidelines for Laboratories, Draft 1.0, 1999.

Effective Date: May 18, 2001

Revision Date: na

1. Scope and Application

This method is designed for the extraction and analysis of petroleum hydrocarbons (>C₁₀-C₃₂) in soils and sediments. This method is most commonly used for the evaluation of offshore sediment samples to detect and quantify contamination of drilling fluid and other petroleum hydrocarbons related to offshore drilling operations.

2. Summary of Method

A 10 gram sediment sample aliquot is spiked with a surrogate (n-dotriacontane) and extracted by vigorous shaking with acetone:hexane. The surrogate is used to monitor the efficiency of the sample preparation steps. The solvent extract is partitioned by the addition of water. A portion of the hexane is recovered, cleaned on a silica-gel micro column, concentrated and analyzed by capillary gas chromatography with flame ionization detection (GC-FID).

Characterization and quantitation of sample components are obtained by comparing instrumental responses with those of prepared multi-component standards. Calibration accuracy is verified by analyzing an independent reference standard. The day-to-day stability of the calibration is confirmed by analyzing calibration check standards with each batch of samples. Sample products are identified by comparison to a library of reference products. Petroleum hydrocarbons are reported on a dry weight basis in three carbon ranges: >C₁₀-C₁₃, >C₁₃-C₂₁ and >C₂₁-C₃₂. The Estimated quantitation limit (EQL) is 0.25 mg/kg for each carbon range.

3. Quality Assurance

Method blanks, spiked blanks (transformer oil), matrix spikes (transformer oil spiked onto soil samples), and replicate samples are analyzed with each batch of twenty samples. The spiked blank QC results are control charted and must meet specific acceptance criteria before sample results are released.

METHOD SUMMARY

Title: Polycyclic Aromatic Hydrocarbons in Soils and Sediments

SOP #: 7010

Reference: USEPA Method 8270C

Effective Date: January, 1997 **Revision Date:** June, 2000

1. Scope and Application

This method is applicable to the determination of polycyclic aromatic hydrocarbons (PAHs) in soils and sediments with a reporting limit of 0.05 mg/kg. The following compounds are routinely determined:

Analyte	Analyte
Naphthalene	Benz[<i>a</i>]anthracene
1-Methylnaphthalene	Chrysene
2-Methylnaphthalene	Benzo[<i>b</i>]fluoranthene
Acenaphthylene	Benzo[<i>k</i>]fluoranthene
Acenaphthene	Benzo[<i>a</i>]pyrene
Fluorene	Perylene
Phenanthrene	Indeno[<i>1,2,3-cd</i>]pyrene
Anthracene	Dibenz[<i>a,h</i>]anthracene
Fluoranthene	Benzo[<i>ghi</i>]perylene
Pyrene	

Other PAHs can be analyzed by this method provided appropriate standards are available.

2. Summary of Method

A representative 5 gram portion of wet soil or sediment is weighed out and spiked with 4 deuterated surrogate PAH compounds. These compounds are used to monitor the efficiency of the sample preparation steps. The sample is extracted for 30 minutes by vigorous shaking with a mixture of 50:50 (v:v) acetone:hexane. The hexane is partitioned from the acetone by the addition of organic free water. If required, interfering compounds are removed using a silica gel solid phase extraction (SPE) clean-up procedure. The extract is analyzed by capillary gas chromatography/mass spectrometry (GC/MS) using selected ion monitoring mode.

The GC/MS system is calibrated with PAH standards of known concentration. Calibration curves are prepared by integrating the areas of target ions of the individual PAH peaks obtained during the calibration runs. Calibration accuracy is verified by analyzing an independent reference standard. The day-to-day stability of the calibration is confirmed by analyzing calibration check standards with each batch of samples. The components in the samples are identified using retention time criteria and qualifier ion ratios. After being detected, the individual peaks are integrated and quantified. The wet weight concentrations for each sample are converted to dry weight concentrations using the sample percent moisture value. The percent moisture of each sample is determined separately by gravimetric analysis.

3. Quality Assurance

A method blank, spiked blanks (each individual PAH), matrix spike (each PAH spiked onto a soil sample), and a replicate sample are analyzed with each batch of twenty samples. The spiked blank QC results are control charted and must meet specific acceptance criteria before sample results are released.

METHOD SUMMARY

Title: Total Sulphur in Rock, Soil and Sediment

SOP #: 4075

Reference: ASTM E1915-97 / LECO Application # 203-601-222

Effective Date: August, 1998

Revision Date: August, 1998

1. Scope and Application

This method is applicable for the analysis of total sulphur in homogeneous, dried rock, soil and sediment samples. The LOQ is 0.01% (dry weight) based on the combustion of a 350 mg sample.

2. Summary of Method (Combustion / IR Detector)

The sample is dried at a temperature of 105C for a minimum of 1 hour. The dried sample is then ground/pulverized and sieved to -200 Mesh. A 0.2g to 0.5g aliquot of dried, homogeneous sample is combusted in a LECO induction furnace. The sulphur present in the sample is oxidized to SO₂ which is swept downstream to an infra-red detection system.

3. Quality Assurance

Quality control effort includes the analysis of reference materials specific to the matrix being analyzed (eg, NIST 638 for limestone and cement, RTS-1 for waste rock and tailings, STSD-3 for sediment) and duplicates.

METHOD SUMMARY

Title: Total Carbon / Organic Carbon in Soils and Sediments

SOP #: 4055

Reference: Total Carbon and Organic Carbon in Sludges - LECO

Effective Date: January, 1995 **Revision Date:** July, 1997

1. Scope and Application

This method is designed for the analysis of total carbon and organic carbon in soil and sediment samples by LECO EC-12 Carbon Analyzer as referenced in Application #130 from LECO Equipment Corp. The LOQ for this procedure is 0.1 %.

2. Summary of Method

A known quantity of air dried and sieved sample is introduced into the instrument with the addition of copper accelerator. An induction furnace releases all carbon in the sample as CO₂ which is swept away with the sparging gas. The CO₂ is then scrubbed out of the gas stream and quantified at the detector as total carbon.

Organic carbon is measured by pre-treating the sample in order to remove the inorganic carbon. The sample is digested with hydrochloric acid in order to drive off all carbonates, then dried prior to the above analysis.

3. Quality Assurance

A minimum of one reagent blank, one duplicate and one certified reference material (usually MESS-1) is analyzed for each set of samples. A total QC effort of 10 % should be maintained.

METHOD SUMMARY

Title: Total Trace Metals in Soils and Sediments

SOP #: #3010 / #4079

Reference: USEPA Method 3052 and Method 200.8

Effective Date: August, 1995

Revision Date: June, 1998

1. Scope and Application

This method is designed for the digestion and analysis of total trace metals in soil and sediment samples. Analytes and their routine LOQs are listed below:

Analyte	LOQ (mg/kg)	Analyte	LOQ (mg/kg)
Aluminum	10	Manganese	2
Antimony	2	Molybdenum	2
Arsenic	2	Nickel	2
Barium	5	Selenium	2
Beryllium	5	Silver	n/a
Boron	n/a	Strontium	5
Cadmium	0.3	Thallium	0.1
Chromium	2	Tin	2
Cobalt	1	Uranium	0.1
Copper	2	Vanadium	2
Iron	20	Zinc	2
Lead	0.5		

2. Summary of Method

A 0.500 gram portion of the air-dried sieved sample is accurately weighed for analysis. An acid mixture (HClO₄: HNO₃: HF) is added, and the samples are slowly heated to dryness. The samples are then cooled, and HCl and HNO₃ are added. After gentle warming, reagent grade water is added and the digestion cycle is completed. The samples are cooled and made to volume with reagent grade water. All samples are then diluted prior to analysis using a Sciex/Perkin Elmer Elan 5000 ICP-MS in accordance with EPA Method 200.8.

3. Quality Assurance

Reagent blanks, certified reference materials, and method spikes are prepared and analyzed in the exact same fashion as mentioned above for the samples. A minimum of one reagent blank and two different certified sediment reference materials (usually MESS-2 and BCSS-1) are prepared and analyzed with every 20 samples. Spiking of samples at a level appropriate to the matrix is performed at a frequency of 10%. Duplicate digestion and analysis of samples is also performed at a frequency of 10%.

Appendix I
Sediment Particle Size Method Summary



1.0 PURPOSE AND SCOPE

To determine particle size distribution in a soil from gravel sizes to the clay size by the pipette method.

This work instruction is applicable to all samples of construction aggregates and soils for which grain size distribution determination by the pipette test is required or requested by the client.

2.0 METHOD

The pipette test will be carried out in general accordance with BS 1377, Part 2.

Testing will include duplicate analysis of samples when deemed appropriate by the Project Officer. The results of the duplicate analysis shall be reviewed by the Project Officer and any difference greater than deemed acceptable by the Project Officer shall be documented.

3.0 DOCUMENTATION

The test results shall be recorded and submitted to the Project Officer on the appropriate report form. The results are reviewed and a computer generated report is prepared for delivery to the client. A sample report is attached for reference.

[MA101 Aggregate Mechanical Sieve Analysis](#)

[MA111 Grain Size Distribution by Pipette Method Laboratory Sheet](#)

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Appendix J
Body Burden Methods Summaries

METHOD SUMMARY

Title: Mercury in Biota Materials

SOP #: 3420

Reference: USEPA Method 245.6

Effective Date: March, 1999

Revised: October, 1999

1. Scope and Application

This method is designed for the digestion and analysis of total mercury in biota samples as referenced in EPA Method 245.6. The EQL for this procedure is 0.01 mg/kg based on an initial soil dry weight of 0.3 grams.

2. Summary of Method

Approximately 0.3 grams of homogenized biota sample is accurately weighed for analysis. Sulphuric acid and nitric acid are added to the sample and it is digested at 58 °C for 30-60 minutes. After cooling in an ice bath (4 °C), an excess of potassium permanganate is added to ensure that the mercury remains in an oxidized state. Potassium persulphate is added and the digests are allowed to stand overnight. Excess potassium permanganate is destroyed with hydroxylamine hydrochloride. All prepared solutions are analyzed for mercury by CVAAS with a Leeman PS200 Mercury Analyzer. The solutions are mixed with stannous chloride which reduces the mercury to its atomic state. The mercury vapour is pumped into the gas/liquid separator where it is removed from solution using nitrogen. The vapour is then swept into the absorption cell. The instrument signal (absorbance) is proportional to the concentration of mercury in the sample. Digested standards are used for daily calibration, and additional standards are used to monitor instrument drift.

Alternatively, the biota samples are dried to constant weight and then digested. Percent moisture is determined on a second portion of the sample.

3. Quality Assurance

Reagent blanks, duplicates, reference materials and method spikes are prepared and analyzed in the same manner as mentioned above for the samples. One reagent blank, one duplicate, one spike and one reference material (e.g. DOLT-2 or DORM-2) is analyzed for every 20 samples with a minimum of one per batch. A total QC effort of 10% should be maintained.



METHOD SUMMARY

Title: Moisture Content

SOP #: 4003

Reference: Handbook of Analytical Method for Environmental Samples, Vol. 1

Effective Date: November, 1995

Revision Date: July, 1997

1. Scope and Application

This method is applicable to the determination of percent moisture in soil, sediments and biota materials. The EQL for this method is 0.5%.

2. Summary of Method

Approximately 1 to 5 grams of homogenized sample is placed into a preweighed labeled aluminum weighing dish. The weight of the wet soil and the aluminum dish is determined using a top loading balance. The samples are placed in the oven at 110°C for two hours. The samples are removed from the oven, re-weighed and the percent moisture is calculated.

3. Quality Assurance

Samples are analyzed in duplicate at a rate of 10 percent.

METHOD SUMMARY

Title: Polycyclic Aromatic Hydrocarbons in Fish and Shellfish

SOP #: 7030

Reference: Based on USEPA Method 8270A

Effective Date: January 1996 **Revision Date:** August, 2001

1. Scope and Application

This method is applicable to the determination of polycyclic aromatic hydrocarbons (PAHs) in tissues samples with EQLs of 0.05 mg/Kg on a wet weight basis. The following compounds are routinely determined:

Analyte	Analyte
Naphthalene	Benz[<i>a</i>]anthracene
1-Methylnaphthalene	Chrysene
2-Methylnaphthalene	Benzo[<i>b</i>]fluoranthene
Acenaphthylene	Benzo[<i>k</i>]fluoranthene
Acenaphthene	Benzo[<i>a</i>]pyrene
Fluorene	Perylene
Phenanthrene	Indeno[<i>1,2,3-cd</i>]pyrene
Anthracene	Dibenz[<i>a,h</i>]anthracene
Fluoranthene	Benzo[<i>ghi</i>]perylene
Pyrene	

Other PAHs can be analyzed by this method provided appropriate standards are available.

2. Summary of Method

The tissue is homogenized in a blender and a 5 g portion is weighed out and spiked with 4 deuterated surrogate PAH compounds (these compounds represent a range of volatilities and are used to monitor the efficiency of the sample preparation steps). The sample is saponified with ethanolic KOH and then extracted with hexane. An aliquot of the extract is removed and interfering compounds are eliminated using a silica gel column clean-up procedure. The extract is then solvent exchanged into isooctane and analyzed by gas chromatography/mass spectrometry (GC/MS) using selected ion monitoring mode.

The GC/MS system is calibrated with PAH standards of known concentration. Calibration curves are prepared by integrating the areas of target ions of the individual PAH peaks obtained during the calibration runs. Calibration accuracy is verified by analyzing an independent reference standard. The day-to-day stability of the calibration is confirmed by analyzing calibration check standards with each batch of samples. The components in the samples are identified using retention time criteria and qualifier ion ratios. After being detected, the individual peaks are integrated and quantified.

3. Quality Assurance

A method blank, spiked blanks (each individual PAH), matrix spike (each PAH spiked onto a tissue sample), and a replicate sample are analyzed with each batch of twenty samples. The spiked blank QC results are control charted and must meet specific acceptance criteria before sample results are released.

METHOD SUMMARY

Title: Total Extractable Hydrocarbons (>C₁₀-C₃₂) in Fish and Shellfish

SOP #: Draft

Reference:

Effective Date: September 2001

Revision Date: February, 2003

1. Scope and Application

This method is designed for the extraction and analysis of petroleum hydrocarbons, including diesel range organics (>C₁₀-C₂₁) and lubricating oils (>C₂₁-C₃₂) in tissues and biota. The EQLs are as follows: >C₁₀-C₂₁ (15 mg/Kg) and >C₂₁-C₃₂ (15 mg/Kg) and are on a wet weight basis.

2. Summary of Method

The tissue is homogenized in blender and a 5 g portion is weighed out and spiked with a surrogate compound (n-dotriacontane). This compound is used to monitor the efficiency of the sample preparation steps. The sample is saponified with ethanolic KOH at 60⁰C. It is then extracted with hexane. An aliquot of the extract is removed and interfering compounds are eliminated using a silica gel column clean-up procedure. The extract is then solvent exchanged into isooctane and analyzed by gas chromatography with flame ionization detection.

The GC-FID system is calibrated with multi-component standards of known concentration which elute in the >C₁₀ – C₃₂ range. A calibration curve is generated for each carbon range (>C₁₀ - C₂₁ and >C₂₁ – C₃₂) using the response factor of the compounds that elute in each range. Calibration accuracy is verified by analyzing an independent reference standard. The day-to-day stability of the calibration is confirmed by analyzing calibration check standards with each batch of samples. Sample products are identified by comparing each product to a library of reference products.

3. Quality Assurance

Method blanks (containing commercially available fish tissue), spiked blanks (transformer oil spiked on commercially available fish tissue), matrix spikes (transformer oil spiked onto tissue samples), and replicate samples are analyzed with each batch of twenty samples. The spiked blank QC results are control charted and must meet specific acceptance criteria before sample results are released.

METHOD SUMMARY

Title: Trace Metals in Biota Samples

SOP #: 3010 / 4081

Reference: USEPA Method 200.8

Effective Date: August, 1995

Revision Date: June, 1998

1. Scope and Application

This method is designed for the digestion and analysis of trace metals in biota samples. Analytes and LOQs (wet weight basis) are as listed below:

Analyte	LOQ (mg/kg)	Analyte	LOQ (mg/kg)
Aluminum	2.5	Manganese	0.5
Antimony	0.5	Molybdenum	0.5
Arsenic	0.5	Nickel	0.5
Barium	1.5	Selenium	0.5
Beryllium	1.5	Silver	0.12
Boron	1.5	Strontium	1.5
Cadmium	0.08	Thallium	0.02
Chromium	0.5	Tin	0.5
Cobalt	0.2	Uranium	0.02
Copper	0.5	Vanadium	0.5
Iron	5	Zinc	0.5
Lead	0.1		

2. Summary of Method

A ~2.5 gram portion (depending upon sample type and estimated moisture content) of the homogenized biota sample is accurately weighed for analysis. High purity HNO₃ is added to each sample, and allowed to stand overnight. The samples are then slowly digested until the acid volume is reduced to less than 1 mL. Additional HNO₃ is added and the digestion cycle is repeated. HNO₃ and reagent grade water is then added to the samples which are gently heated. After cooling, the samples are made to volume. The samples are then diluted prior to analysis using a Sciex/Perkin-Elmer Elan 5000 ICP-MS in accordance to EPA Method 200.8.

3. Quality Assurance

Reagent blanks, certified reference materials, and method spikes are prepared and analyzed in the exact same fashion as mentioned above for the samples. A minimum of one reagent blank and two different biota reference materials (usually DORM-1 and DOLT-2) are prepared and analyzed with each batch of samples. Spiking of samples at a level appropriate to the matrix is performed at a frequency of 10%. Duplicate digestion and analysis of samples is also performed at a frequency of 10%.

Appendix K

White Rose Water Quality Monitoring Program Report

Table of Contents

Summary	4
1.0 Background	6
1.1 Rhodamine Dye Experiment	6
1.2 Workshop and Conference	8
2.0 Water Quality Monitoring Program	9
2.1 Introduction	9
2.2 Chemical Characterization of Produced Water on the SeaRose FPSO	10
2.3 Field Sampling.....	13
2.3.1 2007 and 2008 Field Programs	13
2.3.2 2010 Field Program.....	21
Note: Transect station locations were based on the proposed, rather than the actual, location of the FPSO	25
2.4 Plume Modeling.....	26
2.5 Risk Assessment.....	30
3.0 Conclusion	32
4.0 References.....	33
4.1 Personal Communications	33
4.2 Literature Cited.....	33
5.0 List of Appendices	34
6.0 Insert 1 Map of Near-Field Water Quality Stations and Subsea Structures around the White Rose FPSO.....	34

List of Figures

Figure 1	Water Quality Monitoring Program.....	4
Figure 2	CTD/Fluorometer Stations on November 18 and November 25, 2005.....	7
Figure 3	Rhodamine Concentration (ppb) from 0.5 to 2 km from Source	7
Figure 4	White Rose Water Quality Monitoring Program.....	9
Figure 5	Water Sampling Stations at White Rose – 2008.....	15
Figure 6	Radionuclide Sampling Stations – 2007 and 2008	19
Figure 7	Water Sampling Stations - 2010.....	22
Figure 8	Radionuclide Sampling Stations – 2010	25
Figure 9	Example of DREAM Model Output: Maximum Concentration of Lithium	27
Figure 10	Example of DREAM Model Output: Probability of Detecting Lithium	27

Figure 11	Example of DREAM Model Output: Probability of Detecting Lithium – ZOOM IN, unsmoothed.	28
Figure 12	Simplified Diagram of Main Information Requirements and Model Inputs and Outputs.....	29
Figure 13	Contribution to Risk of Various Constituents of White Rose Produced Water at a Discharge Rate of 28,000 m ³ /day.....	30

List of Tables

Table 1	Summary Statistics for Produced Water Metals and Radionuclides	11
Table 2	Summary Statistics for Produced Water Organic Acids, Ammonia, Phosphorous, Phosphate, Nitrogen and Sulphur	11
Table 3	Summary Statistics for Produced Water BTEX and Hydrocarbons	12
Table 4	Summary Statistics for Produced Water Phenols and Alkyl-Phenols	12
Table 5	Summary Statistics for Produced Water PAHs and Alkyl-PAHs	12
Table 6	Summary Statistics for Surface Seawater Samples - 2008.....	16
Table 7	Summary Statistics for Mid-Depth (40 m) Seawater Samples – 2008	16
Table 8	Summary Statistics for Bottom Seawater Samples – 2008.....	17
Table 9	Summary Statistics for Near-Field Sediment Samples - 2008	21
Table 10	Station Coordinates for 300 and 600 m Stations and Distance from Nearest Subsea Structure.....	23

Summary

In 2000, Husky Energy submitted a produced water dispersion modeling exercise as part of its development plan application for White Rose. In 2004, Husky Energy made a commitment to the C-NLOPB in its Environmental Effects Monitoring (EEM) design document to validate the produced water dispersion model and design a program to assess water quality effects at White Rose. The present document lists activities undertaken by Husky Energy to honour these commitments and describes the White Rose Water Quality Monitoring Program.

Initial activities toward the validation of the original whole-effluent produced water dispersion model for White Rose and the design of a Water Quality Monitoring Program have included tests on the use of rhodamine to validate model results and extensive discussions with experts on requirements for Water Quality Monitoring. Based on rhodamine trial results, feedback from a Husky held workshop and discussions issuing from a Produced Water Conference held in St. John’s in 2007, Husky has focused the White Rose Water Quality Monitoring Program on the identification and measurement of relevant constituents of produced water.

The Program is iterative, with each component feeding information into other components to help refine the overall Program. Components include chemical characterization of the produced water discharge; modeling the distribution of produced water constituents in the environment to identify potential tracers of produced water; evaluating which constituents of produced water pose higher environmental risk; and field sampling (Figure 1).

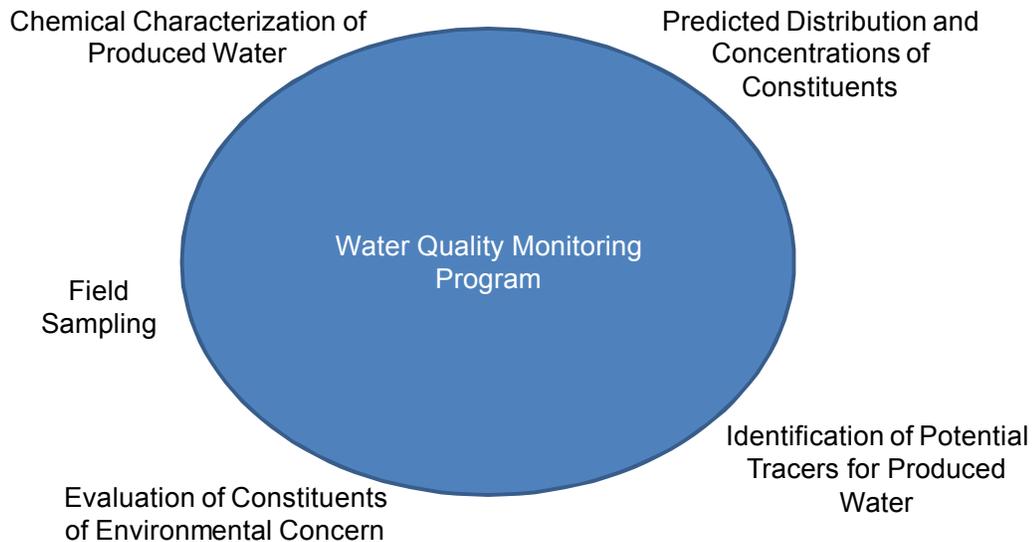


Figure 1 Water Quality Monitoring Program

Detailed chemical characterizations of produced water have been performed on the SeaRose Floating, Production and Storage (FPSO) facility since 2007 and will continue to be performed on a regular basis so that any changes in the chemical composition of produced water can be noted. Characterizations of the discharge include measurement of BTEX, fuel and lube range hydrocarbons, polyaromatic hydrocarbons (PAHs), phenols, organic acids, metals and the naturally occurring radionuclides radium-226, radium-228, and lead-210.

Constituent-based modeling allows predictions of concentrations of individual constituents within the produced water plume. Modeling is performed using the Dose-Related Risk and Effects Assessment Model (DREAM) and the ParTrack Models. These models are components of a software product: Marine Environmental Modeling Workbench (MEMW) developed by SINTEF (Norway) and currently under license to Elisabeth DeBlois Inc (Newfoundland, Canada). DREAM can model up to 200 chemical constituents and, coupled with ParTrack, can account for settling of constituents out of produced water. These models, compared to the previously-used whole-effluent model, better assess the distribution and concentration of constituents in the receiving environment and will help identify possible indicators or tracers that could be used to fine tune field sampling.

DREAM output can also be coupled with the risk analysis methodology Environmental Impact Factor (EIF) to assess the relative environmental risk of constituents of produced water. Husky Energy's primary interest in this risk assessment tool is to help assess produced water management options; but, when relevant, output can also be used to direct field sampling toward high risk constituents.

Husky Energy performed a preliminary field sampling program in 2008. Seawater samples were collected at nine stations. Surface samples were sampled for constituents measured in produced water plus organic and inorganic carbon, total suspended solids, ammonia and some of the process chemicals that are added to the produced water stream before discharge. Because literature suggests that naturally occurring radionuclides may settle out of the produced water plume, sediments were sampled for radium-226, radium-228 and lead-210 in 2007 and 2008. Six sediment stations were sampled in 2007, during sediment collections at the North Amethyst drill centre, and radionuclides were measured at the 51 sediment stations sampled as part of the Sediment Quality component of the 2008 EEM program.

A full water quality sampling program is planned for 2010, with 10 seawater stations in the near-field, from 300 to 800 m from the SeaRose FPSO, and 8 seawater stations in Reference Areas (4 stations in each of two areas approximately 30 km to the North East and North West). Samples collected at each of three depths at these stations will be processed for BTEX, fuel and lube range hydrocarbons, PAHs, phenols, organic acids, metals, radium-226, radium-228, and lead-210. Because recent risk assessment results have shown that a scale inhibitor and a biocide injected into the produced water stream pose higher risk relative to other constituents, these chemicals will also be measured in seawater samples collected in the field. Radionuclides will continue to be measured in sediment. Samples will be collected at 28 stations. Field sampling results will generate information on water quality at White Rose, and they will provide information that can be used to fine-tune plume dispersion modeling which can, in turn, be used to refine the sampling program in future years.

1.0 Background

The following section summarizes Husky Energy's activities to 2007 toward Water Quality Monitoring. Section 2 provides a description of Husky Energy's water monitoring activities since 2007, presents the results, and outlines planned activities for 2010.

1.1 Rhodamine Dye Experiment

In 2000, Husky Energy submitted a produced water modeling exercise (Hodgins and Hodgins, 2000) as part of its development plan application. Near-field modeling was based on the U.S. Environmental Protection Agency buoyant plume model UM (Baumgartner et. al., 1993) and considered dilution of the whole effluent. Results assumed that dispersed oil concentrations would be diluted in proportion to whole effluent dilution. No other constituents were considered.

In 2004, Husky Energy submitted an Environmental Effects Monitoring Program design document to the C-NLOPB that included a commitment to validate produced water model predictions and assess methods to monitor water quality. A report titled "Produced Water Monitoring at White Rose Phase 1: Plume Mapping and Model Validation" detailing Husky's general approach to model validation was submitted to the C-NLOPB in September, 2005.

Husky subsequently held a series of internal meetings to discuss methods to validate the whole-effluent produced water model used at White Rose. Based on the available literature, the use of rhodamine injected into the produced water stream was selected as a method to be tested to locate and map the plume. A work plan was developed and implemented at Terra Nova¹ in November 2005, in collaboration with Petro-Canada.

Rhodamine WT dye (20%) was injected into the produced water discharge for six hours to generate dye concentrations of 50 ppb on release. A series of vertical profiles were then performed on each of two days (Figure 2) with a Turner Designs conductivity, temperature and depth (CTD) meter equipped with a rhodamine fluorometer. Temperature and salinity were also measured to assess if the produced water plume could be detected using these signals.

The Terra Nova produced water plume was mapped to approximately 2 km from source (Figure 3). Trials showed that the plume surfaced, that plume dilution was much greater than expected and that the original plume dispersion model poorly predicted the specific behavior of the plume. No changes in temperature and salinity were noted within the plume (D. Dunbar, pers. comm.). The full report issuing from these field trials is provided in Appendix A.

¹ Produced water was not yet being released at White Rose in 2005. The same model had been applied to the Terra Nova field and both the White Rose and Terra Nova plumes were expected to behave relatively similarly.

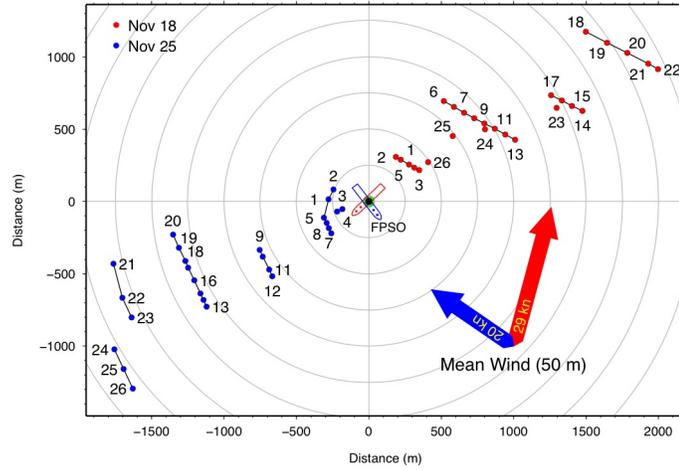


Figure 2 CTD/Fluorometer Stations on November 18 and November 25, 2005

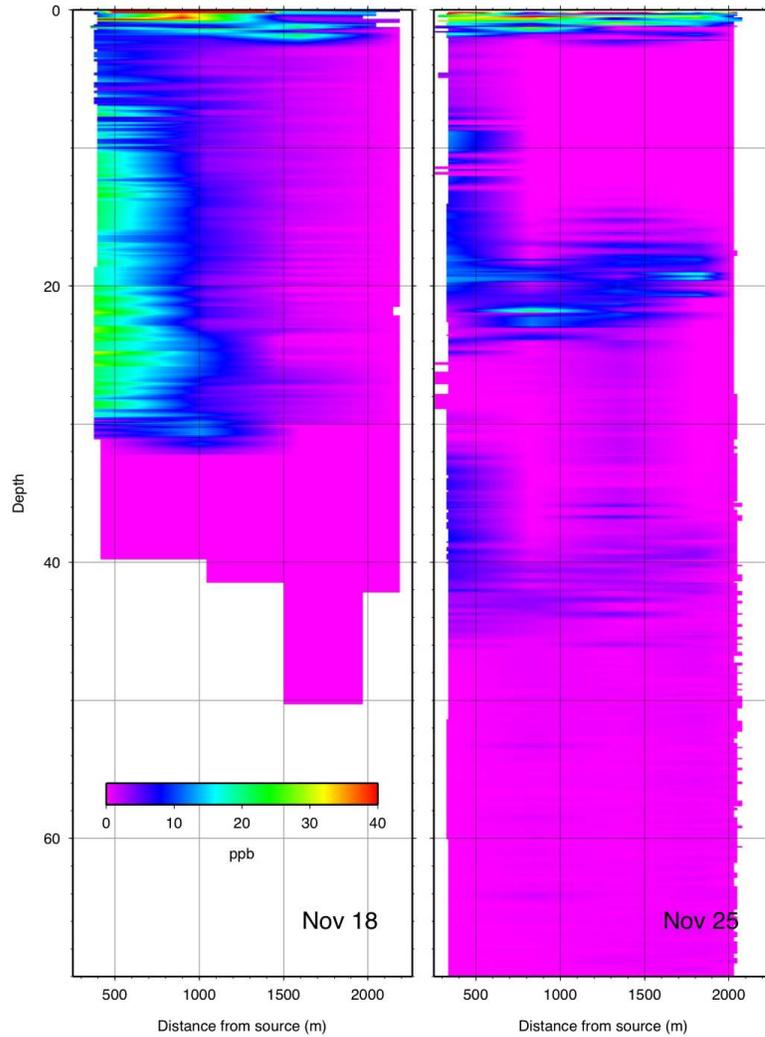


Figure 3 Rhodamine Concentration (ppb) from 0.5 to 2 km from Source

1.2 Workshop and Conference

In 2006, Husky Energy held a workshop with various experts to discuss the rhodamine trial results and Water Quality Monitoring. Recommendations issuing from the workshop are provided in Appendix B. Strong recommendations were made for the measurement of relevant chemicals within the produced water plume and the assessment of environmental risk posed by these chemicals. Subsequent to this, Husky Energy participated in a conference on produced water effects in St. John's in 2007. Recommendations listed in a review performed in support of the conference (Neff et al. 2007) also called for a constituent-based approach to assessing fate and effects of produced water and for the use of environmental risk assessment models and decision tools for produced water management.

2.0 Water Quality Monitoring Program

2.1 Introduction

Based on the results of the rhodamine field exercise, comments from Husky’s workshop and recommendations issuing from the produced water conference (Section 1), Husky is now focusing on the identification of relevant constituents in produced water and fine-tuning of a constituent-based plume dispersion model to refine sampling around the platform.

Husky Energy’s general approach to Water Quality Monitoring is iterative with each component of the program (Figure 4) feeding information into other components to help refine the overall program. Components include chemical characterization of the produced water discharge; modeling the distribution of produced water in the field; identifying potential natural tracers of produced water; evaluating which constituents pose a higher risk; and field sampling.

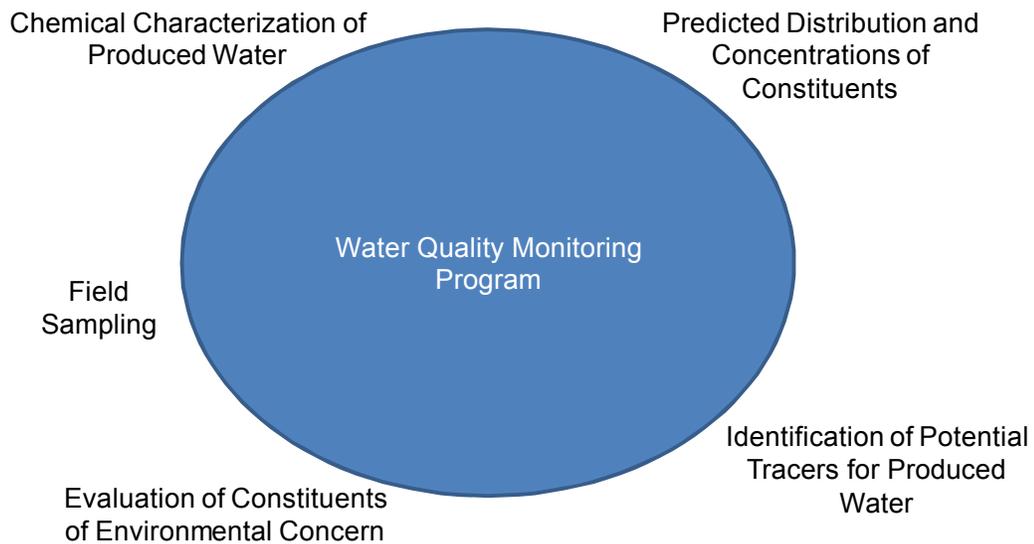


Figure 4 White Rose Water Quality Monitoring Program

Detailed chemical characterizations of the produced water being discharged from the SeaRose FPSO are needed in order to model the distribution and dilution of constituents of produced water. These characterizations also provide context information against which to compare field sampling results.

Constituent-based modeling (DREAM modeling) provides the predicted distribution and concentration of constituents and helps identify which constituents of produced water are in sufficiently high concentration to have the potential to be detected in the field. Model results help focus and fine-tune field sampling.

Risk analysis for constituents of produced water at White Rose is performed using the Environmental Impact Factor (EIF) and is used to help Husky Energy assess produced

water management options (see Section 2.5). However, results can also be used to target field sampling toward those constituents demonstrated to have a higher degree of risk relative to other constituents.

Field sampling is carried out to assess concentrations of constituents in the receiving environment and to validate and fine tune model results. In addition, although the field sampling program is tailored to assess effects of produced water, because this is the largest liquid discharge at White Rose, the sampling program as designed will also provide information on general water quality effects at White Rose, from all liquid discharges.

Components shown in Figure 4 are discussed, in turn, in the sections that follow. Results of chemical characterizations of White Rose produced water are provided in Section 2.2. Results of the 2007 and 2008 field sampling programs, and plans for the 2010 field program, are provided in Section 2.3. Modeling is discussed in Section 2.4. Risk assessment is discussed in Section 2.5.

2.2 Chemical Characterization of Produced Water on the SeaRose FPSO

Husky Energy initiated detailed characterizations of produced water on SeaRose FPSO facility at the White Rose field in August 2007. Chemical characterizations include not only the standard suite of chemicals required by the Offshore Waste Treatment Guidelines (NEB et al., 2002) but extend to include quantification of phenols, naturally occurring radionuclides and organic acids. In order to better assess metals and PAH concentrations, additional PAH groupings are measured and the lowest achievable detection limit is used in quantification of metals. RPC, located in Fredericton, New Brunswick, is contracted for this work and is the only analytical laboratory in the Atlantic Provinces capable of measuring the required constituents at the lower detection limits required.

Results of chemical characterizations are provided in Appendix C. Tables 1 through 5 summarize these results. Only those variables with at least one value above detection limit are listed in Tables 1 through 5.

Table 1 Summary Statistics for Produced Water Metals and Radionuclides

Variable	Units	N	N < RDL	Minimum	Maximum	Median	Mean	SD
Aluminum	µg/L	12	2	ND	19	8.5		
Barium	µg/L	12	0	146	990	369	489.3	341.2
Beryllium	µg/L	12	0	0.13	0.3	0.18	0.19	0.06
Boron	µg/L	12	0	34600	61900	52700	49850	11089
Cadmium	µg/L	12	4	< 0.02	0.08	0.02		
Calcium	µg/L	12	0	377000	770000	437500	520667	165939
Chromium	µg/L	12	10	ND	5	ND		
Iron	µg/L	12	0	2090	5200	2315	3066	1283
Lead	µg/L	12	0	0.07	7.28	1.47	2.492	2.369
Lithium	µg/L	12	0	2940	4770	3370	3698	745
Magnesium	µg/L	12	0	41200	296000	57000	122308	108945
Manganese	µg/L	12	0	13	35	16.2	20.2	8.2
Mercury	µg/L	12	8	ND	0.07	ND		
Molybdenum	µg/L	12	4	ND	0.4	0.2		
Nickel	µg/L	12	1	ND	17	9		
Potassium	µg/L	12	0	252000	341000	277500	289750	35551
Silicon	µg/L	12	0	28100	30700	29450	29392	898
Silver	µg/L	12	10	ND	0.2	ND		
Sodium	µg/L	12	0	10100000	11800000	11150000	11050000	638891
Strontium	µg/L	12	0	50800	134000	76000	86000	30671
Tellurium	µg/L	12	9	ND	0.8	ND		
Thorium	µg/L	12	11	ND	1	ND		
Vanadium	µg/L	12	10	ND	2	ND		
Zinc	µg/L	12	0	3	84	8	21.2	29.6
Radium-228	Bq/L	10	1	ND	7	2.85		
Radium-226	Bq/L	12	4	ND	5	2		
Lead-210	Bq/L	10	7	ND	4	ND		

Notes: RDL = Reportable Detection Limit; ND = Not Detected; SD = Standard Deviation.

Only those variables with at least one value above detection limit are listed. The full suite of variables measured is provided in Appendix C.

Two samples were collected for each of six characterizations. Averages are calculated over all samples collected.

Table 2 Summary Statistics for Produced Water Organic Acids, Ammonia, Phosphorous, Phosphate, Nitrogen and Sulphur

Variable	Units	N	N < RDL	Minimum	Maximum	Median	Mean	SD
Acetic Acid	mg/L	12	0	350	690	565	552	115
Propionic Acid	mg/L	12	0	26	57	49	44.7	10.7
Iso-butyric Acid	mg/L	12	2	ND	5.9	3.25		
Butyric Acid	mg/L	12	0	5.3	16	10.5	10.73	3.88
Iso-valeric Acid	mg/L	12	4	ND	6.7	2.75		
n-valeric Acid	mg/L	12	3	ND	7	2.8		
Ammonia (as N)	mg/L	12	0	3.8	22	20	18.57	4.92
Un-ionized Ammonia @ 5°C (as N)	mg/L	10	0	0.0119	0.1722	0.0889	0.0949	0.0524
Un-ionized Ammonia @ 20°C (as N)	mg/L	10	0	0.0375	0.5379	0.2797	0.2977	0.1634
Kjeldahl Nitrogen	mg/L	12	0	7	25	20	18.4	4.5
o-Phosphate (as P)	mg/L	12	11	ND	0.02	ND		
pH	units	10	0	7.4	7.8	7.55	7.56	0.16
Total Phosphorus	mg/L	8	0	ND	0.3	ND	0.1195	0.0924
Sulfur	µg/L	12	0	143000	506000	281000	299417	139864

Notes: RDL = Reportable Detection Limit; ND = Not Detected; SD = Standard Deviation.

Only those variables with at least one value above detection limit are listed. The full suite of variables measured is provided in Appendix C.

Two samples were collected for each of six characterizations. Averages are calculated over all samples collected.

Table 3 Summary Statistics for Produced Water BTEX and Hydrocarbons

Variable	Units	N	N < RDL	Minimum	Maximum	Median	Mean	SD
Benzene	mg/L	12	0	12	20	15.5	15.8	2.5
Toluene	mg/L	12	0	6.1	11	8.55	8.41	1.54
Ethylbenzene	mg/L	12	0	0.31	0.6	0.495	0.476	0.120
Xylenes	mg/L	12	0	1.6	2.9	2.55	2.35	0.51
VPH C6-C10 (Less BTEX)	mg/L	12	0	3.2	23	6.6	7.95	5.78
EPH >C10-C21	mg/L	12	0	4.3	18	14.5	11.68	5.19
EPH >C21-C32	mg/L	12	0	1.5	12	8.25	7.06	3.91
Modified TPH Tier 1	mg/L	12	0	15	37	28.5	26.8	6.7

Notes: RDL = Reportable Detection Limit; ND = Not Detected; SD = Standard Deviation.

Only those variables with at least one value above detection limit are listed in Tables 1 through 5. The full suite of variables measured is provided in Appendix B.

Two samples were collected for each of six characterizations. Averages are calculated over all samples collected.

Table 4 Summary Statistics for Produced Water Phenols and Alkyl-Phenols

Variable	Units	N	N < RDL	Minimum	Maximum	Median	Mean	SD
PHENOL	µg/L	12	0	1200	7500	2700	3742	2168
o-cresol1	µg/L	12	0	740	2200	1350	1408	469
m,p-cresol	µg/L	12	0	1200	2700	2050	2017	536
Total C2 Phenols (ion patterns)	µg/L	12	0	700	2400	1750	1717	559
Total C3 Phenols (ion patterns)	µg/L	12	0	410	790	625	614	99
Total C4 Phenols (ion patterns)	µg/L	12	0	53	190	135	123.9	44.1

Notes: RDL = Reportable Detection Limit; ND = Not Detected; SD = Standard Deviation.

Only those variables with at least one value above detection limit are listed. The full suite of variables measured is provided in Appendix C.

Two samples were collected for each of six characterizations. Averages are calculated over all samples collected.

Table 5 Summary Statistics for Produced Water PAHs and Alkyl-PAHs

Variable	Units	N	N < RDL	Minimum	Maximum	Median	Mean	SD
Naphthalene	µg/L	12	0	79	580	370	367	157
Acenaphthylene	µg/L	12	0	0.78	1.6	1.1	1.171	0.272
Acenaphthene	µg/L	12	4	ND	3.6	2.835		
Fluorene	µg/L	12	0	10	39	22	23.4	8.6
Phenanthrene	µg/L	12	0	14	56	38.5	36.5	13.1
Anthracene	µg/L	12	8	ND	0.914	ND		
Fluoranthene	µg/L	12	0	0.3	1.2	0.856	0.78	0.31
Pyrene	µg/L	12	0	0.3	1.5	1.2	1.04	0.43
Bz(a)anthracene	µg/L	12	4	ND	1.7	0.408		
Chrysene/Triphenylene	µg/L	12	0	0.55	4.1	1.05	1.783	1.333
Bz(b)fluoranthene	µg/L	12	4	ND	0.2565	0.155		
Bz(k)fluoranthene	µg/L	12	6	ND	0.2565	ND		
Bz(e)pyrene	µg/L	12	8	ND	0.75	ND		
Bz(a)pyrene	µg/L	12	11	ND	0.154	ND		
Bz(g,h,i)perylene	µg/L	12	6	ND	0.205	ND		
C1-Naphthalenes	µg/L	12	0	144	570	240	301	142
C2-Naphthalenes	µg/L	12	0	55	220	165	156	46
C3-Naphthalenes	µg/L	12	0	14	98	66.5	61.4	27.9
C1-Phenanthrenes	µg/L	12	0	10	55	40.5	36.2	15.8
C2-Phenanthrenes	µg/L	12	0	3	46	28.5	26.8	15.6
C3-Phenanthrenes	µg/L	12	2	ND	22	13		
Dibenzothiophene	µg/L	12	2	ND	11	6.7		
C1-Dibenzothiophenes	µg/L	12	2	ND	11	6.05		
C2-Dibenzothiophenes	µg/L	12	4	ND	11	1.85		
Biphenyl	µg/L	12	0	24	71	47	47.3	15.5

Notes: RDL = Reportable Detection Limit; ND = Not Detected; SD = Standard Deviation.

Only those variables with at least one value above detection limit are listed. The full suite of variables measured is provided in Appendix C.

Two samples were collected for each of six characterizations. Averages are calculated over all samples collected.

2.3 Field Sampling

2.3.1 2007 and 2008 Field Programs

2.3.1.1 Seawater

In 2008, seawater samples were collected at eight stations located from 0.3 to 1.3 km from the SeaRose FPSO facility and at one station located approximately 30 km to the North West (Figure 5). Produced water discharge rates on September 20 and 21, 2008, the two days when water sampling took place, were 7,969 m³/day and 4,706 m³/day, respectively.

Samples were collected with niskin bottles at three depths: 10 m from the surface, 40 m depth and 10 m from the bottom. Seawater samples from surface samples and one mid-depth sample (collected at WQ3, Figure 5) were analyzed for the following:

- BTEX
- Fuel and lube range hydrocarbons,
- PAHs
- Phenols,
- Organic acids,
- Metals,
- The naturally occurring radionuclides radium-226, radium-228 and lead-210,
- Inorganic and organic carbon,
- Total suspended solids,
- Ammonia,
- Radioactive tracers (12 in total) injected into wells at white rose, and
- The scale inhibitor used to treat produced water (SCW4453).

Remaining samples were analyzed for the following:

- Metals,
- Radium-226, radium-228 and lead-210,
- Inorganic and organic carbon,
- Total suspended solids, and
- Ammonia.

In all cases, samples were processed at the lower detection limits used for produced water characterizations (Section 2.2 and Appendices C).

CTD data were collected in support of chemistry samples to assess general water mass stratification.

Summary statistics for constituents occurring above laboratory detection limits at the surface, mid-depth (40m) and at the bottom are provided in Tables 6 through 8, respectively. The full suite of analytical results is provided in Appendix D.

BTEX, fuel and lube range hydrocarbons, PAHs, phenols and organic acids were not detected. There was also no indication of radioactive tracers injected downhole or of the scale inhibitor used to treat produced water.

Output from CTD casts are presented in Appendix E. Water mass characteristics for all stations located within 0.3 to 1.3 km from the FPSO were similar. The thermocline at station 27, located approximately 30 km from the FPSO, was located approximately 10 m deeper (30 m versus 20 m or less) than it was at near-field stations.

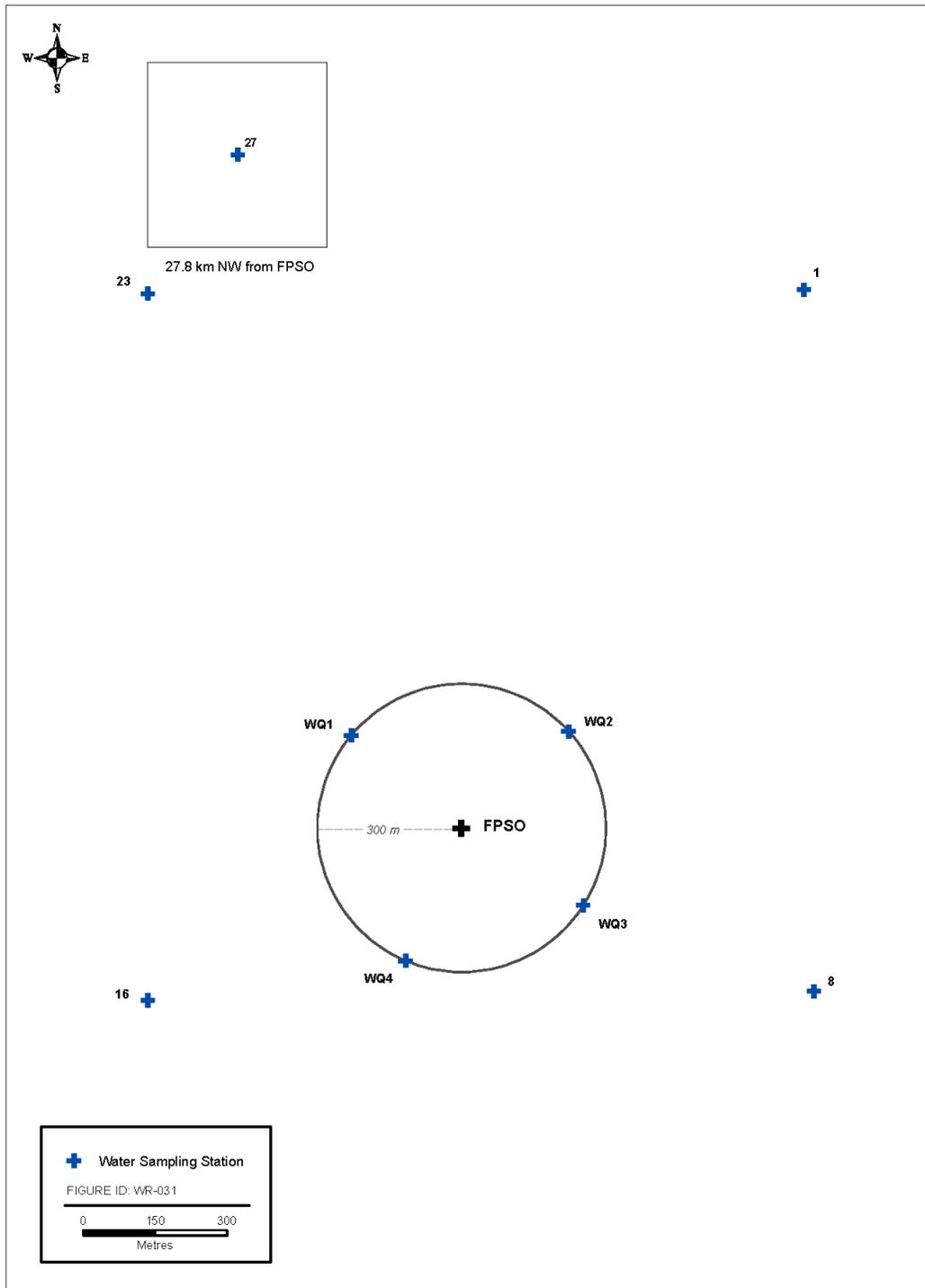


Figure 5 Water Sampling Stations at White Rose – 2008

Table 6 Summary Statistics for Surface Seawater Samples - 2008

Variable	Units	0.3 to 1.3 km from the FPSO							28 km NW of the FPSO		
		N	N <RDL	Minimum	Maximum	Median	Mean	SD	N	N <RDL	Value
Aluminum	µg/L	8	1	ND	8	1			1	1	ND
Barium	µg/L	8	0	4.6	5.5	4.65	4.78	0.31	1	0	4.1
Boron	µg/L	8	0	4280	4430	4335	4331	47	1	0	4390
Cadmium	µg/L	8	1	ND	0.04	0.03			1	0	0.02
Calcium	µg/L	8	0	319000	326000	322500	322250	2252	1	0	321000
Iron	µg/L	8	6	ND	9	ND			1	0	7
Lead	µg/L	8	3	ND	0.19	0.035			1	0	0.05
Lithium	µg/L	8	0	133	152	148.5	146.4	6.8	1	0	137
Magnesium	µg/L	8	0	1250000	1290000	1260000	1266250	15980	1	0	1270000
Manganese	µg/L	8	0	0.3	1	0.7	0.69	0.20	1	0	0.2
Molybdenum	µg/L	8	0	10.7	11.1	10.95	10.93	0.18	1	0	10.6
Potassium	µg/L	8	0	375000	381000	377000	377125	1808	1	0	376000
Silver	µg/L	8	6	ND	0.03	ND			1	1	ND
Sodium	µg/L	8	0	10600000	10900000	10700000	10737500	118773	1	0	10800000
Strontium	µg/L	8	0	6420	6540	6465	6466	41	1	0	6440
Uranium	µg/L	8	0	2.0	2.7	2.35	2.35	0.23	1	0	2.3
Vanadium	µg/L	8	0	1.2	2.1	1.55	1.59	0.28	1	0	0.8
Zinc	µg/L	8	1	ND	34	3			1	1	ND
Radium - 226	Bq/L	8	6	ND	3	ND			1	1	ND
Lead - 210	Bq/L	8	7	ND	2	ND			1	1	ND
Ammonia (as N)	mg/L	8	7	ND	0.14	ND			1	1	ND
pH	units	8	0	7.8	7.9	7.9	7.89	0.04	1	0	7.9
Sulphur	µg/L	8	0	874000	915000	894500	896250	14440	1	0	898000
Total Organic Carbon	mg/L	8	7	ND	0.5	ND			1	1	ND
Total Inorganic Carbon (C)	mg/L	8	0	24.3	26.5	24.65	24.88	0.69	1	0	25.9
Total Suspended Solids	mg/L	8	0	0.5	2.5	1.15	1.26	0.58	1	0	2.0

Notes: RDL = Reportable Detection Limit; ND = Not Detected; SD = Standard Deviation.

Only those variables with at least one value above detection limit are listed. The full suite of variables measured is provided in Appendix D.

Table 7 Summary Statistics for Mid-Depth (40 m) Seawater Samples – 2008

Variable	Units	0.3 to 1.3 km from the FPSO							28 km NW of the FPSO		
		N	N <RDL	Minimum	Maximum	Median	Mean	SD	N	N <RDL	Value
Aluminum	µg/L	8	6	ND	1	ND			1	1	ND
Barium	µg/L	8	0	7.1	7.7	7.4	7.44	0.21	1	0	7.0
Boron	µg/L	8	0	4400	4560	4455	4464	55	1	0	4370
Cadmium	µg/L	8	0	0.04	0.07	0.06	0.058	0.010	1	0	0.03
Calcium	µg/L	8	0	327000	336000	329500	330000	2928	1	0	328000
Chromium	µg/L	8	7	ND	1	ND			1	1	ND
Lead	µg/L	8	5	ND	0.06	ND			1	1	ND
Lithium	µg/L	8	0	138	168	154	154.5	10.6	1	0	138
Magnesium	µg/L	8	0	1280000	1320000	1305000	1303750	14079	1	0	1280000
Manganese	µg/L	8	0	0.6	1.8	1.05	1.10	0.41	1	0	0.2
Molybdenum	µg/L	8	0	11.0	11.2	11.1	11.11	0.08	1	0	11.0
Potassium	µg/L	8	0	381000	391000	385500	385500	3071	1	0	384000
Sodium	µg/L	8	0	10800000	11300000	11000000	11050000	169031	1	0	10900000
Strontium	µg/L	8	0	6590	6770	6635	6646	57	1	0	6580
Uranium	µg/L	8	0	2.2	2.9	2.7	2.64	0.23	1	0	2.6
Vanadium	µg/L	8	0	1.3	2.0	1.5	1.53	0.21	1	0	1.5
Zinc	µg/L	8	1	ND	50	3.5			1	1	ND
Radium - 226	Bq/L	8	6	ND	3	ND			1	1	ND
Lead - 210	Bq/L	8	8	ND	ND	ND			1	0	3
pH	Units	8	0	7.7	7.8	7.8	7.79	0.04	1	0	7.9
Sulphur	µg/L	8	0	893000	945000	923500	922375	15602	1	0	909000
Total Inorganic Carbon (C)	mg/L	8	0	26.0	27.6	27.05	26.86	0.64	1	0	26.7
Total Suspended Solids	mg/L	8	0	1.3	5.2	2.85	3.14	1.35	1	0	4.3

Notes: RDL = Reportable Detection Limit; ND = Not Detected; SD = Standard Deviation.

Only those variables with at least one value above detection limit are listed. The full suite of variables measured is provided in Appendix D.

Table 8 Summary Statistics for Bottom Seawater Samples – 2008

Variable	Units	0.3 to 1.3 km from the FPSO							28 km NW of the FPSO		
		N	N <RDL	Minimum	Maximum	Median	Mean	SD	N	N <RDL	Value
Aluminum	µg/L	8	6	ND	1	ND			1	0	1
Barium	µg/L	8	0	6.5	7.0	6.75	6.74	0.19	1	0	7.2
Boron	µg/L	8	0	4500	4640	4535	4549	46	1	0	4690
Cadmium	µg/L	8	0	0.04	0.07	0.06	0.058	0.009	1	0	0.05
Calcium	µg/L	8	0	332000	338000	335000	335250	2053	1	0	340000
Chromium	µg/L	8	7	ND	1	ND			1	1	ND
Iron	µg/L	8	6	ND	13	ND			1	1	ND
Lead	µg/L	8	2	ND	0.57	0.055			1	0	0.05
Lithium	µg/L	8	0	142	172	166	162.1	11.4	1	0	139
Magnesium	µg/L	8	0	1310000	1340000	1325000	1325000	11952	1	0	1330000
Manganese	µg/L	8	0	0.6	2.1	0.9	1.08	0.49	1	0	0.4
Molybdenum	µg/L	8	0	11.1	11.5	11.3	11.30	0.16	1	0	11.4
Potassium	µg/L	8	0	389000	396000	392000	392250	2121	1	0	396000
Sodium	µg/L	8	0	11100000	11300000	11250000	11225000	88641	1	0	11300000
Strontium	µg/L	8	0	6720	6820	6755	6759	37	1	0	6860
Uranium	µg/L	8	0	2.3	3	2.75	2.73	0.21	1	0	2.6
Vanadium	µg/L	8	0	1.5	1.8	1.6	1.63	0.12	1	0	1.3
Zinc	µg/L	8	2	ND	4	3			1	0	3
Radium - 226	Bq/L	8	6	ND	2	ND			1	0	3
pH	Units	8	0	7.7	7.8	7.8	7.76	0.05	1	0	7.7
Sulphur	µg/L	8	0	924000	953000	940500	939625	9273	1	0	941000
Total Inorganic Carbon (C)	mg/L	8	0	25.4	27.4	26.1	26.38	0.73	1	0	26.3
Total Suspended Solids	mg/L	8	0	1	3	1.8	1.75	0.68	1	0	1.1

Notes: RDL = Reportable Detection Limit; ND = Not Detected; SD = Standard Deviation.

Only those variables with at least one value above detection limit are listed. The full suite of variables measured is provided in Appendix D.

2.3.1.2 Sediment Samples

2.3.1.2.1 Radionuclides

Husky Energy is exploring the use radionuclide accumulations in sediments as a tracer for produced water discharge. Radionuclides in White Rose produced water are being measured as part of chemical characterizations (Section 2.2) and have been measured in seawater samples (Section 2.3.1.1). Radium-226 and Radium-228 are known constituents of produced water and are extremely persistent, with half-lives of 1,620 and 5.76 years, respectively. Lead-210 is a degradation product of Radium-226. These radionuclides may deposit to the sediment relatively shortly after being released. Neff (2002) notes that radium will most often precipitate quickly out of produced water as Ba,RASO₄, particularly in sulphur rich environments, and it might be found in sediments in the vicinity of discharge sources. There is evidence of radium contamination around some near-shore platforms. For offshore platforms off the coast of Louisiana, Neff (2002) reports marginally higher levels of radium isotopes in sediments within 300 m from the discharge point.

The median concentration of radium-228 directly in produced water samples collected at White Rose from 2007 to 2009 (i.e., samples collected at source) was 2.85 Bq/L and only 1 out of 10 samples had concentrations below the laboratory detection limit. The median concentration of radium-226 was 2 Bq/L, with 4 out of 12 concentrations below detection. Lead-210 concentrations have been below laboratory detection limit in most samples collected to date (Section 2.2). Concentrations of these radionuclides in seawater samples, particularly that of radium-228, were relatively low. Radium-228 was not detected in seawater samples collected around White Rose in 2008 (Section 2.3.1.1). Radium-226 was detected in two surface samples, two mid-depth samples and three bottom samples at concentrations of 2 to 3 Bq/L. One of these samples was from a station located approximately 30 km from the FPSO. Radium-226 was not detected in

the remaining 20 samples². Lead-210 was detected in two samples (one surface and one mid-depth sample³) at concentrations of 2 to 3 Bq/L.

Background concentration of radionuclides in marine sediments surrounding White Rose may also be low relative to concentrations in White Rose produced water⁴. Sediment samples were collected at 6 sediment stations in 2007 and 51 stations in 2008 (Figure 6) and processed for radium-228, radium-226 and lead-210. Most samples did not contain detectable levels of radionuclides (Table 8). Where they were detected, levels of radium-228 ranged from 0.01 to 0.03 Bq/g; levels of radium-226 ranged from 0.02 to 0.04 Bq/g; and levels of lead-210 ranged from 0.01 to 0.05 Bq/g. Radium-228 was detected least frequently and lead-210 was detected most frequently (Table 8). Given the low frequency of detection of radionuclides in these marine sediments, any substantial accumulation over time as a result of inputs from produced water may be detectable. Also, of the three radionuclides, and based on frequency of detection in produced water, seawater and sediments, radium-228 appears to be the most promising tracer for produced water.

² The total number of samples provided (n = 27) excludes field replicate samples, labeled '–A' in Appendix D. Field replicates are not taken into account in summary statistics but are used as a double check on remaining samples. It is of note, however, that one '–A' sample did have measurable amounts of radium-226 (2 Bq/L) (Appendix D).

³ Lead-210 was also detected in one mid-depth field replicate at a concentration 2 Bq/L (Appendix D).

⁴ Bq/L (a measure of concentration in liquid) and Bq/g (a measure of concentration in sediments) are not directly comparable, but anticipated concentrations in sediments as a result of produced water discharge can be modeled (see Section 2.4).

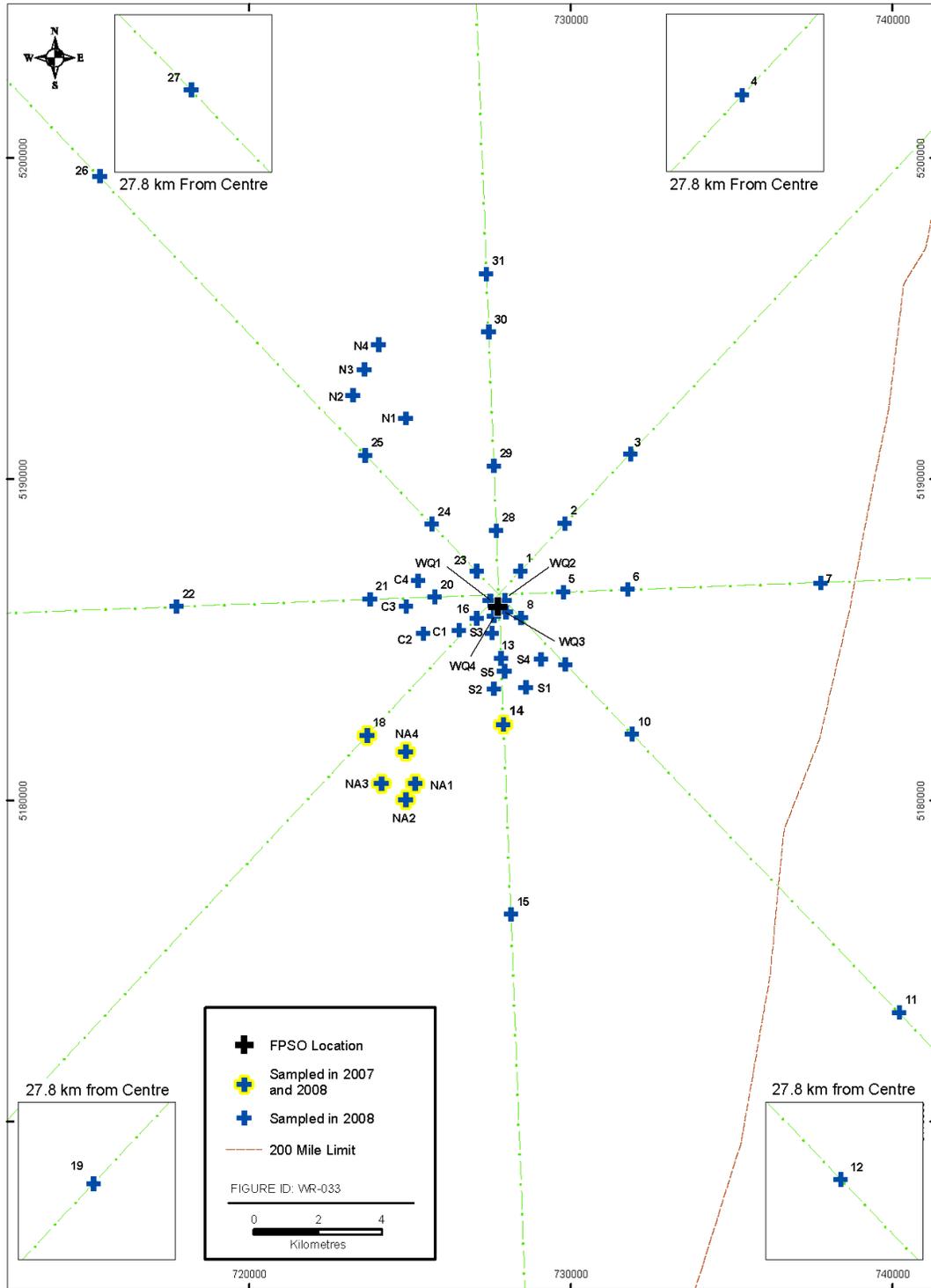


Figure 6 Radionuclide Sampling Stations – 2007 and 2008

Table 8 Radionuclide Levels in Sediment Samples – 2007 and 2008

Station	Distance (km) to FPSO	Year	Radium-228 (Bq/g)	Radium-226 (Bq/g)	Lead-210 (Bq/g)
WQ1	0.3	2008	<0.003	<0.01	0.01
WQ2	0.3	2008	<0.005	<0.02	0.03
WQ3	0.3	2008	<0.004	<0.01	<0.02
WQ4	0.3	2008	<0.003	<0.01	<0.009
16	0.74	2008	<0.006	<0.03	<0.02
8	0.81	2008	<0.004	<0.02	0.05
S3	0.83	2008	<0.004	<0.02	0.03
23	1.29	2008	<0.006	<0.03	<0.03
1	1.32	2008	<0.004	<0.02	<0.02
C1	1.4	2008	<0.006	<0.03	<0.03
13	1.6	2008	<0.003	<0.02	<0.01
C5	1.84	2008	NA	NA	NA
20	1.98	2008	<0.003	<0.02	0.02
S5	2	2008	<0.003	<0.02	<0.01
5	2.1	2008	<0.003	<0.01	<0.01
S4	2.12	2008	0.02	<0.02	<0.02
28	2.37	2008	<0.002	<0.01	0.02
C2	2.45	2008	<0.005	<0.03	<0.02
S2	2.55	2008	<0.004	0.03	<0.02
C4	2.6	2008	<0.004	0.04	<0.02
S1	2.66	2008	<0.006	<0.03	<0.03
17	2.73	2008	NA	NA	NA
9	2.77	2008	<0.003	<0.01	0.02
C3	2.84	2008	<0.003	<0.01	0.03
24	3.29	2008	<0.004	<0.02	<0.02
2	3.34	2008	<0.004	<0.03	0.03
14	3.66	2007	<0.003	<0.01	0.03
		2008	<0.003	0.04	<0.01
21	3.98	2008	<0.004	<0.01	<0.01
6	4.08	2008	<0.005	<0.03	<0.02
29	4.39	2008	<0.004	<0.03	<0.02
NA4	5.33	2007	<0.003	<0.02	0.05
		2008	<0.006	<0.03	0.04
18	5.7	2007	<0.003	<0.02	0.03
		2008	<0.003	<0.01	<0.01
10	5.76	2008	0.03	<0.02	<0.02
NA1	6.07	2007	<0.005	<0.02	0.04
		2008	<0.004	<0.03	<0.02
25	6.26	2008	<0.004	<0.02	<0.01
3	6.31	2008	<0.003	<0.01	0.01
N1	6.53	2008	0.01	<0.03	0.05
NA3	6.58	2007	<0.004	<0.02	0.04
		2008	0.02	<0.02	<0.02
NA2	6.65	2007	<0.005	<0.02	0.04
		2008	<0.003	<0.02	<0.01
N2	7.99	2008	<0.004	<0.01	<0.01
N3	8.48	2008	<0.004	<0.01	<0.02
30	8.58	2008	<0.004	0.02	<0.02
N4	8.97	2008	0.01	<0.02	0.04
15	9.6	2008	<0.004	0.02	<0.02
22	9.99	2008	<0.004	<0.02	<0.02
7	10.05	2008	<0.004	<0.02	<0.02
31	10.38	2008	<0.004	<0.01	<0.01
11	17.78	2008	<0.006	<0.03	0.04
26	18.24	2008	<0.005	<0.02	<0.02
19	27.58	2008	<0.005	<0.02	<0.02
12	27.65	2008	<0.003	<0.02	0.02
27	28.15	2008	<0.006	0.04	0.04
4	28.2	2008	<0.003	0.04	0.03

Notes: Values above detection are highlighted in grey
Units are in dry weight

2.3.1.2.2 Near-Field Sediment Samples

Additional elements (e.g., iron) may precipitate out of produced water (Phil Yeats, pers. comm.). This was also noted during Husky's workshop on produced water monitoring (Appendix B). Husky Energy has collected sediment samples for chemistry analysis as part of baseline collections and the Sediment Quality Component of its EEM Program since 2000. These data are summarized in Husky Energy 2001, 2005, 2006 and 2008. In 2008, Husky Energy supplemented these collections with analyses of chemistry of sediments from four stations located 300 m from the FPSO (WQ stations, Figure 6). Analytical results for these four additional stations are provided in Appendix F. Summary statistics for elements with at least one value above RDL are provided in Table 9.

Table 9 Summary Statistics for Near-Field Sediment Samples - 2008

Variable	Units	N	N < RDL	Min	Max	Median	Mean	SD
Aluminum	mg/kg	4	0	7400	9300	8950	8650	858
Barium	mg/kg	4	0	160	230	200	198	29
Chromium	mg/kg	4	0	3.5	4.8	3.8	3.98	0.57
Iron	mg/kg	4	0	1400	2400	1700	1800	424
Lead	mg/kg	4	0	2.6	3	2.9	2.85	0.17
Manganese	mg/kg	4	0	42	87	52	58	20
Strontium	mg/kg	4	0	42	51	49	48	4
Uranium	mg/kg	4	0	0.2	0.29	0.25	0.248	0.044
Vanadium	mg/kg	4	0	5.9	7.4	6.1	6.38	0.69
Zinc	mg/kg	4	1	ND	6.7	6.5		
>C10-C21 Hydrocarbons	mg/kg	4	0	2.3	3.3	2.35	2.58	0.49
>C21-<C32 Hydrocarbons	mg/kg	4	0	0.6	0.8	0.65	0.68	0.10
Ammonia	mg/kg	4	0	5.5	11	6.7	7.48	2.45
Moisture	%	4	0	17	19	18.5	18.3	1.0
Sulphur	% (wet)	4	0	0.03	0.04	0.03	0.033	0.005
Sulphide	ug/g	4	0	0.3	0.8	0.5	0.53	0.22
Total Carbon	g/kg	4	0	1	1.1	1	1.03	0.05
Total Organic Carbon	g/kg	4	0	0.7	1	0.85	0.85	0.13
Total Inorganic Carbon	g/kg	4	2	ND	0.3	ND		

Notes: Units are in dry wet except where indicated.

RDL = Reportable Detection Limit; ND = Not Detected; SD = Standard Deviation.

Only those variables with at least one value above detection limit are listed. The full suite of variables measured is provided in Appendix F.

2.3.2 2010 Field Program

2.3.2.1 Seawater Samples

Seven of the nine stations sampled for water quality in the 2008 sampling program will be retained for the 2010 field program. Stations 1 and 23 (Figure 5) will be dropped because they are located more than 1 km from the FPSO and preliminary modeling results (Appendix G), as well as current literature (e.g., Neff et al., 2007), indicate that the probability of detecting produced water constituents at those distances is low. Four new stations located 600 m from the FPSO and four new stations in each of two areas located approximately 30 km to the North East and the North West will be added (Figure 7; also see Insert 1 for near-field stations.). For safety reasons, stations located at 300 and 600 m from the FPSO will be located no closer than 50 m from any subsea structure. Station coordinates and distance to the nearest subsea structure for these stations are provided in Table 10. A map of these near-field stations and subsea structures, as well as the spin radius of the FPSO, is provided as an insert (Insert 1) to this document. Distance to nearest subsea structure will be verified for these stations before all field programs. A full list of coordinates for water quality stations is provided in Appendix H.

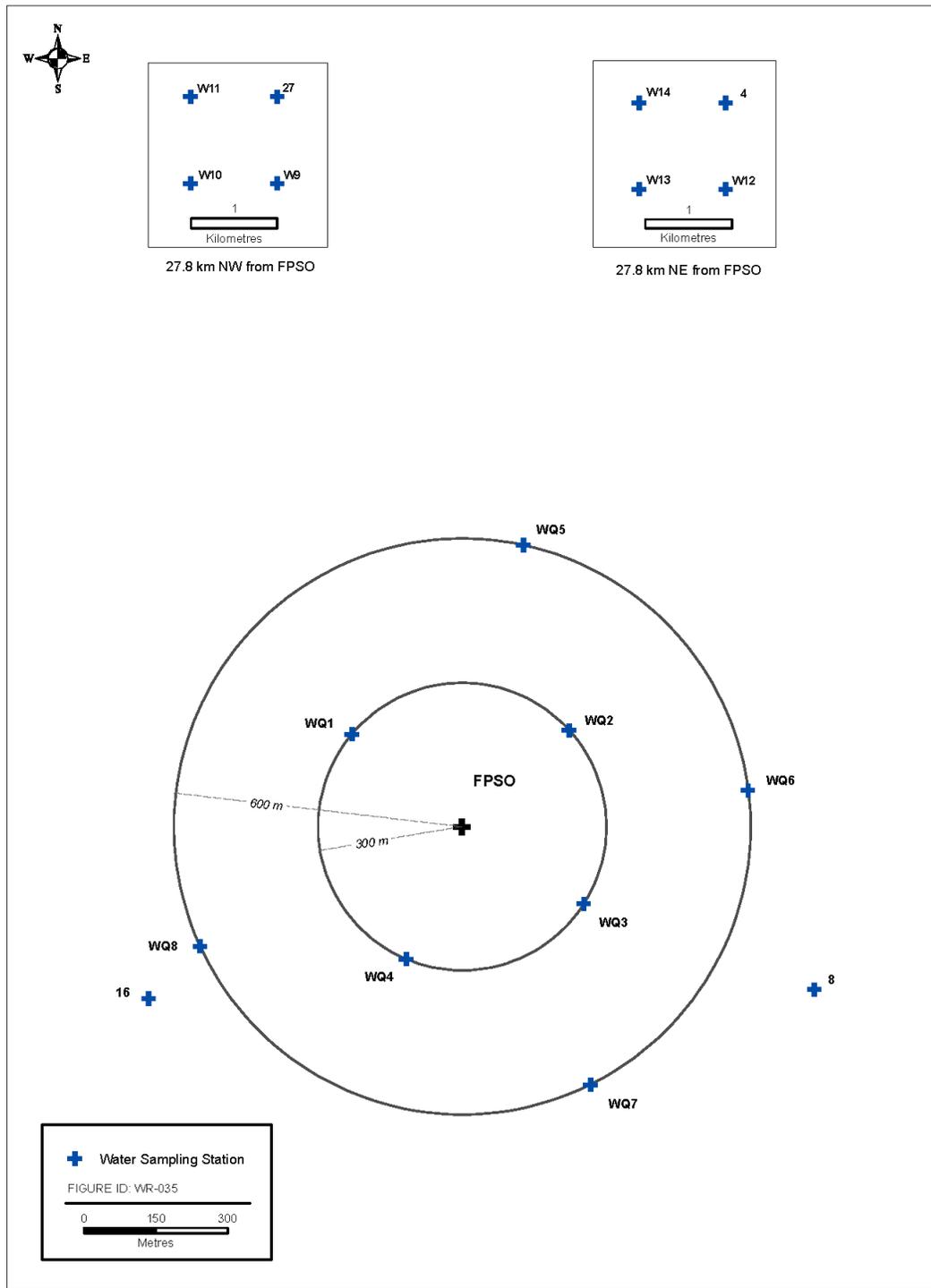


Figure 7 Water Sampling Stations - 2010

Table 10 Station Coordinates for 300 and 600 m Stations and Distance from Nearest Subsea Structure

Station Name	Eastings	Northings	Distance (m)	Structure
WQ1	727495.6	5186218.4	54	WetStore
WQ2	727947.2	5186226.6	112	NDC Umbilical
WQ3	727978.0	5185863.7	75	SDC 10" Production Test
WQ4	727608.8	5185748.4	66	Mooring Leg 4
WQ5	727852.3	5186611.4	125	NDC Umbilical
WQ6	728320.1	5186101.2	126	Mooring Leg 1
WQ7	727992.0	5185487.7	72	SDC 10" Production Test
WQ8	727179.3	5185775.6	177	CDC 10" Production Test

Niskin bottle samples will be taken at three depths at each station, as in 2008. All stations and all depths will be sampled for the following constituents:

- BTEX
- Fuel and lube range hydrocarbons,
- PAHs,
- Phenols,
- Organic acids,
- Metals,
- The naturally occurring radionuclides radium-226, radium-228 and lead-210,
- Inorganic and organic carbon,
- Total suspended solids,
- Ammonia,
- The scale inhibitor SCW4453 and
- The biocide XCide 450 (active ingredient: Gluteraldehyde)

This list is consistent with the list of constituents measured in surface samples in 2008 with the addition of XCide 450. This constituent has been added because a risk assessment of White Rose produced water indicated that the biocide is the main contributor to environmental risk in the discharge (see Section 2.5). Gluteraldehyde is the active constituent of XCide 450, the remainder is water.

CTD casts will be performed at each station. Available current meter and wind data near sampling sites obtained during field sampling will be archived for validation and fine tuning of model results (Section 2.4) as warranted⁵.

2.3.2.2 Sediment Samples

Sediment samples will be collected at all water quality stations and measured for the standard suite of chemicals measured for the Sediment Quality Component of the White Rose EEM program. These samples will also be processed for radium-226, radium-228 and lead-210. In addition, sediment samples from transect stations for the Sediment Quality Program within 3 km from the FPSO will be processed for the radionuclides. Drill centre stations will be dropped since they are superfluous in an assessment of changes in concentrations of radionuclides with distance from the FPSO. Stations beyond 3 km, other than Reference Stations, are superfluous since radionuclides are expected to settle shortly on release to the receiving environment. A total of 28 stations will therefore be sampled for radionuclides (Figure 8).

⁵ If no produced water constituents are detected with the survey design planned for 2010, model results will be used to better direct sampling in 2012.

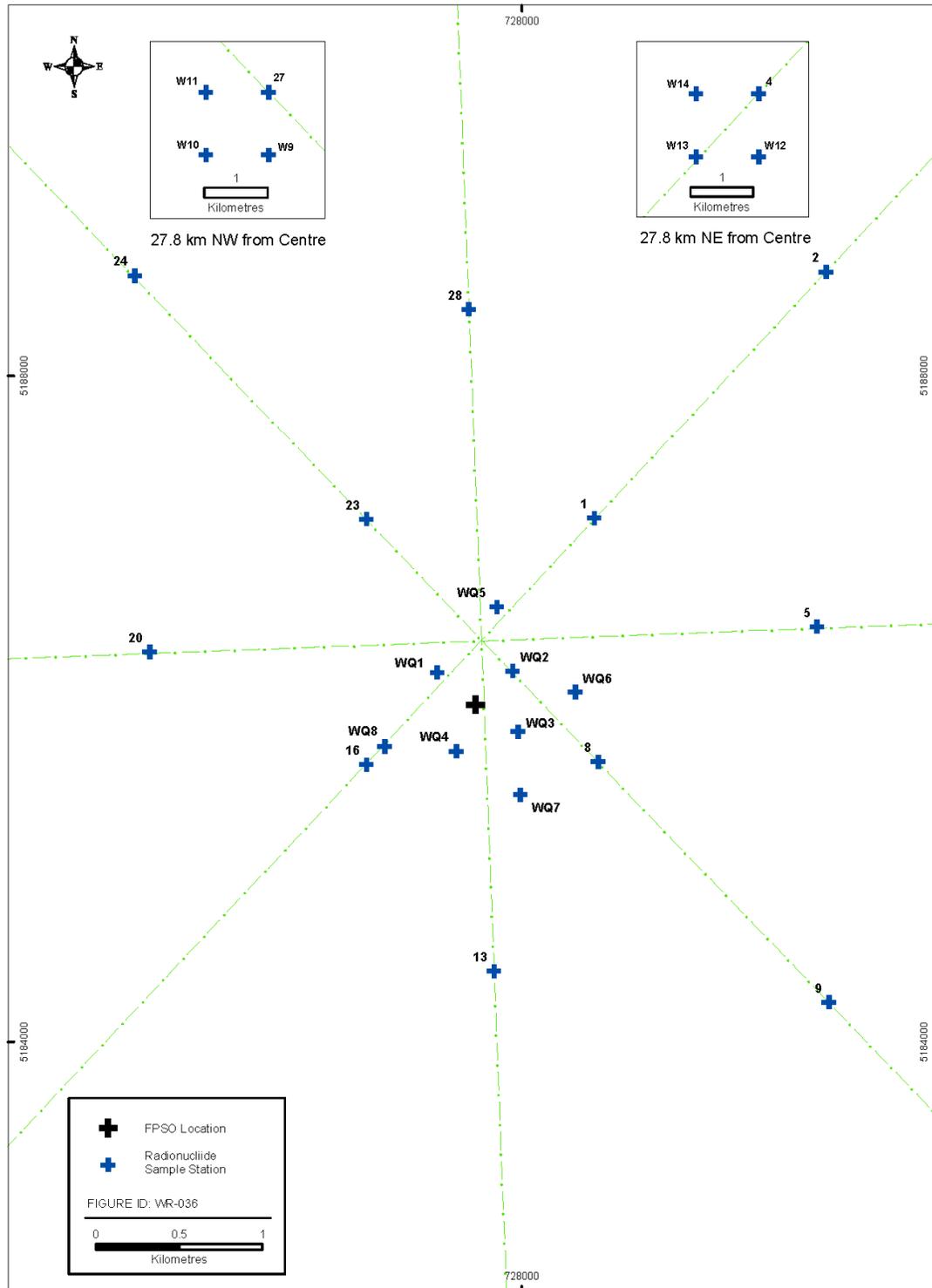


Figure 8 Radionuclide Sampling Stations – 2010

Note: Transect station locations were based on the proposed, rather than the actual, location of the FPSO

2.4 Plume Modeling

Produced water chemical characterization data (Section 2.2), discharge parameters and local wind and current data will serve as input to the Dose-Related Risk and Effects Assessment Model (DREAM) (see Appendix I for details). DREAM has been integrated into a MS Office Compatible Marine Environmental Modeling software package (MEMW) developed by SINTEF (Norway) and is available under license to Elisabeth DeBlois Inc (Newfoundland, Canada). DREAM will be used to predict the concentrations of produced water constituents in the receiving environment. Unlike the original produced water modeling exercise (Section 1), DREAM can simultaneously account for up to 200 chemical constituents within the plume. Distributions can be mapped for constituents of interest and concentrations can be compared to available instrumentation detection limit and background concentrations (Section 2.3) to identify those constituents that can be measured *in-situ* and target field sampling.

Figures 9 to 11 provide examples of DREAM output. Figure 9 shows maximum concentrations, over space, of dissolved lithium⁶ over a 30-day simulation at a produced water release rate of 28,000 m³/day. The model used wind and current data for June 2006. In this and the next two figures, a laboratory detection threshold of 1 ppb was used to filter results (i.e., concentrations less than 1 ppb are not shown in Figure 9 or accounted for in subsequent Figures). Figures 10 and 11 show the probability of detection for lithium above 1 ppb during a discrete sampling exercise. Figure 11 is a zoom-in of those model results, without smoothing across output cells. Additional preliminary output assessing probability of detection in the water column for selected constituents are provided in Appendix G⁷.

Husky Energy contracted SINTEF to add the probability maps feature to their modeling software. In this example of the maps, model output was set at 6 hrs. Cell size was approximately 125X125X10 m. Probability of detection (%) for any given cell was calculated as the number of model outputs above threshold in that cell over the total number of outputs in the 30-day simulation X 100. Cell size and model output intervals can be changed in these models to increase the spatial resolution of the output or better mimic a discrete sampling event, as required and as is reasonable⁸. Thresholds can be changed to match theoretical laboratory detection limits. More details on model input variables and settings will be provided in the final report that will issue from this work. For this report, these graphics are included as examples of what can be generated.

⁶ Lithium was selected for this example because of its high concentration in produced water relative to that of seawater, and because lithium is expected to remain dissolved in the water column (Phil Yeats, pers. comm.).

⁷ The assumption for all tested constituents in Appendix G was that these would remain in solution, even if this is not necessarily the expectation (see below on modeling deposition of constituents).

⁸ There is a trade-off between computational time/resources required and added information gained by increasing output volume.

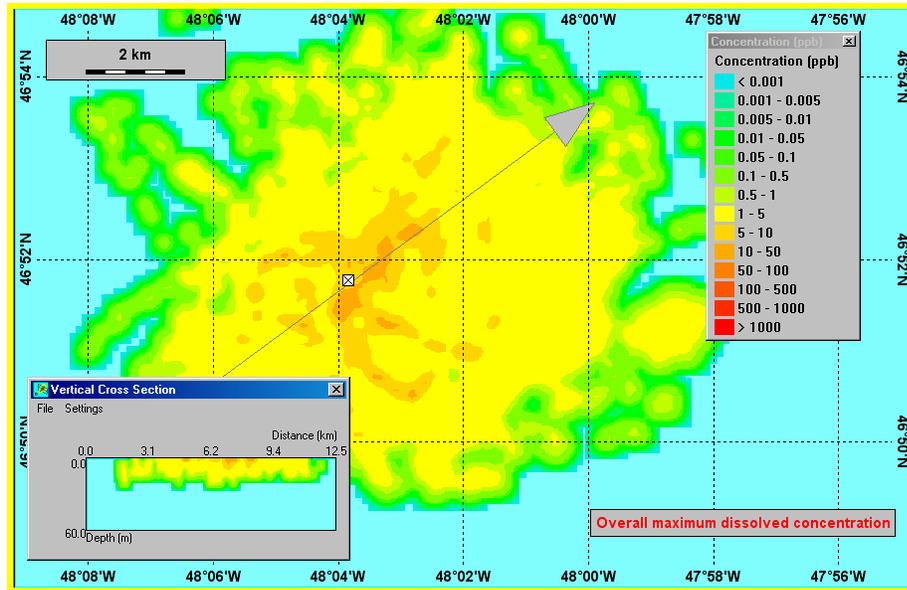


Figure 9 Example of DREAM Model Output: Maximum Concentration of Lithium

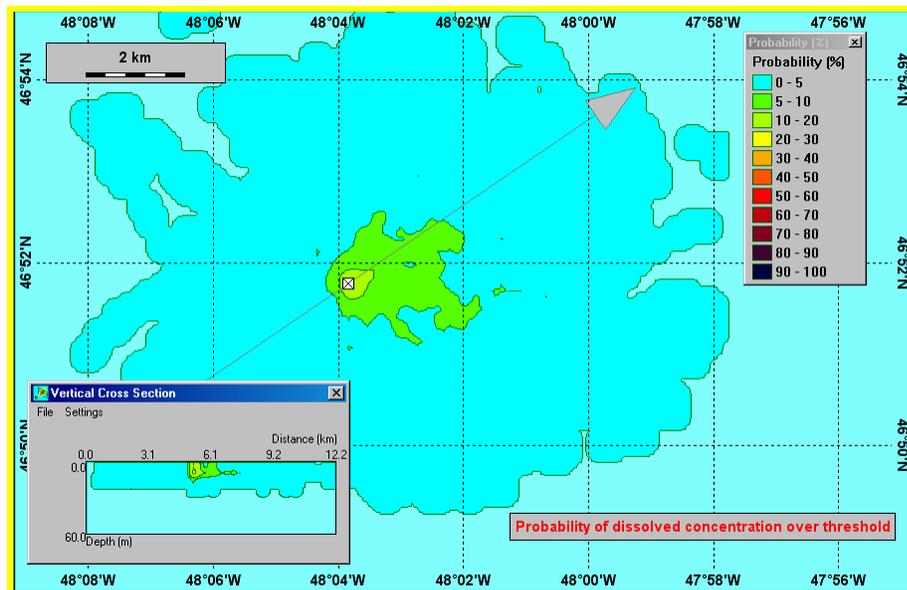


Figure 10 Example of DREAM Model Output: Probability of Detecting Lithium

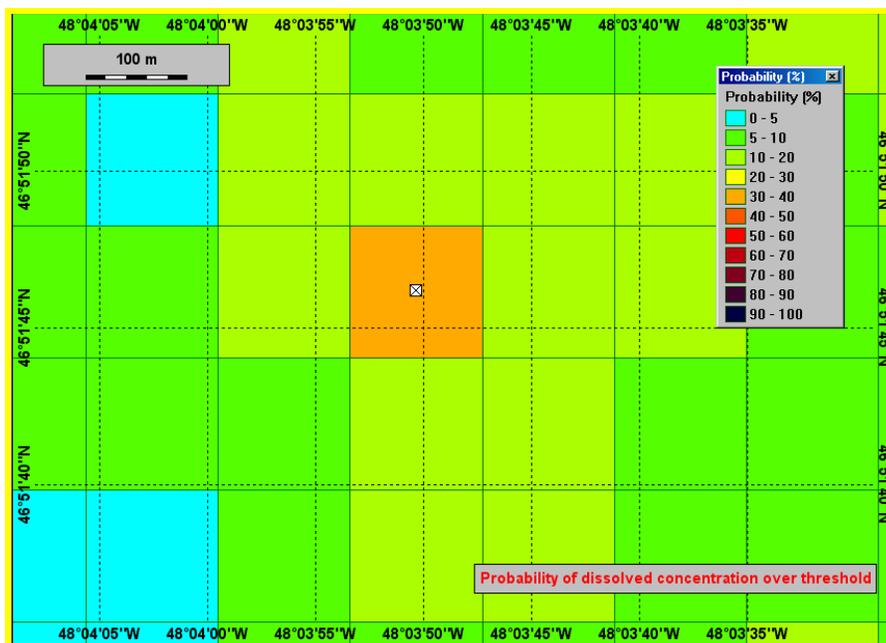


Figure 11 Example of DREAM Model Output: Probability of Detecting Lithium – ZOOM IN, unsmoothed.

Given that some of the constituents in the produced water plume may settle out, modeling with and without settling of constituents will be performed (Figure 12). The assumption that all constituents in produced water are fully miscible in water (i.e., modeling without settling) is a worst-case-scenario assumption for water quality. Conversely, if some constituents are settling out, then modeling with a settling component could potentially provide a more realistic assessment of constituent concentrations in both sediment and water. Carrying out both these exercises will provide an estimate of theoretical minima and maxima in the water column and will better allow the identification of potential tracers or indicators of produced water in both sediment and water. This approach was adopted by Rye (in prep.) to determine theoretical radionuclide concentrations in the North Sea, because there was uncertainty about the specific fate of produced water radionuclides in that environment.

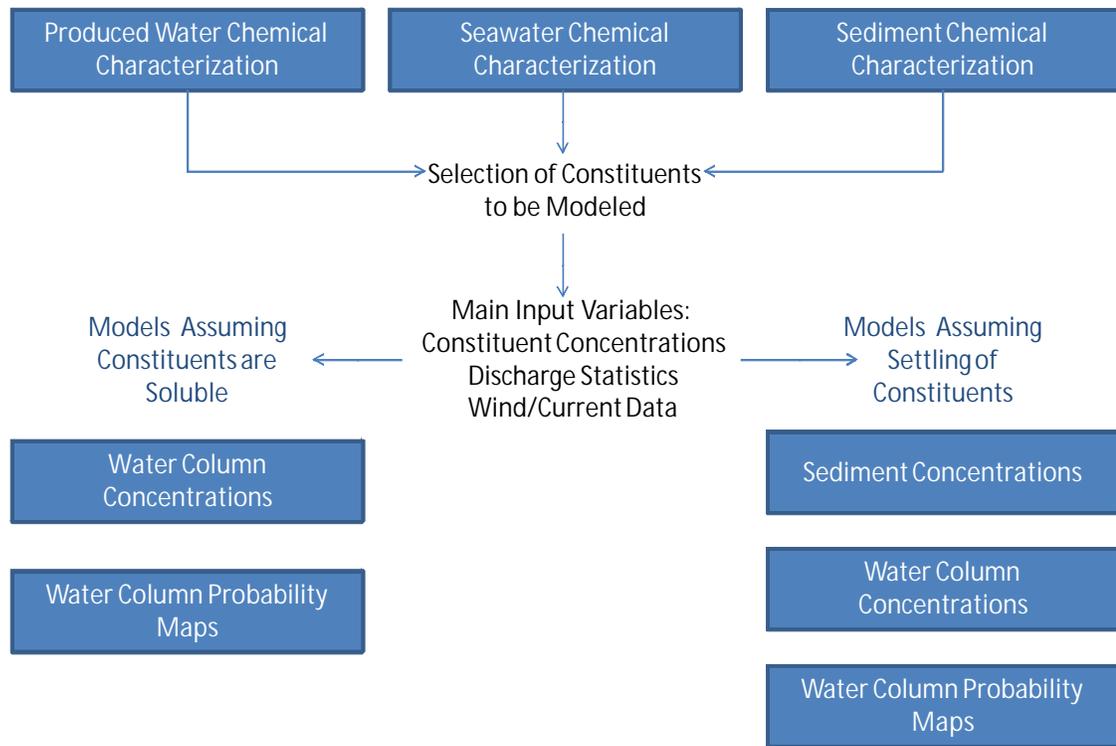


Figure 12 Simplified Diagram of Main Information Requirements and Model Inputs and Outputs

Modeling the settling of constituents will require using the DREAM module of MEMW with the sedimentation module: ParTrack; and it will require knowledge of constituent fates upon release to the marine environment. SINTEF is currently contracted to identify and report on which constituents of the produced water plume will be expected to settle out and to provide realistic model input parameters to MEMW. Outputs from these models will display the accumulation of constituents on the seafloor after a set release period along with water column concentrations.

Expected concentrations and probability of detection in the water column and expected concentrations in sediments will be calculated for constituents with high concentrations in the produced water plume (Section 2.2) relative to that of seawater or sediments (Section 2.3) or high risk constituents (see Section 2.5) At present, likely candidates include barium, boron, lead, lithium, manganese, silicon, strontium, radium-228, acetic acid, ammonia, >C₁₀-C₂₁ hydrocarbons, phenols and naphthalene, and the process chemicals SCW4453 and XCide 450.

Produced water constituents will first be modeled at a produced water discharge rate of 28,000 m³/day. Constituents with non-zero probability of detection in the receiving environment will then be modeled at a discharge rate of 20,000m³/day and, if warranted, at a discharge rate of 10,000 m³/day. Those constituents with zero probability of detection at 28,000 m³/day will have zero probability of detection at lower discharge rates. Therefore, modeling at lower discharge rates will be unwarranted.

2.5 Risk Assessment

DREAM can be linked to the Environmental Impact Factor (EIF) to generate estimates of the potential environmental risk to the water column associated with the produced water discharge. The EIF methodology was designed as a management tool to assess the potential environmental benefit achieved when alternate produced water management options are considered. The method, as defined by OLF (2003), relies on a number of conservative assumptions and therefore provides relative rather than actual risk (see Appendix J). The EIF approach, which is based on both the fate of produced water constituents in the marine environment and laboratory estimates of toxicity, is able to discriminate among the various contributors to environmental risk and calculate the risk contribution from each of them.

Husky Energy has modeled the environmental risk associated with the constituents of its produced water plume at discharge rates of 10,000, 20,000 and 28,000 m³/day. Preliminary results were presented to the C-NLOPB in December 2009. At all discharge rates, the biocide XCide 450 was identified as the main contributor to environmental risk. At 28,000 m³/day, hydrocarbons and phenols collectively contributed to 29% of the risk. Metals accounted for 1.2% of the risk and the scale inhibitor SCW4453 contributed to 0.7% of the risk. XCide 450 contributed to 69% of the risk at that discharge rate (Figure 13). Because of reduced dilution at lower discharge rates, XCide 450 accounted for 86% and 72% of the risk at discharge rates of 10,000 and 20,000 m³/day, respectively, and other constituents accounted for less.

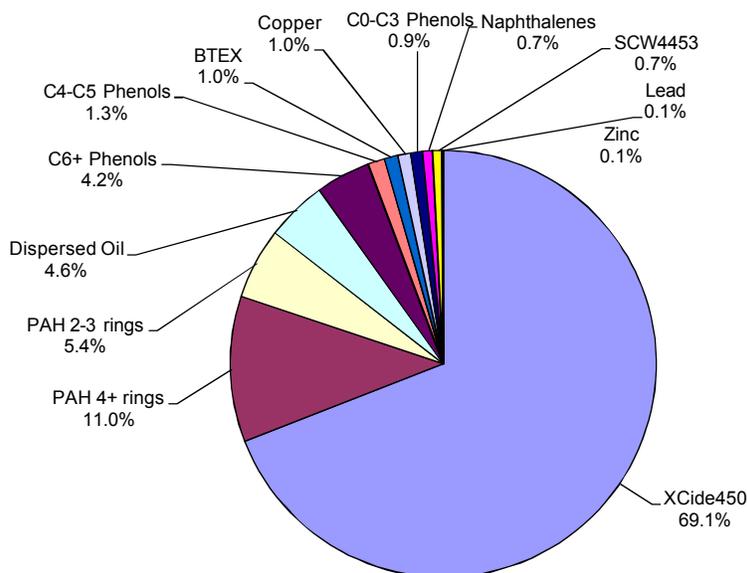


Figure 13 Contribution to Risk of Various Constituents of White Rose Produced Water at a Discharge Rate of 28,000 m³/day

Husky Energy’s primary interest in EIF is as an aid to assess management options for produced water. However, risk assessment results can also help target field sampling. As described in Section 2.3, water samples to be collected in 2010 will be processed for gluteraldehyde concentration. The active ingredient in XCide 450 is gluteraldehyde, the

remainder is water. The 2010 field program will assess if residual amounts of this biocide can be measured *in-situ*. As noted in Section 2.3, remaining constituents listed in Figure 13 will also be measured in water samples.

3.0 Conclusion

Husky Energy's Water Quality Monitoring Program is iterative and relies on detailed knowledge of produced water constituents, anticipate concentrations in the receiving environment obtained from constituent-based modeling and targeted sampling. Information obtained at any step in the process is used to improve the overall program. As such, the program is not static but will evolve as more information becomes available.

To date, the program has included detailed characterizations of produced water, field sampling in 2007 and 2008, preliminary modeling of constituent concentrations in the receiving environment. Risk assessment results have also been used to refine the 2010 field program. Supporting activities carried out to accomplish these tasks have included extensive discussion with analytical laboratories on capabilities and modifications to the MEMW software package to generate maps that indicate the probability of detection for water column constituents based on laboratory detection limits.

Planned activities include completion of modeling to predict constituent concentrations in the receiving environment and an enhanced field sampling program for 2010. Support activities that will be carried out to accomplish these task include the determination of input parameters for constituents expected to settle out of the produced water plume. This and any additional risk assessment results that may become available will be used to hone the field program on an ongoing basis.

Chemical characterizations of produced water will continue to be performed on a regular basis, as this information is key to determining what can be measured *in-situ*.

4.0 References

4.1 Personal Communications

Dr. Don Dunbar, Lorax Environmental, Vancouver, British Columbia, Canada.

Dr. Phillip Yeats, Scientist Emeritus, Fisheries and Oceans Canada, Dartmouth, Nova Scotia, Canada.

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5.0 List of Appendices

Appendix A - Rhodamine Trial Results

Appendix B - Summary of Recommendations from Husky Energy's Produced Water Workshop

Appendix C - Chemical Characterizations of Produced Water

Appendix D - Chemical Characterization of Seawater Samples

Appendix E - CTD Profiles

Appendix F - Chemical Characterization of Near-field Sediment Samples

Appendix G - Preliminary Graphics from DREAM Modelling of Constituents in the Water Column

Appendix H - Coordinates for Water Quality Stations for the 2010 Field Program

Appendix I - Technical Description of Physical-Chemical Fates Components of DREAM

Appendix J - Summary of EIF Methodology

Appendix A

Rhodamine Trial Results

A Rhodamine Dye Study of the Dispersion of Produced Water Discharged From the Terra Nova FPSO

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Lorax Environmental Services Ltd.

Vancouver, BC

February 2006



Table of Contents

1. Introduction	1-1
1.1 Study Objectives	1-2
1.2 The Terra Nova FPSO and Produced Water Discharge.....	1-2
2. Methods	2-1
2.1 Dye Tracking	2-1
2.2 Other Field Measurements.....	2-2
2.3 Data Analysis.....	2-4
3. Results	3-1
3.1 Description of Data Presentation	3-7
3.2 November 18 Results.....	3-9
3.2 November 25 Results.....	3-17
4. Summary.....	4-1
5. Conclusions	5-1
5.1 Potential Methods Improvement.....	5-1
5.2 Communications	5-3

1. Introduction

The Terra Nova Floating Production Storage and Offloading Vessel (FPSO) (Figure 1) discharges a high temperature, high salinity plume of produced water. Since produced water may adversely affect water quality it is necessary to understand the behaviour of the produced water plume after discharge from the FPSO, and its subsequent far-field dispersion. The initial dilution is expected to be high enough to erase signatures of the produced water's physical properties, such as temperature, salinity, or turbidity that might be used to track the plume. The addition of an appropriate inert tracer to the produced water permits the detection of produced water at the low concentrations expected after initial dilution of the plume. This report describes a vessel-based field study that tracked a fluorescent dye added to the produced water discharged from the Terra Nova FPSO on November 18 and again on November 25, 2005.

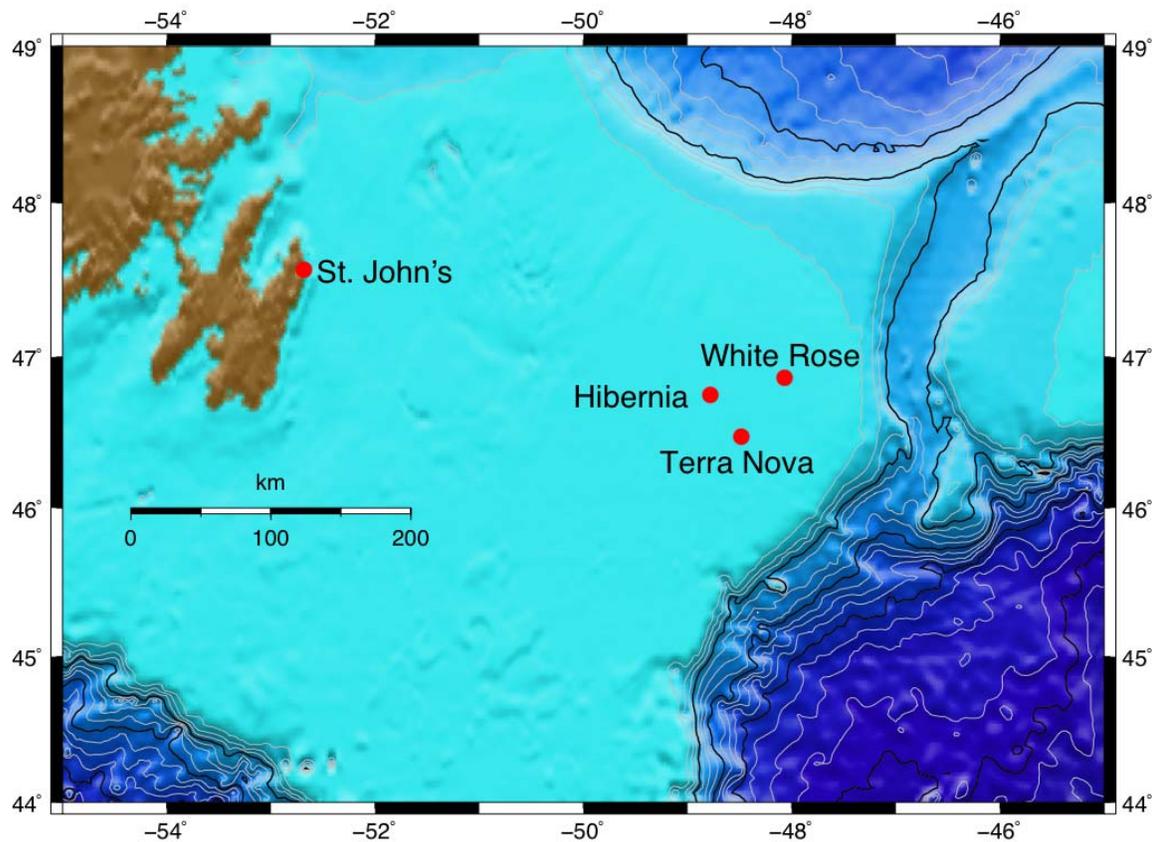


Figure 1 Location of Terra Nova Oil Field

1.1 Study Objectives

The long term objective of this work is to develop a methodology for monitoring produced water on the Grand Banks. The immediate goal of the present study is to provide a proof-of-concept for adding Rhodamine dye to a produced water stream and making subsequent vessel-based measurements of dye concentration for quantifying the distribution of produced water in the open ocean.

1.2 The Terra Nova FPSO and Produced Water Discharge

The Terra Nova FPSO has a length of 292 m, a beam of 45.5 m, and a maximum draught of 20 m (Figure 2). Produced water is discharged downward through a caisson located approximately mid-ship toward the port side and approximately 67 m aft of the Turret Area which remains at a fixed location, and about which the FPSO can pivot (Figure 3). The depth of discharge can vary from 13-20 m, depending on the vessel draught. On November 18th the FPSO draught was 15.7 m, while on November 25th it was 15.6 m.

Throughout the duration of this study the FPSO was positioned at 48° 28.86'W, 46° 28.53'N—approximately 350 km east-southeast off the coast of Newfoundland. This position corresponds to the centre of the Turret Area of the vessel where the sub-sea connections are located. The heading of the FPSO is occasionally modified with time depending on wind and sea conditions; consequently the UTM coordinates of the produced water discharge may vary by as much as 70 m in either direction. This variation is significant, and must be included in the data analysis.

The produced water is discharged from the FPSO at a temperature of 60° C and with a salinity from 65 to 70 ppt. Using the standard UNESCO equation of state for seawater, this yields a corresponding density of at least 1030 kg/m³. In addition, Petro-Canada has reported corrected densities exceeding 1050 kg/m³. In either case, the density of the produced water exceeds the ambient seawater density, which has a maximum value of 1029 kg/m³. In the absence of any other source of buoyancy, the produced water will fail to surface under all anticipated discharge conditions. However, the produced water plume is routinely observed at the ocean surface, indicating that there is sufficient air added in prior to discharge to provide the buoyancy necessary to transport a portion of the produced water to the surface.

The fraction of produced water that surfaces depends on the temperature and salinity of the produced water, its air content, the depth of discharge, and vertical density stratification arising from the ambient ocean temperature above the discharge depth.

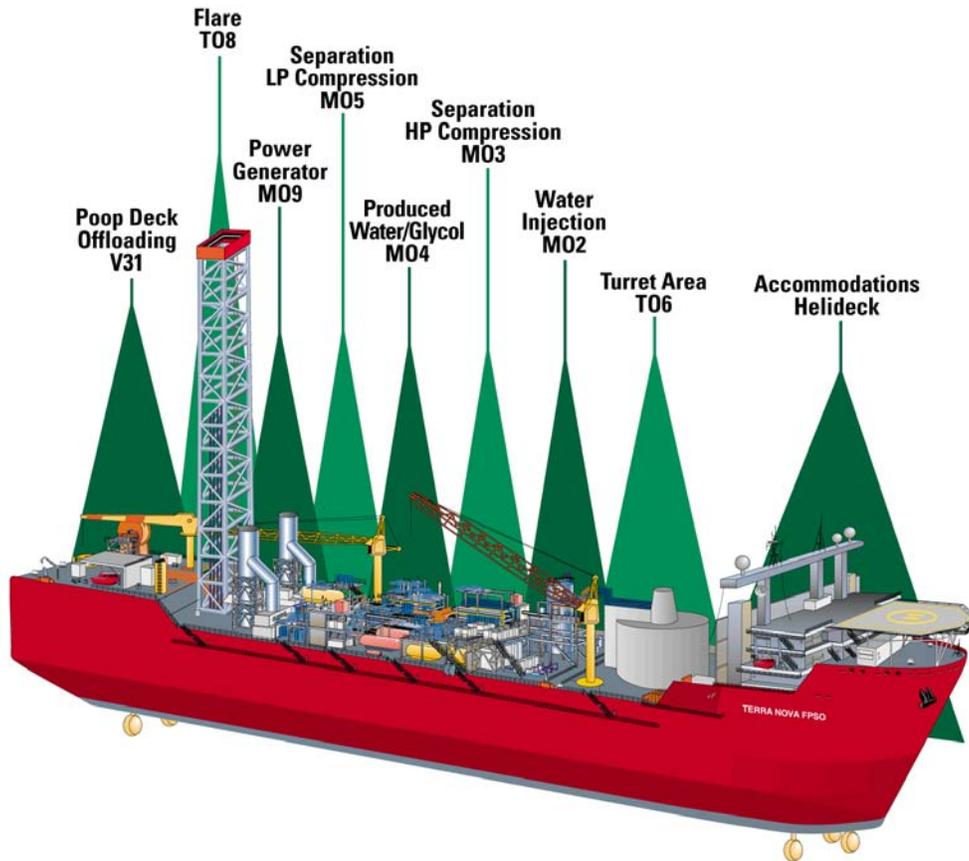


Figure 2: Photograph and Schematic of Terra Nova FPSO

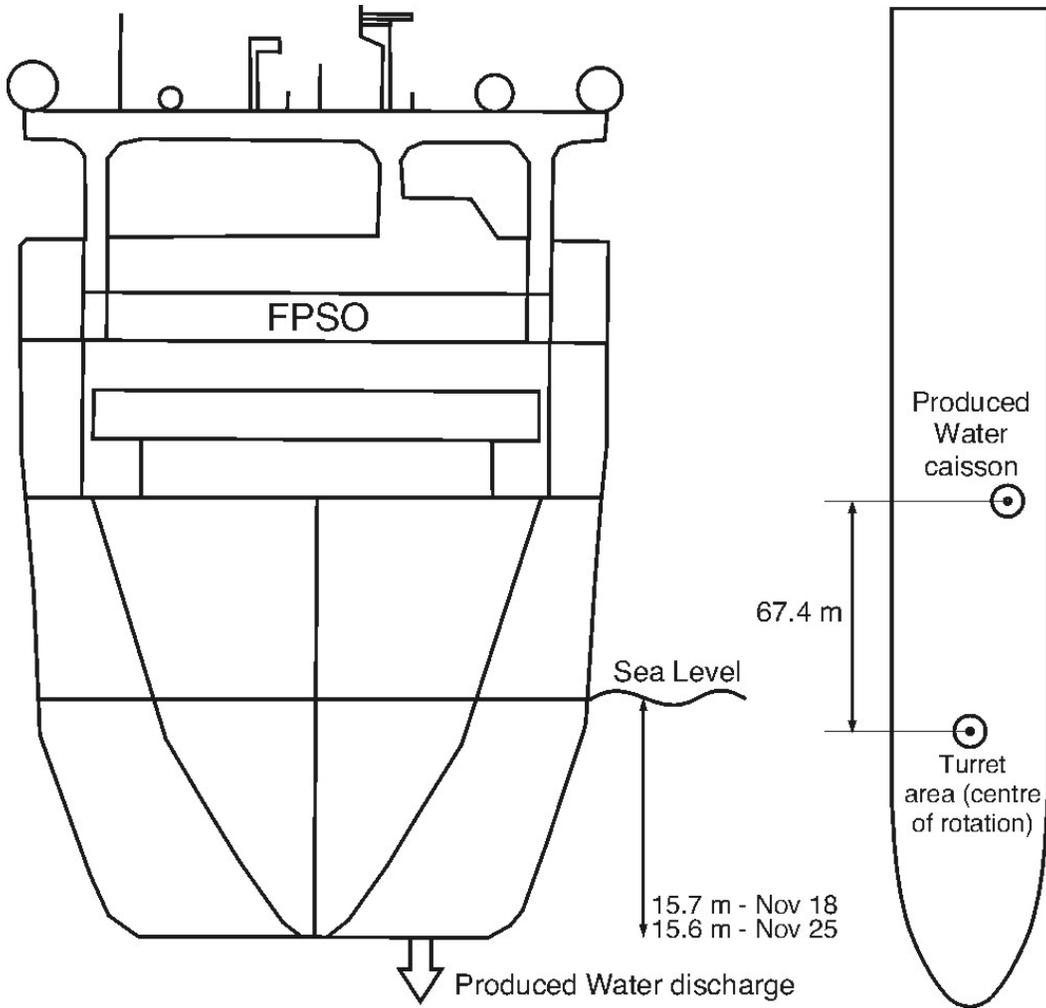


Figure 3: Schematic of FPSO showing location and depth of produced water discharge

2. Methods

2.1 Dye Tracking

The concentration of produced water (produced water) in ocean water was determined by adding a known concentration of Rhodamine WT fluorescent dye as a tracer to the produced water prior to discharge (see Appendix 1 for work instructions for the experiment). Fluorescence in the water surrounding the Terra Nova FPSO was then measured in order to quantify the concentration of produced water as it was diluted with ambient seawater. For the values of Rhodamine concentration ([Rh]) used in this study, fluorescence is linearly proportional to the active dye concentration and therefore provides a measure of produced water concentration in the water column.

Rhodamine WT is a fluorescent dye commonly used to measure water circulation and dispersion. It can be quantified at low concentrations, <0.2 part per billion ($\mu\text{g/L}$), using a fluorometer, which shines light at a wavelength of 530 nm and measures the light emitted from the dye at 600 nm. Other benefits of using Rhodamine WT are that it does not degrade significantly over the time scales of typical plume studies (less than eight hours); it is non-toxic at concentrations above those used in this study; and it does not adsorb to particles in the water column. This study used a Turner Designs SCUFA fluorometer with turbidity channel to measure fluorescence in the water column. The fluorometer was connected to a Seabird SBE 19plus conductivity, temperature, depth (CTD) probe which measured fluorescence as well as salinity, temperature and depth every 0.25 seconds and logged the data after averaging four measurements.

Rhodamine dye was added to the produced water stream by Petro-Canada crew onboard the FPSO by pumping a 20% Rhodamine WT ('Keyacid' Rhodamine WT Liquid supplied by A.S. Paterson Company Ltd.) solution at a constant rate into the produced water stream (see Appendix 1). Dye pumping rates were 22 and 16.5 L/h on November 18 and 25, respectively. Rates were pre-determined based on a projected produced water flow rate of $350 \text{ m}^3/\text{h}$ and a secondary dilution of 2 to 1 as the produced water plume moved away from the FPSO, to produce a plume with 50 ppb of dye. produced water flow rate was monitored on the FPSO and these data were used with the dye pumping flow rate to calculate the concentration of dye in the produced water stream entering the ocean.

Water column fluorescence was measured in vertical profiles. The CTD/fluorometer was lowered vertically over the side of the vessel *MV Atlantic KingFisher* from the surface to

near the bottom. The station keeping ability of the ship is excellent and the vertical profiles were achieved with minimal wire angle. Vertical profiles were made along transects perpendicular to the presumed long-axis of the plume, thereby recording vertical and horizontal distribution of produced water at a given distance from the FPSO. Several transects were made at various distances, up to 2.2 km from the FPSO, in order to measure dilution of produced water as it was carried away from the FPSO.

The ship's position for each profile was recorded using the vessel's DGPS. The position of the CTD was determined by knowing the distance from the bridge to the davit used for deploying the CTD and the heading of the ship. Similarly, the heading of the FPSO was recorded in order to calculate the location of produced water discharge relative to the known position at the turret.

2.2 Other Field Measurements

Current velocity was recorded at 4 locations and 5 depths in order to help interpret the fluorescence results. Other ancillary measurements included wind velocity and wind gusts (speed only) recorded at 50 m elevation at the FPSO, surface water temperature at the FPSO, and tidal current.

Sub-surface temperature and current data were obtained from instruments located at the Henry Goodrich platform and the Terra Nova permanent array. Current data from the Henry Goodrich are not available for November 18. Locations of these instruments, together with the locations of all CTD casts used in this study relative to the FPSO are shown in Figure 4.

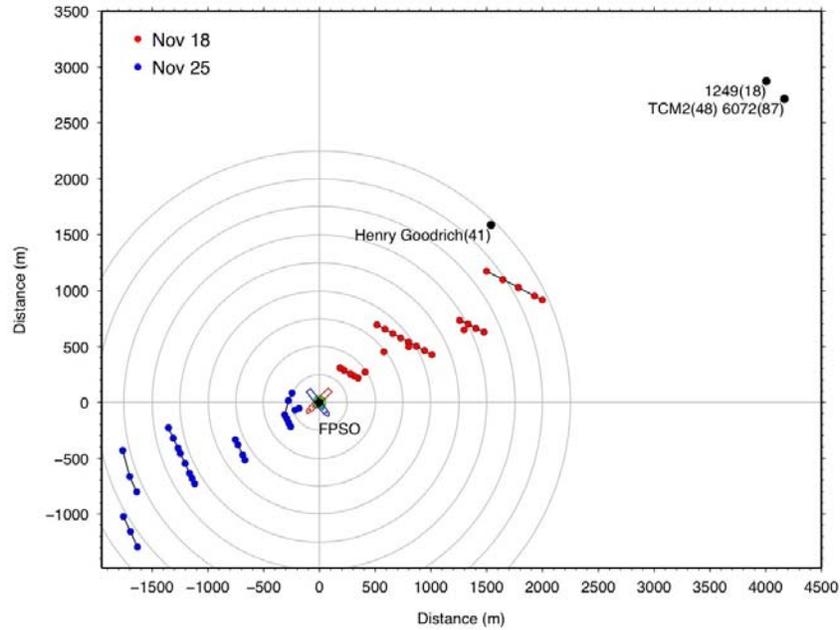


Figure 4: Locations of current meters and CTD casts

These measurements were supplemented by tidal currents obtained from the Bedford Institute of Oceanography (BIO) website which provides access to current predictions from their tidal hydrodynamic model.

Table 1 Data and Instrumentation used in the Study

Data Type	Instrument	Station	Manufacturer	Model	Latitude (N)	Longitude (W)	Depth / Elevation	Sample Rate
Current velocity	Current Meter	TCM2	Aanderaa	RCM-7	46° 29.92'	48° 25.53'	48 m	Var.
		6072		RCM-4			87 m	
		1249	Neil Brown	ACM	46° 30.01'	48° 25.65'	18 m	
		Henry Goodrich		DRCM	46° 29.36'	48° 27.61'	41 m	
		FPSO (TAPMS)			46° 28.53'	48° 28.86'	Surface	
FPSO (MET)								
Wind Speed & Direction	Anemometer	FPSO TAPMS			46° 28.53'	48° 28.86'	50 m	Var.
		FPSO MET						
Wind Gust		FPSO MET						

Ocean Temperature	FPSO MET	46° 28.53'	48° 28.86'	Surface	Var.
Vessel Heading	FPSO TAPMS	46° 28.53'	48° 28.86'		
	FPSO MET				

2.3 Data Analysis

Time-series data collected during this survey have a variety of sampling times and rates, and most of the data from the FPSO have irregular sampling rates. Similarly, the vertical spacing between samples taken by the CTD is not uniform. To simplify analysis, all scalar and vector time-series were sub-sampled and digitally filtered prior to analysis and plotting. Speed and direction vector data were first converted to orthogonal scalar components. Time-series data were linearly interpolated to 1 minute intervals prior to passing through a boxcar filter with a 5 minute window. This process effectively removes the energy in the data with periods of less than 5 minutes and results in a set of data with a consistent set of sampling times at 5 minute intervals. The CTD data were linearly interpolated and sub-sampled at intervals appropriate to a particular analysis or plotting method.

3. Results

The Rhodamine dye concentration data collected on November 18 and 25, 2005 together with other relevant data are presented in this section. Figure 5 shows the times, depths, and locations of all CTD casts included in the analysis for these two dates. Colours are used to distinguish the two days, with red and blue corresponding to November 18th and 25th, respectively.

The upper panel in Figure 5 shows the times and depths of each CTD cast. The times when Rhodamine dye pumping was turned on and off are indicated by vertical yellow lines. The origin of the plot is at the location of the caisson on the FPSO where the produced water and dye are injected through the bottom into the ocean. The FPSO is drawn to scale and is oriented in the direction of the mean heading maintained during each survey period. The mean wind speed and direction over the same period are also shown.

In subsequent sections of this report, images of [Rh] along several vertical sections are shown and discussed. These sections are indicated on Figure 5 as lines connecting three or more CTD positions.

The complete set of [Rh] measurements and the down-cast temperature and density (σ_t^1) vertical profiles from the two survey days are plotted with depth in Figure 6. The CTD data have been partitioned by both the day and the direction of the CTD cast (i.e., up or down casts). Temperatures very near the surface range from 6 to 8°. Below the surface, to a depth of approximately 35 m, the temperature is fairly constant at approximately 6°. Below 35 m, to a depth of between 50 and 55 m the temperature decreases to -0.5° or less. This strong thermocline is mirrored in the density profile which increases from 1025.5 to 1026.5 kg/m³ at 60 m.

The plot of [Rh] in the left-hand panel of Figure 6 reveals a 0.14 ppb offset as indicated by the concentration of points on the left edge of the plot at all depths. Consequently, 0.14 ppb has been subtracted from all of the [Rh] measurements.

¹ σ_t = density – 1000 (kg/m³)

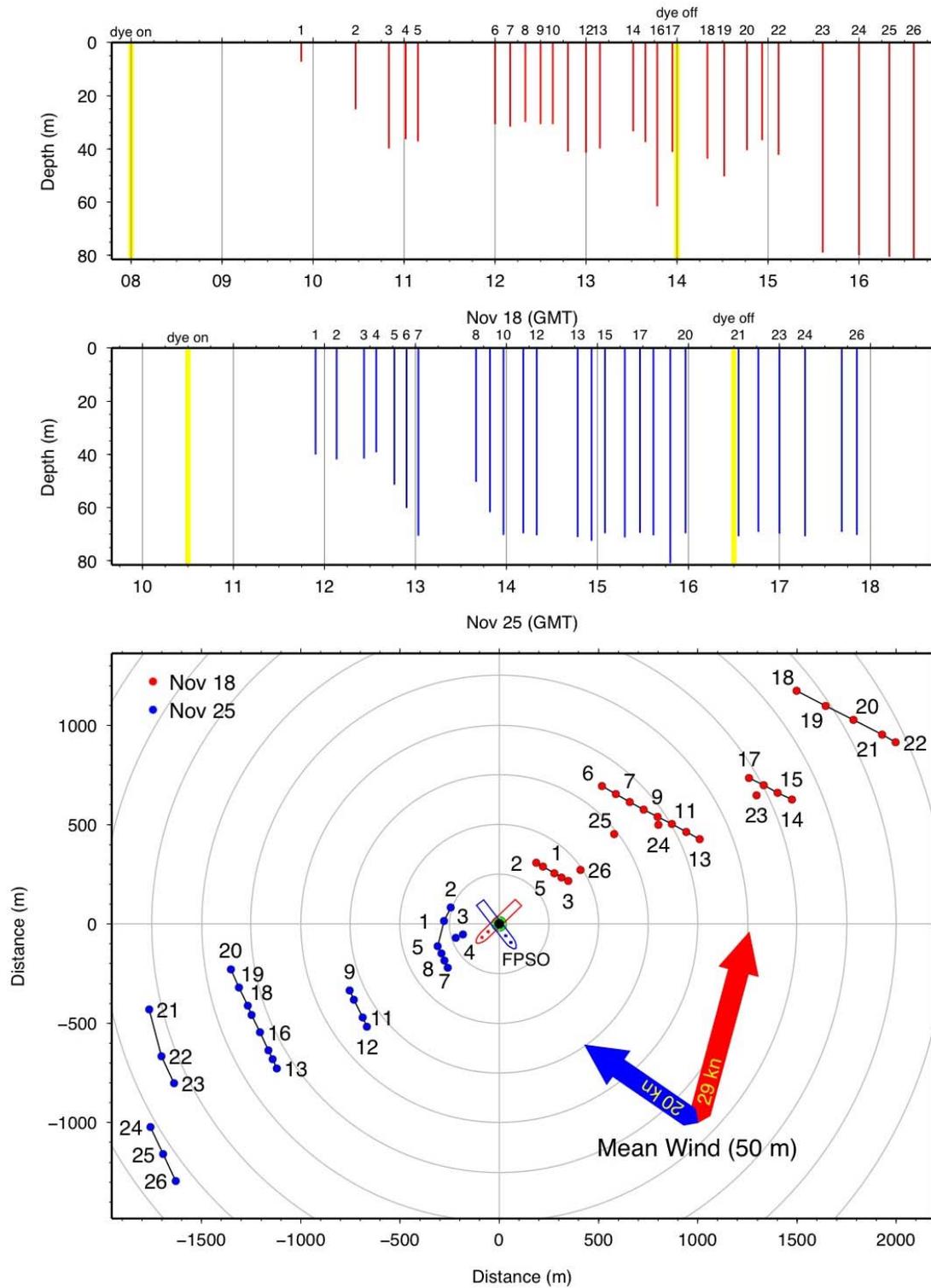


Figure 5: Times and locations of CTD cast on each field day. Connected locations identify vertical slices

The pycnocline—defined by the region of rapid density change— is located between 35 and 50 m and corresponds to the range of depths where [Rh] decreases rapidly to below 1 ppb. It is evident, however, that dye concentrations up to 1 ppb occur to depths of at least 80 m at some locations.

Variations in [Rh] with depth and distance from the FPSO are shown in Figure 7, where the range of observed values for [Rh] has been partitioned into five equal-sized populations, or quintiles, with each quintile containing 20% of the [Rh] measurements. The boundaries of the quintiles are listed in Table 2.

Table 2: Distribution of [Rh]

Quintile (20%)	[Rh] concentration range (ppb)
1	0.0 – 1.0
2	1.0 – 3.2
3	3.2 – 7.2
4	7.2 – 13.2
5	> 13.2

As expected, Figure 7 confirms that [Rh] decreases with increasing distance from the source at the FPSO. The figure also clearly shows a thin, relatively high concentration layer (>13 ppb) at the surface that is present at all distances from the FPSO. In addition, there are low concentrations of dye (<1 ppb) extending down to 80 m on both days. It is also apparent that the produced water plume splits into at least two layers with little or no dye measured between them. Presumably, this results from the high air content in the discharge that transports some of the produced water to the surface, while leaving a relatively dense component to move downward.

Another view of the variation in [Rh] with depth and distance from the FPSO is provided in Figure 8 which depicts variations in concentration using a colour spectrum. The values displayed were determined by taking the largest value of [Rh] along each transect, and at each depth. This figure clearly illustrates the high values of [Rh] present in a thin surface layer up to 2 km from the FPSO.

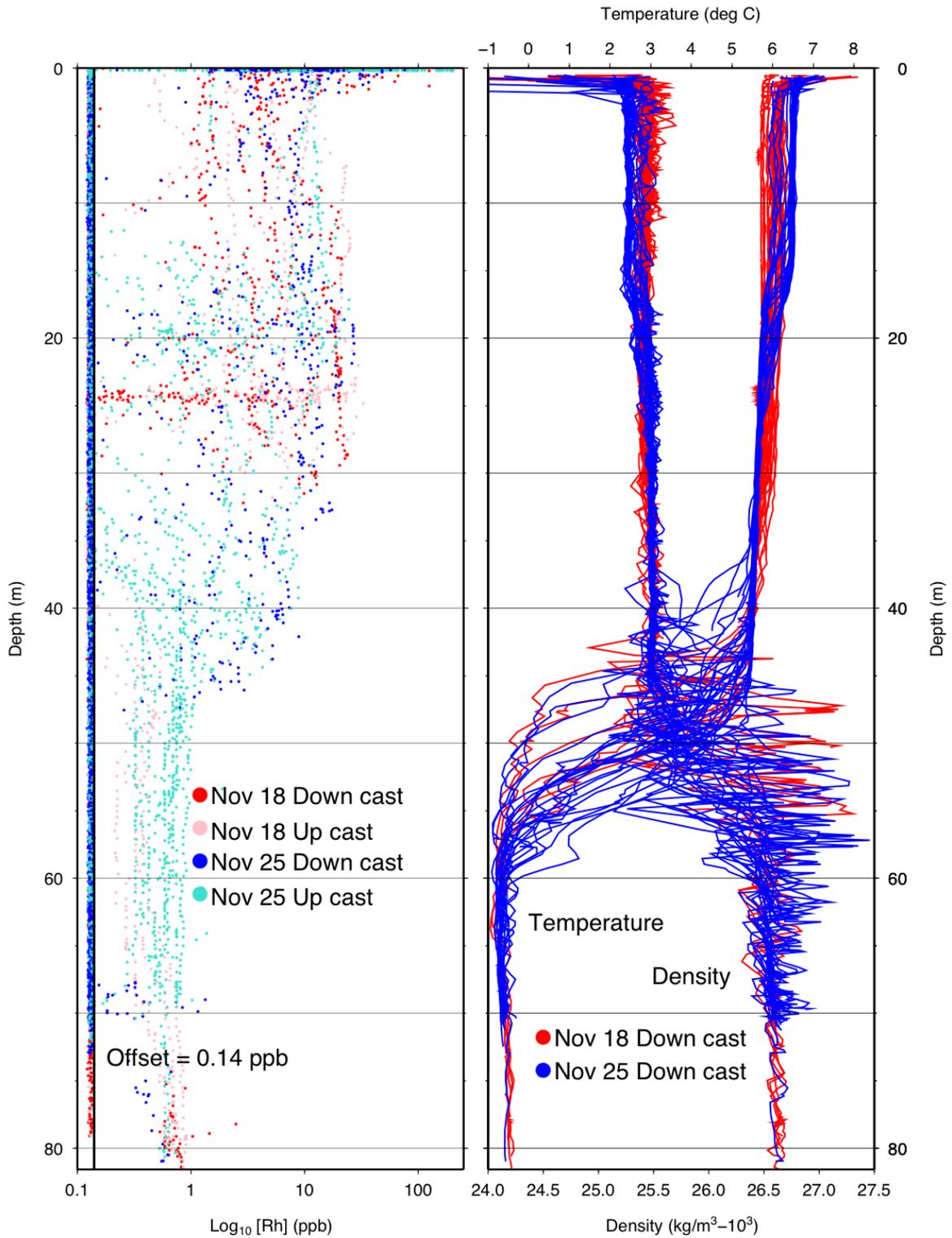


Figure 6: Left: [Rh] variation with depth from all CTD casts. Note that the [Rh] is on a log scale. Right: temperature and density profiles from all CTD down-casts

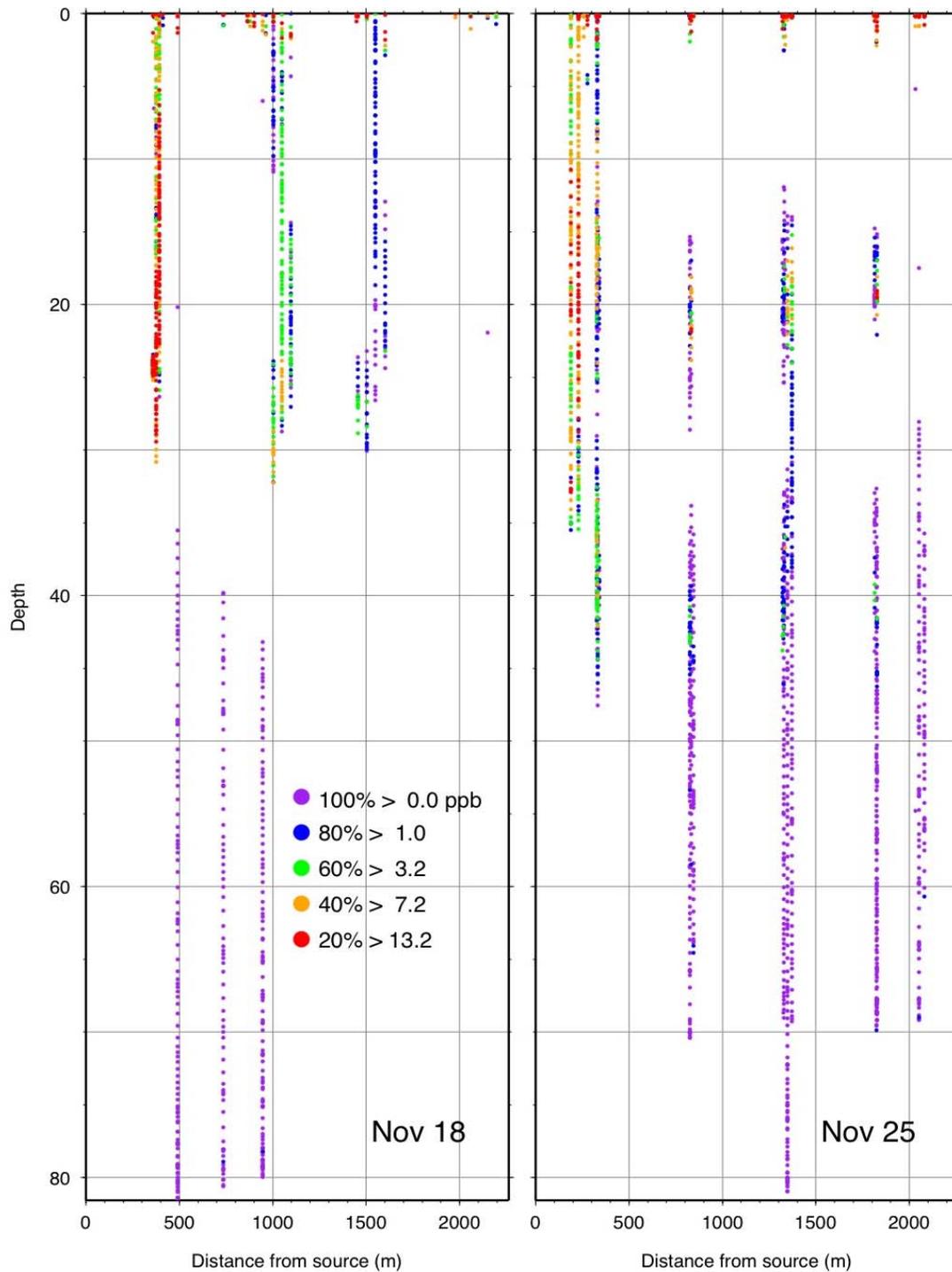


Figure 7: Variation of [Rh] with depth and distance from the FPSO using all CTD casts. Colours partition the data into five concentration ranges, each corresponding to 20% of the total number of measurements.

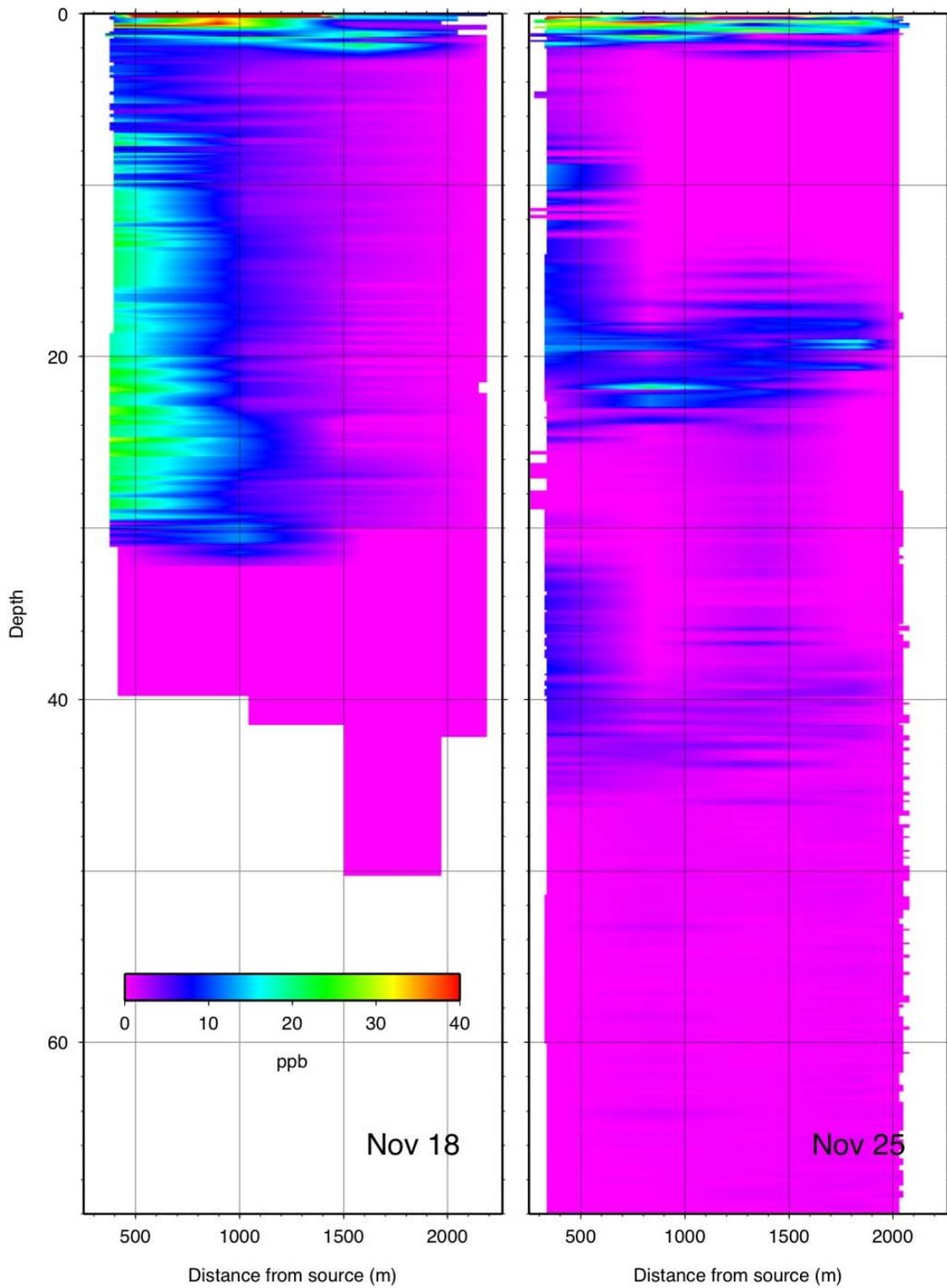


Figure 8: Variations in maximum [Rh] with depth and distance from the source

3.1 Description of Data Presentation

The following two sections provide details of data collected during each field day. Data pertaining to the CTD casts for each day are summarized in a table at the beginning of each section. The entries in the tables for each CTD cast are as follows:

1. Cast identification number (e.g., for plots)
2. GMT Time of cast (HH:MM)
3. Longitude (48° W plus m' s'')
4. Latitude (46° N plus m' s'')
5. D Distance from the produced water caisson to the CTD location
6. θ Bearing from the produced water caisson to the CTD location (°T)
7. H_m Maximum depth reached by the CTD
8. H_r Maximum depth at which Rhodamine dye was detected
9. R_x Maximum concentration of Rhodamine dye measured during the cast
10. S_x Total amount of dye in the depth range sampled by the CTD
11. The percentage of Rhodamine dye within a set of depth ranges

In addition, the following plots are presented for each of the two days.

Produced Water and Rhodamine Dye (Figures 9 & 14)

Panels in these plots show the cumulative mean concentration of dye at the point of discharge; the cumulative discharge volumes of produced water and dye; and the produced water and Rhodamine dye flow rates. The cumulative volumes are defined as

$$V_{Rh}(t) = \int_0^t Q_{Rh} dt, \quad (0.1)$$

$$V_{PW}(t) = \int_0^t Q_{PW} dt$$

where $Q_{Rh}(t)$ and $Q_{PW}(t)$ are the flow rates of Rhodamine dye and produced water, respectively (e.g., m³/s). The cumulative mean dye concentration is then defined as

$$[\overline{Rh}](t) = [Rh]_0 \frac{V_{Rh}(t)}{V_{Rh}(t) + V_{PW}(t)} \quad (0.2)$$

where $[Rh]_0$ is the concentration of the Rhodamine dye prior to being mixed into the produced water stream. The dye is packaged as a 20% solution, hence the value for

$[Rh]_0$ is constant at 200 ppt, or $2 \cdot 10^8$ ppb (note that the units displayed on the axis are ppm). The values of $\overline{[Rh]}(t)$ can be used to calculate produced water dilution at a particular time using

$$D_{pw}(t) = \frac{\overline{[Rh]}(t)}{[Rh](t)} \quad (0.3)$$

where $[Rh](t)$ is the measured Rhodamine dye concentration at a particular location and time t .

Time-series (Figures 10 & 15)

Time-series of measurements made by various instruments during the field program are presented in a series of panels with their respective locations identified by line colour. The following properties are shown:

- Conductivity
- Current Direction
- Current Speed
- FPSO heading
- Salinity
- Surface Current
- Ocean Temperature
- Wind Direction
- Wind Gust
- Wind Speed

Tidal Current (Figures 11 & 16)

Tidal currents at the location of the FPSO were downloaded from a Bedford Institute of Oceanography website that uses output from a numerical model to generate time-series of depth-mean tidal currents. A plot of current vectors for each survey period is presented above a particle path generated by integrating the tidal current components from the time that dye was first released into the produced water stream. This provides an indication of the path that the dye would take if there were no other effects such as wind and inertial currents.

CTD Casts and Dye Concentration (Figures 12 & 17)

These multi-panel plots show the time and maximum depth of each CTD cast. In addition, the measurements of [Rh] for both the down- and up-cast are shown as red and green lines, respectively. Near the bottom of each panel there is a plot of the tidal current vectors at two minute intervals

Dye Concentration Along Transects (Figures 13 & 18)

Most of the CTD casts were made along transects intended to sample the produced water plume across its width. Dye concentrations measured along each transect were interpolated horizontally to produce vertical slices that have been contoured and coloured to show spatial variability in the dye concentration. The set of slices for each field day are presented with the upper 2 m expanded to provide more detail near the surface. In addition, the range of times and distances from the FPSO are included in each panel.

3.2 November 18 Results

Dye injection from: 08:00 – 14:00 (06:00 duration)
Survey from: 09:52 – 16:36 (06:44 duration)
Mean Wind: SSW at 29 kn (195°T)

Table 3 summarized the data from the 26 vertical profiles of CTD/fluorescence. There is a significant fraction of the dye in the surface layer for many of the casts within 2 km of the source. Beyond 2 km all of the dye is found in the upper 2 m. A maximum concentration of 14.2 ppb beyond 2 km compares to a maximum of 45.6 ppb within 400 m, indicating that the dilution in the surface layer of produced water is diluted more slowly than the sub-surface layer.

Table 3: CTD casts from the November 18 field survey (sorted by distance from the FPSO)

n	Time GMT	Lon 48° W m' s"	Lat 46° N m' s"	D m	θ deg	H _m m	H _r m	R _x ppb	S _x mgm ²	% of dye in depth range (m)					
										0 2	2 10	10 15	15 20	20 25	25 >25
2	10:28	28' 42.14"	28' 41.46"	360	31	25.2	25.2	23.7	9.3	43				53	4
1	09:52	28' 40.55"	28' 40.80"	363	37	7.2	6.5	1.3	0.5	100					
5	11:09	28' 37.91"	28' 39.63"	377	48	37.3	30.8	30.8	373	4	14	7	17	31	27
4	11:01	28' 36.24"	28' 38.96"	392	53	36.4	26.3	45.6	334	6	26	31	25	12	1
3	10:50	28' 34.67"	28' 38.37"	411	58	39.8	0.8	5.3	1.3	100					
26	16:36	28' 31.71"	28' 40.05"	492	57	81.6	81.5	11.9	102	90					10
25	16:20	28' 23.46"	28' 45.73"	736	52	80.6	80.5	39.9	11.5	43					57
6	12:00	28' 26.04"	28' 53.62"	866	37	30.6	0.5	16.3	3.3	100					
7	12:10	28' 22.80"	28' 52.27"	880	42	31.6	0.8	4.8	1.9	100					
8	12:20	28' 19.58"	28' 50.87"	900	47	29.9	0.8	39.7	19.4	100					
9	12:30	28' 16.33"	28' 49.59"	929	52	30.7	0.0	0.0	0.0						
24	16:00	28' 13.00"	28' 47.04"	945	58	80.0	79.9	12.1	13.5	64					36
10	12:38	28' 13.12"	28' 48.34"	964	56	30.7	1.4	6.3	4.2	100					
11	12:48	28' 09.83"	28' 47.07"	1004	60	41.0	32.2	19.4	95.1	44	8			3	45
12	13:00	28' 06.51"	28' 45.70"	1049	64	41.5	28.7	31.3	173	16	20	15	16	19	14
13	13:09	28' 03.34"	28' 44.45"	1097	67	39.8	27.0	24.4	38.7	25		3	31	36	5
23	15:36	27' 49.63"	28' 51.33"	1449	63	79.1	0.5	26.0	7.2	100					
17	13:57	27' 51.24"	28' 54.14"	1457	60	41.1	28.8	16.6	15.4	35				9	55
16	13:47	27' 47.83"	28' 52.95"	1505	62	61.5	30.0	18.2	15.4	32				5	64
15	13:39	27' 44.63"	28' 51.60"	1550	65	37.5	26.5	3.9	31.0	14	44	30	10	2	
14	13:31	27' 41.32"	28' 50.44"	1602	67	33.3	24.3	21.3	34.3	55	18	1	14	12	
18	14:20	27' 39.39"	29' 08.14"	1903	52	43.7	0.0	0.0	0.0						
19	14:31	27' 32.60"	29' 05.54"	1978	56	50.3	0.2	6.6	0.7	100					
20	14:46	27' 26.15"	29' 03.11"	2060	60	40.5	1.0	14.2	5.3	100					
21	14:56	27' 19.54"	29' 00.51"	2151	64	36.8	21.9	6.1	1.2	100					
22	15:07	27' 16.34"	28' 59.23"	2197	65	42.2	0.7	7.9	2.5	100					

See text for an explanation of each column

Produced Water and Rhodamine Dye (Figure 9)

Figure 9 shows the produced water and Rhodamine dye flow rates, the cumulative volume of produced water and Rhodamine dye discharged, and the cumulative mean concentration of dye at the point of discharge. The dye injection rate was held constant throughout at 22.5 L/h. The produced water flow rate varied from 210 to 500 m³/h. Mean dye concentration varied from 11-12 ppm.

Time-series (Figure 10)

The BIO derived tidal current speed ranged from 10-13 cm/s over the sampling period, while other current speeds varied more widely. The current speed at 18 m depth increased from 0-5 cm/s at the start to more than 20 cm/s near the end of the day. The deeper currents at 87 m were significantly larger except towards the end.

Tidal Current (Figure 11)

Tidal currents are persistently northward for the entire sampling period with a westward bearing at the beginning and an eastward bearing toward the end. Current speeds are typically 10 cm/s. The net particle displacement from the tide is northward.

CTD Casts and Rhodamine Dye Concentration (Figure 12)

Many of the CTD casts show a disparity between the up- and down-casts. Typically, the data from the up-cast is discarded because it is sampling through water that has been disturbed by the instrument on its way down. However, the noted disparity suggests that the CTD was sampling different portions of the produced water plume on its way up and down. This tends to be more common for the deeper casts where a longer period of time elapses between samples at the same depth. For example, the up-casts for casts 14, 15 and 16 suggest that the up-casts may be in higher dye concentrations than the down-casts.

Dye Concentration Along Transects (Figure 13)

The bottom panel of Figure 13 shows that the CTD casts captured most of the width of the plume. Cast No. 1 stopped at a depth of less than 10 m; however, had it been lowered to 40 m it appears likely that it would have encountered the plume. High dye concentrations are evident in the upper 2 m in all of the panels. The horizontal spacing of the casts is, for the most part, too large to resolve the fine structure of the plume, but does provide useful information on a larger scale.

In the section from casts 14-17 it appears that the length of the transect is inadequate to capture the complete width of the plume at this distance.

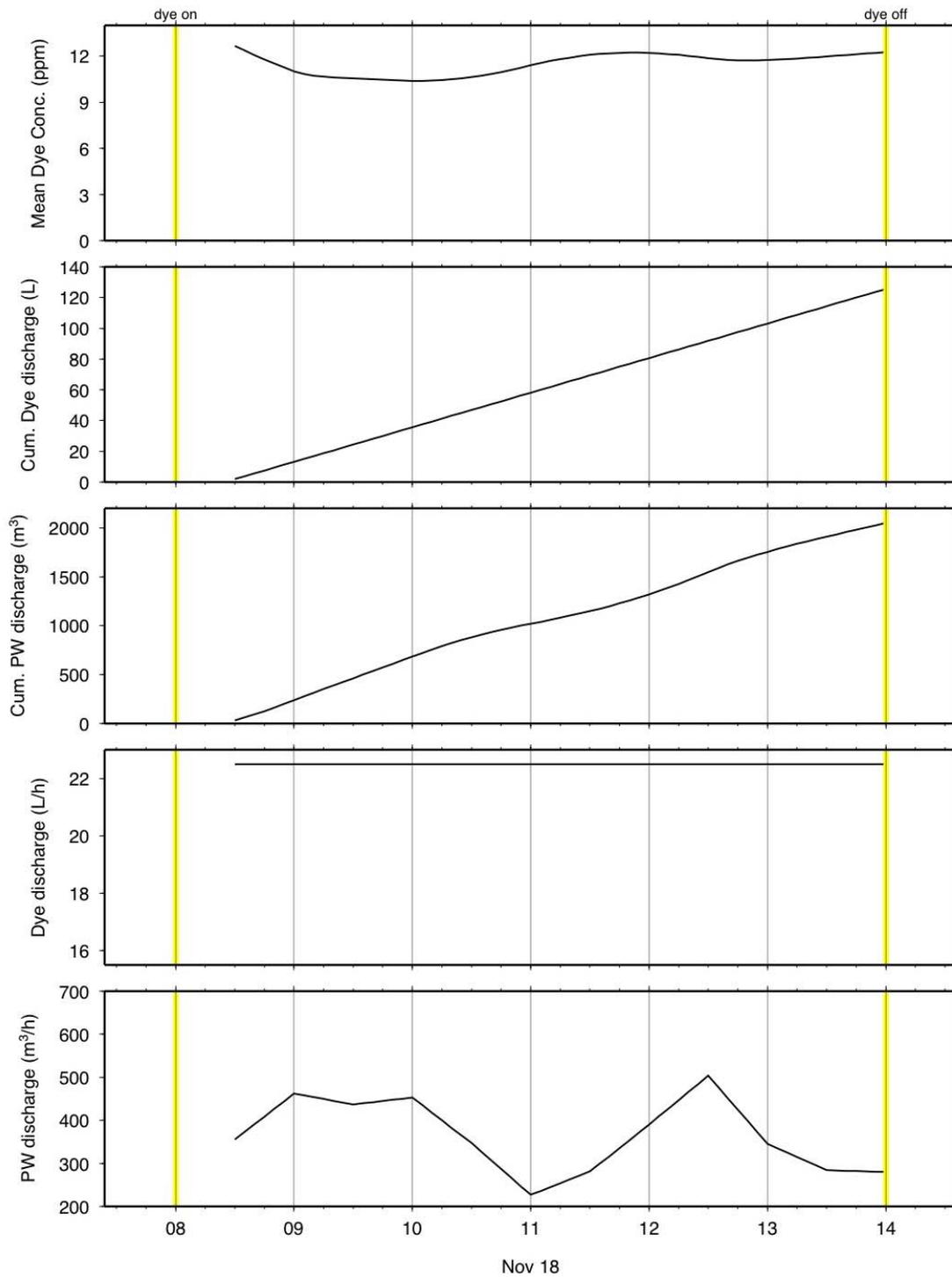


Figure 9: Mean [Rh] at discharge; cumulative produced water and dye volumes; and instantaneous produced water and dye discharge rates for November 18.

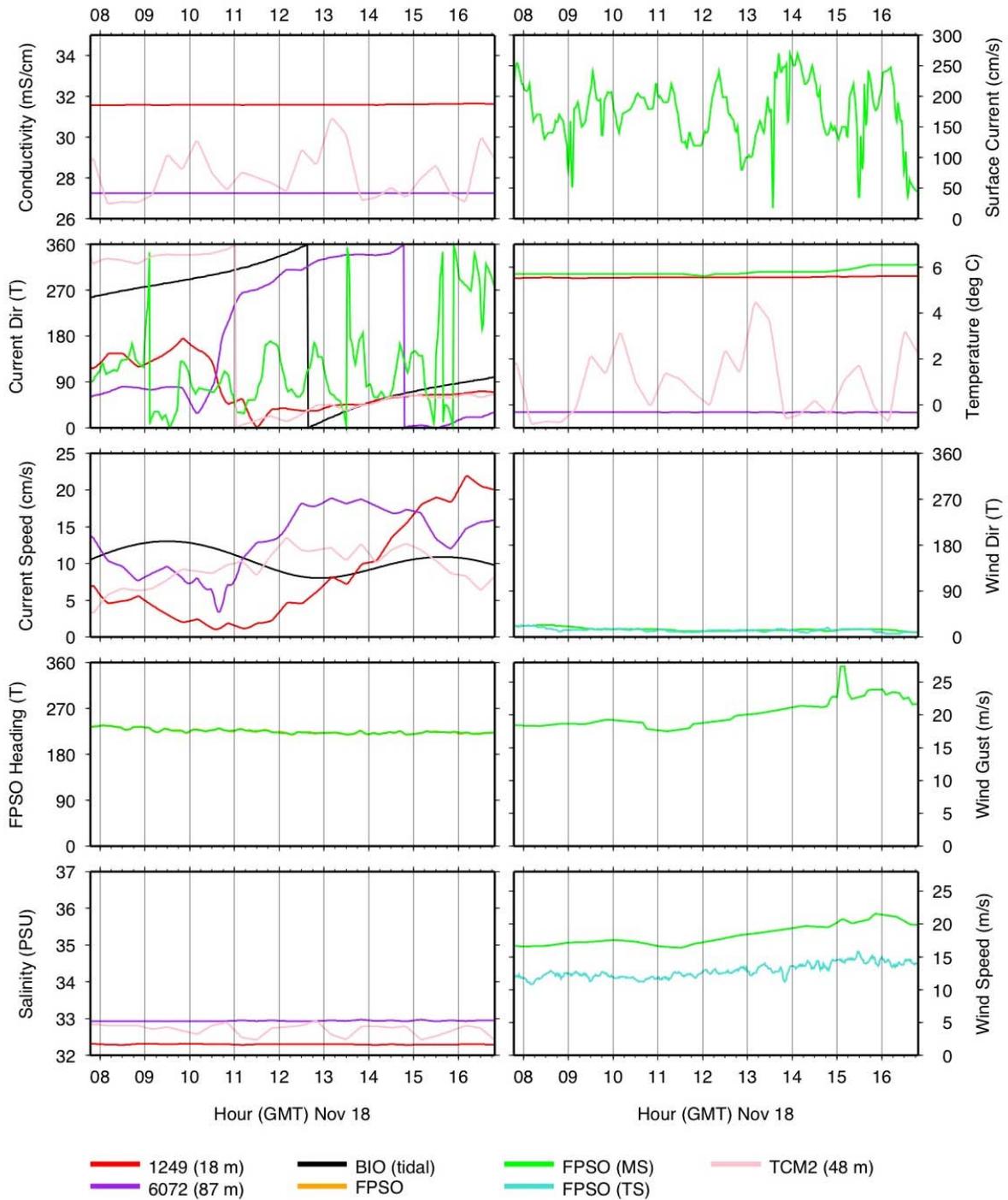


Figure 10: Time-series of ocean properties, and current and wind velocity for November 18

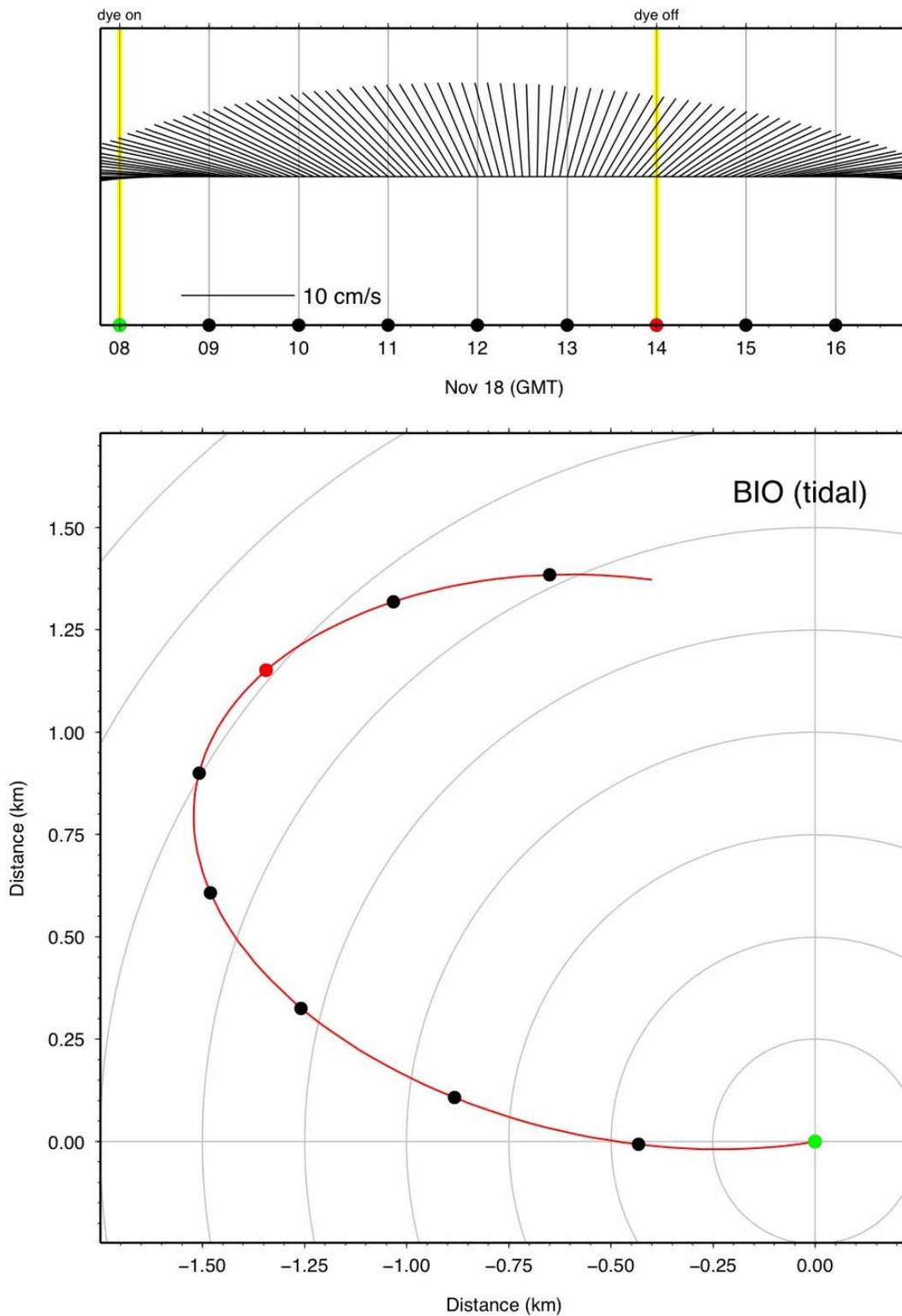


Figure 11: Top: 5 minute tidal current vectors from BIO tidal model. Bottom: Simulated particle path using BIO tidal currents. For November 18.

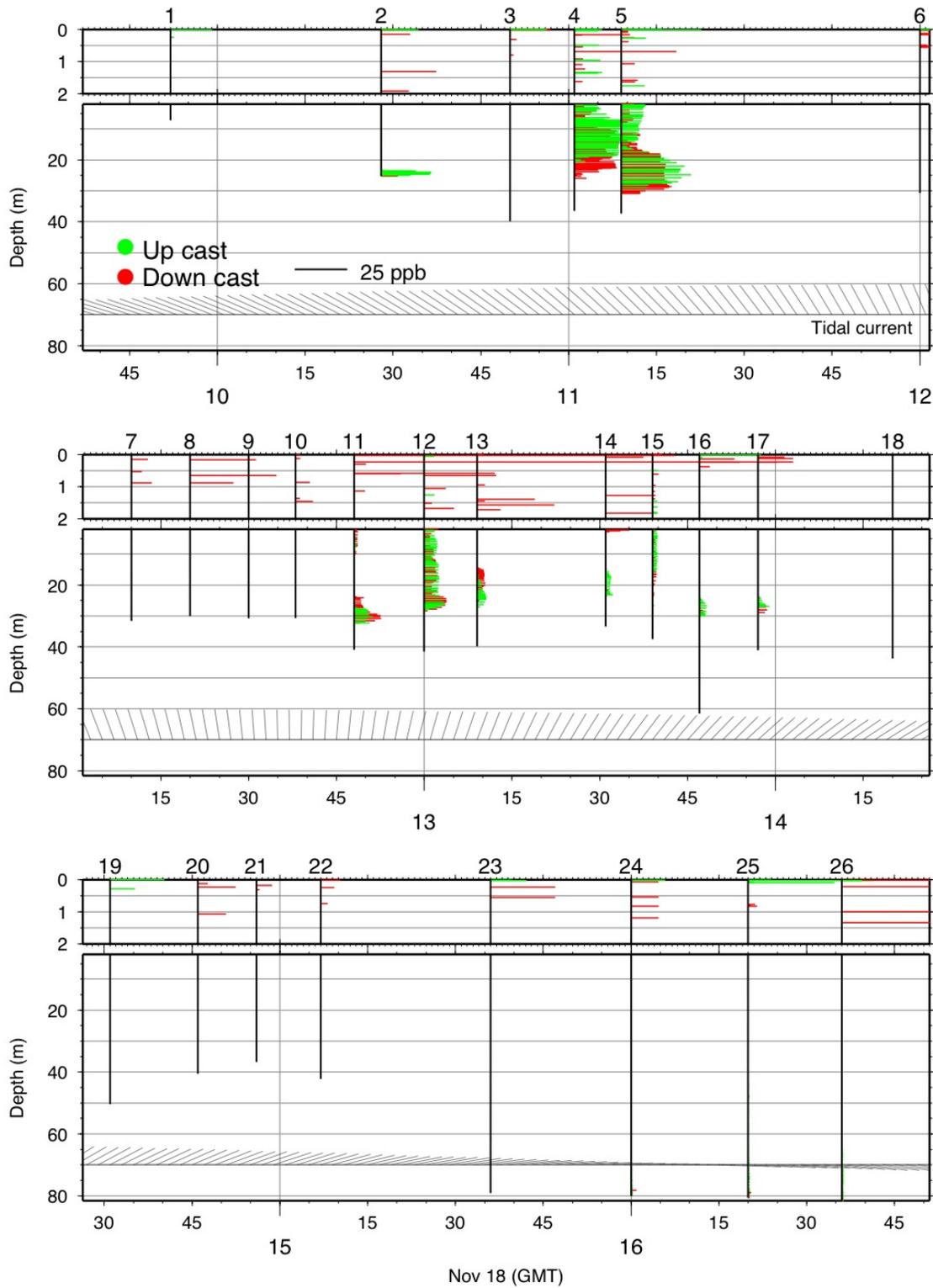


Figure 12 [Rh] from CTD casts for November 18. Horizontal axes show hours and minutes (GMT) at 15 minute interval

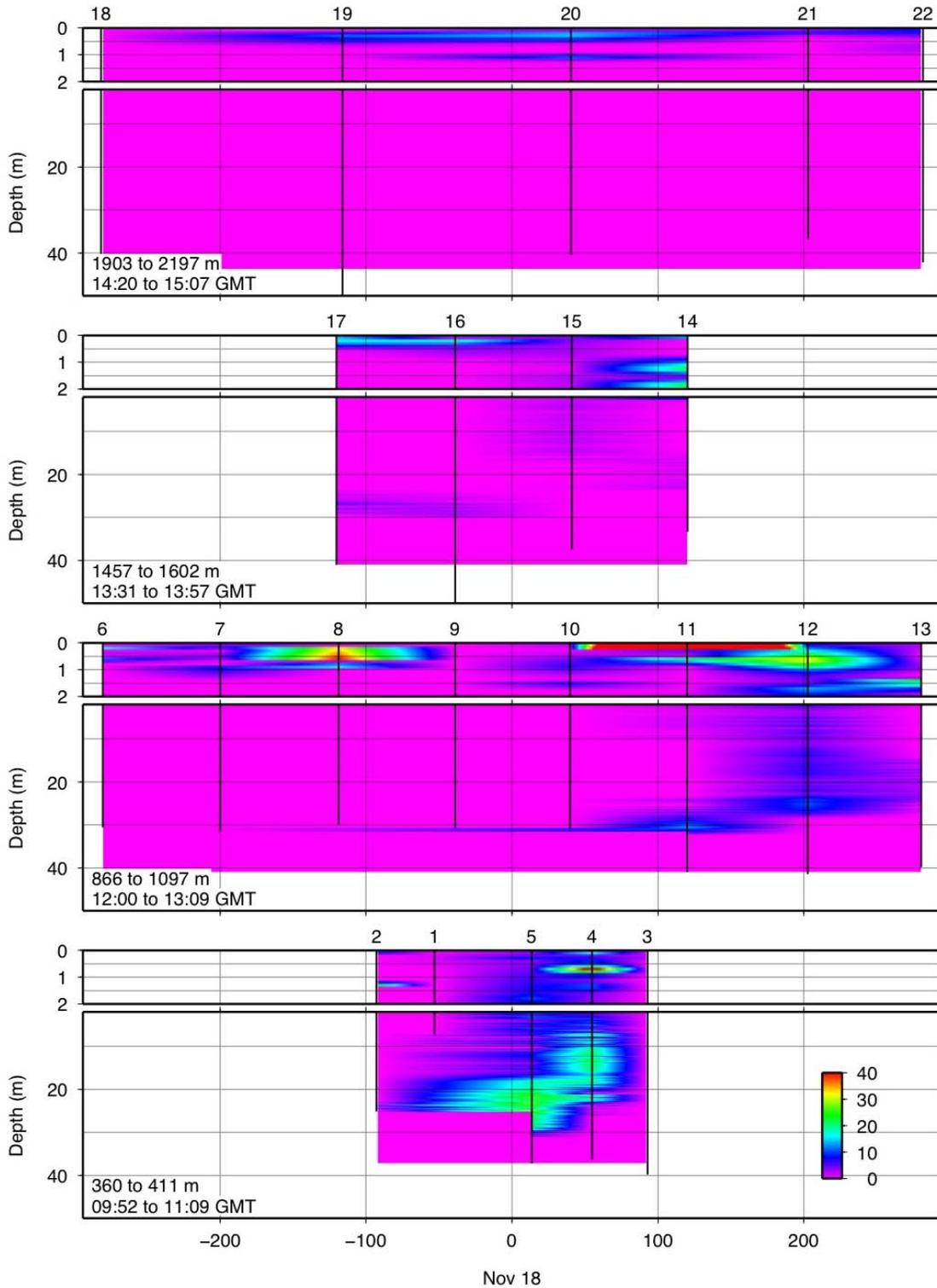


Figure 13 [Rh] variation with depth along transects for November 18.

3.2 November 25 Results

Dye injection from: 10:30 – 16:30 (06:00 duration)
 Survey from: 11:54 – 17:51 (05:57 duration)
 Mean Wind: SE at 20 kn (124°T)

Table 4: CTD casts from November 25 field survey (sorted by distance from the FPSO)

n	Time GMT	Lon 48° W m' s"	Lat 46° N m' s"	D m	θ deg	H _m m	H _r m	R _x ppb	S _x mg/m ²	% of dye in depth range (m)					
										0 2	2 10	10 15	15 20	20 25	25 >25
3	12:26	28' 59.94"	28' 30.16"	190	254	41.7	35.4	20.8	309	4	18	20	19	14	23
4	12:34	29' 01.66"	28' 29.65"	229	252	39.2	35.4	26.8	405	5	20	13	25	22	16
2	12:08	29' 02.63"	28' 34.63"	258	289	42.0	1.6	9.9	4.4	100					
1	11:54	29' 04.33"	28' 32.50"	279	273	40.1	4.7	28.7	12.4	91	10				
6	12:54	29' 05.20"	28' 27.19"	327	243	60.1	42.2	39.7	146	12		8	35	9	36
5	12:46	29' 06.04"	28' 28.36"	330	250	51.5	43.7	32.1	132	12	26	21	9	7	25
7	13:02	29' 04.51"	28' 25.99"	332	236	70.7	47.5	65.9	62.8	13		4	16	0	67
8	13:40	29' 03.74"	28' 24.81"	340	230	50.3	41.6	7.4	16.1				54	13	33
9	13:49	29' 27.16"	28' 21.62"	825	246	61.8	53.3	1.6	9.5	3			6	23	68
10	13:58	29' 26.22"	28' 20.12"	826	243	70.4	70.3	10.0	30.4	28			4	4	64
11	14:11	29' 24.25"	28' 17.14"	834	236	69.6	58.4	41.8	76.9	34			17	38	10
12	14:20	29' 23.36"	28' 15.63"	844	232	70.5	64.5	1.3	7.8						100
16	15:18	29' 48.59"	28' 15.26"	1323	246	71.2	43.7	31.2	25.6	55			7	5	33
15	15:05	29' 46.78"	28' 12.29"	1326	241	69.6	68.6	56.8	13.3	45			10	4	41
17	15:28	29' 50.43"	28' 18.18"	1328	250	69.6	42.6	8.7	16.2	33	1		23	11	33
14	14:56	29' 45.85"	28' 10.80"	1330	239	72.5	69.0	3.7	8.8	11					89
18	15:37	29' 51.32"	28' 19.71"	1333	252	70.4	41.1	3.8	15.8	11		7	41	11	30
13	14:47	29' 44.89"	28' 09.26"	1336	237	71.1	36.7	7.3	7.8	25	35		3		37
19	15:48	29' 53.20"	28' 22.66"	1349	256	81.0	80.9	27.2	50.4	10		1	28	39	23
20	15:58	29' 55.04"	28' 25.66"	1372	260	69.7	69.2	9.3	67.2	2		2	30	30	37
21	16:33	30' 14.62"	28' 19.59"	1816	256	70.8	43.8	29.5	24.6	48		1	17		34
23	17:00	30' 09.25"	28' 07.39"	1824	244	69.9	69.8	11.3	24.0	36	5				59
22	16:46	30' 12.06"	28' 11.86"	1828	249	69.2	69.1	18.5	53.0	19			47	11	24
24	17:17	30' 15.13"	28' 00.39"	2033	240	70.9	54.7	9.6	5.1	100					
25	17:41	30' 12.37"	27' 55.94"	2052	236	69.2	69.1	41.2	19.5	47					53
26	17:51	30' 09.64"	27' 51.45"	2083	232	70.3	60.6	23.8	10.4	78					22

See text for an explanation of each column

The general spatial distribution of the plume on November 25 is south-westward of the FPSO as indicated by the positions of the CTD casts in Figure 5. As with the data from November 18, Table 4 shows that there is a significant fraction of the dye in the surface layer for many of the casts. However, there is significantly more dye below a depth of 25 m than in the previous data set. Also as before, the dye concentration in the surface layer does not decrease quickly with increasing distance from the FPSO.

Produced Water and Rhodamine Dye (Figure 14)

Figure 14 shows the produced water and Rhodamine dye flow rates, the cumulative volume of produced water and Rhodamine dye discharged, and the cumulative mean concentration of dye at the point of discharge. The dye injection rate was held constant throughout at 16.0 L/h. The produced water flow rate varied from 220 to 600 m³/h. Mean dye concentration varied from 5-9 ppm.

Time-series (Figure 15)

The BIO derived tidal current speed is lower than before, ranging from 5-8 cm/s over the sampling period. The current at 18 m depth at station 1249 is weaker as well, varying from 0-13 cm/s. The deeper currents at 87 m are slightly stronger than at shallower depths, but as with the other currents, it is weaker than on November 18.

Tidal Current (Figure 16)

Tidal currents during the survey are southward for most of the sampling period with a brief eastward bearing at the beginning that soon changes to westward for the remainder of the survey. Current speeds are typically 10 cm/s. The net particle displacement from the tide is southward and westward. This is consistent with the observed location of the produced water plume, indicating that the tidal current has had a dominant influence on the plume position on this day.

CTD Casts and Rhodamine Dye Concentration (Figure 17)

As before, many of the CTD casts show a disparity between the dye concentrations in the up- and down-casts. The profiles at casts 5-7 indicate that the plume has split into two layers: from 10-20 m depth and from 30-45 m depth.

Dye Concentration Along Transects (Figure 18)

The vertical distribution of dye is similar to that on November 18th in that there is a significant portion of the dye volume in the surface layer. There is also clear evidence of separation of the plume into multiple layers. The higher dye concentrations in the deeper waters on this day may be related to the less energetic currents noted above, with a resulting lower rate of advection and mixing.

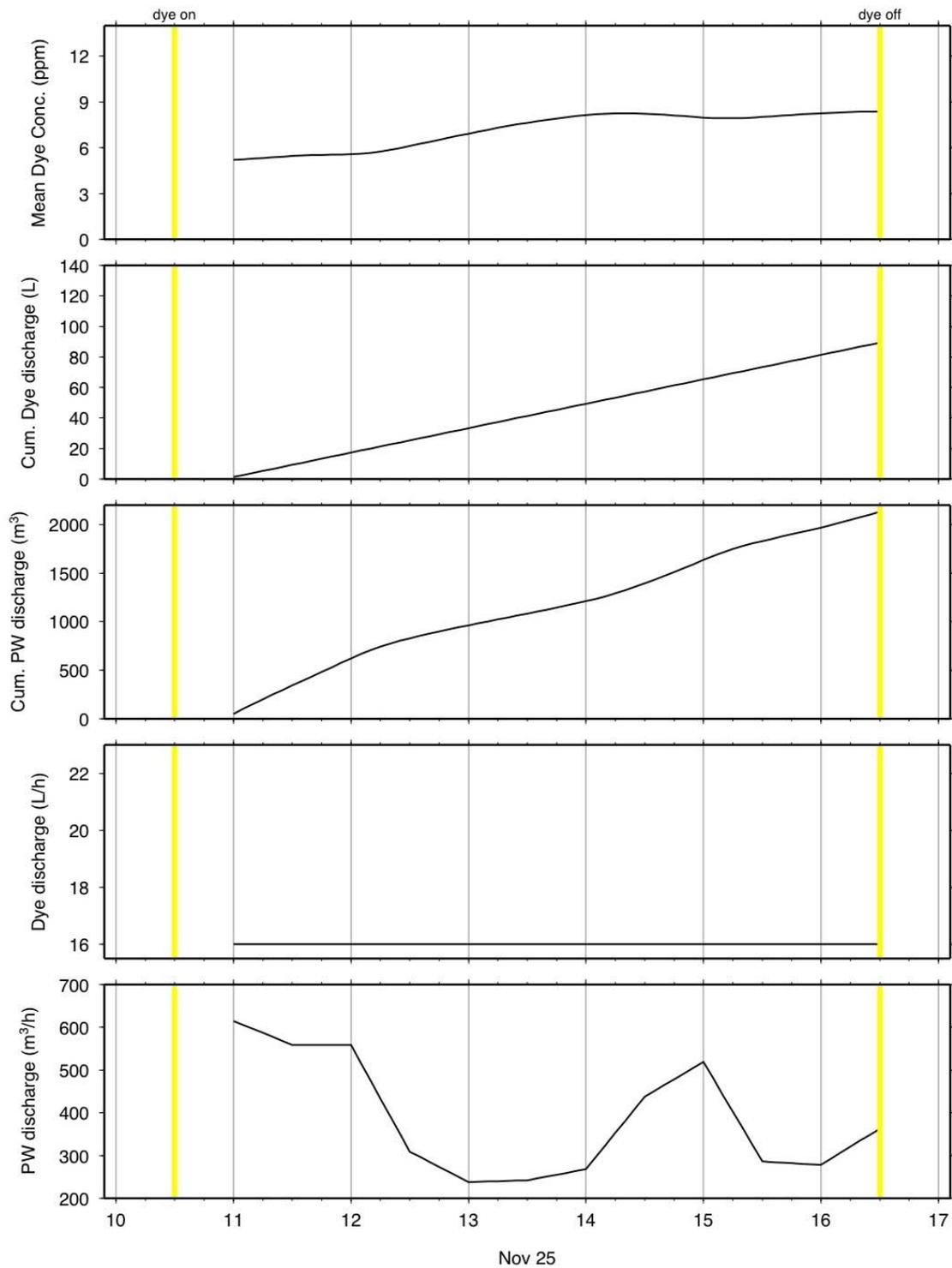


Figure 14: Mean [Rh] at discharge; cumulative produced water and dye volumes; and instantaneous produced water and dye discharge rates for November 25.

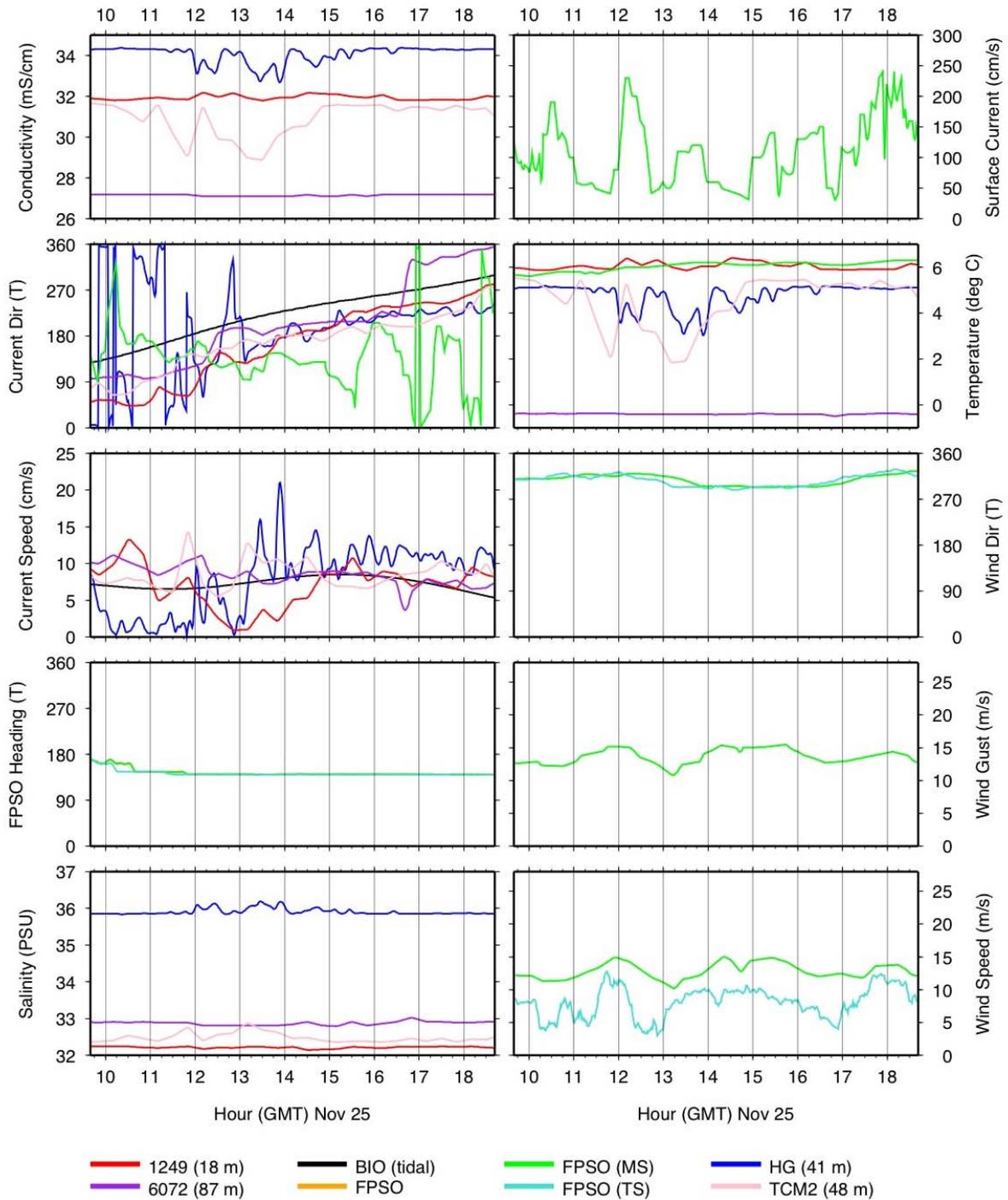


Figure 15: Time-series of ocean properties, and current and wind velocity for November 25

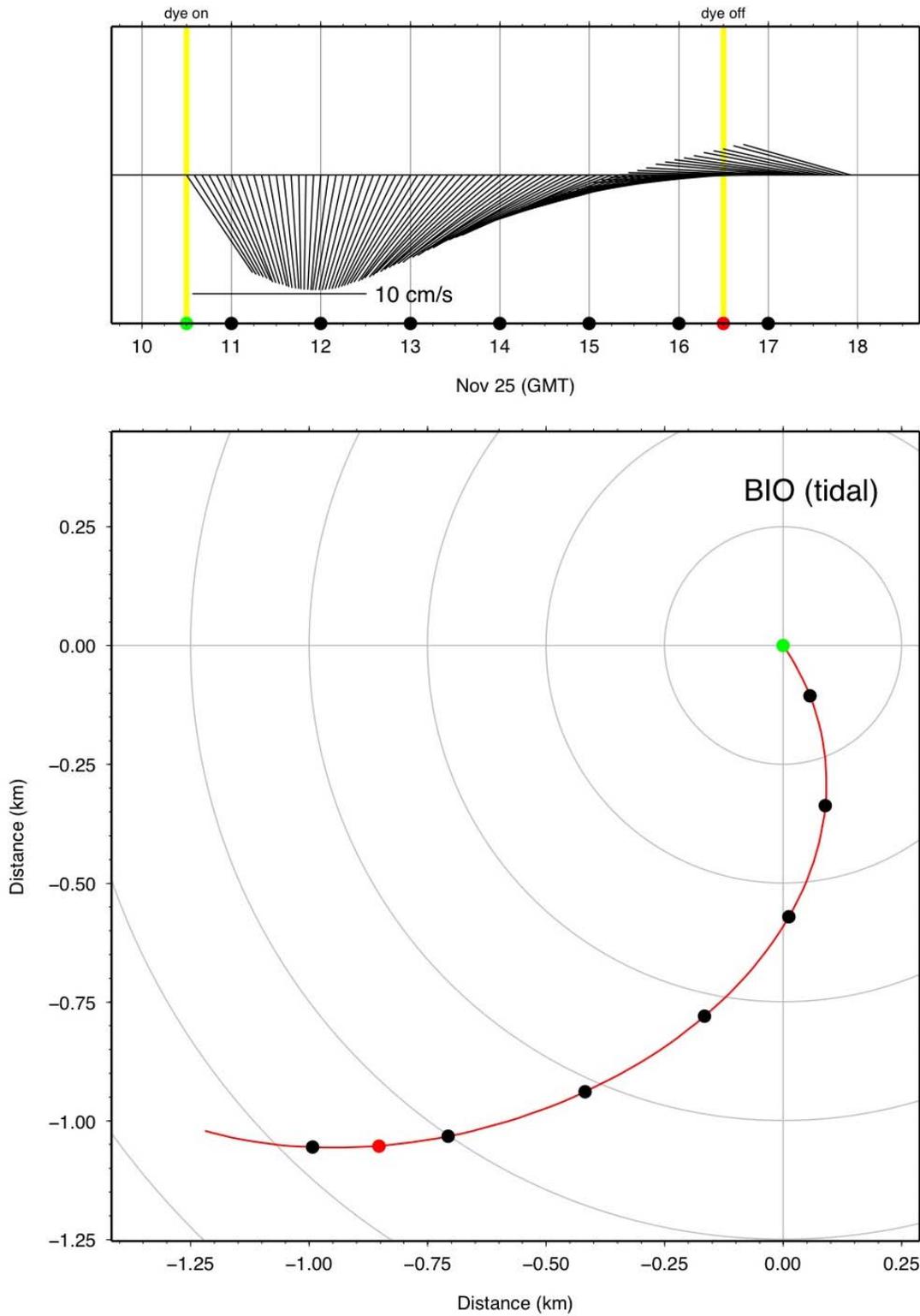


Figure 16: Top: 5 minute tidal current vectors from BIO tidal model. Bottom: Simulated particle path using BIO tidal currents. For November 25.

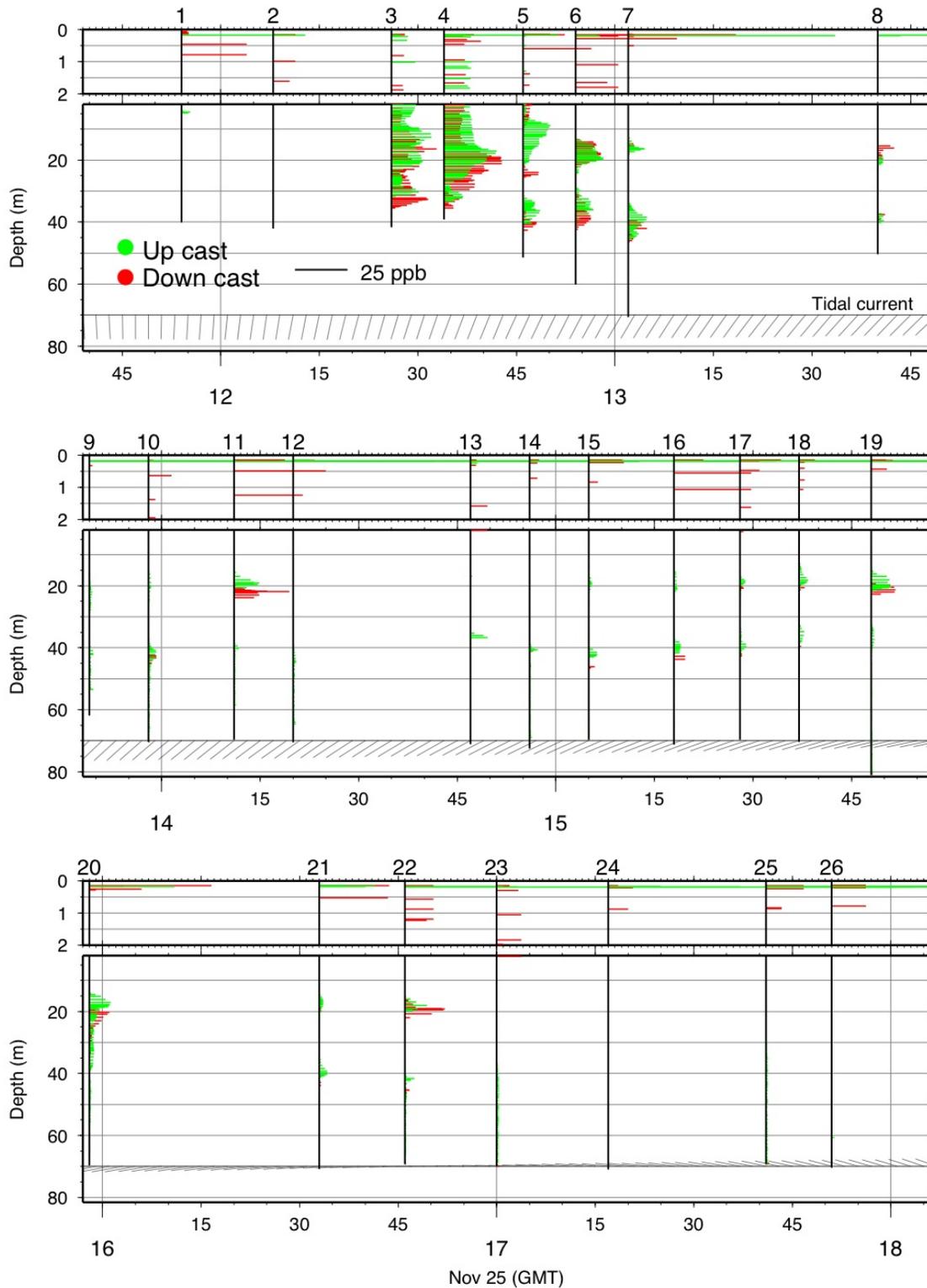


Figure 17: [Rh] from CTD casts for November 25. Horizontal axes show hours and minutes (GMT) at 15 minute interval

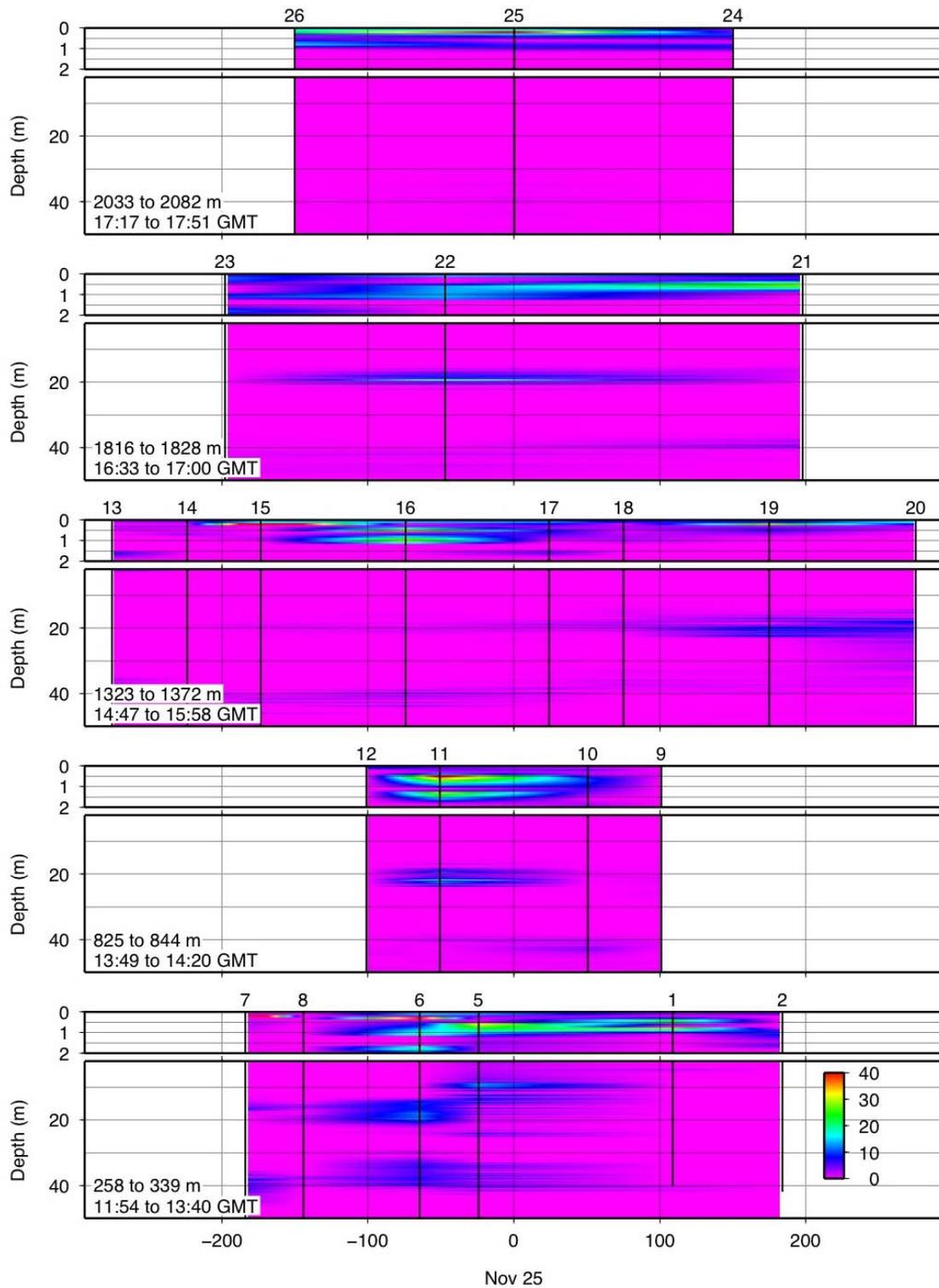


Figure 18: [Rh] variation with depth along transects for November 25.

4. Summary

A field study was completed from November 18 and 25, 2005 in the vicinity of the Terra Nova FPSO. The purpose of the study was to determine the feasibility of using Rhodamine dye to determine near- and far-field dilution of produced water plumes from oil and gas operations in the Newfoundland offshore.

Weather, seas and visibility during the study were good, with mean winds of 20 to 30 kn, that did not hinder data collection. Good sets of data were collected on two field days from the *MV KingFisher* using a CTD fitted with a fluorometer for measuring Rhodamine dye concentration.

In general, the attempt to gather the necessary data for determining plume dilution was a success. The project demonstrated that it is possible to collect a high-quality data set from a small surface vessel during the late fall on the Grand Banks of Newfoundland. The data have provided valuable information on the behaviour of the Terra Nova plume by revealing the depth range over which it extends and the persistence of elevated near-surface dye concentrations.

5. Conclusions

This study was successful in obtaining the data required for determining the distribution and dilution of produced water in the field. As a test of the field procedures, data analyses, and reporting, the study was successful in identifying key components of field work and ways in which the study could be improved. These are described below.

Comments from the chief field technician onboard the *MV KingFisher* are summarized as follows:

- Overall, the choice of vessel and equipment worked well as did the computer program. No changes are recommended to these.
- The *MV KingFisher* is one of the most stable and best handling vessels on the east coast. In particular, its ability to hold a fixed position was noted as among the best.
- The presence of a technician from the company that supplied the winch onboard the *MV KingFisher* was useful for troubleshooting. In addition, his knowledge of the operation and programming of the CTD was reassuring.
- Wind speeds are less of a concern than the sea state since the wind direction often changes frequently with the result that the seas do not have an opportunity to get large.
- A wave height of 4 m was estimated to be the maximum under which measurements could be made in this way.

5.1 Potential Methods Improvement

- In this study, produced water flow rate varied by a factor of three while dye injection rates stayed constant, therefore the concentration of dye in the produced water discharged from the FPSO varied over the course of the field work. Since the concentration of dye in the produced water varied with time, it was not possible to calculate how much the produced water had been diluted as it was carried away from the ship. For dilution of produced water to be measured, either produced water flow rate and dye injection rate need to be kept constant, or dye injection rate needs to vary in proportion to produced water flow rate.

- Concentration of dye in the produced water stream before being discharged should be verified with samples taken before the produced water is discharged from the FPSO. Samples of produced water with dye fully mixed into it should be collected at regular intervals or whenever there is a change in flow rate and analyzed by fluorometry after dilution with ambient seawater to a concentration in the linear range of measurements by the fluorometer.
- Because fluorescence is affected slightly by the composition of the water the dye is in, calibration of the fluorometer should be done in ambient seawater as well as in the laboratory. Calibration should include determining the range of concentrations over which fluorescence is linearly proportional to dye concentration. Calibration requires accurate measurement of volumes of dye and ambient dilution water and should be done in a laboratory setting.
- This study found that a portion of the produced water plume is buoyant and therefore reaches the surface layer where it remains. This plume could be continually monitored to get a high resolution map of surface distribution of produced water. Surface water can be pumped to a chamber on the deck of the ship which has a self logging fluorometer. This was done for the present study, but the method can be improved. Position of the vessel should be logged continuously by a GPS with antenna at the location of the fluorometer onboard the ship. The seawater intake for the study reported here was from 5 m but the study found that most of the surface portion of the plume is in the upper 1 m, therefore the closer that the seawater intake is to the surface the better for measuring maximum dye concentration. Also, the delay in time between intake and filling the container holding the fluorometer should be known. Alternatively, the self logging fluorometer could be mounted to the hull of the ship near the surface, but this would only be useful in calm seas.
- Since air bubbles seem to contribute to the buoyancy of the Terra Nova plume, at least, the method could be improved by developing a buoyant plume model that simulates the effect of air mixed into the produced water. This would lead to more effective planning of future field programs by permitting more accurate predictions of produced water plume behaviour under varying stratification and other conditions.
- In the present study, time and GPS position were recorded manually in conjunction with each CTD profile. No detailed vessel heading data were recorded, although an approximate heading was noted. Any future study should

provide continuous recordings of the survey vessel's GPS position and vessel heading together with a time stamp. This information is required to accurately calculate the position of the CTD at the time that a profile is performed.

- Because high surface concentration of dye can be maintained for 2 km or more, it is recommended that the dye injection time be increased by 2 hours to 8 hours; that the time lag between the start of dye injection and the first measurements be decreased from 2 hours to 1 hour; and that the total sampling time be increased by 3 hours. In addition, the maximum distance sampled should be increased in an attempt to find the end of the plume, if possible.
- This study shows that a significant portion of the produced water plume rises to the surface layer, where it continues to reside while slowly being diluted as it moves away from the FPSO. Aerial remote sensing of the surface-layer could provide measurements with much higher spatial resolution, and effectively permit snapshots of the surface plume position to be made.

5.2 Communications

In an operation such as this field study, in which a diverse group of people participated, there is a strong reliance on effective communication between participants to ensure a successful outcome. This is particularly true when perceived problems arise that require resolution before the project can proceed. In order to circumvent potential problems, the following recommendations are provided:

- Information relevant to planning, including any and all known characteristics or observations of the produced water plume should be provided to the project planners well in advance of the field program.
- Data requests by project planners before and subsequent to the field program should be accompanied by a list of items to be checked off by the data supplier(s). Where appropriate, data supplied should include: time zone, location (latitude, longitude), units for each data channels, instrument manufacturer and model, sampling rates, depth or elevation.
- Unless safety is an issue, the sampling program would benefit if decision to modify/discontinue sampling were made in consultation with project planners.

APPENDIX 1
WORK PLAN FOR FIELD SURVEY

**Work Plan for Horizontal
and Vertical Mapping
of the Terra Nova Produced
Water Plume Using a Dye Tracer**

**Prepared for:
Husky Energy &
Petro-Canada**

**Prepared by:
Jacques Whitford
and
Lorax Environmental Services Ltd.**

November, 2005

TABLE OF CONTENTS

	Page No.
1.0 INTRODUCTION	1
2.0 METHODS	1
2.1 Initially Locating the Plume	5
2.2 Plume Mapping	7
2.3 Data Requirements	8
2.4 Dye Pumping Requirements	9
3.0 PERSONNEL	9
4.0 COMMUNICATIONS	10
5.0 REPORTING	10

LIST OF APPENDICES

Appendix 1	Petro-Canada Work Pack
Appendix 2	Dye Pumping Requirements
Appendix 3	Vertical and Horizontal Profiles
Appendix 4	Data Sheet

LIST OF TABLES

	Page No.	
Table 1	Dye Injection Rate at Various Produced Water Flow Rates, and Parameters Used in Calculation of Dye Injection Rate	3

LIST OF FIGURES

	Page No.	
Figure 1	Predicted Initial Dilution of Produced Water as it is Discharged into the Ocean	2
Figure 2	Dye Injection Rate Needed at Various Produced Water Flow Rates	2
Figure 3	Calculated Trajectories of a Particle at 20m Depth when Wind is Coming from	6
Figure 4	Calculated Trajectories of a Particle at 20m Depth when Wind is Coming from the North at Various Speeds	7
Figure 5	Idealized Sample Plan Showing Horizontal Transects and Vertical Profiles	8

1.0 INTRODUCTION

The Terra Nova FPSO discharges a high temperature, high salinity plume of produced water. Produced water from the FPSO has the potential to affect water quality. Therefore it is useful to know the zone of influence around the FPSO where produced water and associated components may not have been diluted to background levels. When produced water (PW) is discharged it will undergo an initial dilution with ambient seawater which is expected to erase natural signatures of PW such as temperature, salinity, or turbidity. Therefore a tracer of the produced water is needed to identify the plume. A tracer is an inert dissolved substance that will move along with the plume and be detectable at very low concentrations. The work plan described here is a vessel-based field study to track a fluorescent dye tracer introduced to the produced water discharge. The overall goal of the study is to define the horizontal and vertical extent of the plume and the dilution of plume water. This study is a component of Phase 1 of Produced Water Monitoring at the White Rose FPSO. The long-term goal of the Terra Nova field work is to improve on methods and approaches used to assess water quality around offshore oil platforms and apply these methods to White Rose (see Husky Energy 2005 for details on longer term goals).

2.0 METHODS

Plume distribution and dilution will be determined by adding a fluorescent dye (Rhodamine WT) as a tracer to the produced water. This dye is commonly used to measure flow rate, circulation and dispersion of both freshwater and seawater. The Rhodamine WT that will be used for this study is manufactured by Keystone Aniline Corp. of Chicago, USA and distributed by A.S. Paterson Co. Ltd.

The dye plume will be developed by injecting a 20% solution of Rhodamine WT dye into the produced water discharge at a rate that is calculated to produce a dye concentration of 50 ppb ($= \mu\text{g/L}$) following initial dilution. Details Petro-Canada responsibilities with respect to Rhodamine dye injection, as well on details on preliminary trials with Fluorescein (to be performed by Petro-Canada staff) to aid in the Rhodamine trials are provided in Appendix 1.

Initial Rhodamine dilution is a non-linear inverse function of discharge rate (Figure 1). For the expected PW flow rate of approximately $9000 \text{ m}^3/\text{d}$ (± 1000) the dye injection rate required is 22.8 L/h (± 1.1). Other PW flow rates have been observed in the past and the range of observed flows was used to calculate various dye injection rates (Appendix 2). The results are shown in Figure 2 and Table 1.

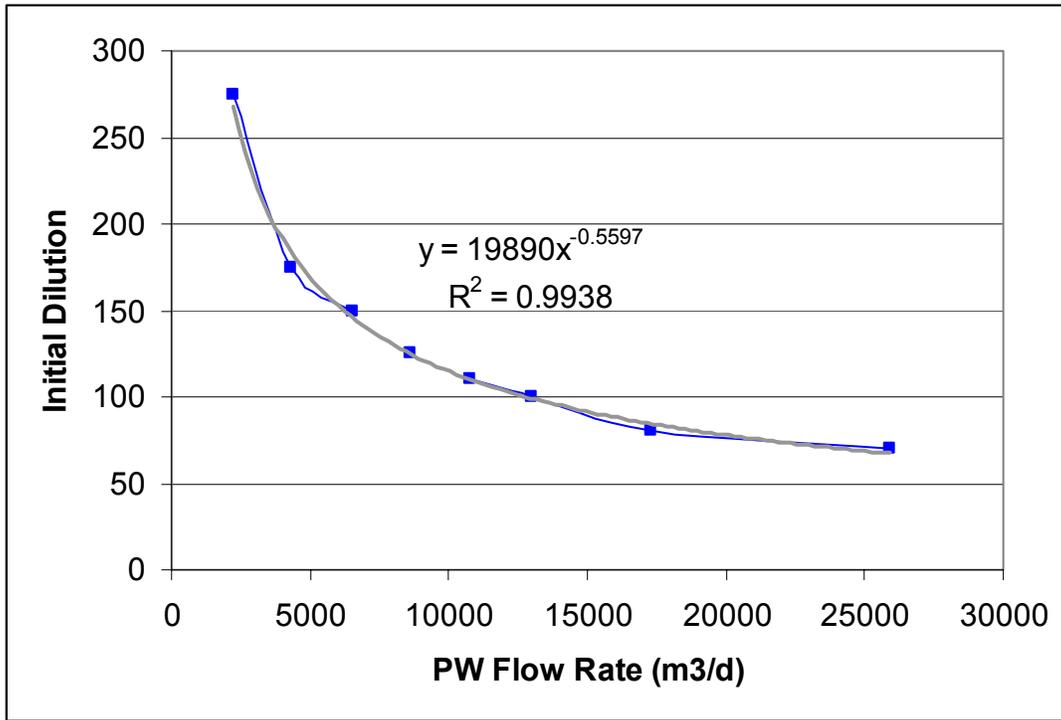


Figure 1 Predicted Initial Dilution of Produced Water as it is Discharged into the Ocean

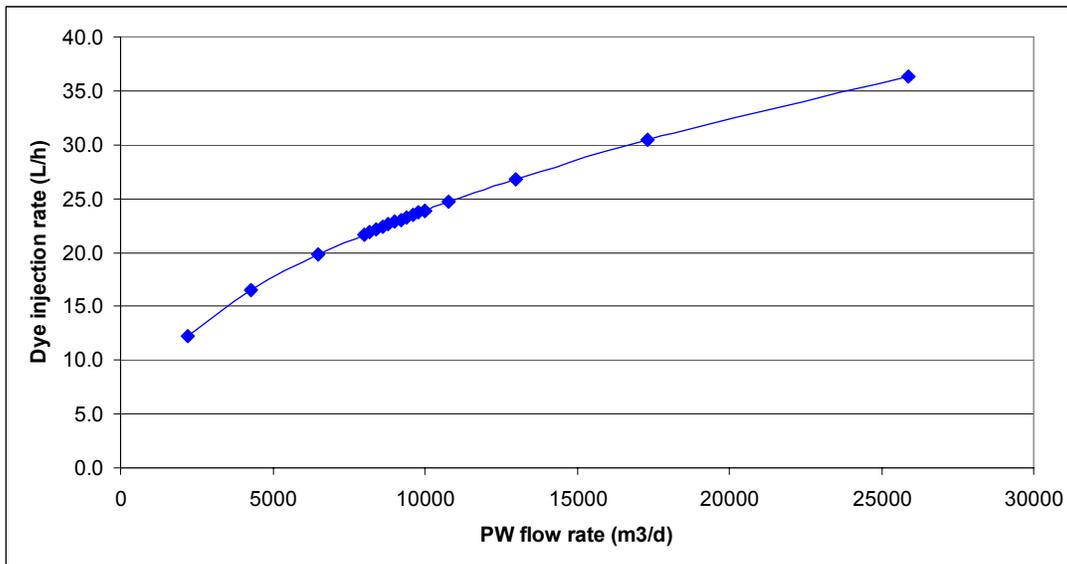


Figure 2 Dye Injection Rate Needed at Various Produced Water Flow Rates

Table 1 Dye Injection Rate at Various Produced Water Flow Rates, and Parameters Used in Calculation of Dye Injection Rate

Rhodamine WT concentration	g/mL	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Target concentration	ug/L	50	50	50	50	50	50	50	50	50	50	50	50
PW flow rate	m ³ /d	2200	4300	6500	8000	8400	8800	9000	9400	9800	10800	13000	17300
“	m ³ /h	92	179	271	333	350	367	375	392	408	450	542	721
“	m ³ /s	0.025	0.050	0.075	0.093	0.097	0.102	0.104	0.109	0.113	0.125	0.150	0.200
Initial dilution (from Appendix 1)		275	175	150							110	100	80
Initial dilution (from fitted equation)		268	184	146	130	126	123	122	119	116	110	99	84
Secondary dilution		2	2	2	2	2	2	2	2	2	2	2	2
Total dilution		535	368	292	260	253	246	243	238	232	220	198	169
Realized flow	m ³ /s	13.6	18.3	22.0	24.1	24.6	25.1	25.4	25.8	26.3	27.5	29.8	33.8
Dye injection rate by weight	g/s	0.7	0.9	1.1	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.5	1.7
Dye injection rate by volume	mL/s	3.4	4.6	5.5	6.0	6.1	6.3	6.3	6.5	6.6	6.9	7.5	8.5
“	mL/min	205	275	330	361	369	377	380	388	395	412	447	507
“	L/h	12.3	16.5	19.8	21.7	22.1	22.6	22.8	23.3	23.7	24.7	26.8	30.4
PW dye concentration	ug/L	26772	18399	14600	12998	12648	12323	12169	11876	11602	10988	9905	8441
Planned duration	h	6	6	6	6	6	6	6	6	6	6	6	6
Weight of dye injected	Kg	15	20	24	26	27	27	27	28	28	30	32	37
Volume of dye injected	L	74	99	119	130	133	136	137	140	142	148	161	183

The nominal detection limit of the rhodamine fluorometers (Turner Designs SCUFA Rhodamine Fluorometer) is 0.04 parts per billion (ppb), therefore there will be a strong signal from the core of the plume following initial dilution. Assuming a more conservative working detection limit of 0.1 ppb, then the maximum secondary dilution detectable will be 500 times or more. Experience has shown that following initial dilution, a relatively stable plume is formed and this should be traceable for hundreds of metres downstream of the FPSO. Current meter data from 20m depth (approximately equal to the depth of discharge from the FPSO) shows that currents of 20 cm/s are common in October. At this current speed, the plume will be carried for several kilometers over the planned eight hours of tracking.

The electronics package used for detecting the dye plume consists of a Turner SCUFA Rhodamine fluorometer integrated with a Seabird SBE19+ CTD (conductivity, temperature, depth sensor). This instrument will be deployed from the ship using a winch equipped with conducting cable and slip rings to allow for transfer of data in real-time to a shipboard computer.

The CTD and fluorometer can be towed horizontally or vertically. Horizontal tows will be achieved by keeping the ship at a constant velocity (approximately 2 knots perpendicular to the long axis of the plume) and adjusting depth of the instrument using the amount of cable let out by the winch. Vertical profiles will be made through the plume, mainly in the centre of the plume as identified by the horizontal tows. The CTD records data at rate of 2 Hz, therefore if the plume is 100m wide horizontally and 20m thick vertically there will be over a hundred readings horizontally and 80 vertically if a haul speed of 0.5 m/s is used. This amount of data will be sufficient to contour the concentration of dye at increasing distance from the ship.

Towing the CTD in an undulating pattern has been suggested, and has been used in the past. Experience shows that this mode of towing results in a minimum of readings in the core of the plume and the vast majority of the time the instrument is above or below the plume. Once the depth of the plume core is detected and the plume is relatively stable, making readings in horizontal and vertical (X and Y) directions through the core will achieve the maximum amount of data needed for contouring the horizontal and vertical extent of the plume. If initial concentration of the dye in the produced water is also known, then contours of dilution will also be possible using the data collection mode described above. These will be the two key components of the field work: (1) identifying the plume core if there is not visual cue to its location, and (2) achieving a known, constant concentration of dye in the produced water stream (see Appendix 1 for instruction to Petro-Canada for maintaining constant dye concentration and sampling produced water with dye fully mixed to verify measures of initial dye concentration).

An onboard data acquisition system will log salinity, temperature, depth, fluorescence, and location (from a GPS mounted near the winch). During towed deployment of the CTD there will be some uncertainty as to exact position of the instrument behind the ship. Length of wire let out, depth of the instrument and heading of the ship will have to be used to post-correct the GPS reading logged during

towing. Vertical position during towed deployment will be maintained by speed of the ship and length of wire let out.

2.1 Initially Locating the Plume

The produced water has a relatively high temperature (approximately 60° C) which contributes to making the PW less dense than surrounding water. The PW also has a higher salinity (approximately 65 ppt) than ambient seawater which contributes to making it more dense than the surrounding seawater. Calculations of the density of the plume water formed after discharge and initial dilution show that the plume water will not have a positive buoyancy and will be trapped at approximately 20 m, below the pycnocline. If this is the case, finding the location of the plume will require towing the CTD horizontally at the expected trapping depth until the dye is detected. However, if the water column is sufficiently mixed, then the trapping depth might vary quite a bit. If this is the case, then vertical profiles will be required to assess water mass characteristics. Also if predictions that the plume will be trapped under the pycnocline are incorrect, then a vertical search pattern could be required to identify trapping depth.

Clues as to where to start the search for the plume will include visual observations from the FPSO and real time current data. A conference call with personnel involved in this study and familiar with the FPSO report that bubbles from the PW discharge can often be seen surfacing on the starboard side of the ship. If this is the case at the time of this study, then this will be the best guide as to where to begin profiling. Another aid used to predict the location of the plume will be real time current data. If the plume is not located on the starboard side of the FPSO, then profiles (horizontal and/or) vertical will be performed to the left and right of the expected surfacing area, and, if required, on the port side of the FPSO.

Use of 2004 measurements of wind velocities at 100m from the sea surface were used to calculate the movement of a particle under the various wind regimes. Examples of the calculated movements are shown in Figures 3 and 4. These calculations show that the trajectory of the plume will be difficult to predict from real time wind measurements, since other factors such as the length of time that the wind has blown in a given direction and tidal currents will play a part in determining the direction that the plume is carried. Therefore, real time current data, rather than wind data, will be reported to the survey crew.

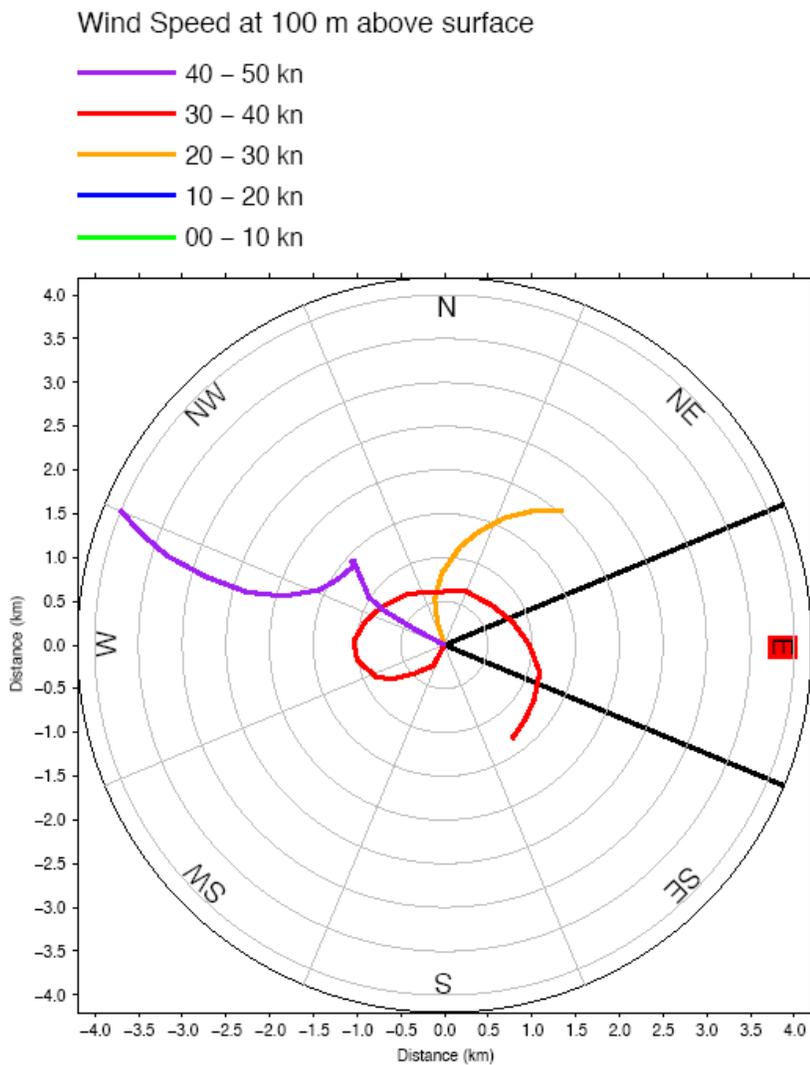


Figure 3 Calculated Trajectories of a Particle at 20m Depth when Wind is Coming from the East at Various Speeds

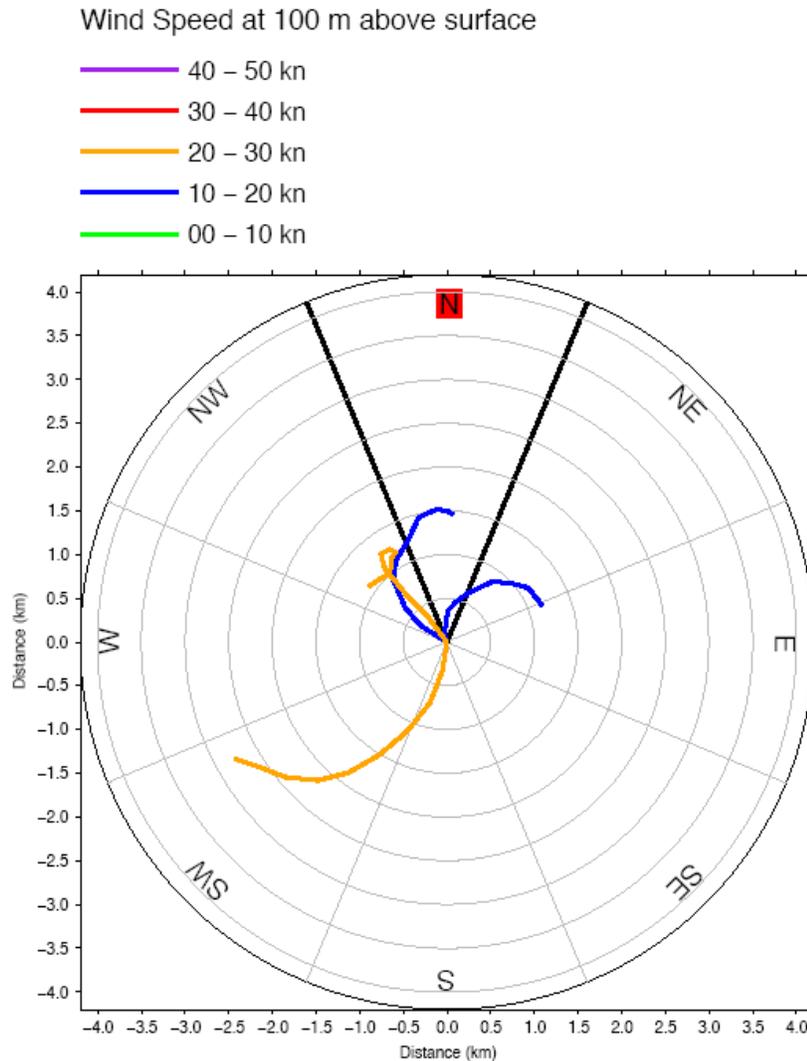


Figure 4 Calculated Trajectories of a Particle at 20m Depth when Wind is Coming from the North at Various Speeds

2.2 Plume Mapping

The vertical extent of the plume will likely be limited to tens of meters by a pycnocline that occurs at around 20m in October 2004. *If this pycnocline is present at the time of the study, then the plume may be restricted to a thin layer below the pycnocline. If wind mixing has eroded the pycnocline then the vertical extent of the plume will be greater.* Vertical extent of the plume will be determined by taking vertical CTD profiles (see Appendix 3) along the width of the plume, beginning near the core of the plume and continuing until the ship has moved off of the plume and no dye is detected by the fluorometer (Figure 5). Near the FPSO, profiles will be located 40 m apart. As the plume widens,

profiles will be taken at greater distances (Figure 5). Distances between vertical profiles provided in Figure 5 are only rough guidelines and these distance will need to be adjusted based on information obtained in the field. It is recommended that sets of vertical profiles be taken at 500 m intervals along the length of the plume. Once the full extent of the plume has been mapped, a horizontal transect at the depth of maximum concentration of the plume should be performed (Figure 5; Appendix 3). If time then allows, additional vertical profiles should be conducted at mid-locations along the length and width of the plume, and additional horizontal profiles should be performed. If the plume is lost, horizontal tows should be performed around the last known location and depth of the plume.

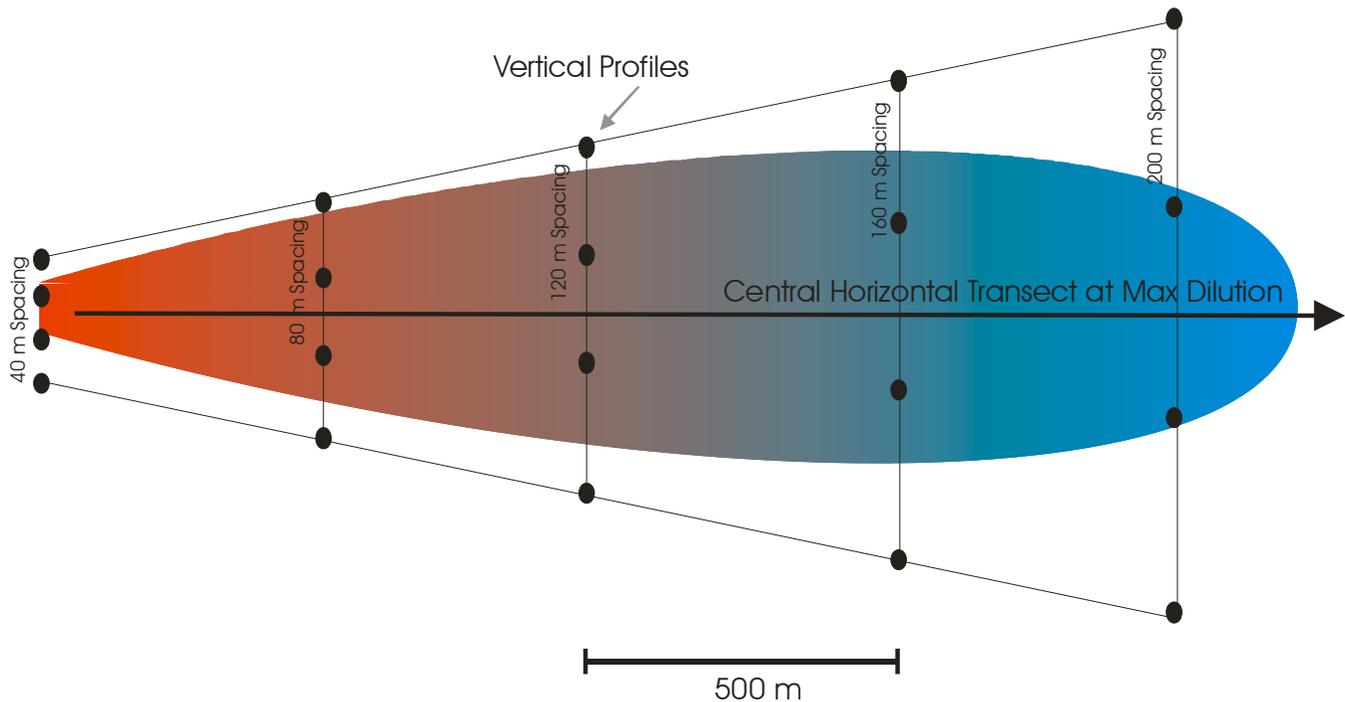


Figure 5 Idealized Sample Plan Showing Horizontal Transects and Vertical Profiles

2.3 Data Requirements

Ship position during the experiment should be recorded at all times. The field crew should obtain a record of ship position before leaving the vessel.

The location of vertical profiles and the start and end location of horizontal transects should be recorded. Sampling time should be recorded at the beginning of each profile/transect. Sampling time should be also be recorded at the end of horizontal transects.

Wire angle and wire length for the CTD/fluorometer should be measured every time a change in these parameters occurs. An example of the data sheet for these measurements is provided in Appendix 4.

2.4 Dye Pumping Requirements

The addition of Rhodamine WT dye to the produced water stream will be done by pumping liquid dye solution into the produced water in a way that it will be fully mixed with produced water prior to entering the ocean. Ideally the produced water stream will have a constant flow rate for the expected 6 hours of dye addition. This will allow dye to be added at a constant rate to produce a constant concentration. Ideally, a constant concentration of dye would be achieved. In the calculations of dye pumping rate done by Don Hodgins (Appendix 2), it is assumed that produced water flow rate will vary over the course of the dye injection. This will complicate the dye addition mechanism because dye addition will have to be adjusted to match changes in produced water flow. If comparable changes are not made to the dye injection rate, then the calculation of dilution will be complicated because of varying initial concentration in the water which is being diluted. 150 ml samples of undiluted produced water with the dye fully mixed into it should be collected every hour and following a measured change to the flow rate. The samples will be given to the personnel aboard the survey vessel at the earliest convenience. Dye concentration in these samples will be measured using the same fluorometer that is attached to the CTD by diluting the 150 ml sample with 20 L of seawater.

Responsibilities for the Petro-Canada relating to the dye injection are provided in Appendix 1 and summarized below.

- design, manufacture, install, test and operate a dye pumping injection system for Rhodamine WT accommodating the range of possible PW flows,
- obtain 150ml samples of the produced water downstream of the injection point for measurement of Rhodamine concentration, salinity and density, every hour for 6 hours of injection,
- monitor and record produced water flow and temperature every 30 minutes for 9 h (3 h before injection, 6 h during injection),
- prepare report sections on design and experience, lessons learned with the dye pumping systems (include photographs).

3.0 PERSONNEL

Craig Hollett will lead the field exercise.

Matt Hynes and Robbie Boland will operate the winch, CTD and fluorometer and keep data records.

Elisabeth DeBlois is the land contact for field personnel.

Dave Taylor is the land contact at Husky Energy.

Francine Wight is the land at Petro-Canada.

Katrina Lewis, at Petro-Canada, will oversee dye injection and data collection onboard the Terra Nova FPSO.

4.0 COMMUNICATIONS

The survey crew will forward a progress report to Elisabeth DeBlois at Elisabeth.deblois@jacqueswhitford.com at the end of each sampling day. This report will be forwarded via email to the following Husky Energy, Petro-Canada and Lorax personnel:

Contact	email	Work Phone	Cell Phone	Home
Dave Taylor	Taylor.StJohns@huskyenergy.ca; dtaylor@nfld.com	709 724 3967	709 685 8194	709 834 2461
Francine Wight	fwight@petro-canada.ca	709 778 3726	709 685 0272	709 579 4936
Katrina Lewis	klewis@petro-canada.ca	709 778 3702		
Rob Goldblatt	goldblatt@lorax.ca	604 688 7173	778 227 2812	604 436 2802
Don Dunbar	dsd@lorax.ca	604 688 7173	604 970 2997	604 926 8325
David Jones	djones@eos.ubc.ca	604 822 5730		604 415 0445

The crew lead should contact David Jones or Rob Goldblatt directory if technical difficulties arise. Rob Goldblatt should then inform Elisabeth DeBlois of the nature of difficulties. Additional communications from the survey crew to land personnel are to be coordinated through Elisabeth DeBlois. Telephone contact information is provided below:

Elisabeth DeBlois:

Work: 709 576 1458 (ext 269)

Cell: 709 728 4299

Home: 709 754 5470

5.0 REPORTING

A debriefing meeting will be held with land and field personnel to discuss issues that arose during the execution of the program.

A report will be produced assessing the PW monitoring methodology including lessons learned by all parties' involved and potential means for improvement. If mapping is successful, the report will

summarize the CTD/fluorometer data in a way that the extent of the plume and dilution of the plume can be visualized.

APPENDIX 1

Petro-Canada Work Pack



**Q PACK /
MODIFICATION**
TN-PE-EV10-M04-001



1	Job No:	WO # 70019325	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
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Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer



**Q PACK /
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1	Job No:	WO # 70019325	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
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APPROVALS									
REV	DESCRIPTION	RESPONSIBLE ENG./PROJECT ENG.		HSEQ		ONSHORE LEAD		APPROVED	
D0	ISSUED AFC	Katrina Lewis		Francine Wight		Craig Hodder		Sherry Power	

3. Statement of Problem:-

The Terra Nova FPSO discharges a high temperature, high salinity plume of produced water. Produced water from the FPSO has the potential to affect water quality. Therefore it is useful to know the zone of influence around the FPSO where produced water and associated components may not have been diluted to background levels. When produced water (PW) is discharged it will undergo an initial dilution with ambient seawater which is expected to reduce natural signatures of PW such as temperature, salinity, or turbidity. Therefore a tracer of the produced water is needed to identify the plume.

A tracer is an inert dissolved substance that will move along with the plume and be detectable at very low concentrations. The work plan described here is a vessel-based field study to track a fluorescent dye tracer introduced to the produced water discharge. The fluorescent dye to be used is Rhodamine WT and this dye is commonly used to measure flow rate, circulation and dispersion of both freshwater and seawater.

The overall goal of the study is to define the horizontal and vertical extent of the plume and the dilution of plume water. This study is a component of Phase 1 of Produced Water Monitoring at the White Rose FPSO. The long-term goal of the Terra Nova field work is to improve on methods and approaches used to assess water quality around offshore oil platforms and apply these methods to White Rose.

4. Work Schedule:

Specific start and end dates are not shown as work will be scheduled by offshore planning.

Table 1. Summary of Manpower Required

	Day 1	Day 2	Day 3	Day 4
Core POB	1	1	1	1
Man Hours	6 hrs	12 hrs	12 hrs	12 hrs
Discipline	Water Monitor	Water Monitor	Water Monitor	Water Monitor
		Lab Tech	Lab Tech	Lab Tech
		Production Coordinator	Production Coordinator	Production Coordinator

Day 2, 3 and 4 – work to be divided between water monitor, lab technician and production coordinator as per discussion with onshore/offshore production leads and onshore OIM.



**Q PACK /
MODIFICATION**
TN-PE-EV10-M04-001



1	Job No:	WO # 70019325	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
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5 Scope of Work: Refer to Work Plan provided by Lorax Environmental (See Appendix A)

The duration of the work will take 4 days to complete. Prior to commencement of work, a pump skid provided by Baker Petrolite is required to be installed at drain valve WH-390043 downstream of degasser vessel VA-39001. Refer to drawing number TN-BR-PR78-T00-082-01 found in Section 7.

The first day will involve injection of Fluorescein dye into the produced water stream. The purpose of this is to determine if the produced water surfaces and to sketch the visible plume. This test is to be performed when the sea states are relatively calm and good visibility. Fluorescein dye exists offshore in 1L bottles. Fluorescein dye will require dilution prior to injection. Refer to the following test program for details.

Day 1

1. Inject Fluorescein dye downstream of degasser at drain valve WH-390043 for 10 minutes. Fluorescein dye should be diluted to meet a target concentration of 2 ppm in order to be visible. Refer to Figure 1 for mixing rates of Fluorescein.
2. Stop injection and watch overboard for dye to surface. Record time that injection is initiated and terminated and time Fluorescein surfaces. Record observations. Take pictures and sketch plume.
3. Repeat batch injection of Fluorescein once each batch has cleared from the ocean. This is to be repeated 2 additional times to gain confidence in the observations. If plume is observed and is larger than necessary for observation then the initial 10 minute injection length can be shortened. If Fluorescein does not surface within 30 minutes repeat batch injection.
4. Flush pump, transfer lines and calibration pot with fresh water for a minimum of 15 minutes once test is completed.
5. Report conclusions of study to survey crew carrying out the Rhodamine study and onshore contact. Contact information is as follows:

Offshore Personnel aboard supply vessel
Craig Hollett
David Jones

Onshore Contact
Elisabeth DeBlois
Email: elisabeth.deblois@jacqueswhitford.com
Tel: (709)576-1458

The next three days will involve injection of Rhodamine dye into the produced water stream. The dye plume will be developed by injecting a 20% solution of Rhodamine WT dye into the produced water discharge at a rate that is calculated to produce a dye concentration of 50 ppb following initial dilution. Ideally the produced water stream will have a constant flow rate for the expected 6 hours of dye addition. This will allow dye to be added at a constant rate to produce a constant concentration. For the expected PW flow rate of approximately 9000 m³/d (±1000) the dye injection rate required is 22.8 L/h (± 1.1).

Ideally, a constant concentration of dye is to be achieved. It is assumed that produced water flow rate will vary over the course of the dye injection. This will complicate the dye addition mechanism because dye addition will have to be adjusted to match changes in produced water flow. 150 ml samples of produced water with the dye fully mixed into it should be collected every hour and following any significant change to the flow rate.

This test is to be performed when the sea states are relatively calm and good visibility. The captain aboard the supply vessel in conjunction with David Jones from Lorax Environmental will determine if this test will go ahead and will notify personnel onboard the FPSO. Refer to the following test program for details.



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TN-PE-EV10-M04-001



1	Job No:	WO # 70019325	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
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Day 2

1. Ensure well rates are stable and produced water rates are greater than 8000m³/day.
2. Record produced water flow rate from both FT-390001 and FT-200150 and produced water temperature from TI-200132 every 30 minutes for a 3 hour period prior to injection of Rhodamine.
3. Inject Rhodamine dye downstream of degasser at drain valve WH-390043 for a 6 hour period. Injection rate is dependant upon produced water flowrate. At the produced water flow rate shown in step 1 this would be 22-24 L/h. The injection rate can be determined from the graph in Figure 2 or read off of Table 2.
4. Notify survey crew aboard supply vessel that injection has begun.
5. Record Rhodamine injection rate, produced water injection rate and produced water temperature every 30 minutes for the 6 hour injection period or when there is any significant change in produced water flow rate (+/- 50 m³/hr).
6. Collect 150 mL samples of produced water with dye fully mixed from sample connection SC-016 every hour.
7. Samples are to be labelled to include the following information:
 - Sample #
 - Time sample was taken
 - Flowrate of produced water at time sample was taken
 - Rhodamine dye injection rate at time sample was taken

Samples are to be given to the personnel aboard the survey vessel at the earliest convenience.

Day 3

Same as Day 2.

Day 4

Same as Day 2.

Once the test has been completed all samples are to be transferred to the survey crew for analysis if not already done so. Take photographs of pump skid. Flush pump, transfer lines and calibration pot for a minimum of 15 minutes following the completion of the test. Disconnect pump and reinstate drain valve WH-390043.

Provide a summary regarding working experience with the pump skid.

Data sheets to be completed by FPSO personnel are found at the end of this section.

Note: Produced water analyzer is to remain online; however readings may be affected during injection time.



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MODIFICATION**
TN-PE-EV10-M04-001



1	Job No:	WO #	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
		70019325			

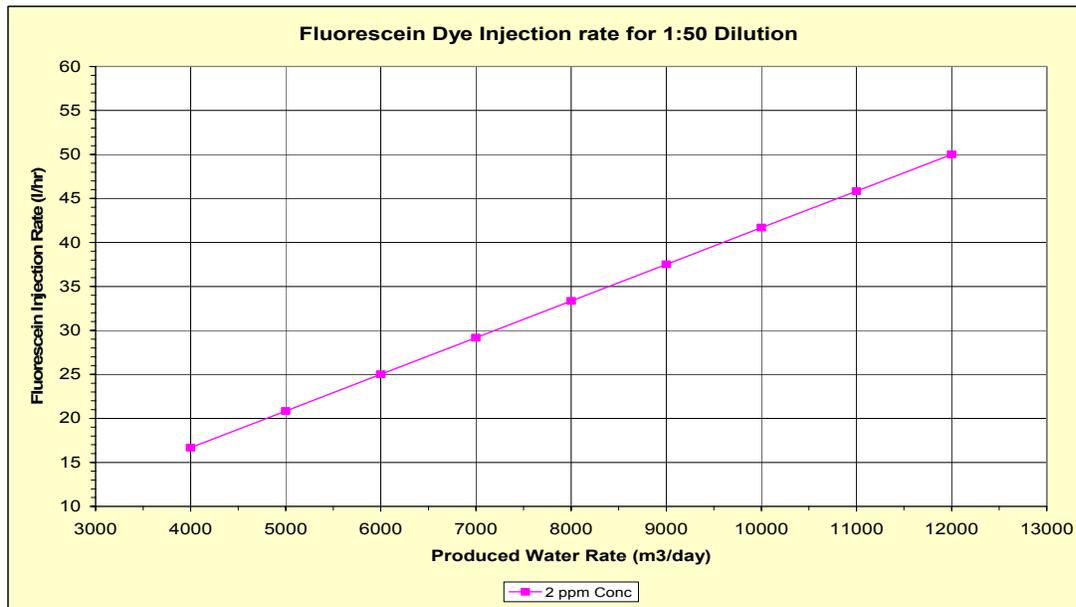


Figure 1. Mixing chart for Fluorescein Dye

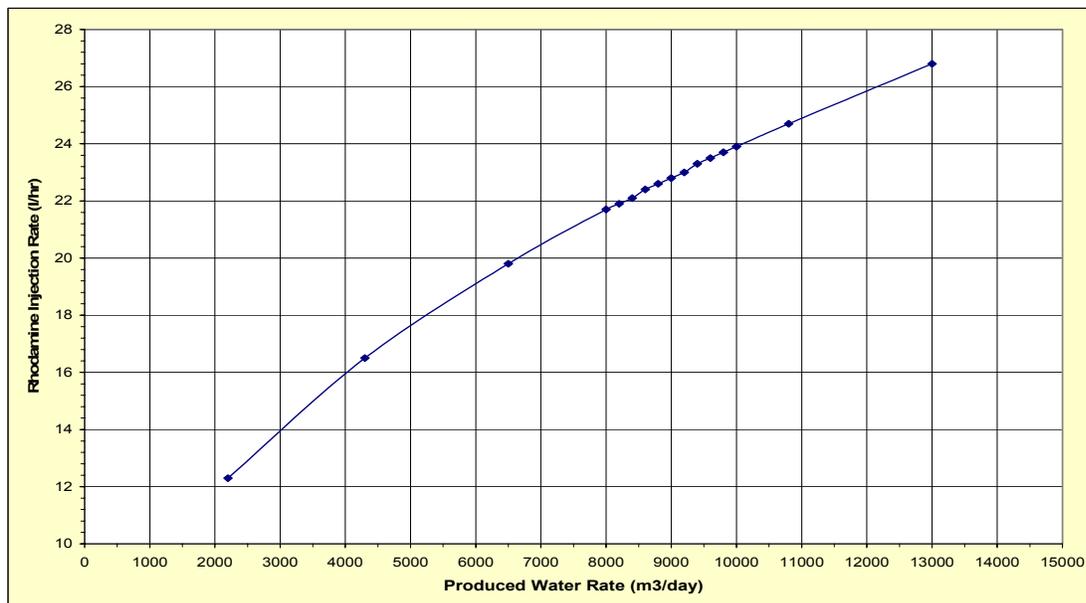


Figure 2. Estimated Rhodamine WT injection rates as a function of produced water flow



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TN-PE-EV10-M04-001



1	Job No:	WO # 70019325	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
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Table 2. Summary of Rhodamine dye Injection Rates

PW flow (m ³ /day)	Dye injection rate (L/hr)	Volume (L) of solution injected
2200	12.3	73.6
4300	16.5	98.9
6500	19.8	118.6
8000	21.7	130
8200	21.9	131.4
8400	22.1	132.8
8600	22.4	134.2
8800	22.6	135.6
9000	22.8	136.9
9200	23	138.2
9400	23.3	139.5
9600	23.5	140.8
9800	23.7	142.1
10000	23.9	143.4
10800	24.7	148.3
13000	26.8	161

		Q PACK / MODIFICATION TN-PE-EV10-M04-001			
1	Job No:	WO #	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
		70019325			

6 Safety Engineering

Safe job analysis and tool box talk shall be carried out as required by Terra Nova Control of Work System and Procedures (CWSP) TN-PE-OP03-X00-101.

A PHA was not required. Both Fluorescein and Rhodamine WT Dyes have been approved by Petro Canada. Refer to Section 9 for MSDS sheets.

A review of this work pack shall be completed offshore by operations and the appropriate permits/certificates will be prepared and approved offshore.

7 Drawings

The following marked up drawings are included in this section for general reference:

Table 3. List of Drawings

Title	Document Number	Revision
General Arrangement	TN-YF-MR58-V00-103	91
Process P&ID MP1 Separator	TN-BR-PR78-T00-012-02	L3
Utility P&ID Produced Water Degasser	TN-BR-PR78-T00-082	L2



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TN-PE-EV10-M04-001



1	Job No:	WO # 70019325	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
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8 Equipment and Materials

This section contains a list of equipment required to complete the Work. All temporary equipment must comply with the Temporary Equipment Manual TN-PE-MN04-X00-004.

Table 4. Summary of Equipment required.

Item	Description	Qty
1	Portable chemical injection pneumatically operated pump skid to be supplied by Baker Petrolite	1
2	Small SS tote tank to be provided by Baker Petrolite	1
3	1/2" x 50' Thermoplastic hose c/w 1/2" M/NPT one end and 3/4" M/NPT other end Material 316SS	1
4	3/4"x25' Clear Braid hose one end 3/4" M/NPT other end 2" F/Camlock 316SS	1

Lorax Environmental will supply Rhodamine WT Dye. Fluorescein Dye already exists offshore. Refer to Section 9 for MSDS sheets for both Dyes.



**Q PACK /
MODIFICATION**
TN-PE-EV10-M04-001



1	Job No:	WO #	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
		70019325			

9	<p>Occupational HS&E</p> <p>This section includes the MSDS sheets for Fluorescein and Rhodamine WT Dyes. Handling procedures of these chemicals are found within the MSDS sheets.</p>
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RISK ASSESSMENT APPROVAL			
OFFSHORE LOSS PREVENTION SUPERVISOR		OFFSHORE CONSTRUCTION SUPERVISOR/G.F.	



**Q PACK /
MODIFICATION**
TN-PE-EV10-M04-001



1	Job No:	WO # 70019325	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
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10	<p>Maintenance & Operations Manual Amendments</p> <p>Operation manual for portable pump skid is included in this section.</p>
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11	<p>Assurance and Verification Requirements (tick box to indicate attachment required) Offshore.</p>
-----------	--

<input type="checkbox"/> Authorisation Work Order <input type="checkbox"/> Jobcards <input type="checkbox"/> Construction checklists <input type="checkbox"/> Commissioning checklists <input type="checkbox"/> Pressure Test Records	<input type="checkbox"/> NDT reports <input type="checkbox"/> Welding Procedures <input type="checkbox"/> Weld Log/Fabrication Log <input type="checkbox"/> Bolt Tensioning Records <input type="checkbox"/> As-Built Drawings (as per drawing index)	<input type="checkbox"/> Other (please specify) <input type="checkbox"/> Independent Verification Body Scope
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**Q PACK /
MODIFICATION**
TN-PE-EV10-M04-001



1	Job No:	WO # 70019325	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
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12	Close out Report
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13	This is to certify that the scope of work outlined within this workpack has been fully completed. All work has been conducted, checked, inspected and accepted to applicable TSG procedures and specifications. Please sign and date below to acknowledge the return of ownership of the above systems and associated equipment from TSG to Platform Operations
-----------	---

Constr. Superintendent	FPSO Eng (accepted)	Sys Owner (accepted)	OIM (endorsement)	
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**Q PACK /
MODIFICATION**
TN-PE-EV10-M04-001



1	Job No:	WO # 70019325	2	Title:	Horizontal and Vertical Mapping of the Terra Nova Produced Water Plume Using a Dye Tracer
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14	Supplementary Information Index		
<u>SUPPLEMENTARY SECTIONS</u>	<u>DESCRIPTION</u>	<u>INCLUDED</u> (delete as appropriate)	
1	DRAWINGS (INCLUDING ADDITIONAL FIELD COPY)	<u>YES</u>	
2	WEIGHT CONTROL	<u>NO</u>	
3	JOB CARDS	<u>NO</u>	
4	ADDITIONAL WORKSCOPE DETAILS / VENDOR WORKSCOPES	<u>YES</u>	
5	CONSTRUCTION RISK ASSESSMENT	<u>NO</u>	
6	CONSTRUCTION CHECKSHEETS	<u>NO</u>	
7	SAFETY & ENVIRONMENTAL	<u>YES</u>	
8	COMMISSIONING CHECKSHEETS	<u>NO</u>	
9	COMMISSIONING PROCEDURE & CHECKSHEETS	<u>NO</u>	
10	MAINTENANCE & OPERATION MANUAL AMENDMENTS	<u>NO</u>	
11	PLAN (Project Schedule)	<u>NO</u>	
12	VENDOR INFORMATION	<u>YES</u>	

Rhodamine Dye Test

Trial 1

	Time	PW Flow Rate		PW Temperature
		FT-390001	FT-200150	TI-200132
	minutes	m3/hr	m3/hr	Deg C
Prior to Injection	0			
	30			
	60			
	90			
	120			
	150			
	180			

Note: Record data every 30 mins and when PW rate changes +/- 50m3/hr. Take sample every hour.

	Time	PW Flow Rate		PW Temperature	Rhodamine Injection Rate
		FT-390001	FT-200150	TI-200132	Rate
		m3/hr	m3/hr	Deg C	L/hr
During Injection					

Trial 1

	Time	PW Flow Rate		PW Temperature	Rhodamine Injection Rate
		FT-390001	FT-200150	TI-200132	
		m3/hr	m3/hr	Deg C	L/hr
During Injection					

Rhodamine Dye Test

Trial 2

	Time	PW Flow Rate		PW Temperature
		FT-390001	FT-200150	TI-200132
	minutes	m3/hr	m3/hr	Deg C
Prior to Injection	0			
	30			
	60			
	90			
	120			
	150			
	180			

Note: Record data every 30 mins and when PW rate changes +/- 50m3/hr.
Take sample every hour.

	Time	PW Flow Rate		PW Temperature	Rhodamine Injection Rate
		FT-390001	FT-200150	TI-200132	Rate
		m3/hr	m3/hr	Deg C	L/hr
During Injection					

Rhodamine Dye Test

Trial 3

	Time	PW Flow Rate		PW Temperature
		FT-390001	FT-200150	TI-200132
	minutes	m3/hr	m3/hr	Deg C
Prior to Injection	0			
	30			
	60			
	90			
	120			
	150			
	180			

Note: Record data every 30 mins and when PW rate changes +/- 50m3/hr. Take sample every hour.

	Time	PW Flow Rate		PW Temperature	Rhodamine Injection Rate
		FT-390001	FT-200150	TI-200132	Rate
		m3/hr	m3/hr	Deg C	L/hr
During Injection					

APPENDIX 2

Dye Pumping Requirements

MEMORANDUM

To: Elizabeth DeBlois, Jacques Whitford
From: Don Hodgins, Lorax
Subject: Pumping rates for dye injection
Project: Husky/Petro Canada produced water plume studies
Date: September 30, 2005
Copies: Don Dunbar

PRODUCED WATER FLOW

Figure 1 illustrates the variations in produced water flow recorded by Petro Canada during July-August 2005. Figure 2 illustrates the variations in flow over a 72-h period; the purpose of this plot is to show that variations within a day can be quite significant in terms of planning a dye injection where it is desirable to maintain an approximately constant concentration of dye in the effluent flow stream once it become established in the receiving water. Some basic statistics of these data show that:

- Average flows can vary by more than a factor of 2 between different discharge periods,
- Short-term variations are significant, with one standard deviation ranging from 18% to 27% of the mean value,
- These short-term variations occur within the space of a day, and thus must be taken into account for injecting dye,
- Fluctuations in flow can be rapid: maximum values range up to about 0.3 m³/s, while recorded minimums can fall to as low as 0.002 m³/s (disregarding periods of no flow).

Accordingly, dye injection rates have been calculated for a range of flows (0.025, 0.30) m³/s. A pumping system should ideally be adjustable so that as produced water flow rates change, the amount of dye injected can be modified to keep the concentration relatively constant beside the FPSO. Maintaining a constant concentration allows for a quantitative estimate of dilution, and helps the survey team to track the plume by knowing what to expect by way of peak concentrations in the receiving water (see below for the 'target concentration').

RHODAMINE WT INJECTION RATES

Calculation strategy

The dye pumping rates are designed to give a dyed plume with concentrations exceeding 50 ppb¹ within about 100 m of the FPSO (the target concentration). This concentration should allow fairly rapid detection of the core of the plume with a reasonably sensitive fluorometer. Assuming secondary dilution beyond this range of the order of 50 times over distances of about 2 km, the plume should be traceable down to concentrations of less than 1 ppb and distances of 2-3 km. The traceable range will, of course, depend also on sea state conditions and the trapping depth of the plume.

¹ One ppb = 1 µg/L

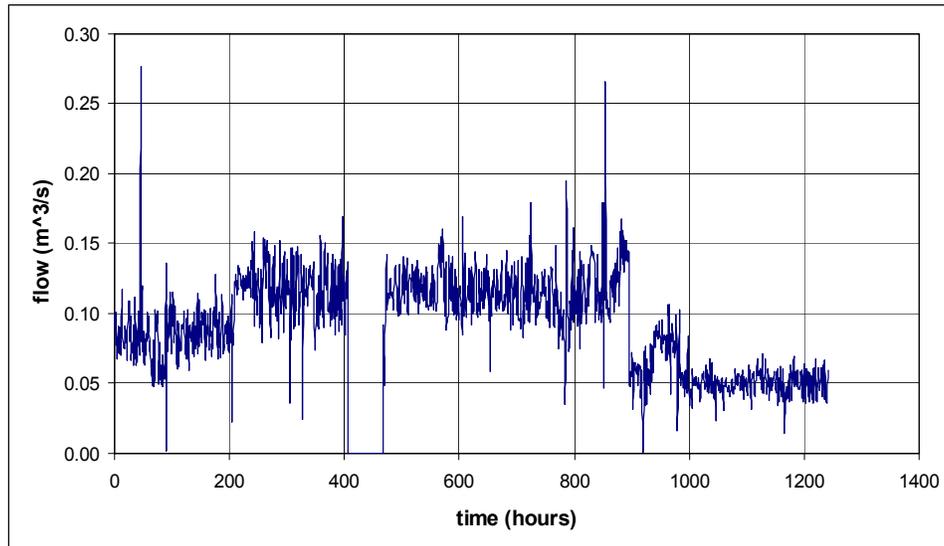


Figure 1 Measured produced water flow rates at Terra Nova, July-August 2005.

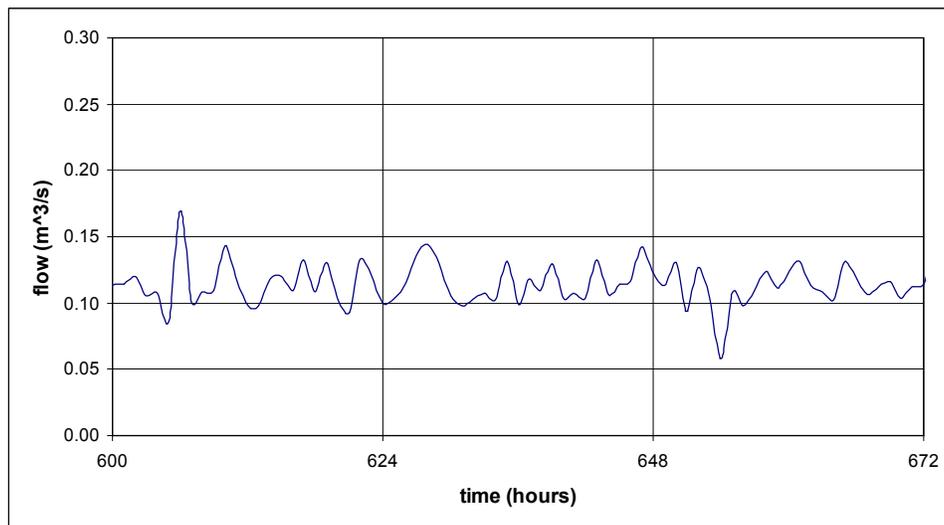


Figure 2 Measured produced water flow rates at Terra Nova during a 72-h period selected from the time-series in Figure 1.

The pumping time is specified as 6 h. Pumping should commence approximately 30 min before the start of surveying; this will allow a definite plume to become established on one side of the FPSO. Following an initial set of measurements close to the FPSO, the plume should be traced in the down-current direction as it spreads. Several passes through the plume, from close to background detection to high concentrations next to the ship, are normally made in the ensuing time.

Key Assumptions

The calculations shown in Table 1, below, were made on the basis of several key assumptions. It has not been possible to verify all of these assumptions, but they are reasonable based on past experience. The produced water flows are speculative for October-November conditions, being derived only from recorded flows in July-August 2005.

The assumptions are:

- The in situ fluorometer has a measurement range of at least 0.5 to 200 ppb, with a background reading in seawater of less than 0.5 ppb.
- The supply of Rhodamine WT in liquid form is at least a 20% solution (0.2 g/mL of active fluorescent dye). Note, it has not been possible to confirm this specification with suppliers, but is a reasonable assumption. This specification should be stated when placing an order for the dye. It can be checked by making a standard dilution series and measured with a calibrated fluorometer.
- The produced water flow will fall into the specified range.
- Initial dilution calculated with the UM plume model has been increased by a factor of 2 to account for secondary dilution around the hull of the FPSO. The degree of secondary dilution is presently unknown, and so the factor of 2 is purely an estimate to provide a margin of safety.

Rhodamine WT Pumping Rates

The dye pumping rates are expressed in Table 1 in units of mL/s and mL/min (bold text), the latter being the more usual for pump specification. The total weight of dye required for the 6 h pumping duration is given in the last line of the table.

The planned pumping rates range from 200 mL/min to around 550 mL/min for the produced water flow range examined here (Figure 3). If produced water flows are greater than 0.3 m³/s (26,000 m³/day), then the pumping rate can be scaled in proportion to the produced water flow rate as a rough approximation.

FLUORESCCEIN DYE INJECTION RATES

Supplier information (see e.g., www.caturner.com) indicates that fluorescein dye (a.k.a. Uranine, Acid yellow 73, and various other marketing product names) is visible in seawater under normal light conditions at concentrations exceeding 1 ppm (volumetric dilution). C.A. Turner (supplier) confirmed that their product (Fluorescent Green #SL-572-L) yields a concentration of 1 ppm when 16 US fl oz of dye is dissolved in 12,000 US gallons of water.

Assumptions:

- Produced water characteristics: temperature 60 deg Celsius, Salinity 64.6 ppt,
- Produced water flows have the same range as used for Rhodamine above,
- Fluorescein will be visible at concentrations of 1 ppm (volume/volume basis),
- No secondary dilution is assumed since this is to be a visible detection over a short period of time.

The estimated dye injection rates (Figure 4) range from about 4,000 mL/min for low flows, to over 13,000 mL/min for the high flow range.

Observation: These seem to be relatively high rates of dye injection, compared with dye tracing studies using Rhodamine and a measuring fluorometer. They result from the requirement for a relatively high concentration of dye for detection (1 ppm), relatively high rates of initial dilution and, perhaps, a relatively low concentration of dye in the supplier's liquid format. The last factor cannot be confirmed with the supplier; they will only confirm that 16 oz in 12,000 US Gallons gives a 1 ppm concentration.

It may be difficult to design a pumping system to accommodate both the high pumping rates and the range of pumping rates required to match the produced water flow variations. However, since the objective is only to confirm visually that effluent does or does not rise to the surface, it might be worth considering a much simpler method of introducing the dye stuff. Petro Canada might wish to look into inserting the dye as a kind of 'batch' injection by pumping at a single high rate (say 1000 mL/min) for a minute or two using a simple pump with minimum adjustment, or inserting the dye in powdered form directly into the flow stream (if possible). The 'batch' injections could be repeated a few times to gain confidence in the observations, allowing time for each batch to clear in the ocean before repeating the injection.

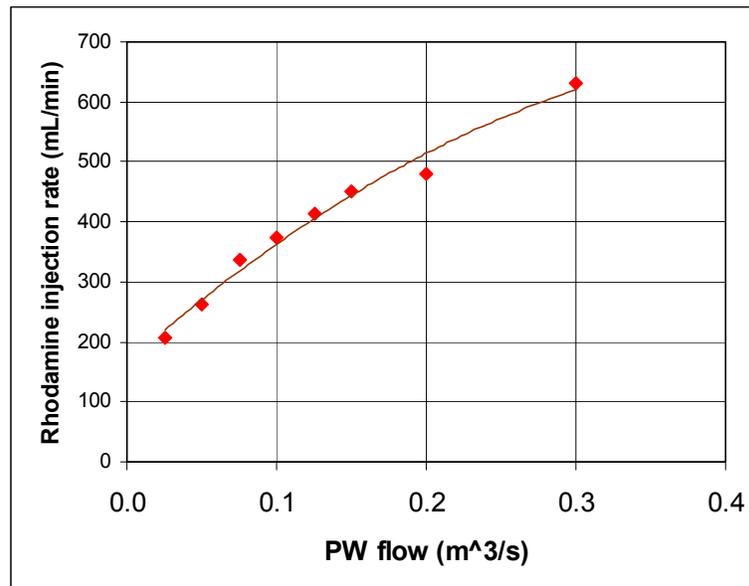


Figure 3 Estimated Rhodame WT injection rates as a function of produced water flow.

Table 1 Estimated Rhodamine WT Dye Injection Rates and Weights for a 6-h Survey

<i>Rhodamine WT concentration</i>	<i>Cr</i>	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	g/mL
<i>effluent flow</i>	<i>Q</i>	2.2	4.3	6.5	8.6	10.8	13.0	17.3	25.9	MLD
<i>effluent flow</i>	<i>Q</i>	0.025	0.050	0.075	0.10	0.13	0.15	0.20	0.30	m ³ /s
<i>initial dilution</i>	<i>De</i>	275	175	150	125	110	100	80	70	
<i>secondary dilution</i>	<i>Ds</i>	2	2	2	2	2	2	2	2	
<i>total dilution</i>	<i>Dt</i>	550	350	300	250	220	200	160	140	
<i>target concentration</i>	<i>C</i>	50	50	50	50	50	50	50	50	microg/L
<i>dye injection rate</i>	<i>qr</i>	3.4	4.4	5.6	6.3	6.9	7.5	8.0	10.5	mL/s
	=	206	263	338	375	413	450	480	630	mL/min
<i>effluent dye concentration</i>	<i>Ce</i>	27500	17500	15000	12500	11000	10000	8000	7000	microg/L
<i>planned duration</i>	<i>Tp</i>	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	h
<i>weight injected</i>	<i>W</i>	74	95	122	135	149	162	173	227	Kg

Table 2 Estimated Fluorescein Dye Injection Rates

<i>Q</i> m ³ /s	<i>flow after init dil</i> m ³ /s	<i>flow after init dil</i> US gal/s	<i>Uranine @ 1 ppm</i> US fl oz/s	<i>Uranine @ 1 ppm</i> mL/s	<i>Uranine @ 1 ppm</i> mL/min
0.025	6.9	1816	2.4	71.6	4297
0.050	8.8	2312	3.1	91.1	5469
0.075	11.3	2972	4.0	117.2	7031
0.100	12.5	3303	4.4	130.2	7812
0.125	13.75	3633	4.8	143.2	8594
0.150	15	3963	5.3	156.2	9375
0.200	16	4227	5.6	166.7	10000
0.300	21	5548	7.4	218.7	13125

2289 Burrard Street, Vancouver, BC V6J 3H9 CANADA
 Telephone: (604) 688-7173 Facsimile: (604) 688-7175

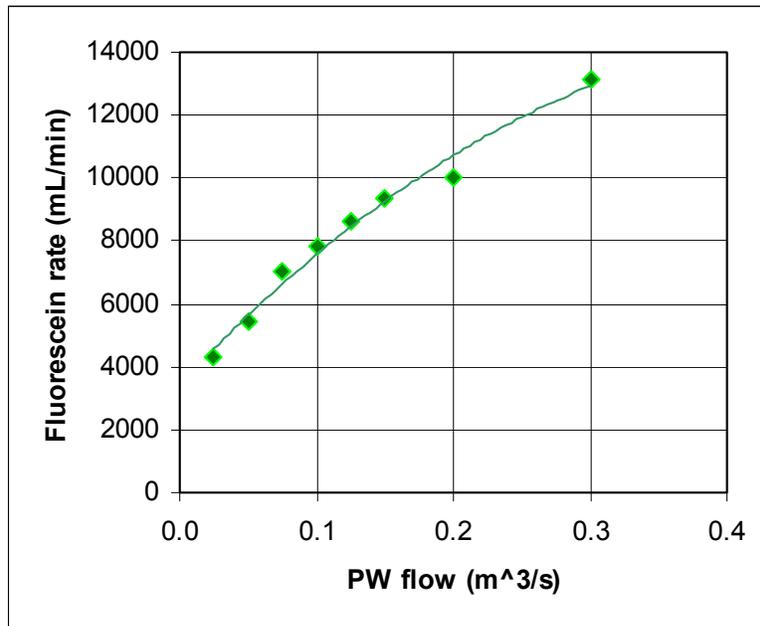


Figure 4 Estimated fluorescein injection rates as a function of produced water flow.

APPENDIX 3

Dye Plume Tracing Instructions

Dye Plume Tracing Instructions

CTD vertical profiling

1. At start of each cast record time CTD is turned on,
2. Lower CTD at approximately 0.5 m/s.
3. Stop the profile at 50m deep if no fluorescence is detected, or where fluorescence returns to zero if profiling within the plume.
4. Record wire angle during profile.
5. record the time the CTD is turned off.
6. Record observations such as sea state, ability to track the plume, and any other relevant information.

CTD horizontal towing

1. With the ship moving at a slow and steady speed (e.g. 1-2 kt) and the CTD in the water, position the CTD to approximately 20m or the depth of maximum fluorescence measured during previous profiles.
2. Record the length of wire deployed and the angle of wire.
3. Record observations such as sea state, ability to track the plume, and any other relevant information.

APPENDIX 4

Data Sheet

Appendix B

Summary of Recommendations from Husky Energy's Produced Water Workshop

Date of Workshop: Wednesday, March 31, 2006

Place: Main Boardroom, Jacques Whitford, 607 Torbay Rd, St. Johns

Attendance: Robin Anderson (DFO), Elisabeth DeBlois (Jacques Whitford), Don Dunbar (Lorax Environmental), Jerry Payne (DFO), Francine Wight (Petro-Canada), Urban William (Petro-canada), Dave Taylor (Husky Energy), Ken Lee (DFO), Len Zedel (Memorial University), Kim Coady C-NLOPG), Tahir Hussain (Memorial University).

Summary of Specific Recommendations from Husky Energy's Produced Water Workshop	
1)	The end goal should be the development of a risk assessment model for produced water effects. Protocols need to be developed for the measurement of produced water dispersion and for measurement or assessment of relevant chemicals within produced water.
2)	An agreed upon current model for the Grand Banks is required to improve plume modeling results. Real time current data and, specifically, surface current data are also required. Plume modeling could also be improved by including hydrodynamics modeling around the FPSO.
3)	Rhodamine experiment results and fine-tuning of a plume/chemical dispersion model could be used to direct sampling around platforms.
4)	Modeling of any change in primary production could be improved through use of real ranges of nutrient concentrations in the produced water being released on the Grand Banks.
5)	The use of satellite or air-borne imagery could be considered to measure any increase in chlorophyll concentration around platforms.
6)	DNA analysis could provide a means of assessing change in community structure and function around platforms.
7)	Given its rapid precipitation rate, ferric hydroxide from produced water should accumulate in sediments in measurable amounts around platforms.

Appendix C

Chemical Characterization of Produced Water

RPC ID		73222-01	73222-02	76054-01	76054-02	81265-01	81265-02	84194-1	84194-2	96753-01
Client ID	Units	Produced Water A August 24/07	Produced Water B August 24/07	Produced Water A November	Produced Water B November	Produced Water A May 27/08	Produced Water B May 27/08	Produced Water A August 20/08	Produced Water B August 20/08	Produced Water A September 01/09
METALS										
Aluminum	µg/L	5	5	7	8	11	11	9	9	< 5
Antimony	µg/L	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Arsenic	µg/L	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Barium	µg/L	990	949	877	884	485	486	253	243	147
Beryllium	µg/L	0.13	0.13	0.15	0.13	0.22	0.19	0.17	0.16	0.21
Boron	µg/L	61900	61800	58800	61100	53800	55200	51400	51600	34600
Cadmium	µg/L	0.02	0.02	< 0.02	< 0.02	0.08	0.08	0.02	0.04	0.06
Calcium	µg/L	437000	438000	388000	394000	377000	377000	438000	429000	715000
Chromium	µg/L	< 1	< 1	< 1	< 1	5	5	< 5	< 5	< 5
Cobalt	µg/L	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Copper	µg/L	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Iron	µg/L	2170	2110	2240	2180	2090	2160	2410	2390	4350
Lanthanum	µg/L	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Lead	µg/L	0.99	0.92	3.37	1.95	3.43	5.21	7.28	5.12	0.15
Lithium	µg/L	4770	4770	4550	4610	3130	3140	3560	3480	3180
Magnesium	µg/L	42800	42800	43500	44300	41200	41400	71000	69700	241000
Manganese	µg/L	17.0	16.3	13.0	14.2	15.0	13.2	16.1	15.6	26
Mercury	µg/L	< 0.05	< 0.05	0.03	0.07	0.04	0.04	< 0.025	< 0.025	< 0.025
Molybdenum	µg/L	0.3	0.4	0.1	0.1	0.2	0.2	< 0.2	< 0.2	0.3
Nickel	µg/L	2	2	2	2	8	6	17	17	10
Potassium	µg/L	341000	340000	270000	277000	259000	258000	258000	252000	330000
Selenium	µg/L	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Silicon	µg/L	30700	30500	29900	30100	28400	28700	28600	28100	28600
Silver	µg/L	< 0.02	< 0.02	< 0.02	< 0.02	0.16	0.20	< 0.05	< 0.05	< 0.05
Sodium	µg/L	11800000	11700000	11500000	11100000	10100000	10100000	10400000	10500000	11600000
Strontium	µg/L	133000	134000	116000	118000	77400	77600	63100	62300	74600
Sulfur	µg/L	144000	143000	151000	152000	257000	258000	309000	304000	432000
Tellurium	µg/L	< 0.5	0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.7	0.8	< 0.5
Thallium	µg/L	< 2	< 2	< 2	< 2	< 2	< 2	< 5	< 5	< 5
Thorium	µg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0	< 0.05	< 0.05
Uranium	µg/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Vanadium	µg/L	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.2	< 0.1	< 0.1	< 0.1
Zinc	µg/L	84	83	8	3	4	8	18	20	8
ORGANIC ACIDS										
Acetic Acid	mg/L	610	590	510	540	690	650	670	650	510
Propionic Acid	mg/L	57	57	50	52	50	50	48	47	36
Iso-butyric Acid	mg/L	5	5	5.9	5.6	3.4	3.6	3.1	2.9	2.6
Butyric Acid	mg/L	16	16	16	13	11	11	10	9.7	7.6
Iso-valeric Acid	mg/L	6	6	6.7	4.9	2.9	2.9	2.6	2.6	< 2.0
n-valeric Acid	mg/L	7	7	5.8	4.6	<2.0	3.0	3.5	2.6	2.1

RPC ID		73222-01	73222-02	76054-01	76054-02	81265-01	81265-02	84194-1	84194-2	96753-01
Client ID	Units	Produced Water A August 24/07	Produced Water B August 24/07	Produced Water A November	Produced Water B November	Produced Water A May 27/08	Produced Water B May 27/08	Produced Water A August 20/08	Produced Water B August 20/08	Produced Water A September 01/09
HYDROCARBONS - ATLANTIC MUST										
Benzene	mg/L	14	14	13	12	15	15	18	18	16
Toluene	mg/L	6.8	6.8	6.8	6.1	8.0	8.4	10	9.6	8.7
Ethylbenzene	mg/L	0.35	0.36	0.35	0.31	0.37	0.49	0.60	0.58	0.6
Xylenes	mg/L	1.8	1.8	1.8	1.6	2.0	2.5	2.8	2.7	2.8
VPH C6-C10 (Less BTEX)	mg/L	15	23	4.1	3.2	3.7	6.0	4.3	3.9	7.2
EPH >C10-C21	mg/L	4.3	5.5	16	15	14	8.9	16	15	18
EPH >C21-C32	mg/L	2.8	3.1	12	11	7.9	3.9	8.7	8.6	12
Modified TPH Tier 1	mg/L	22	32	32	29	26	19	29	28	37
PHENOLS										
Phenol	µg/L	7500	6700	2800	1900	1200	1200	2600	2600	5900
o-cresol ¹	µg/L	1800	1600	1000	1400	740	750	1300	1300	1700
m,p-cresol	µg/L	2600	2400	1800	2500	1200	1200	1800	1800	2400
Total C2 Phenols (ion patterns)	µg/L	2300	1900	1500	1500	1600	1500	2400	2300	2100
Total C3 Phenols (ion patterns)	µg/L	700	560	410	630	620	520	790	690	670
Total C4 Phenols (ion patterns)	µg/L	53	54	95	95	120	140	140	140	130
Total C5 Phenols (ion patterns) ¹	µg/L	<20	<20	<20	<20	<20	<20	< 20	< 20	< 20
4-n-hexylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
2,5-diisopropylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
2,6-diisopropylphenol	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
2-tert-butyl-4-ethylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
6-tert-butyl-2,4-dimethylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
4-n-heptylphenol	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
2,6-dimethyl-4-(1,1-dimethylpropyl)phenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
4-(1-ethyl-1-methylpropyl)-2-methylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
4-n-octylphenol	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
4-tert-octylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
2,4-di-sec-butylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
2,6-di-tert-butylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
4-n-nonylphenol*	µg/L	<20	<20	<20	<20	<20	<20	< 20	< 20	< 20
2-methyl-4-tert-octylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
2,6-di-tert-butyl-4-methylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
4,6-di-tert-butyl-2-methylphenol ¹	µg/L	<10	<10	<10	<10	<10	<10	< 10	< 10	<10
RADIONUCLIDES										
Radium-228	Bq/L	6	7	NA	NA	4.3	3.8	3	2.7	< 0.2
Radium-226	Bq/L	< 1	4	4.4	4.5	<0.9	5.0	3	3.0	< 0.9
Lead-210	Bq/L	4	2	NA	NA	<0.9	4	<1	<1	< 0.8

RPC ID		73222-01	73222-02	76054-01	76054-02	81265-01	81265-02	84194-1	84194-2	96753-01
Client ID	Units	Produced Water A August 24/07	Produced Water B August 24/07	Produced Water A November	Produced Water B November	Produced Water A May 27/08	Produced Water B May 27/08	Produced Water A August 20/08	Produced Water B August 20/08	Produced Water A September 01/09
PAHS										
Naphthalene	µg/L	270	260	500	510	550	580	440	400	340
Acenaphthylene	µg/L	1.6	1.6	0.90	1.0	1.4	1.4	0.93	0.78	1.1
Acenaphthene	µg/L	1.4	1.5	2.6	2.7	3.5	3.6	2.5	2.3	< 3.0
Fluorene	µg/L	11	10	19	20	39	36	22	20	28
Phenanthrene	µg/L	14	14	38	39	55	56	33	33	45
Anthracene	µg/L	< 0.1	< 0.1	0.63	0.91	0.6	0.8	< 0.10	< 0.10	< 0.10
Fluoranthene	µg/L	0.3	0.3	0.81	0.84	1.2	1.1	0.91	0.95	1.1
Pyrene	µg/L	0.4	0.3	1.3	1.3	1.5	1.5	1.1	1.2	1.4
Bz(a)anthracene	µg/L	< 0.1	< 0.1	0.21	0.25	<0.1	<0.1	1.7	1.7	1.5
Chrysene/Triphenylene	µg/L	0.9	0.9	3.0	3.1	3.9	4.1	1.2	1.0	1.1
Bz(b)fluoranthene	µg/L	< 0.1	< 0.1	0.25	0.26	<0.1	<0.1	0.19	0.19	0.18
Bz(k)fluoranthene	µg/L	< 0.1	< 0.1	0.25	0.26	<0.1	<0.1	0.19	0.19	0.18
Bz(e)pyrene	µg/L	< 0.1	< 0.1	0.66	0.75	<0.1	<0.1	< 0.10	< 0.10	< 0.10
Bz(a)pyrene	µg/L	< 0.1	< 0.1	< 0.10	0.15	<0.1	<0.1	< 0.10	< 0.10	< 0.10
Indenopyrene	µg/L	< 0.1	< 0.1	< 0.10	< 0.10	<0.1	<0.1	< 0.10	< 0.10	< 0.10
Bz(g,h,i)perylene	µg/L	< 0.1	< 0.1	0.14	0.21	0.2	0.2	0.17	0.17	< 0.10
Dibz(a,h)anthracene	µg/L	< 0.1	< 0.1	< 0.10	< 0.10	<0.1	<0.1	< 0.10	< 0.10	< 0.10
C1-Naphthalenes	µg/L	151	144	240.00	240.00	470	480	240	230	230
C2-Naphthalenes	µg/L	95	55	190.0	200.0	180	160	160	170	140
C3-Naphthalenes	µg/L	14	15	78.00	85.00	98	95	70	74	63
C1-Phenanthrenes	µg/L	10	10	50.00	48.00	55	53	37	40	43
C2-Phenanthrenes	µg/L	3	5	22.00	18.00	41	41	42	46	40
C3-Phenanthrenes	µg/L	<1.0	<1.0	13.00	13.00	22	19	21	22	14
Dibenzothiophene	µg/L	<1.0	<1.0	6.00	6.00	7.7	7.3	9.7	11	6.1
C1-Dibenzothiophenes	µg/L	<1.0	<1.0	6.00	6.00	9.1	9.1	10	11	6.4
C2-Dibenzothiophenes	µg/L	<1.0	<1.0	3.00	3.00	11	9.8	2.7	3.1	< 0.10
C3-Dibenzothiophenes	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	< 0.10	< 0.10	< 0.10
Perylene	µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	< 0.10	< 0.10	< 0.10
Biphenyl	µg/L	25	24	37	38	69	71	53	47	48
OTHER										
Ammonia (as N)	mg/L	22	20	22	22	20	20	17	3.8	20
Un-Ionized Ammonia @ 5°C (as N)	mg/L	0.137	0.099	0.172	0.172	0.063	0.063	0.053	0.012	0.099
Un-Ionized Ammonia @ 20°C (as N)	mg/L	0.429	0.311	0.538	0.538	0.198	0.198	0.168	0.038	0.311
Kjeldahl Nitrogen	mg/L	25	18	20	20	20	20	13	7	18
Nitrate + Nitrite (as N)	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
o-Phosphate (as P)	mg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01
pH	units	7.7	7.6	7.8	7.8	7.4	7.4	7.4	7.4	7.6
Total Oil & Grease	mg/L	40	30	20	20	20	20	50	30	20
Total Phosphorus	mg/L	0.08	0.07	0.06	0.06	NA	NA	NA	NA	0.19

RPC ID		73222-01	73222-02	76054-01	76054-02	81265-01	81265-02	84194-1	84194-2	96753-01
Client ID		Produced Water A	Produced Water B	Produced Water A	Produced Water B	Produced Water A	Produced Water B	Produced Water A August 20/08	Produced Water B August 20/08	Produced Water A September 01/09
	Units	August 24/07	August 24/07	November	November	May 27/08	May 27/08			

¹ Identification of these compounds by GC/MSD was based on mass spectra generated from the analysis. These are not 100% positive identifications but rather are probability based matches using a mass spectra database. Quantitation of these analytes is achieved using surrogate alkyl phenol standards.

* A mixture of ring and chain isomers.

RPC ID		96753-02	100606-01	100606-02
Client ID	Units	Produced Water B September 01/09	Produced Water A	Produced Water B
METALS				
Aluminum	µg/L	< 5	19	18
Antimony	µg/L	< 0.5	< 1	< 1
Arsenic	µg/L	< 10	< 10	< 10
Barium	µg/L	146	202	209
Beryllium	µg/L	0.23	0.30	0.30
Boron	µg/L	35600	36200	36200
Cadmium	µg/L	0.07	< 0.02	< 0.02
Calcium	µg/L	726000	770000	759000
Chromium	µg/L	< 5	< 5	< 5
Cobalt	µg/L	< 0.5	< 0.5	< 0.5
Copper	µg/L	< 5	< 5	< 5
Iron	µg/L	4290	5200	5200
Lanthanum	µg/L	< 0.2	< 0.2	< 0.2
Lead	µg/L	0.07	0.92	0.49
Lithium	µg/L	3260	2980	2940
Magnesium	µg/L	245000	296000	289000
Manganese	µg/L	26	35	35
Mercury	µg/L	< 0.025	< 0.025	< 0.025
Molybdenum	µg/L	0.3	< 0.1	< 0.1
Nickel	µg/L	10	< 10	12
Potassium	µg/L	334000	280000	278000
Selenium	µg/L	< 10	< 10	< 10
Silicon	µg/L	29200	30200	29700
Silver	µg/L	< 0.05	< 0.05	< 0.05
Sodium	µg/L	11700000	11200000	10900000
Strontium	µg/L	73000	52200	50800
Sulfur	µg/L	439000	506000	498000
Tellurium	µg/L	< 0.5	< 0.5	< 0.5
Thallium	µg/L	< 5	< 5	< 5
Thorium	µg/L	< 0.05	< 1	< 1
Uranium	µg/L	< 0.1	< 0.1	< 0.1
Vanadium	µg/L	< 0.1	< 2	< 2
Zinc	µg/L	9	5	4
ORGANIC ACIDS				
Acetic Acid	mg/L	506	350	350
Propionic Acid	mg/L	36	27	26
Iso-butyric Acid	mg/L	2.6	< 2.0	< 2.0
Butyric Acid	mg/L	7.6	5.6	5.3
Iso-valeric Acid	mg/L	< 2.0	< 2.0	< 2.0
n-valeric Acid	mg/L	2.0	< 2.0	< 2.0

RPC ID		96753-02	100606-01	100606-02
Client ID	Units	Produced Water B September 01/09	Produced Water A	Produced Water B
HYDROCARBONS - ATLANTIC MUST				
Benzene	mg/L	16	19	20
Toluene	mg/L	8.9	9.8	11
Ethylbenzene	mg/L	0.6	0.5	0.6
Xylenes	mg/L	2.9	2.6	2.9
VPH C6-C10 (Less BTEX)	mg/L	7.3	8.6	9.1
EPH >C10-C21	mg/L	16	6.8	4.7
EPH >C21-C32	mg/L	10	3.2	1.5
Modified TPH Tier 1	mg/L	33	19	15
PHENOLS				
Phenol	µg/L	5200	4700	2600
o-cresol ¹	µg/L	2200	2000	1100
m,p-cresol	µg/L	2300	2700	1500
Total C2 Phenols (ion patterns)	µg/L	2000	800	700
Total C3 Phenols (ion patterns)	µg/L	650	590	540
Total C4 Phenols (ion patterns)	µg/L	140	190	190
Total C5 Phenols (ion patterns) ¹	µg/L	< 20	< 20	< 20
4-n-hexylphenol ¹	µg/L	<10	< 10	< 10
2,5-diisopropylphenol ¹	µg/L	<10	< 10	< 10
2,6-diisopropylphenol	µg/L	<10	< 10	< 10
2-tert-butyl-4-ethylphenol ¹	µg/L	<10	< 10	< 10
6-tert-butyl-2,4-dimethylphenol ¹	µg/L	<10	< 10	< 10
4-n-heptylphenol	µg/L	<10	< 10	< 10
2,6-dimethyl-4-(1,1-dimethylpropyl)phenol ¹	µg/L	<10	< 10	< 10
4-(1-ethyl-1-methylpropyl)-2-methylphenol ¹	µg/L	<10	< 10	< 10
4-n-octylphenol	µg/L	<10	< 10	< 10
4-tert-octylphenol ¹	µg/L	<10	< 10	< 10
2,4-di-sec-butylphenol ¹	µg/L	<10	< 10	< 10
2,6-di-tert-butylphenol ¹	µg/L	<10	< 10	< 10
4-n-nonylphenol*	µg/L	< 20	< 20	< 20
2-methyl-4-tert-octylphenol ¹	µg/L	<10	< 10	< 10
2,6-di-tert-butyl-4-methylphenol ¹	µg/L	<10	< 10	< 10
4,6-di-tert-butyl-2-methylphenol ¹	µg/L	<10	< 10	< 10
RADIONUCLIDES				
Radium-228	Bq/L	1.0	1.1	1.0
Radium-226	Bq/L	< 0.8	0.9	0.8
Lead-210	Bq/L	< 0.9	< 0.2	< 0.2

RPC ID		96753-02	100606-01	100606-02
Client ID	Units	Produced Water B September 01/09	Produced Water A	Produced Water B
PAHS				
Naphthalene	µg/L	300	79	170
Acenaphthylene	µg/L	1	1.2	1.1
Acenaphthene	µg/L	< 3.0	< 3.0	< 3.0
Fluorene	µg/L	25	22	28
Phenanthrene	µg/L	40	32	39
Anthracene	µg/L	< 0.10	< 0.10	< 0.10
Fluoranthene	µg/L	0.87	0.55	0.45
Pyrene	µg/L	1.2	0.70	0.62
Bz(a)anthracene	µg/L	1.2	0.82	0.57
Chrysene/Triphenylene	µg/L	1.0	0.63	0.55
Bz(b)fluoranthene	µg/L	0.15	0.16	0.13
Bz(k)fluoranthene	µg/L	0.15	< 0.10	< 0.10
Bz(e)pyrene	µg/L	< 0.10	0.30	0.23
Bz(a)pyrene	µg/L	< 0.10	< 0.10	< 0.10
Indenopyrene	µg/L	< 0.10	< 0.10	< 0.10
Bz(g,h,i)perylene	µg/L	< 0.10	< 0.10	< 0.10
Dibz(a,h)anthracene	µg/L	< 0.10	< 0.10	< 0.10
C1-Naphthalenes	µg/L	210	410	570
C2-Naphthalenes	µg/L	130	170	220
C3-Naphthalenes	µg/L	56	46	43
C1-Phenanthrenes	µg/L	41	25	22
C2-Phenanthrenes	µg/L	35	16	13
C3-Phenanthrenes	µg/L	13	3.2	2.7
Dibenzothiophene	µg/L	5.4	9.5	9.8
C1-Dibenzothiophenes	µg/L	5.2	5.8	6.1
C2-Dibenzothiophenes	µg/L	< 0.10	1.0	0.91
C3-Dibenzothiophenes	µg/L	< 0.10	< 0.10	< 0.10
Perylene	µg/L	< 0.10	< 0.1	< 0.1
Biphenyl	µg/L	43	47	65
OTHER				
Ammonia (as N)	mg/L	20	18	18
Un-Ionized Ammonia @ 5°C (as N)	mg/L	0.079	NA	NA
Un-Ionized Ammonia @ 20°C (as N)	mg/L	0.248	NA	NA
Kjeldahl Nitrogen	mg/L	21	19	20
Nitrate + Nitrite (as N)	mg/L	< 0.05	< 0.05	< 0.05
o-Phosphate (as P)	mg/L	< 0.01	< 0.01	< 0.01
pH	units	7.5	NA	NA
Total Oil & Grease	mg/L	30	< 20	< 20
Total Phosphorus	mg/L	0.17	0.029	0.30

RPC ID		96753-02	100606-01	100606-02
Client ID	Units	Produced Water B September 01/09	Produced Water A	Produced Water B

¹ Identification of these compounds by GC/MSD was based on the analysis. These are not 100% positive probability based matches using a mass spectra database. Identification of analytes is achieved using surrogate alkyl phenol standards.

* A mixture of ring and chain isomers.

Appendix D

Chemical Characterization of Seawater Samples

BTEX, fuel and lube range hydrocarbons, phenols, PAHs, organic acids, radionuclides, metals, ammonia, inorganic organic carbon, total suspended solids, radioactive tracers and SCW85546 (scale inhibitor)

Variable	Unit	RDL	27-Sur	WQ1-Sur	WQ1-Sur A	WQ2-Sur	1-Sur	8-Sur	16-Sur	23-Sur	WQ3-Sur	WQ4-Sur	WQ3-Mid
Benzene	mg/L	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Toluene	mg/L	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ethylbenzene	mg/L	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Xylenes	mg/L	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
VPH C6-C10 (Less BTEX)	mg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
EPH >C10-C21	mg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
EPH >C21-C32	mg/L	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Modified TPH Tier 1	mg/L	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Phenol	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
o-cresol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
m,p-cresol	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Total C2 Phenols (ion patterns)	µg/L	20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Total C3 Phenols (ion patterns)	µg/L	20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Total C4 Phenols (ion patterns)	µg/L	20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Total C5 Phenols (ion patterns)	µg/L	20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
4-n-hexylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
2,5-diisopropylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
2,6-diisopropylphenol	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
2-tert-butyl-4-ethylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
6-tert-butyl-2,4-dimethylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
4-n-heptylphenol	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
2,6-dimethyl-4-(1,1-dimethylpropyl)phenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
4-(1-ethyl-1-methylpropyl)-2-methylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
4-n-octylphenol	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
4-tert-octylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
2,4-di-sec-butylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
2,6-di-tert-butylphenol	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
4-n-nonylphenol*	µg/L	20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
2-methyl-4-tert-octylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
2,6-di-tert-butyl-4-methylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
4,6-di-tert-butyl-2-methylphenol ¹	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Naphthalene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Acenaphthylene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Acenaphthene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fluorene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Phenanthrene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Anthracene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fluoranthene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

BTEX, fuel and lube range hydrocarbons, phenols, PAHs, organic acids, radionuclides, metals, ammonia, inorganic organic carbon, total suspended solids, radioactive tracers and SCW85546 (scale inhibitor)

Variable	Unit	RDL	27-Sur	WQ1-Sur	WQ1-Sur A	WQ2-Sur	1-Sur	8-Sur	16-Sur	23-Sur	WQ3-Sur	WQ4-Sur	WQ3-Mid
Pyrene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bz(a)anthracene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Chrysene/Triphenylene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bz(b)fluoranthene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bz(k)fluoranthene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bz(e)pyrene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bz(a)pyrene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Indenopyrene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bz(g,h,i)perylene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dibz(a,h)anthracene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
C1-Naphthalenes	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
C2-Naphthalenes	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
C3-Naphthalenes	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
C1-Phenanthrenes	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
C2-Phenanthrenes	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
C3-Phenanthrenes	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Dibenzothiophene	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
C1-Dibenzothiophenes	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
C2-Dibenzothiophenes	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
C3-Dibenzothiophenes	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
1-methylnaphthalene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
2-methylnaphthalene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Perylene	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Biphenyl	µg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Acetic Acid	mg/L	2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Propionic Acid	mg/L	2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Iso-butyric Acid	mg/L	2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Butyric Acid	mg/L	2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Iso-valeric Acid	mg/L	2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
n-valeric Acid	mg/L	2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Radium - 228	Bq/L	0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.1	<0.2	<0.2
Radium - 226	Bq/L	0.6	<1	<1	<0.8	3	<1	<1	2	<0.7	<0.6	<1	<1
Lead - 210	Bq/L	0.7	<2	<1	<1	<1	<1	<1	<0.8	2	<0.7	<1	<1
Aluminum	µg/L	1	< 1	1	2	1	2	8	1	2	1	< 1	1
Antimony	µg/L	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Arsenic	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Barium	µg/L	1	4.1	5.5	4.3	4.7	4.6	4.6	4.7	4.6	4.6	4.9	7.7
Beryllium	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

BTEX, fuel and lube range hydrocarbons, phenols, PAHs, organic acids, radionuclides, metals, ammonia, inorganic organic carbon, total suspended solids, radioactive tracers and SCW85546 (scale inhibitor)

Variable	Unit	RDL	27-Sur	WQ1-Sur	WQ1-Sur A	WQ2-Sur	1-Sur	8-Sur	16-Sur	23-Sur	WQ3-Sur	WQ4-Sur	WQ3-Mid
Boron	µg/L	50	4390	4430	4360	4330	4290	4280	4340	4340	4300	4340	4470
Cadmium	µg/L	0.01	0.02	0.04	0.04	0.02	0.04	0.03	0.04	0.03	0.02	< 0.02	0.07
Calcium	µg/L	50	321000	326000	322000	322000	319000	323000	321000	320000	324000	323000	329000
Chromium	µg/L	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1
Cobalt	µg/L	0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Copper	µg/L	5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Iron	µg/L	5	7	9	5	< 5	< 5	6	< 5	< 5	< 5	< 5	< 5
Lanthanum	µg/L	0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Lead	µg/L	0.02	0.05	0.04	0.06	< 0.02	0.03	0.06	< 0.02	0.19	< 0.02	0.06	< 0.02
Lithium	µg/L	1	137	139	137	149	148	147	152	152	151	133	152
Magnesium	µg/L	10	1270000	1290000	1270000	1250000	1250000	1260000	1270000	1290000	1260000	1260000	1310000
Manganese	µg/L	0.1	0.2	0.8	1.1	0.7	0.7	0.7	0.6	0.7	1.0	0.3	1.1
Mercury	µg/L	0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
Molybdenum	µg/L	0.1	10.6	10.7	10.8	11.1	10.8	10.7	11.1	11.0	11.1	10.9	11.1
Nickel	µg/L	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Potassium	µg/L	20	376000	381000	376000	376000	375000	377000	376000	377000	377000	378000	388000
Selenium	µg/L	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Silver	µg/L	0.02	< 0.02	0.02	0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.03	< 0.02	< 0.02
Sodium	µg/L	50	10800000	10900000	10800000	10600000	10700000	10700000	10800000	10900000	10700000	10600000	11200000
Strontium	µg/L	10	6440	6540	6460	6460	6420	6470	6440	6420	6490	6490	6620
Sulfur	µg/L	100	898000	914000	899000	874000	892000	884000	897000	915000	905000	889000	929000
Tellurium	µg/L	0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Thallium	µg/L	2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Uranium	µg/L	0.1	2.3	2.0	1.9	2.1	2.5	2.3	2.5	2.4	2.3	2.7	2.2
Vanadium	µg/L	0.1	0.8	1.2	1.8	1.6	1.5	1.4	1.8	1.7	2.1	1.4	2.0
Zinc	µg/L	1	< 2	3	8	2	3	3	< 2	2	3	34	4
Ammonia (as N)	mg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.14	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
pH	Units		7.9	7.8	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.8
Un-ionized Ammonia @ 5°C (as N)	mg/L	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Un-ionized Ammonia @ 20°C (as N)	mg/L	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Total Inorganic Carbon (C)	mg/L	0.5	25.9	26.5	26.1	24.6	24.3	25.0	24.7	24.9	24.5	24.5	27.6
Total Organic Carbon (C)	mg/L	0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Suspended Solids	mg/L	0.5	2.0	1.3	2.7	2.5	1.0	0.5	1.4	1.0	1.0	1.4	4.8
Radioactive Tracer T-140a	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-140c	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-158a	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-158b	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-158c	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

BTEX, fuel and lube range hydrocarbons, phenols, PAHs, organic acids, radionuclides, metals, ammonia, inorganic organic carbon, total suspended solids, radioactive tracers and SCW85546 (scale inhibitor)

Variable	Unit	RDL	27-Sur	WQ1-Sur	WQ1-Sur A	WQ2-Sur	1-Sur	8-Sur	16-Sur	23-Sur	WQ3-Sur	WQ4-Sur	WQ3-Mid
Radioactive Tracer T-158d	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-158e	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-176a	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-190a	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-190b	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-190c	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radioactive Tracer T-194a	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
SWC85546	mg/L		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

RDL = Reportable Detection Limit; ND = Not Detected

Sur = Surface; Mid = Mid-depth (40 m)

¹ Identification of these compounds by GC/MSD was based on mass spectra generated from the analysis. These are not 100% positive identifications but rather are probability based matches using a mass spectra database. Quantitation of these analytes is achieved using surrogate alkyl phenol standards.

* A mixture of ring and chain isomers.

Radionuclides, metals, ammonia, total inorganic carbon and total suspended solids

Variable	Unit	RDL	27-Mid	27-Bot	WQ1-Mid	WQ1-Bot	WQ2-Mid	WQ2-Bot	1-Mid	1-Bot	8-Mid	8-Bot	16-Mid	16-Bot
Radium - 228	Bq/L	0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2
Radium - 226	Bq/L	0.6	<1	3	<1	<1	2	<1	<1	<0.6	3	2	<0.9	<0.8
Lead - 210	Bq/L	0.7	3	<1	<1	<1	<1	<1	<1	<0.8	<1	<1	<1	<0.7
Aluminum	µg/L	1	<1	1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
Antimony	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Arsenic	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Barium	µg/L	1	7.0	7.2	7.4	6.5	7.3	6.5	7.3	6.9	7.4	7.0	7.1	6.7
Beryllium	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Boron	µg/L	50	4370	4690	4520	4580	4480	4570	4400	4540	4420	4510	4560	4520
Cadmium	µg/L	0.01	0.03	0.05	0.04	0.06	0.06	0.05	0.05	0.07	0.07	0.06	0.06	0.06
Calcium	µg/L	50	328000	340000	332000	334000	329000	337000	327000	337000	330000	332000	336000	336000
Chromium	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cobalt	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Copper	µg/L	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Iron	µg/L	5	<5	<5	<5	<5	<5	<5	<5	8	<5	13	<5	<5
Lanthanum	µg/L	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Lead	µg/L	0.02	<0.02	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	0.05	<0.02	0.57	0.05	0.06
Lithium	µg/L	1	138	139	138	142	143	152	152	155	156	162	160	172
Magnesium	µg/L	10	1280000	1330000	1300000	1330000	1320000	1310000	1320000	1330000	1290000	1320000	1300000	1340000
Manganese	µg/L	0.1	0.2	0.4	0.7	0.8	0.9	0.6	1.6	2.1	1.8	0.9	0.6	0.7
Mercury	µg/L	0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Molybdenum	µg/L	0.1	11.0	11.4	11.2	11.1	11.2	11.5	11.1	11.2	11.0	11.1	11.1	11.5
Nickel	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Potassium	µg/L	20	384000	396000	386000	393000	385000	394000	383000	392000	384000	389000	391000	392000
Selenium	µg/L	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Silver	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sodium	µg/L	50	10900000	11300000	11000000	11300000	11300000	11100000	11200000	11200000	10900000	11200000	11000000	11300000
Strontium	µg/L	10	6580	6860	6670	6720	6620	6780	6590	6790	6650	6720	6770	6770
Sulfur	µg/L	100	909000	941000	920000	953000	945000	934000	934000	933000	911000	943000	921000	944000
Tellurium	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Thallium	µg/L	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Uranium	µg/L	0.1	2.6	2.6	2.8	2.6	2.5	2.7	2.5	2.3	2.6	3.0	2.9	2.9
Vanadium	µg/L	0.1	1.5	1.3	1.4	1.5	1.6	1.6	1.3	1.8	1.5	1.5	1.5	1.6
Zinc	µg/L	1	<2	3	50	3	3	<2	3	4	4	3	<2	3
Ammonia (as N)	mg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
pH	units		7.9	7.7	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Un-ionized Ammonia @ 5°C (as N)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Radionuclides, metals, ammonia, total inorganic organic carbon and total suspended solids

Variable	Unit	RDL	27-Mid	27-Bot	WQ1-Mid	WQ1-Bot	WQ2-Mid	WQ2-Bot	1-Mid	1-Bot	8-Mid	8-Bot	16-Mid	16-Bot
Un-ionized Ammonia @ 20°C (as N)	mg/L	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Total Inorganic Carbon (C)	mg/L	0.5	26.7	26.3	27.5	26.9	27.3	26.1	26.9	25.8	27.2	26.0	26.0	26.1
Total Organic Carbon (C)	mg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Suspended Solids	mg/L	0.5	4.3	1.1	2.7	1.8	1.8	2.1	5.2	2.1	2.8	1.8	1.3	3

RDL = Reportable Detection Limit; ND = Not Detected

Mid = Mid-depth (40 m); Bot = Bottom

Radionuclides, metals, ammonia, total inorganic organic carbon and total suspended solids

Variable	23-Mid	23-Bot	23-Mid A	WQ3-Bot	WQ4-Mid	WQ4-Bot
Radium - 228	<0.1	<0.2	<0.2	<0.1	<0.2	<0.1
Radium - 226	<0.7	2	2	<1	<0.9	<0.8
Lead - 210	<0.8	<1	2	<1	<0.8	<1
Aluminum	< 1	< 1	3	1	1	< 1
Antimony	< 1	< 1	< 1	< 1	< 1	< 1
Arsenic	< 10	< 10	< 10	< 10	< 10	< 10
Barium	7.7	6.8	8.6	6.6	7.6	6.9
Beryllium	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Boron	4420	4530	4430	4500	4440	4640
Cadmium	0.05	0.06	0.05	0.04	0.06	0.06
Calcium	327000	334000	332000	334000	330000	338000
Chromium	< 1	1	< 1	< 1	< 1	< 1
Cobalt	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Copper	< 5	< 5	< 5	< 5	< 5	< 5
Iron	< 5	< 5	14	< 5	< 5	< 5
Lanthanum	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Lead	0.06	0.18	0.31	0.05	0.05	0.08
Lithium	168	172	167	170	167	172
Magnesium	1280000	1320000	1310000	1340000	1310000	1310000
Manganese	1.0	1.3	0.8	0.9	1.1	1.3
Mercury	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
Molybdenum	11.0	11.3	11.0	11.3	11.2	11.4
Nickel	< 1	< 1	< 1	< 1	< 1	< 1
Potassium	381000	391000	387000	391000	386000	396000
Selenium	< 10	< 10	< 10	< 10	< 10	< 10
Silver	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Sodium	10800000	11300000	11100000	11300000	11000000	11100000
Strontium	6600	6740	6670	6730	6650	6820
Sulfur	893000	938000	927000	948000	926000	924000
Tellurium	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Thallium	< 2	< 2	< 2	< 2	< 2	< 2
Uranium	2.8	2.8	2.8	2.8	2.8	2.7
Vanadium	1.5	1.6	1.1	1.6	1.4	1.8
Zinc	4	4	46	< 2	3	2
Ammonia (as N)	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
pH	7.8	7.7	7.8	7.7	7.7	7.7
Un-Ionized Ammonia @ 5°C (as N)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Radionuclides, metals, ammonia, total inorganic organic carbon and total suspended solids

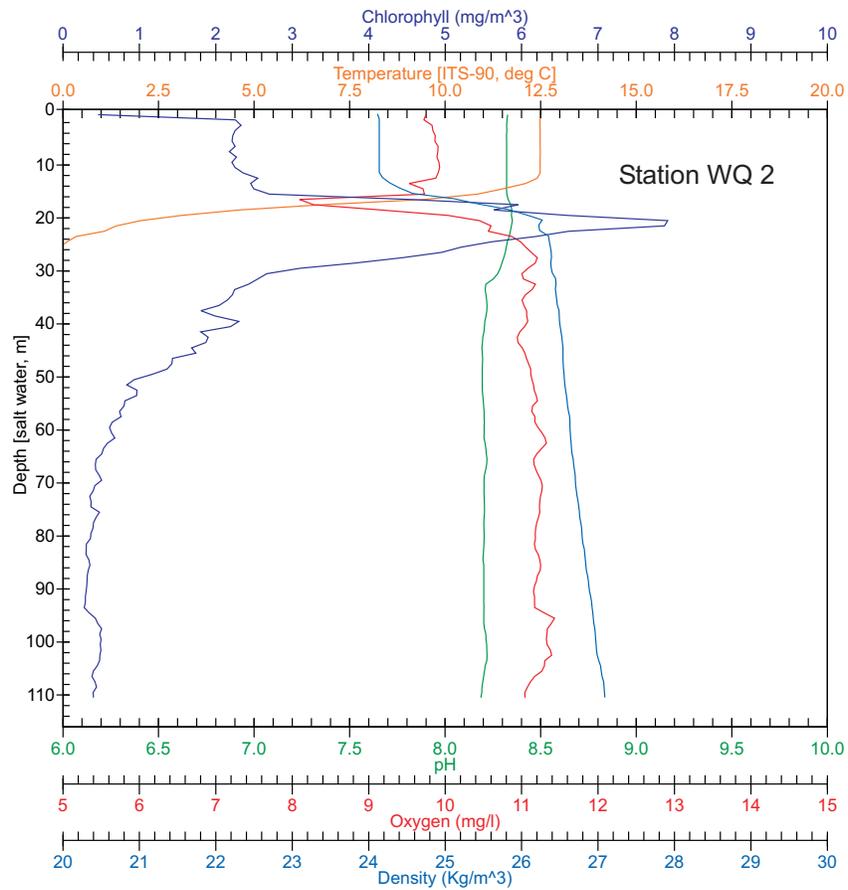
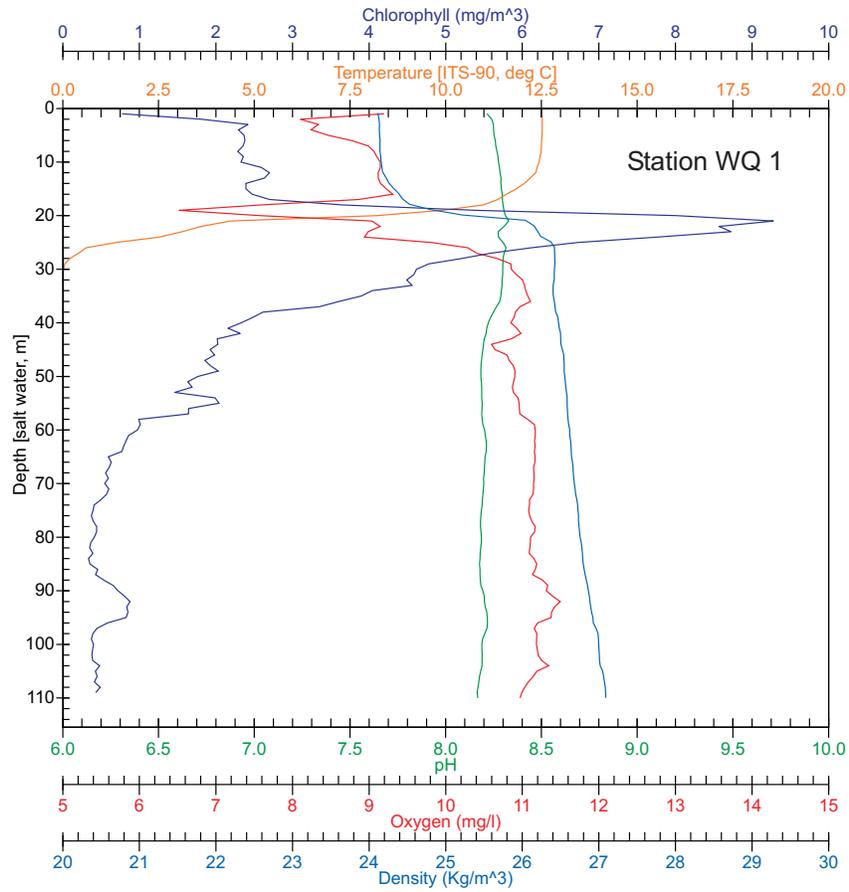
Variable	23-Mid	23-Bot	23-Mid A	WQ3-Bot	WQ4-Mid	WQ4-Bot
Un-ionized Ammonia @ 20°C (as N)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Total Inorganic Carbon (C)	26.2	27.4	26.8	27.3	26.2	25.4
Total Organic Carbon (C)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Suspended Solids	2.9	1.0	1.8	1.2	3.6	1.0

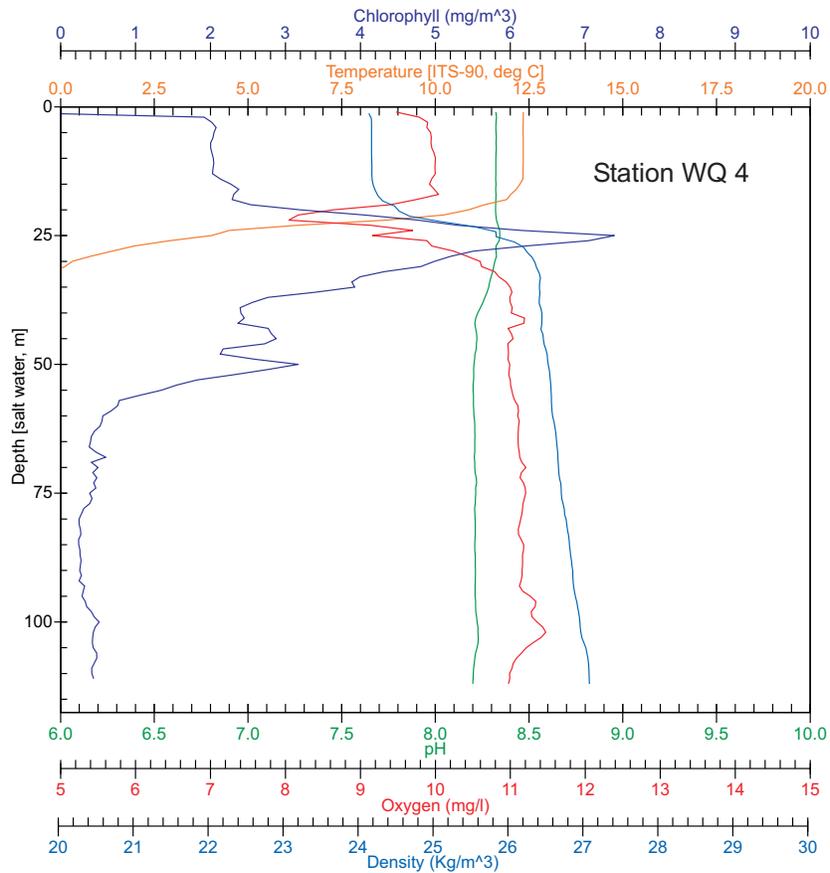
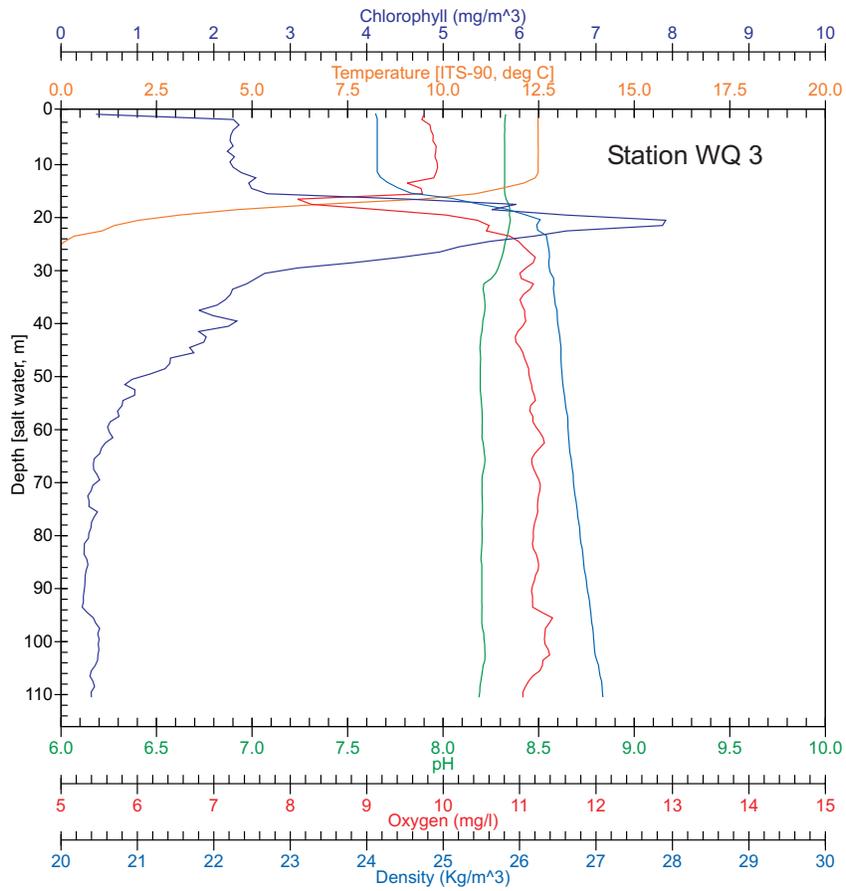
RDL = Reportable Detection Limit; N

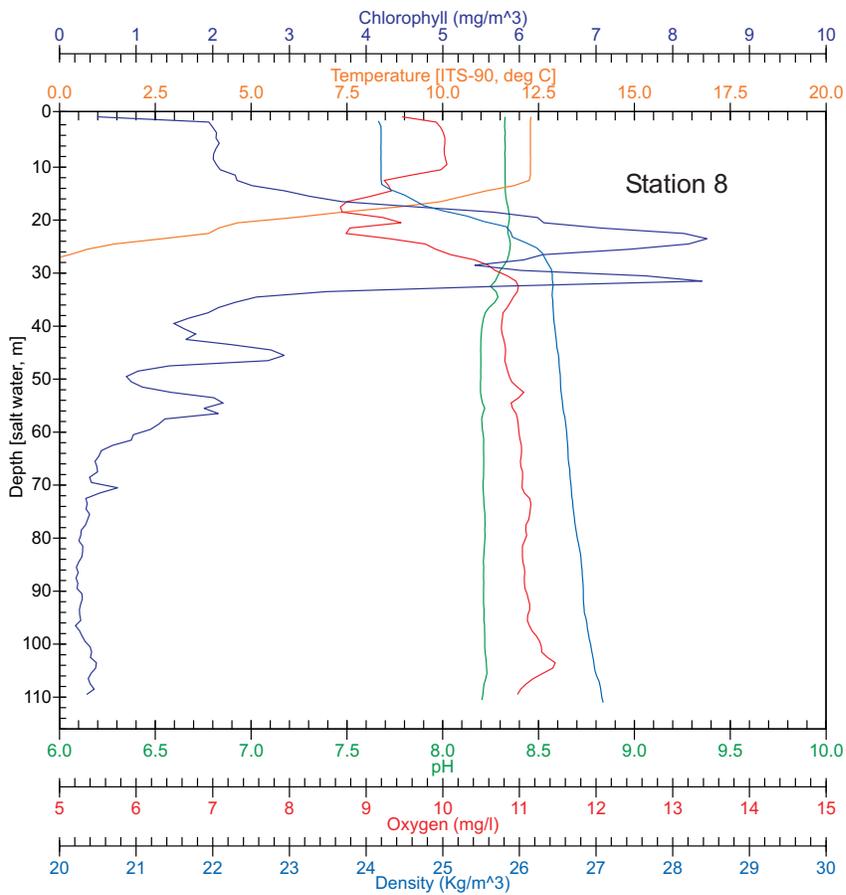
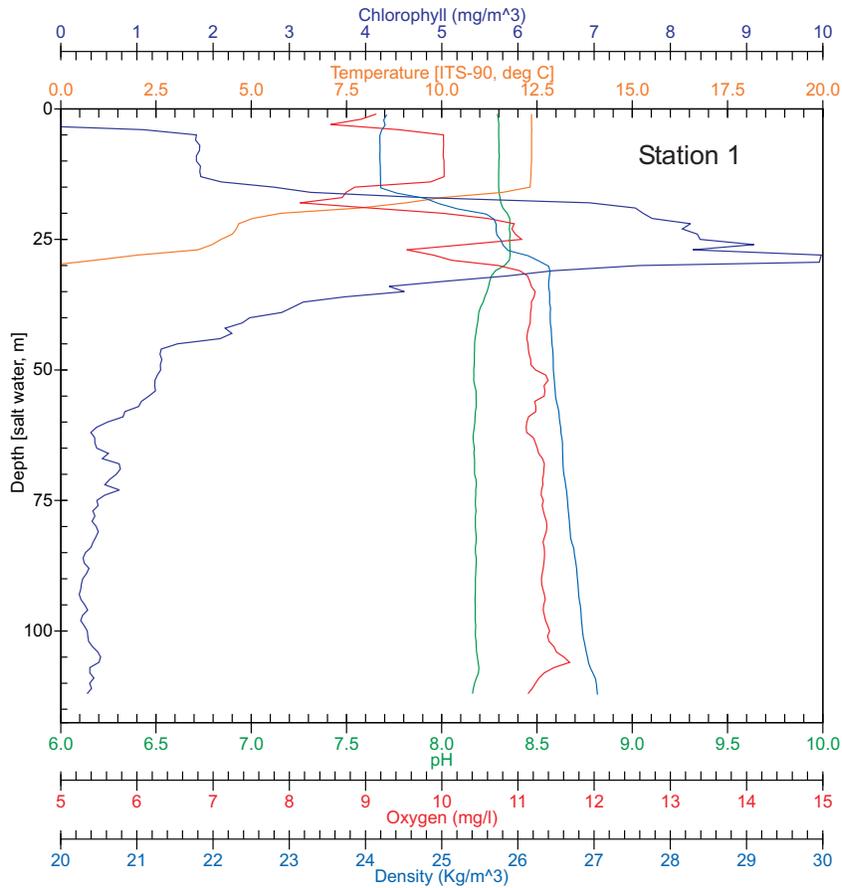
Mid = Mid-depth (40 m); Bot = Bottor

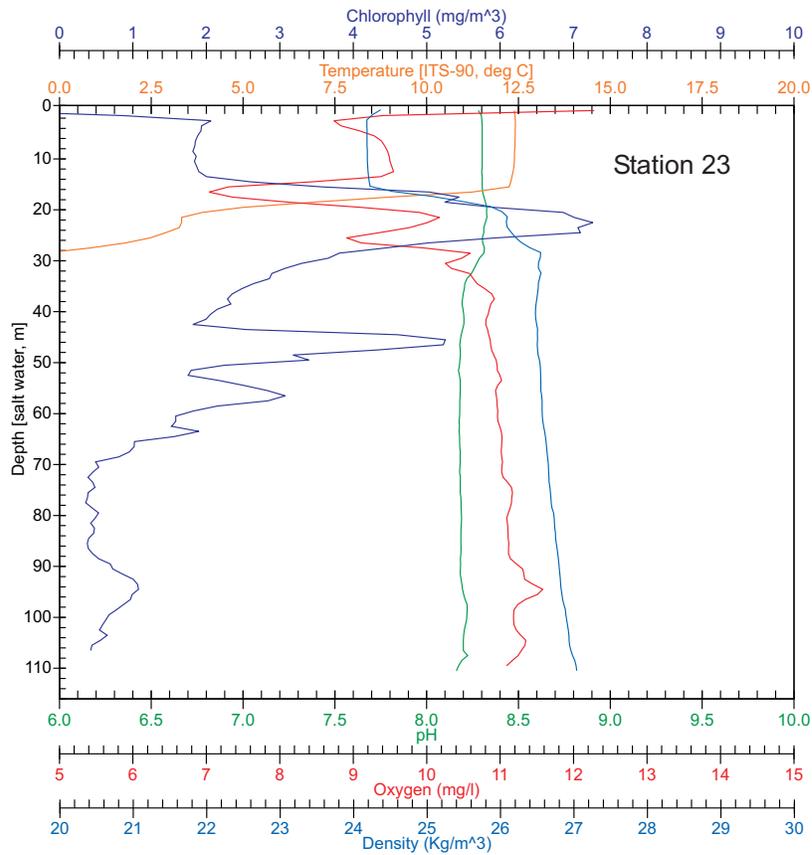
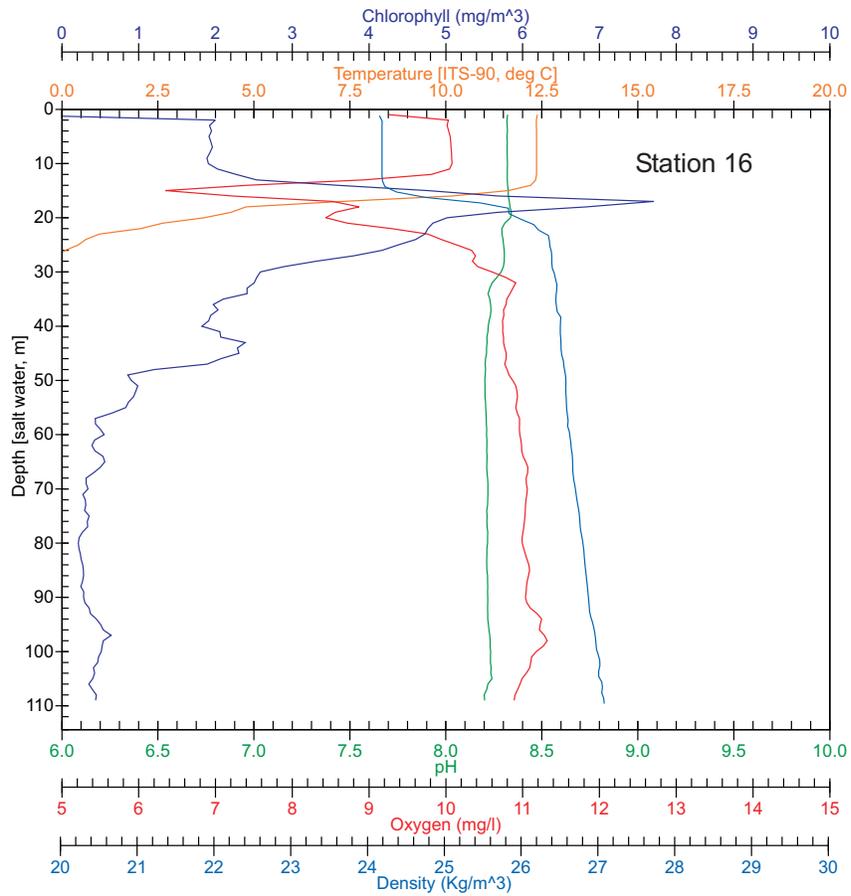
Appendix E

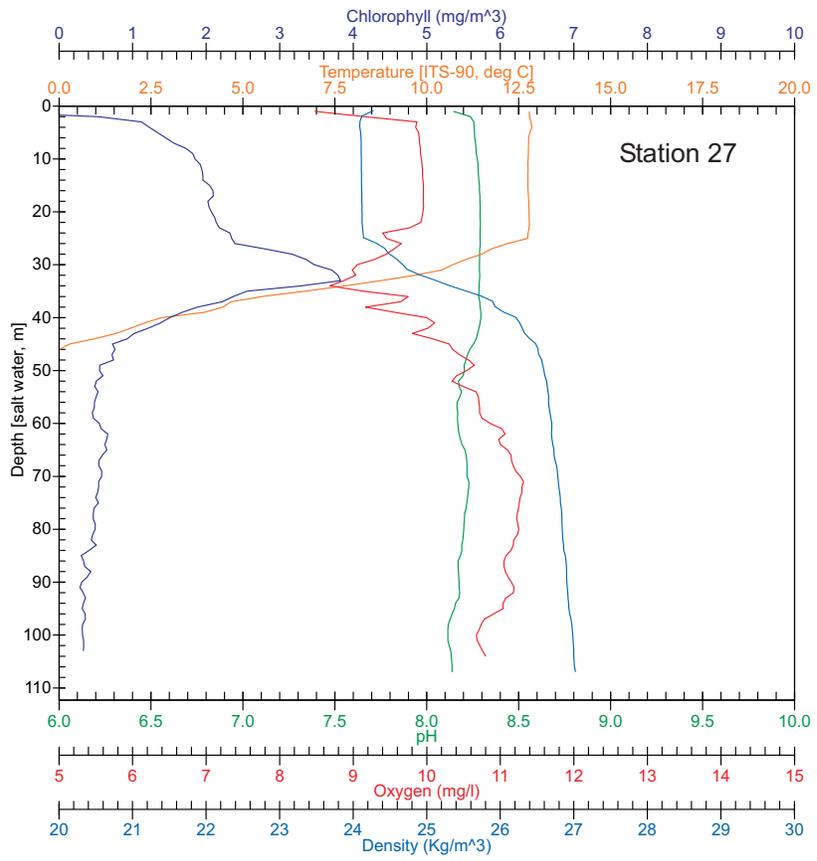
CTD Profiles











Appendix F

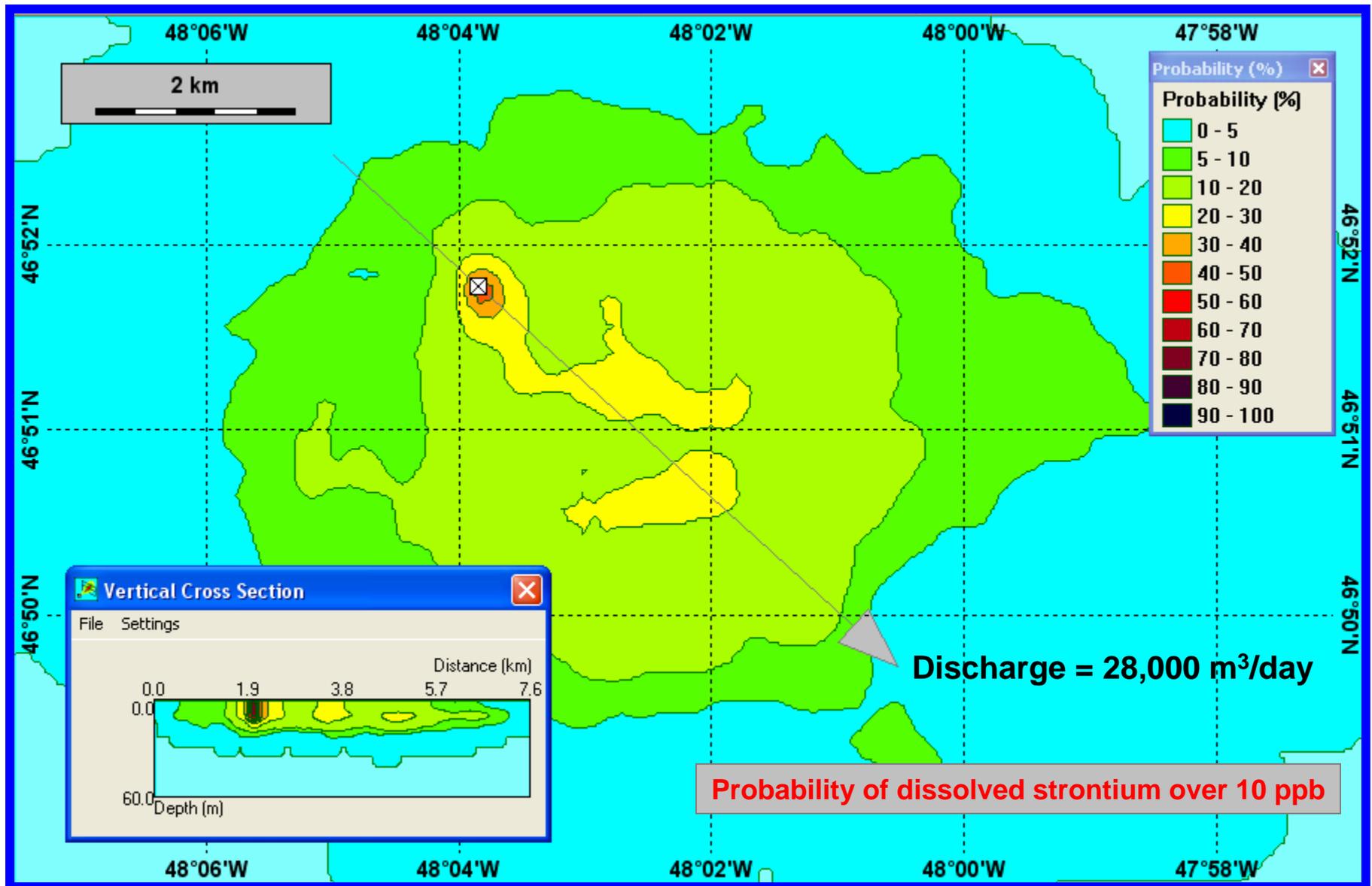
Chemical Characterization of Near-Field Sediment Samples

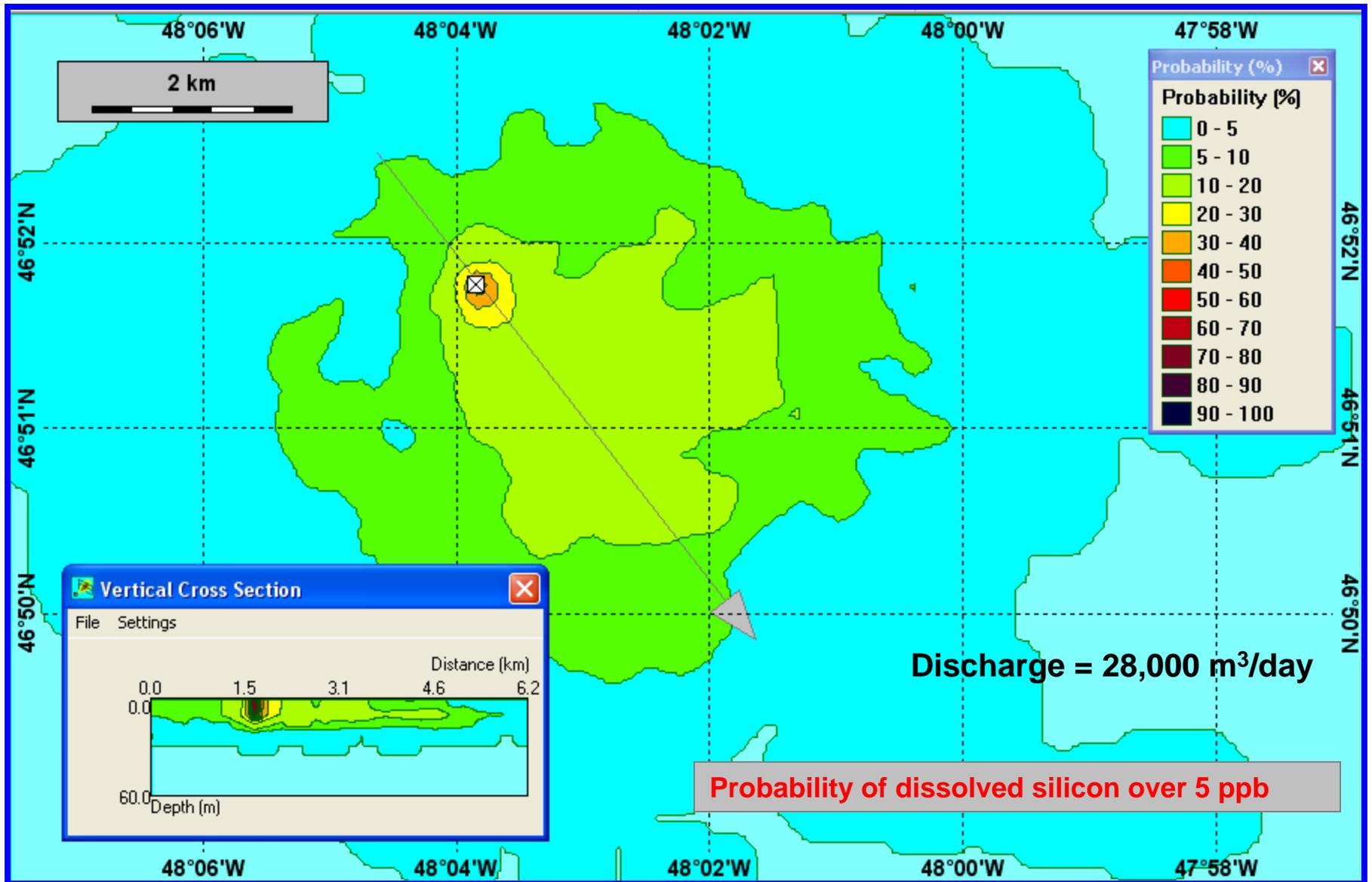
Variable	Units	RDL	WQ1	WQ2	WQ3	WQ4
Ammonia-N	mg/kg	0.3	5.5	7.2	11	6.2
Total Inorganic Carbon (C)	g/kg	0.2	0.3	0.2	<0.2	<0.2
Moisture	%	1	18	17	19	19
Organic Carbon (TOC)	g/kg	0.2	0.7	0.8	1.0	0.9
Total Carbon-combustion IR	g/kg	0.2	1.0	1.0	1.1	1.0
Sulphur (S)	% (wet)	0.01	0.03	0.03	0.04	0.03
Sulphide	ug/g	0.2	0.3	0.6	0.4	0.8
Mercury (Hg)	mg/kg	0.01	<0.01	<0.01	<0.01	<0.01
Total Cadmium (Cd)	mg/kg	0.050	<0.050	<0.050	<0.050	<0.050
Total Aluminium (Al)	mg/kg	10	9100	7400	9300	8800
Total Antimony (Sb)	mg/kg	2.0	<2.0	<2.0	<2.0	<2.0
Total Arsenic (As)	mg/kg	2.0	<2.0	<2.0	<2.0	<2.0
Total Barium (Ba)	mg/kg	5.0	200	160	230	200
Total Beryllium (Be)	mg/kg	2.0	<2.0	<2.0	<2.0	<2.0
Total Cadmium (Cd)	mg/kg	0.15	<0.15	<0.15	<0.15	<0.15
Total Chromium (Cr)	mg/kg	2.0	3.8	3.8	4.8	3.5
Total Cobalt (Co)	mg/kg	1.0	<1.0	<1.0	<1.0	<1.0
Total Copper (Cu)	mg/kg	2.0	<2.0	<2.0	<2.0	<2.0
Total Iron (Fe)	mg/kg	50	1700	1700	2400	1400
Total Lead (Pb)	mg/kg	0.50	2.9	2.6	3.0	2.9
Total Lithium (Li)	mg/kg	2.0	<2.0	<2.0	<2.0	<2.0
Total Manganese (Mn)	mg/kg	2.0	51	53	87	42
Total Molybdenum (Mo)	mg/kg	2.0	<2.0	<2.0	<2.0	<2.0
Total Nickel (Ni)	mg/kg	2.0	<2.0	<2.0	<2.0	<2.0
Total Selenium (Se)	mg/kg	2.0	<2.0	<2.0	<2.0	<2.0
Total Strontium (Sr)	mg/kg	5.0	50	42	51	48
Total Thallium (Tl)	mg/kg	0.10	<0.10	<0.10	<0.10	<0.10
Total Tin (Sn)	mg/kg	2.0	<2.0	<2.0	<2.0	<2.0
Total Uranium (U)	mg/kg	0.10	0.22	0.20	0.28	0.29
Total Vanadium (V)	mg/kg	2.0	6.0	6.2	7.4	5.9
Total Zinc (Zn)	mg/kg	5.0	5.5	6.5	6.7	<5.0
Benzene	mg/kg	0.03	<0.03	<0.03	<0.03	<0.03
Toluene	mg/kg	0.03	<0.03	<0.03	<0.03	<0.03
Ethylbenzene	mg/kg	0.03	<0.03	<0.03	<0.03	<0.03
Xylene (Total)	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
C6 - C10 (less BTEX)	mg/kg	3	<3	<3	<3	<3
>C10-C21 Hydrocarbons	mg/kg	0.3	2.3	2.3	3.3	2.4
>C21-<C32 Hydrocarbons	mg/kg	0.3	0.6	0.8	0.7	0.6
1-Chloronaphthalene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
1-Methylnaphthalene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
2-Chloronaphthalene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
2-Methylnaphthalene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Acenaphthene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Acenaphthylene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Anthracene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Benzo(a)anthracene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Benzo(a)pyrene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Benzo(b)fluoranthene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Benzo(g,h,i)perylene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Benzo(k)fluoranthene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Chrysene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Dibenz(a,h)anthracene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Fluoranthene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Fluorene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Indeno(1,2,3-cd)pyrene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Naphthalene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Perylene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Phenanthrene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05
Pyrene	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05

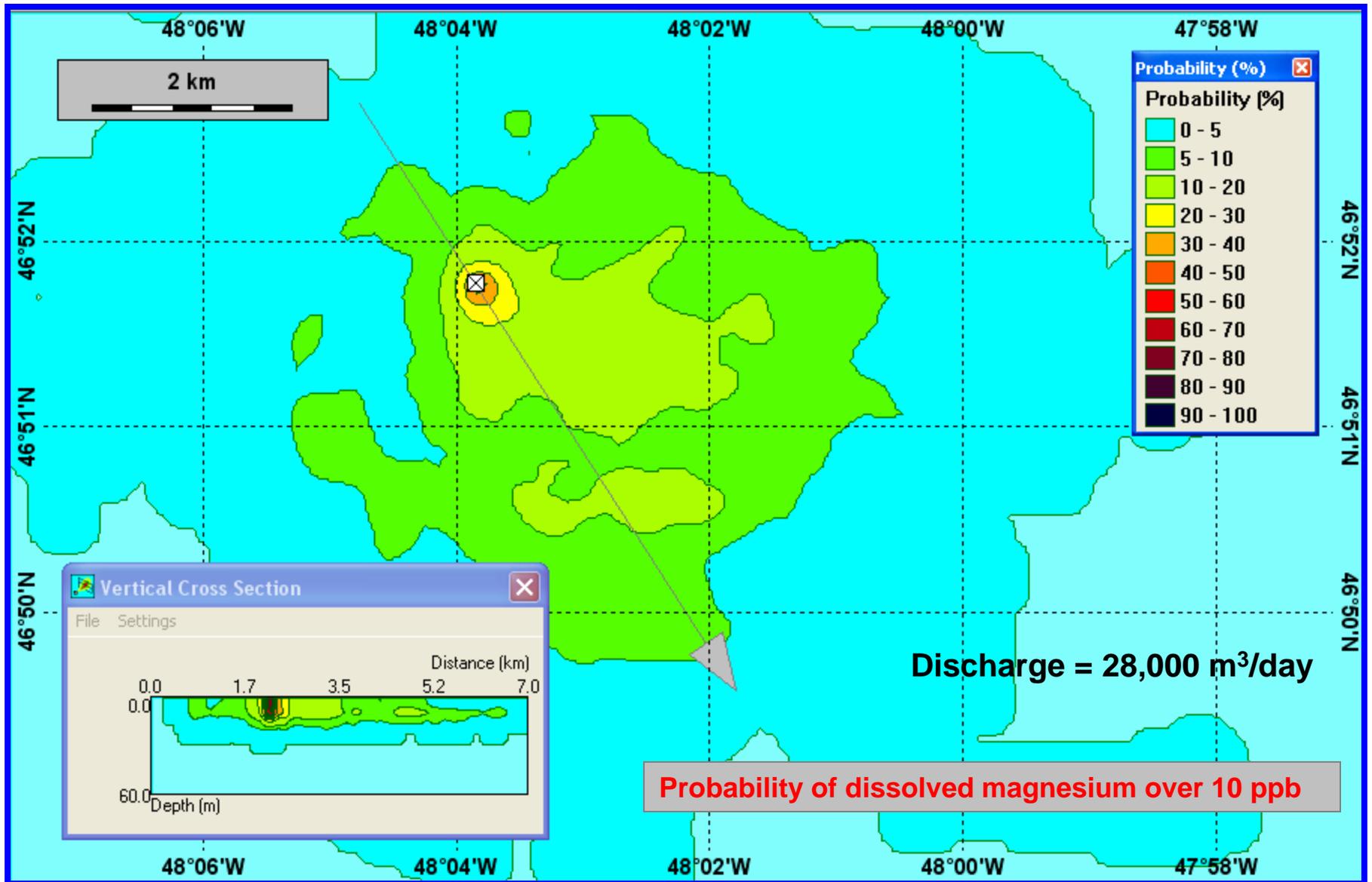
Units are in dry weights unless indicated
RDL = Reportable Detection Limit

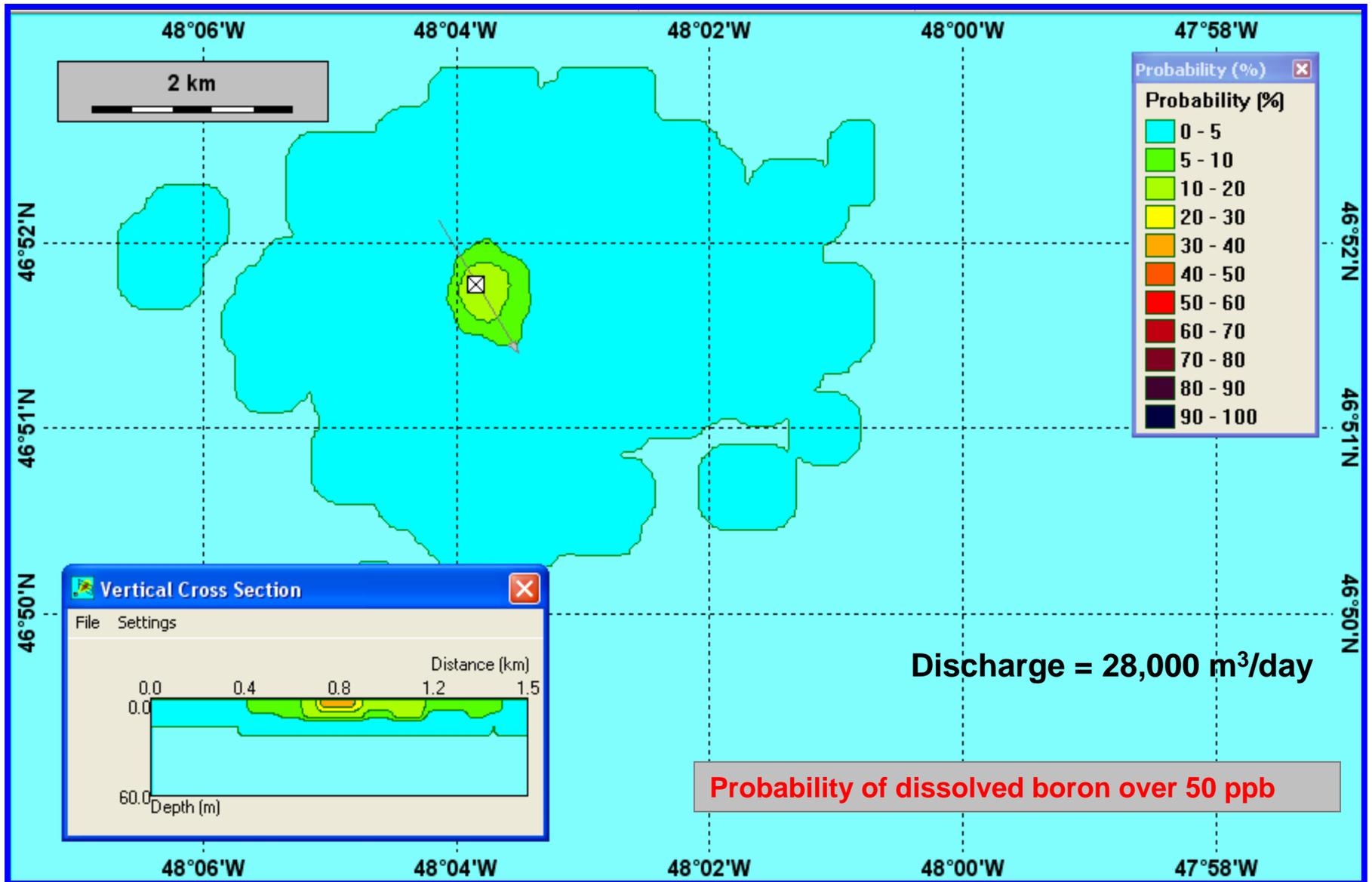
Appendix G

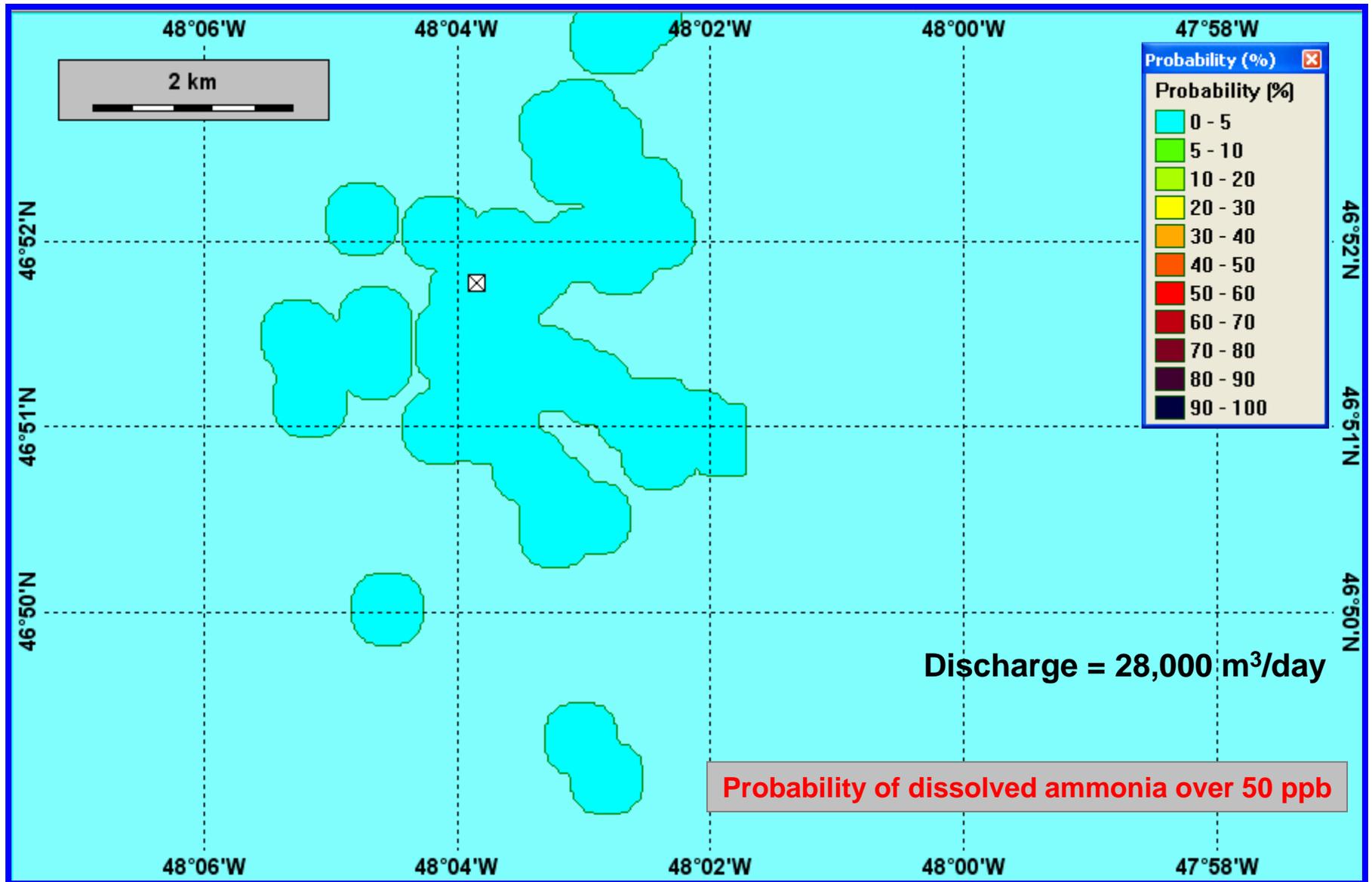
Preliminary Graphics from DREAM Modeling of Constituents in the Water Column

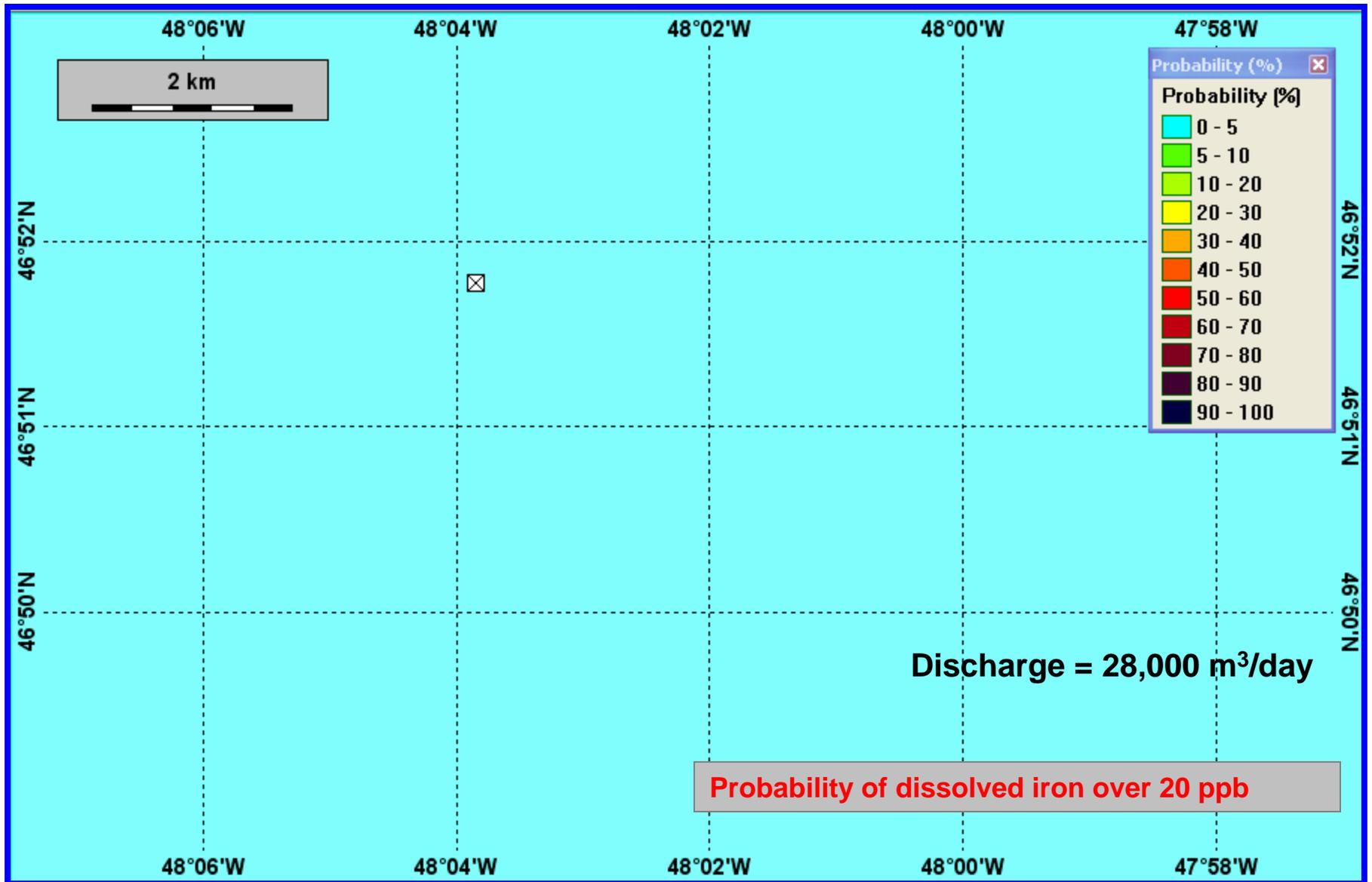


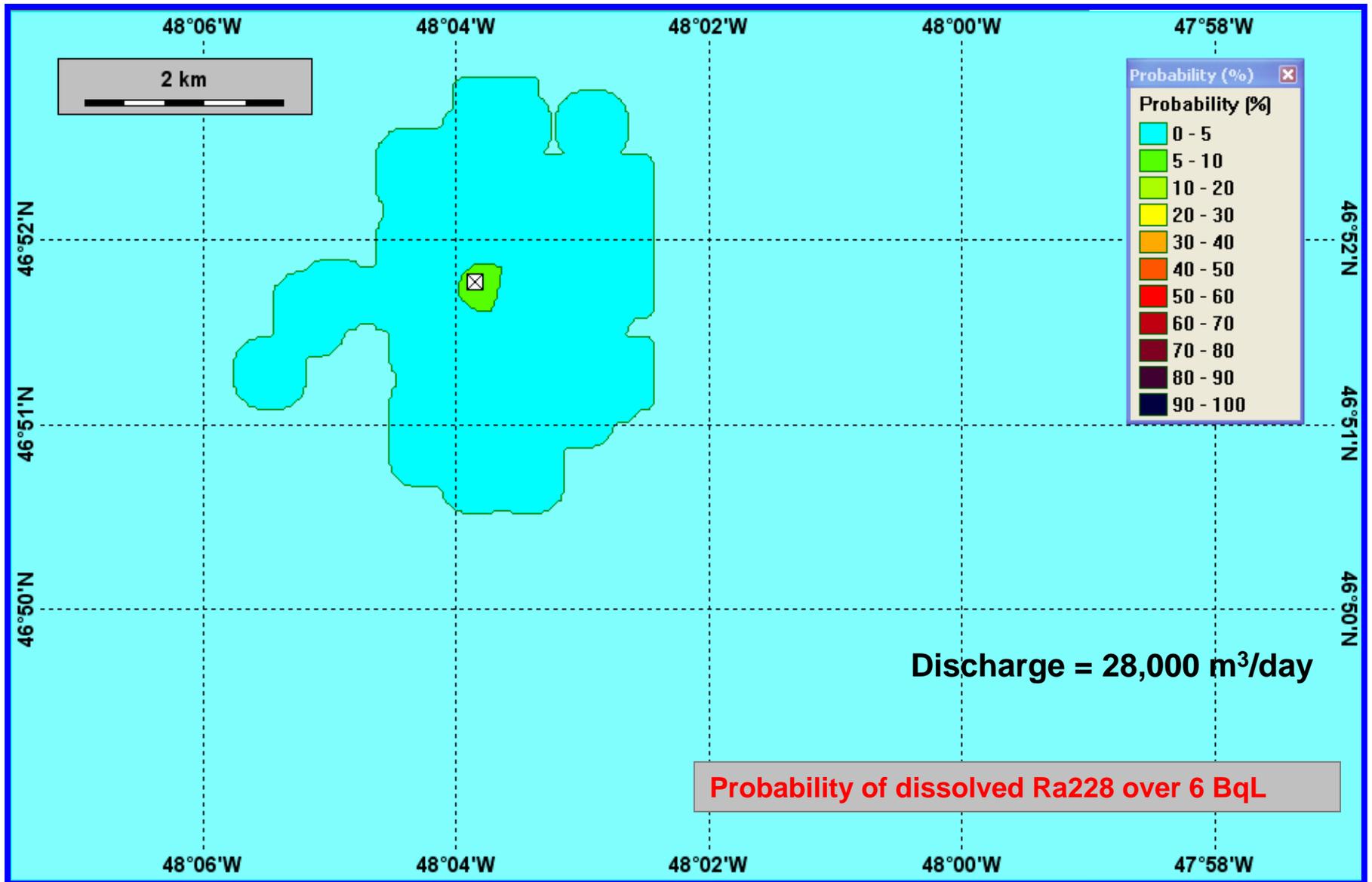


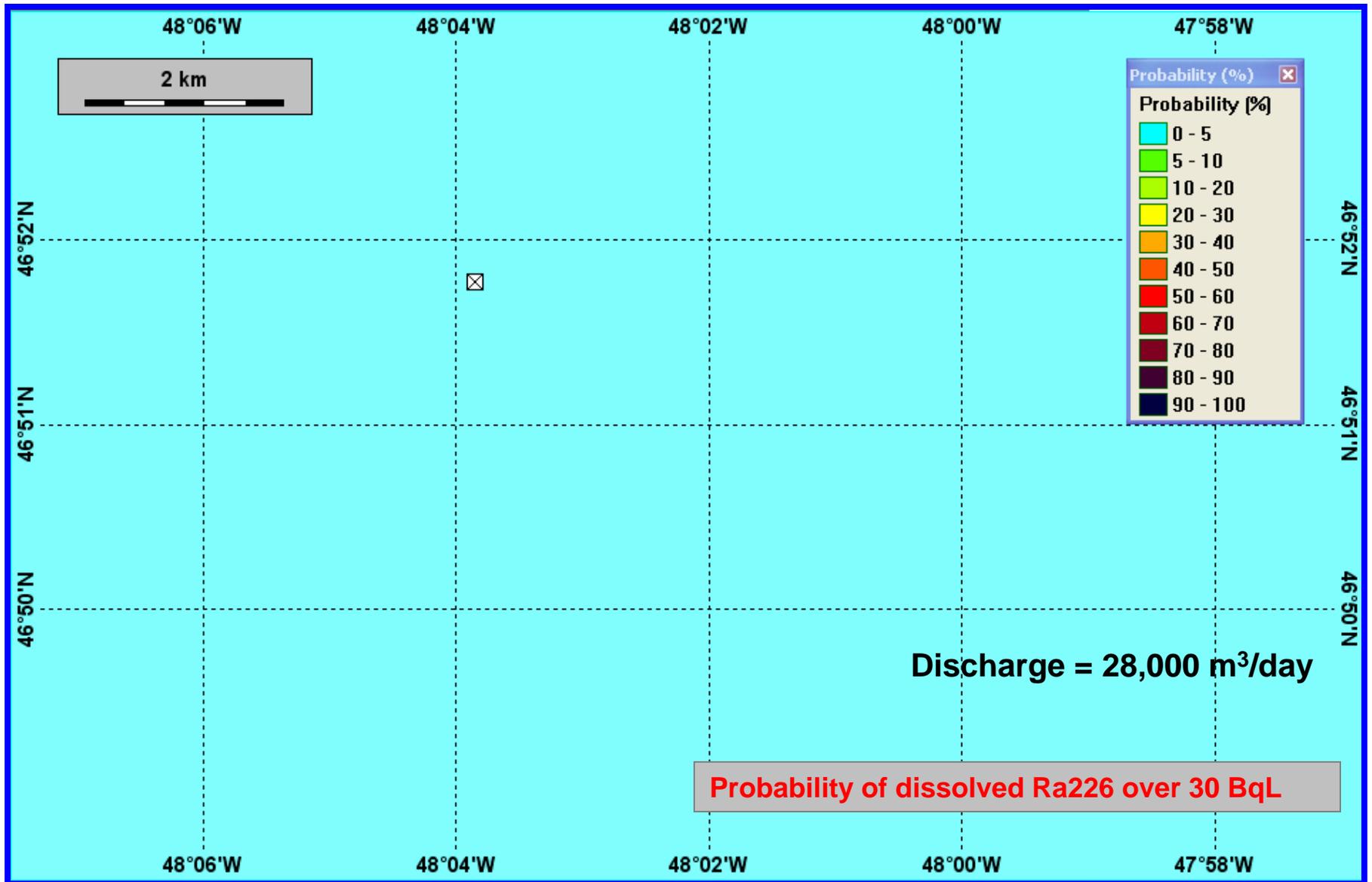


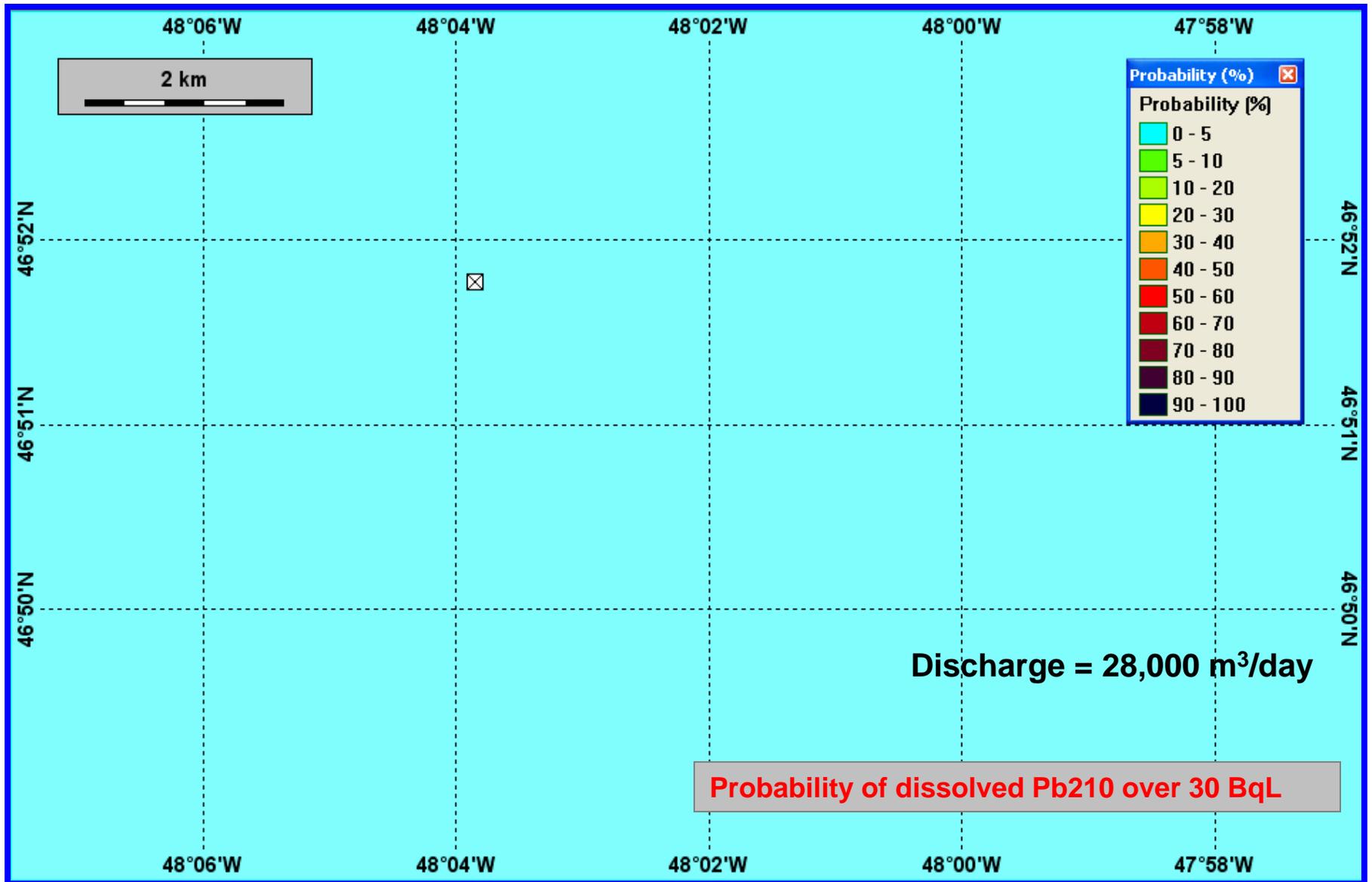












Appendix H

Coordinates for Water Quality Stations for the 2010 Field Program

Station Coordinates for the 2010 Water Sampling Program

Name	Eastings	Northings
WQ1	727495.60	5186218.40
WQ2	727947.20	5186226.60
WQ3	727978.00	5185863.70
WQ4	727608.80	5185748.40
WQ5	727852.26	5186611.35
WQ6	728320.14	5186101.22
WQ7	727991.96	5185487.66
WQ8	727179.29	5185775.61
WQ9	708497.81	5205585.08
WQ10	707497.81	5205585.08
WQ11	707497.81	5206585.08
WQ12	746787.66	5205806.03
WQ13	745787.66	5205806.03
WQ14	745787.66	5206806.03
4	746787.66	5206806.03
8	728457.98	5185685.16
16	727072.34	5185666.32
27	708497.81	5206585.08

Appendix I

Technical Description of Physical-Chemical Fates Components of DREAM

DREAM: a Dose-Related Exposure Assessment Model

Technical Description of Physical-Chemical Fates Components

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Abstract

The 3-dimensional, multiple component pollutant transport, exposure, dose, and effects assessment model DREAM is described. This software tool has been designed to support rational management of environmental risks associated with operational discharges of complex mixtures. Each component in the mixture is described by a set of physical-chemical-toxicological parameters. Because petroleum hydrocarbons constitute a significant fraction of many industrial releases, DREAM incorporates a complete surface slick model, in addition to the processes governing pollutant behavior in the water column.

Exposure, uptake, depuration, and effects for fish and zooplankton are computed simultaneously with the physical-chemical transport and fates. Thus the mass balance can account for the fraction of each chemical component that is associated with biological organisms. This paper describes the physical-chemical fates portion of the model system, and comparisons of model calculations with both analytical solutions and field measurements.

Introduction

The potential for environmental impact from produced water discharges to the North Sea has received increased attention over the past few years because of the increasing discharge volumes and the possible long term (chronic) effects of chemical compounds present in the discharged water. The volume of produced water discharges in the Norwegian sector is about 100 millions m³ per year, approximately 10 percent of the total discharges in the area. The chemical composition of the discharged water is complex, including dispersed oil, dissolved hydrocarbons, organic acids, phenols, metals, and traces of chemicals added in the separation and production

processes. The composition is field-dependent and a number of studies have been performed to characterize produced water from fields in the North Sea (Brendhaug et al, 1992; Tibbets et al, 1992; Reed and Johnsen, 1996).

DREAM (Dose-related Risk and Effects Assessment Model) is a software tool designed to support rational management of environmental risks associated with operational discharges of complex mixtures. The model has seen development over a number of years (Reed, 1989; Reed et al, 1996; French et al, 1996; Johnsen et al, 1998). The present version (2.0) includes exposure, uptake, depuration and effects calculations for fish and zooplankton exposed to complex mixtures of chemicals. Governing physical-chemical processes are accounted for separately for each chemical in the mixture:

- Vertical and horizontal dilution and transport,
- Dissolution from droplet form,
- Volatilization from the dissolved or surface phase,
- Particulate adsorption/desorption and settling,
- Degradation,
- Sedimentation to the sea floor.

The algorithms used in the computations, and verification tests of the resulting code, are discussed in this paper.

General Model Concepts

The model solves the generalized transport equation:

$$\frac{\delta C_i}{\delta t} + \vec{V} \cdot \vec{\nabla} C_i = \vec{\nabla} \cdot D_k \vec{\nabla} C_i + \sum_{j=1}^n r_j C_i + \sum_{j=1}^n \sum_{i=1}^n r_{ij} C_i \quad 1$$

where

- C_i = concentration of the i^{th} chemical constituent in the release,
- t = time,
- \vec{V} = advective transport vector,
- $\vec{\nabla}$ = gradient operator,
- D_k = turbulent dispersion coefficient in $k = x, y, z$ directions.

The first term on the left-hand side of Equation 1 is the temporal rate of change of the concentration of a particular constituent at a particular spatial location. This rate of change is computed by solving the other terms in Equation 1 using Lagrangian particles to represent the concentration field. The terms r_j are process rates, including

- addition of mass from continuous release,
- evaporation from surface slicks,
- spreading of surface slicks,
- emulsification of surface slicks,
- deposition from water surface onto coastline (beaching),
- entrainment and dissolution into the water column,
- resurfacing of entrained oil,
- volatilization from water column,
- dissolution from sediments to water column,
- deposition from water column to bottom sediments,
- removal from coastline to water column/water surface,
- mass removal by cleanup.

The degradation terms Γ_{ij} appear in the model to track degradation by-products as transfer of mass from one component to another. Changing toxicological properties are in this way retained in the model.

Chemical concentrations in the water column are computed from the time- and space-variable distribution of pseudo-Lagrangian particles. These particles are of two types, those representing dissolved substances, and those representing oil droplets or other particles with non-neutral buoyancy. These latter particles are pseudo-Lagrangian in that they do not move strictly with the currents, but may rise or settle according to their physical characteristics.

Each mathematical particle represents conceptually a Gaussian cloud (or “puff”) of dissolved chemicals, droplets, or sinking particles, as described for example by Csanady (1973). Concentration fields are built up in the model from the superposition of all of these clouds of contaminants. Each cloud consists of an ellipsoid with a particle at its center, and semi-axes a function of the time-history of the particle. (Ellipsoids encountering boundaries are truncated, with mass being conserved through reflection from the boundary, sorption to the boundary, or some combination of the two.)

Particles representing dissolved substances carry with them the following attributes:

x , y , and z spatial coordinates,
 mass of each chemical constituent represented by the particle,
 distance to and identity of the nearest neighbor particle,
 time since release,
 spatial standard deviations in x , y , and z .

Particles representing non-dissolved substances, such as oil droplets or drill muds or cuttings, carry two additional attributes:

- mean droplet diameter,
- droplet density.

The standard deviations σ_i are computed simply as (Csanady, 1973):

$$\sigma_i = \sqrt{2K_i t}, \quad 2$$

where i represents the x , y , or z direction, t is time since release, and K_i is a turbulent dispersion coefficient.

Concentrations are computed within one of three user-specified three-dimensional grid systems. The first is a translating, expanding grid that follows the evolution of a release, thus providing higher resolution during the early stages, and lower resolution as time progresses. The second is a fixed grid, with resolution defined by the user. The third is a grid with fixed horizontal resolution, but time-variable vertical resolution. This latter grid is useful, for example, in resolving surface releases of oil, in which the near-surface vertical evolution may be of particular interest.

As mentioned earlier, the position of each particle locates the center of a moving, spreading ellipsoidal cloud, with axes a function of the time-history of the particle. The theoretical distribution of mass within the ellipsoid is Gaussian, with standard deviations in x , y , and z directions given by Equation 2. Each such ellipsoid will typically contribute mass to many cells in

the concentration field, and neighboring ellipsoids will typically overlap spatially. Thus a given cell in the concentration field will in general contain a concentration resulting from the presence of multiple nearby particle clouds. This hybrid numerical – analytic scheme removes much of the dependence of the computed concentration field on both the number of particles and the resolution of the physical 3-dimensional grid.

Definition of the Physical Environment

Coastline

The model performs physical transport computations within a user-defined rectangular grid of arbitrary resolution, limited by the spatial resolution of the underlying map or nautical chart data. Unless otherwise specified, the coastal data supplied with the model has a resolution of approximately 1 km. The dataset is derived from the United States Defense Mapping Agency’s digital chart of the world (DCW) database. (See the internet site <http://www.nlh.no/ikf/gis/dcw/> for details, downloads, and associated links.)

An example land-water and bathymetric grid is shown in Figure 1. The grid is about 90 km north-south, and 120 km east-west. This particular grid was specified to be 100 cells in both directions, such that each cell is 0.9 km north-south, and 1.2 km east-west.

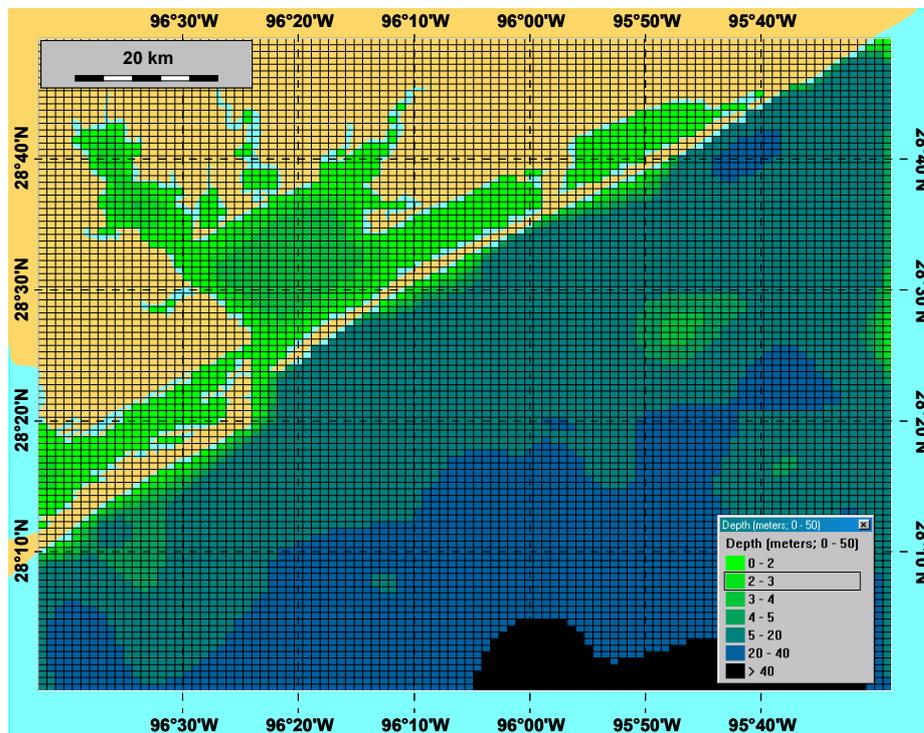


Figure 1 Example rectangular grid used to define the simulated physical environment. This grid, which displays the bathymetry, is about 90 km north-south, and 120 km east-west. This particular grid was specified to be 100 cells in both directions, such that each cell is about 0.9 km north-south, and 1.2 km east-west.

Bathymetry

Bathymetry is defined by one or more gridded datasets, stored in a database supplied with the model. This database is equipped with import filters for specified data formats, as described in the Appendix to the Users Manual. The dataset supplied with the model, SeaTopo 6.2, covers from 72 degrees S to 72 degrees N latitude, provides a resolution of 3 to 10 km, and is based on a combination of satellite altimetry and ship soundings (Smith and Sandwell, 1994, 1997; http://topex.ucsd.edu/marine_topo/mar_topo.html). Figure 2 presents example bathymetric grids based on this dataset.

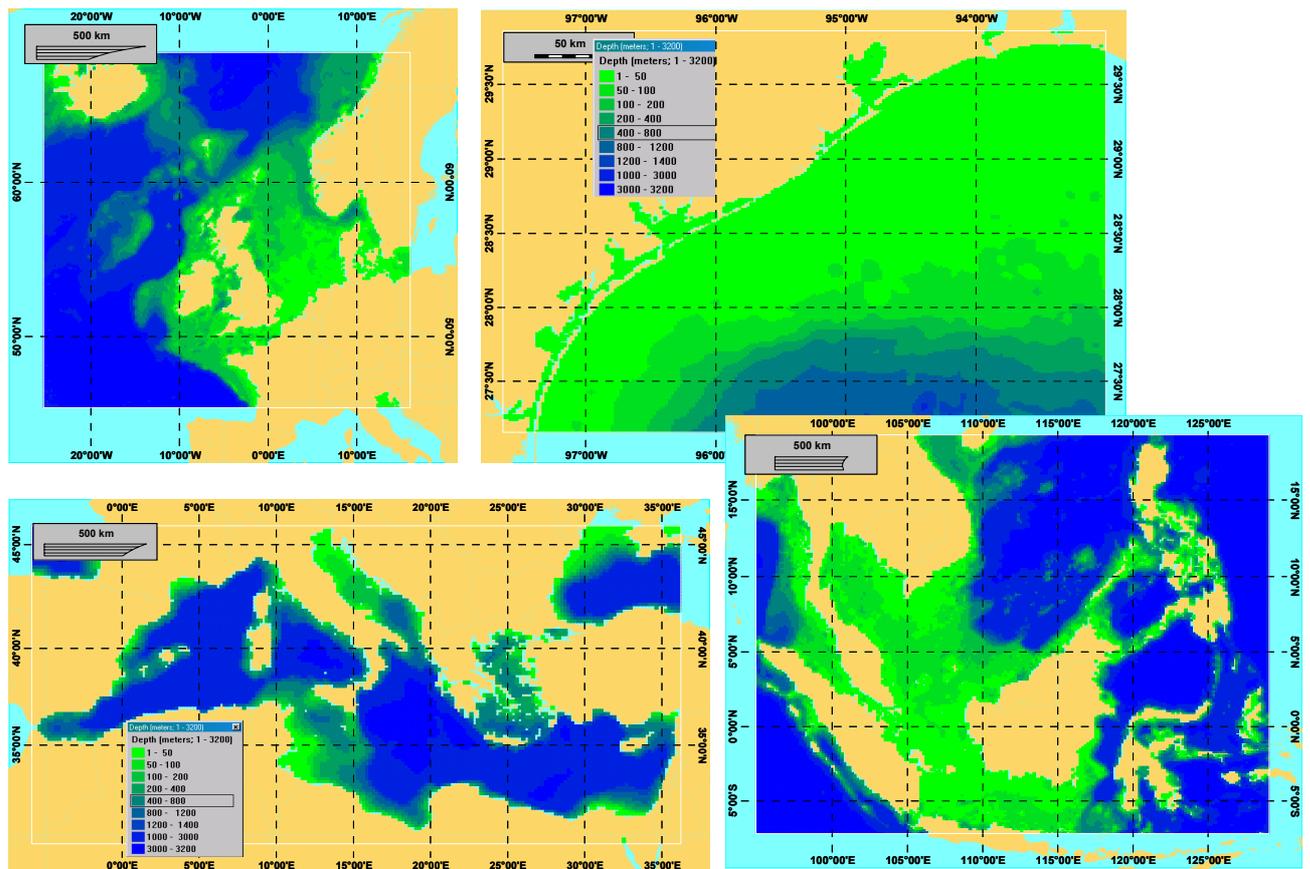


Figure 2 Example bathymetric grids produced from the SeaTopo 6.2 data set: (a) Northeast Atlantic, (b) Northwest Gulf of Mexico, (c) Mediterranean Sea, (d) Gulf of Thailand.

Winds

This version (2.0) of the model is run with a wind time series defined at a single point, in which case the model assumes a spatially uniform wind field. It is also possible to run the model (versions after 2.0) with time series from arbitrarily spaced stations or gridded wind fields, in which case a linearly interpolated wind vector is applied. Input winds are assumed by the model to be measured at 10 m over the sea surface. Otherwise the correction

$$U_{10m} = U_z (10/z)^{1/7}$$

3

where z is the height in meters of the measurement, may be applied to the time series.

Currents

The model will run with either two- or three-dimensional current fields. Two-dimensional fields may be either steady or time varying, supplied from hydrodynamic models or estimated by the user from local knowledge or current atlases. Three-dimensional time-varying fields from hydrodynamic models can be imported for selected formats. Linear interpolation in space is applied to derive the current vector at a given spatial position. No interpolation in time is applied.

Waves

Equations 2 and 3 are used to compute wave height (H) and period (T) as functions of wind speed (U), water depth (d), fetch (F), and gravitational acceleration (g). These equations are taken from the U.S. Army Corps of Engineers Shore Protection Manual (1984).

$$\frac{gH}{U_A^2} = 0.283 \tanh \left[0.530 \left(\frac{gd}{U_A^2} \right)^{3/4} \right] \tanh \left\{ \frac{0.00565 \left(\frac{gF}{U_A^2} \right)^{1/2}}{\tanh \left[0.530 \left(\frac{gd}{U_A^2} \right)^{3/4} \right]} \right\} \quad 4$$

$$\frac{gT}{U_A} = 7.54 \tanh \left[0.833 \left(\frac{gd}{U_A^2} \right)^{3/8} \right] \tanh \left\{ \frac{0.0379 \left(\frac{gF}{U_A^2} \right)^{1/3}}{\tanh \left[0.833 \left(\frac{gd}{U_A^2} \right)^{3/8} \right]} \right\} \quad 5$$

Local depth and fetch are determined in the model from the grid data. At an open grid boundary, a fetch of 100 km (i.e. virtually non-limiting) is assumed.

Wave height and period are computed and stored on a rectangular grid matching that used to define land and water. On start-up, a set of four fetch grids is computed and stored, one grid for each major compass point. (A direction variance of $\pm 45^\circ$ is used to select the appropriate fetch grid.) At each change in the wind speed or direction, a new pair of wave height and period grids is calculated. This procedure allows for variations in wave height due to changes in fetch, such that “shadows” downwind of islands are achieved. However, the approach does not include wave shoaling, diffraction, reflection, or wave-current interactions.

Physical-Chemical Fates Processes

Processes governing the behavior of pollutants in **DREAM** are presented in Figure 3. **DREAM** employs surface oil spill model algorithms to simulate the behavior and fates of surface slicks. Such slicks can occur in the model as the result of rising oil droplets, or if oil is released at the air-water interface. In the water column, horizontal and vertical advection and dispersion of entrained and dissolved hydrocarbons are simulated by random walk procedures. Vertical turbulence is a function of wind speed (wave height) and depth; horizontal turbulence is a function of the age of a pollutant 'cloud'. Pollutants near the sea surface may evaporate to the atmosphere. Partitioning between particulate-adsorbed and dissolved states is calculated based on linear equilibrium theory. The contaminant fraction that is adsorbed to suspended particulate matter settles with ambient particles. Contaminants at the bottom are mixed into the underlying sediments, and may dissolve back into the water. Degradation in water and sediments is represented as a first order decay process, with the possibility of producing intermediate metabolites. Results of model simulations are stored at discrete time-steps in data files for subsequent viewing and analysis.

For spilled oil, processes such as advection, spreading, entrainment and vertical mixing in the water column are not directly dependent on oil composition, although all tend to be linked through macro-characteristics such as viscosity and density. Other processes, such as evaporation, dissolution, and degradation are directly dependent on oil composition. Both types of process are described here.

Advection and Dispersion

Advection is simulated as the superposition of a mean local velocity plus a random turbulent component. The mean local velocity is in general the sum of climatological, tidal, and wind-driven plus wave-driven (Stokes) components. In many cases, these components must be composed by the user for a specific location and time. In the best of cases, full 3-dimensional hydrodynamic modeling data is available, driven by reliable atmospheric and oceanic boundary conditions.

Advection in the water column is performed as the simple vector sum of the spatially interpolated local components, plus a random component representing environmental turbulence. A turbulent component w' is computed as

$$w' = \sqrt{6K/\Delta t},$$

6

for the turbulent dispersion coefficient K estimated for horizontal or vertical directions, as appropriate.

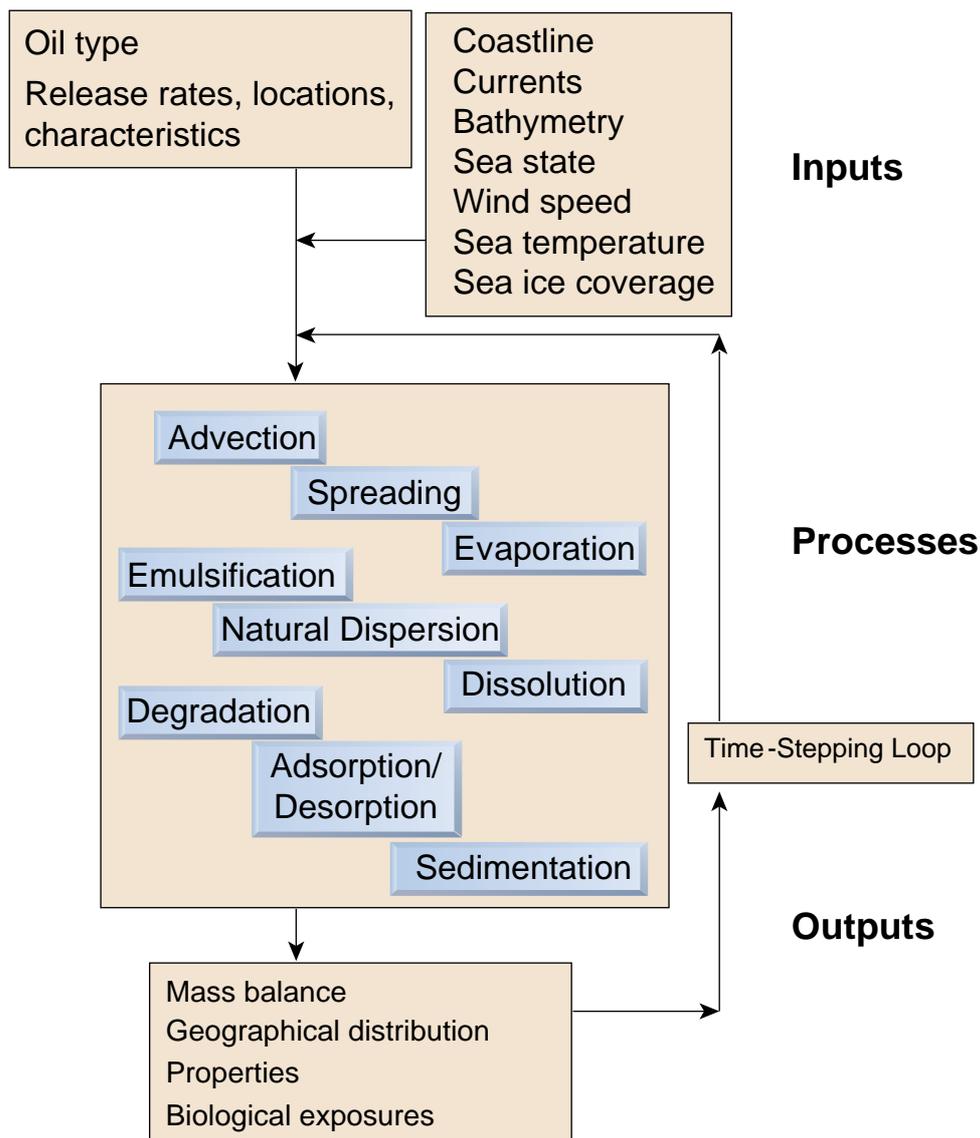


Figure 3 General layout of the DREAM model.

The horizontal dispersion coefficient can be approximated from data on dye diffusion studies reported by Okubo (1971, 1974) as reviewed by Bowden (1983):

$$K_x = 0.0027 t^{1.34}$$

7

for K in cm^2/sec and time t in seconds. As the variance of a cloud increases, the cloud is dispersed by turbulence associated with increasingly larger spatial scales, such that the apparent dispersion coefficient increases with time. Kullenberg (1982) points out that the data supports a maximum at about $10^6 \text{ cm}^2/\text{s}$, or $100 \text{ m}^2/\text{day}$. This maximum is applied here.

If the model is run with input from a 3-dimensional hydrodynamic model in which the horizontal and vertical dispersion coefficients are computed, these values can be used in place of the more generalized approach described above.

The vertical turbulent diffusion coefficient above the pycnocline is related to the wave conditions following Ichiye (1967):

$$K_z = 0.028 \frac{H^2}{T} \exp(-2kz) \quad 8$$

where H is the wave height, T is the wave period and k is the wave number. Below the pycnocline depth, K_z is assumed to be a constant equal to $10^{-4} \text{ m}^2/\text{s}$ (Kullenberg, 1984). In the absence of a pycnocline (e.g. winter conditions in the southern North Sea), the Ichiye equation is assumed to apply from surface to bottom.

The vertical displacement of oil droplets or sinking particles is computed as the superposition of the random turbulent velocity and a rise (or settling) velocity. The differential vertical velocity is computed using the harmonic mean of two extremes, since the drag coefficient is a function of the Reynolds number (Johansen, 2000):

$$w_{\text{rise}} = 1 / (w_1^{-1} + w_2^{-1}), \text{ combined solution, composed of} \quad 9$$

$$w_1 = d^2 g' / 18 \nu, \text{ (for Reynolds number} < 1000), \text{ and} \quad 10$$

$$w_2 = \sqrt{3d|g'|}, \text{ (for Reynolds number} > 1000), \quad 11$$

where

$$g' = g(\rho_\alpha - \rho_o) / \rho_\alpha$$

g = gravitational acceleration

ν = kinematic viscosity of water ($\sim 1 \times 10^{-6} \text{ m}^2/\text{s}$)

In the absence of hydrodynamic model data, the model computes a wind-driven flow in the surface mixed layer (i.e., above the pycnocline). This wind-driven, or Ekman, transport is summed with the background and tidal current vectors entered by the user to calculate the total current. To define the wind-driven transport, the Navier-Stokes equations are simplified by assuming homogeneity in the water in the wind-driven mixed layer, by neglecting the surface slope and land boundaries, and using a constant (local) value for the Coriolis parameter (Ekman, 1905). Averaging the equations of motion over a mixed layer depth, H , gives,

$$\frac{du}{dt} = fV + \frac{\tau_{xs}}{\rho_w H} - \frac{\tau_{xH}}{\rho_w H} \quad 12$$

and

$$\frac{dv}{dt} = -fu + \frac{\tau_{ys}}{\rho_w H} - \frac{\tau_{yH}}{\rho_w H} \quad 13$$

The variable f is the Coriolis parameter, defined as $2 \Omega \sin(\phi)$, where ϕ is the local latitude, and ω is the earth's rate of rotation. H is taken to be the minimum of 25 m and the depth of the pycnocline. The surface stress terms are related to the wind velocities U and V in quadratic form by

$$\tau_{xs} = \rho_a C_d U (U^2 + V^2)^{1/2} \quad 14$$

$$\tau_{ys} = \rho_a C_d V (U^2 + V^2)^{1/2} \quad 15$$

and the stress at the bottom of the wind driven layer is defined as

$$\tau_{xH} = \rho_w R_H u \quad 16$$

$$\tau_{yH} = \rho_w R_H v \quad 17$$

where u and v are the eastward and northward ocean current velocity components averaged over the wind-driven depth H , f is the Coriolis parameter, R_H is the linear stress coefficient, ρ_a is the density of air, and ρ_w is the density of seawater. The surface drag coefficient is C_d defined in equations and .

The depth of flow is considered constant over each sampling interval in the wind record resulting in the following solution to the above set of ordinary coupled differential equations (Reed, 1980):

$$u(t) = e^{-\frac{R_H t}{H}} [(u_0 - u_\infty) \cos(ft) + (v_0 - v_\infty) \sin(ft)] + u_\infty \quad 18$$

$$v(t) = e^{-\frac{R_H t}{H}} [(v_0 - v_\infty) \cos(ft) + (u_0 - u_\infty) \sin(ft)] + v_\infty \quad 19$$

With the asymptotic velocity components being

$$u_\infty = (\rho_a R_s / \rho_w) (R_H U + HfV) / (R_H^2 + H^2 f^2) \quad \text{and} \quad 20$$

$$v_\infty = (\rho_a R_s / \rho_w) (R_H V - HfU) / (R_H^2 + H^2 f^2) \quad 21$$

Behavior of surface slicks

DREAM focuses primarily on underwater releases, such that surface phenomena are of secondary interest. Oil droplets contained in produced water, for example, may rise to the surface and form a surface slick, such that related processes must also be represented in the model. DREAM uses the same algorithms for these processes as used in the oil spill contingency and response model OSCAR2000. These algorithms are described in detail in (Reed et al, 2001), with a brief summary being included here.

Spreading of oil on the sea surface involves a number of interacting forces and processes. The classical analyses by Fay (1969), Hoult (1972), and Fanneløp and Waldman (1972) account for passive spreading due to gravity, momentum, and viscous forces. These classical analyses account only for quiescent spreading of the thick portion of the slick.

Turbulent spreading rapidly overtakes this quiescent spreading in importance. Turbulent spreading occurs as the result of horizontal and vertical shears in the velocity field around an oil slick, combined with the entrainment and resurfacing of oil droplets. Since these processes are also included here, the model produces thinner oil sheens as time progresses.

Evaporation is controlled by the vapor pressures of the individual components, and their molar fractions at any location in the surface slick. The evaporative mass transfer rate is computed according to common chemical engineering practice (Thibodeaux, 1979; Mackay et al, 1980; Sebastio and Soares, 1995; Reed et al, 1999b).

Natural dispersion of oil from the sea surface into the water column is described in Reed et al. (1992), and is based on the empirical formulation of Delvigne and Sweeney (1988):

The algorithms for water uptake and changes in oil properties are calibrated to laboratory weathering data, derived following published procedures (Daling et al, 1990, 1997). Laboratory weathering data relates the different oil properties to fraction evaporated. The following table shows an example of a lab data table for a North Sea crude.

Table 1

Property	Fresh oil	150°C+	200°C+	250°C+
Boiling temp. (°C)	-	197	254	305
Volume topped (%)	0	14.6	27.8	36.9
Residue (wt. %)	100	88.1	76.9	67.2
Specific gravity (kg/l)	0.853	0.883	0.895	0.913
Pour point (°C)	-6	9	12	21
Flash point (°C)	-	51.2	93.9	126
Viscosity at 13°C (cP)	15	33	67	254
Viscosity of 50% emulsion (cP)	-	880	1420	2700
Viscosity of 75% emulsion (cP)	-	5300	8600	16000
Viscosity of max water (cP)	-	-	-	-
Max. water content (%)	-	90	85	72
Halftime for water uptake (hrs)	-	0.22	0.27	0.56
Stability ratio	-	0.85	0.86	1.0

Dissolution from oil droplets and slicks

Dissolution, like evaporation, is dependent on the molar fraction of each component in a drop or a surface slick. In addition, the ambient concentration may be important, especially near the source. The equation governing dissolution of component *i* from a droplet or slick is

$$dm_i / dt = K_d A (F_i S_i - C_i).$$

43

Here,

- K_d = dissolution mass transfer coefficient (m/s)
- A = interfacial surface area for a droplet or a surface slick (m²)
- F_i = molar fraction of component *i* remaining in the slick or droplet
- S_i = solubility of the *i*th component (grams/m³; ppm)
- C_i = ambient concentration of the *i*th component (grams/m³).

For a surface slick, the mass transfer coefficient K_d is computed as (Thibodeaux, 1979)

$$K_d = Sh_i D_i / L \quad 44$$

For slicks on the surface, the flat plate correlation for the Sherwood Number is used

$$Sh_i = \text{Sherwood Number} = 0.578 Re^{0.5} Sc_i^{0.33}, \quad 45$$

and

$$Re = \text{Reynolds Number} = U_{rel} L / \nu_w$$

$$Sc_i = \text{Schmidt Number} = \nu_w / D_i$$

U_{rel} = relative velocity between the oil and the water (m/s)

L = slick width (m)

ν_w = kinematic viscosity of water $\sim 8.9 \times 10^{-7} \text{ m}^2/\text{s}$ at 25 °C

D_i = molecular diffusivity of component i (m^2/s)

For droplets, the mass transfer correlation for spheres is used for the Sherwood number:

$$Sh = 2 + 0.347 Re^{0.62} Sc_i^{0.31}. \quad 46$$

For droplets, the relative velocity is the rise velocity (Equation 11), and droplet diameter replace slick width as the characteristic length in the Reynolds number calculation.

These are standard chemical engineering approaches (e.g. Thibodeaux, 1979), not of themselves new in this model.

Adsorption/Dissolution Partitioning

Adsorption plays an important role in the transport and fate of pollutants in the aquatic environment. Adsorption determines the extent of partitioning of a pollutant between the suspended particulate phase and the dissolved phase, and therefore modulate toxic effects as well as the rate of removal from the water column to the sediments.

The relationship between the equilibrium concentration of pollutant in water phase (C_w) and the equilibrium concentration in solid phase (C_s) can be represented by plotting C_s vs. C_w at a constant temperature. There are several theories to describe these adsorption isotherms, the two most popular being the Langmuir isotherm (Equation 47) and Freundlich isotherm (Equation 48)

$$C_s = \frac{K_1 K_2 C_w}{1 + K_1 C_w} \quad 47$$

$$C_s = K_f C_w^{1/n} \quad 48$$

where K_f is a constant.

In the aquatic environment, the water phase concentration of a pollutant, C_w , is usually low. Under this condition, n in the Freundlich equation is typically equal to 1, the $K_1 C_w$ term in the Langmuir equation becomes insignificant compared to 1, and both equations reduce to the linear equation,

$$C_s = K_p C_w C_{ss} \quad 49$$

where the concentration of suspended sediments, C_{ss} , has been separated out in the definition of the partition coefficient.

The partition coefficient of a chemical, K_p , is not only a function of temperature and pH, it is also affected by the physical and chemical characteristics of the adsorbing solid. Studies of the sorption-desorption behavior of organic compounds, especially hydrophobic, non-ionic compounds, concluded that organic carbon or organic matter content of the sorbent is the major determining factor in the adsorption process. If K_p is normalized with the organic carbon fraction f_{oc} of the solid,

$$K_{oc} = \frac{K_p}{f_{oc}} \quad 50$$

then K_{oc} becomes independent of the sorbents. Furthermore, the organic carbon-based partition coefficient shows excellent correlations with both K_{ow} (octanol/water partition coefficient) and water solubility S , two chemical properties which are more readily available for most chemicals:

$$\log K_{oc} = A \log K_{ow} + B \quad 51$$

$$\log K_{oc} = a \log S + b \quad 52$$

It is therefore possible to estimate K_{oc} from either K_{ow} or solubility. The correlation constants A , B and a , b are usually structure-dependent. Table 2 shows some of the K_{oc} - K_{ow} - S correlation equations and literature references which have been used in computing K_{oc} .

Volatilization from the Water Column

The procedure outlined by Lyman et al., (1982), as implemented in Reed et al(1989) and French et al (1996) is also used here. For each chemical in a release, the Henry's Law constant (H) is computed:

$$H = P_{vp}/(S/M_w) \quad 53$$

P_{vp} = vapor pressure (atm)

S = solubility (mg/l)

M_w = molecular weight (g/mole)

If $H < 3 \times 10^{-7}$, volatilization can be neglected. For $H > 3 \times 10^{-7}$, a non-dimensional Henry's Law constant H' is calculated:

$$H' = H/R T \quad 54$$

R = gas constant (atm - m³/mole - °K)

T = temperature (°K)

The liquid-phase exchange coefficient (K_5),

$$K_5 = 20 \sqrt{44/M_W} \quad 55$$

and the gas-phase exchange coefficient (K_6),

$$K_6 = 3000 \sqrt{18/M_W} \quad 56$$

are then used to compute an overall mass transfer coefficient (K_7):

$$K_7 = (H' K_5 K_6) / (H' K_6 + K_5) \quad 57$$

The coefficients K_5 , K_6 , and K_7 are in cm/hr. The actual mass transfer rate from the water column to the atmosphere for this constituent is then

$$dm/dt = K_7 m/d \quad 58$$

in which m is the amount of pollutant mass, assumed distributed evenly over the depth d . The volatilization depth for dissolved substances is limited to the maximum of one half the wave height, or a diffusive depth d ,

$$d = \sqrt{(2 D_z \Delta t)} \quad 59$$

where

D_z = vertical diffusivity (m²/sec)

Δt = model time step (sec)

Degradation

One advantage of a multiple-component model with the flexibility to define and add new components is that the model can account for transformation of components via degradation transformation pathways. shows schematically how these transfers are accommodated for hydrocarbons in the model, using aliphatic hydrocarbons as an example. The actual degradation rates by component are given in Table 3. Although we know that degradation products may be more soluble and toxic than the original components, we still have insufficient information on rates and characteristics of metabolic products to model this complex process with confidence.

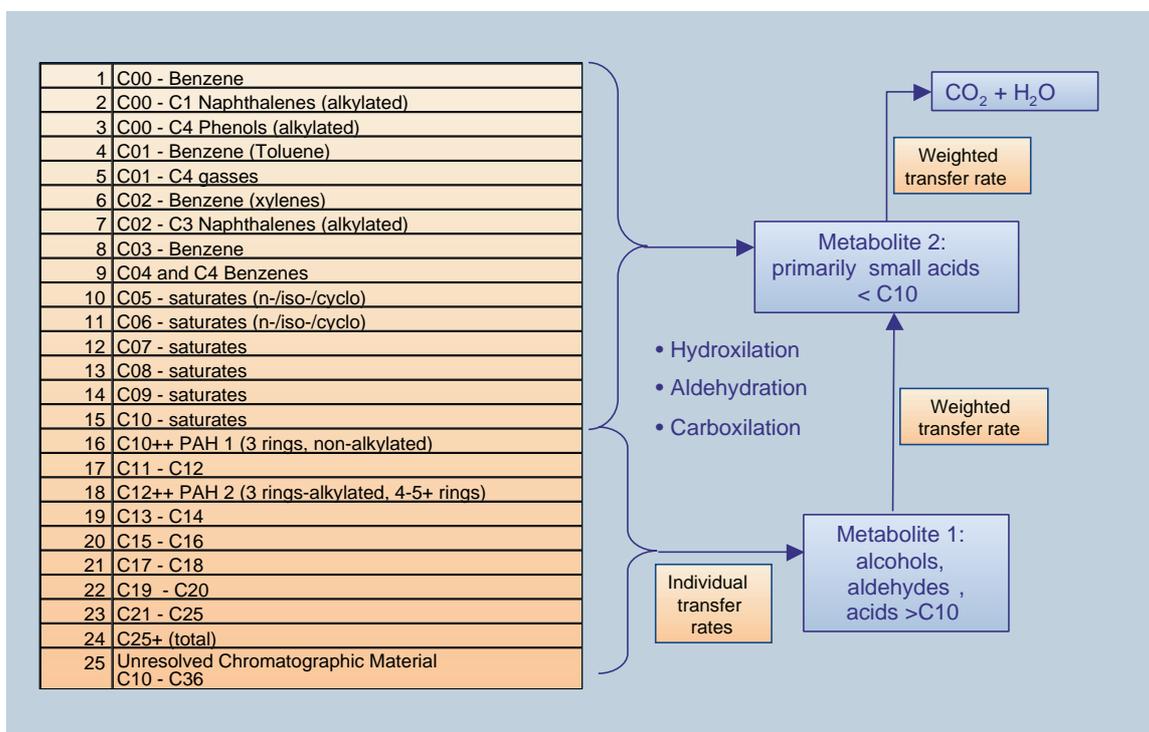


Figure 4 Degradation pathway schematic for hydrocarbons. Each substance, including degradation products, is assigned a degradation pathway, potentially with multiple branches at each step in the pathway.

Table 2 Parameters used to define individual oil components or component groups. Measured transformation rates for dissolved components in WAF and droplets are from a Statfjord oil (Brakstad and Faksness, 2000; Brakstad et al., 2000). Values for sediments are estimated from the literature. Solubilities are literature values. Components sorted by decreasing vapor pressure.

Chemical Component Group	Component or	Transform-ation Rates WAF (day ⁻¹)	Transform-ation Rates Aerobic Sediments (day-1)	Transform-ation Rates Droplets (day-1)	Vapor Pressure (atm.)	Solubility (mg/l)
1	C1-C4 gasses	1.00E+00	1.00E+00	1.00E-01	2.96E+01	4.00E+01
2	C5-saturates (n-/iso-/cyclo)	2.88E-01	1.00E-01	1.00E-01	6.27E-01	9.50E+01
3	C6-saturates (n-/iso-/cyclo)	2.48E-01	1.00E-01	1.00E-01	1.90E-01	3.25E+01
4	Benzene	2.66E-01	1.00E-01	1.00E-01	1.29E-01	1.78E+03
5	C7-saturates	2.67E-01	1.00E-01	1.00E-01	8.70E-02	9.00E+00
6	C1-Benzene (Toluene)	4.62E-01	1.00E-01	1.00E-01	3.83E-02	5.15E+02
7	C8-saturates	2.67E-01	1.00E-01	1.00E-01	2.86E-02	4.35E+00
8	C2-Benzene (xylenes)	4.33E-01	1.00E-01	1.00E-01	1.06E-02	1.75E+02
9	C9-saturates	2.67E-01	1.00E-01	1.00E-01	7.76E-03	2.05E-01
10	C3-Benzene	4.33E-01	1.00E-01	1.00E-01	4.30E-03	5.75E+01
11	C10-saturates	2.00E-01	7.3E-03	1.02E-01	1.68E-03	1.00E-04
12	C4 and C4 Benzenes	3.85E-01	1.00E-01	1.00E-01	1.19E-03	1.25E+01
13	C11-C12	2.00E-01	7.7E-03	8.25E-02	4.90E-04	1.00E-04
14	Phenols (C0-C4 alkylated)	2.00E-01	8.94E-02	1.00E-02	2.93E-04	5.10E+04
15	Naphthalenes (C0-C1-alkylated)	6.30E-01	4.0E-02	1.73E-01	1.32E-04	2.75E+01
16	C13-C14	2.00E-01	6.7E-03	7.37E-02	5.88E-05	1.00E-04
17	Unidentified Chrom Mat: C10 - C36	1.17E-01	1.00E-03	1.00E-02	4.45E-05	1.50E+02
18	Naphthalenes (C2-C3-alkylated)	4.95E-01	3.6E-02	6.08E-02	1.26E-05	5.50E+00
19	C15-C16	2.00E-01	3.9E-03	7.07E-02	7.80E-06	1.00E-04
20	PAH 1 (3 rings, non-alkylated)	4.62E-01	2.54E-02	6.60E-03	3.11E-06	3.65E+00
21	C17-C18	2.00E-01	4.9E-03	7.07E-02	1.20E-06	1.00E-04
22	C19-C20	2.00E-01	4.0E-03	6.35E-02	1.97E-07	1.00E-05
23	C21-C25	2.00E-01	4.1E-03	6.47E-02	1.82E-08	1.00E-06
24	PAH 2 (3 rings-alkylated, 4-5+ rings)	4.08E-01	1.8E-03	1.00E-03	1.72E-09	1.01E-01
25	C25+ (total)	2.00E-01	3.3E-03	3.76E-02	1.14E-09	1.00E-06
not measured; estimated values						
measured or literature values						

Nearfield Module

The **DeepBlow** model (Johansen, 1997, 2000) was developed in response to the interest in petroleum exploration in deep waters (i.e. depths exceeding about 500 m). Previous models of underwater blowouts have been based on analyses of buoyant plumes in stagnant waters, where the buoyancy was mainly related to the gas released at or near the sea bed (Fanneløp and Sjøen 1980, Milgram 1983, Rye 1994, Engebretsen 1997). However, blowouts in deep waters may behave significantly differently in many major aspects (Johansen, 1997). Non-ideal gas behavior, increased dissolution of gas in oil and water under high pressures, hydrate formation, and effects of cross-flow on entrainment of ambient water into the plume, are factors that may cause a significant reduction in buoyancy flux. Thus existing blowout models may produce unrealistic predictions of plume behavior and surface spreading when applied to blowouts in deep water.

DeepBlow is a Lagrangian model, the plume being represented by a series of non-interfering elements. Each element, which can be thought of as a cylinder or section of a bent cone, is characterized by its mass, location, width (radius), length (thickness), average velocity, pollutant concentration, temperature and salinity. These parameters will change as the element moves along the trajectory, i.e. the element increases in mass due to shear-induced and forced entrainment, while rising by buoyancy and becoming sheared over by the cross flow.

Zheng and Yapa (1997*a* and *b*) extended the Lagrangian plume concept of Lee and Cheung (1990) to multiphase plumes in order to represent sub-sea blowouts with oil, gas and entrained sea-water. In their model, the plume was considered as a mixture of non-miscible fluids (oil droplets and gas bubbles dispersed in seawater). The gas mass was preserved in the plume elements, while the density of the gas was assumed to change according to the ideal gas law. Possible effects of the slip velocity between gas bubbles and the rising plume were neglected in Zheng and Yapa's model. The **DeepBlow** model, also takes into consideration that gas bubbles may escape vertically out of a sloping plume. Also, reductions in the gas mass due to processes such as hydrate formation and dissolution of gas into seawater have been taken into account. These appear to be especially important in deep water. The modifications required to account for such effects have been described in detail in Johansen (2000). With these modifications included, the model provides a description of the plume formed from a sub-sea blowout in deep water that may serve as starting conditions for the oil drift and fate simulations.

DeepBlow has been further modified to function as a near-field module for produced water or other releases of complex mixtures in an aquatic environment. This module is activated automatically whenever a release is specified to originate under water. >Depending on depth and other input parameters, the module automatically computes the near-field plume, and the release of dissolved and droplet-related pollutants from the plume and into the far field.

Water Column Concentrations: Verification Tests

Verification: comparisons with analytic solutions

Several relatively simple tests of the model are possible using analytic solutions to simplified forms of Equation 1. These tests allow objective comparison of model behavior with known solutions.

Analytic Test 1: 3-D steady state, isotropic spreading

In this first test, we assume a continuous release of some conservative substance in a uniform, steady, 3-dimensional current field, far from any boundaries. For convenience we align the x-axis with the direction of the current. Neglecting all removal and transformation processes, and assuming isotropic turbulence, the steady-state solution to Equation 1 is (Csanady, 1973):

$$C = (q / 4 \pi K r) \exp(-U(r - x) / (2 K)), \quad 60$$

where

C = concentration,

q = mass release rate,

K = turbulent dispersion coefficient,

U = current speed in the downstream (x) direction, and

$r = \sqrt{x^2 + y^2 + z^2}$.

If we select a release rate of 1000 kg/s, a current velocity of 0.1 m/s, with +x to the right, and a dispersion coefficient of 1 m²/s, Figure 6 gives a set of resulting concentration contours in the x-y plane. (Because of symmetry, the solution is the same in the x-z and y-z planes.)

The numerical solution from the model for the same input parameters is given in Figure 7. The figure shows a horizontal slice through the resulting plume at the depth of the release ($z = 0$).

Table 3 shows that differences in the widths of contours 5 km downstream from the source are within 6% for the case with a diffusion coefficient of 1 m²/s.

The model is operating in these tests with a concentration grid defined by 200 x 200 cells in the north-south and east-west directions, but only 10 levels in the vertical. The isotropic assumption on dispersion in this test imposes an unrealistically large vertical dimension, so that the problem is greatly under-resolved in the vertical. Reducing the vertical dispersion by a factor of 10 (Figures 7-9) reduces this problem, allowing greater similitude between the model and the analytical solution Table 3.

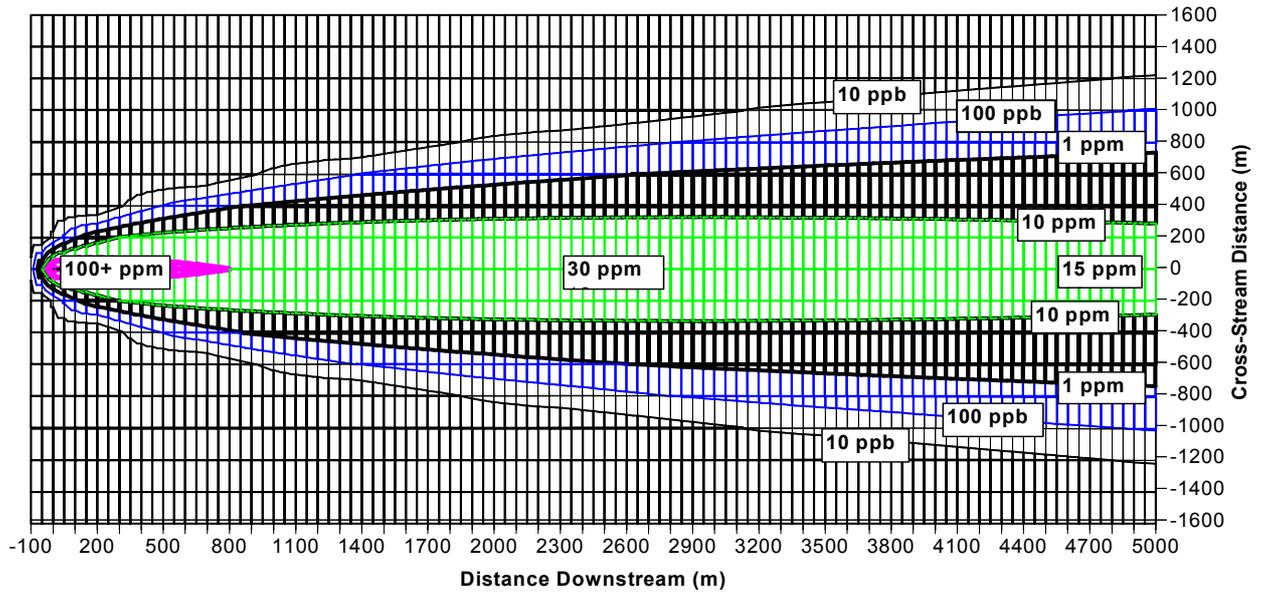


Figure 6 Analytic steady state solution for 3-dimensional, continuous release with isotropic dispersion in a steady current (Equation 60). Horizontal plane through source. Release rate is 1000 kg/s; current velocity is 0.1 m/s to the right; dispersion coefficient is 1 m²/s.

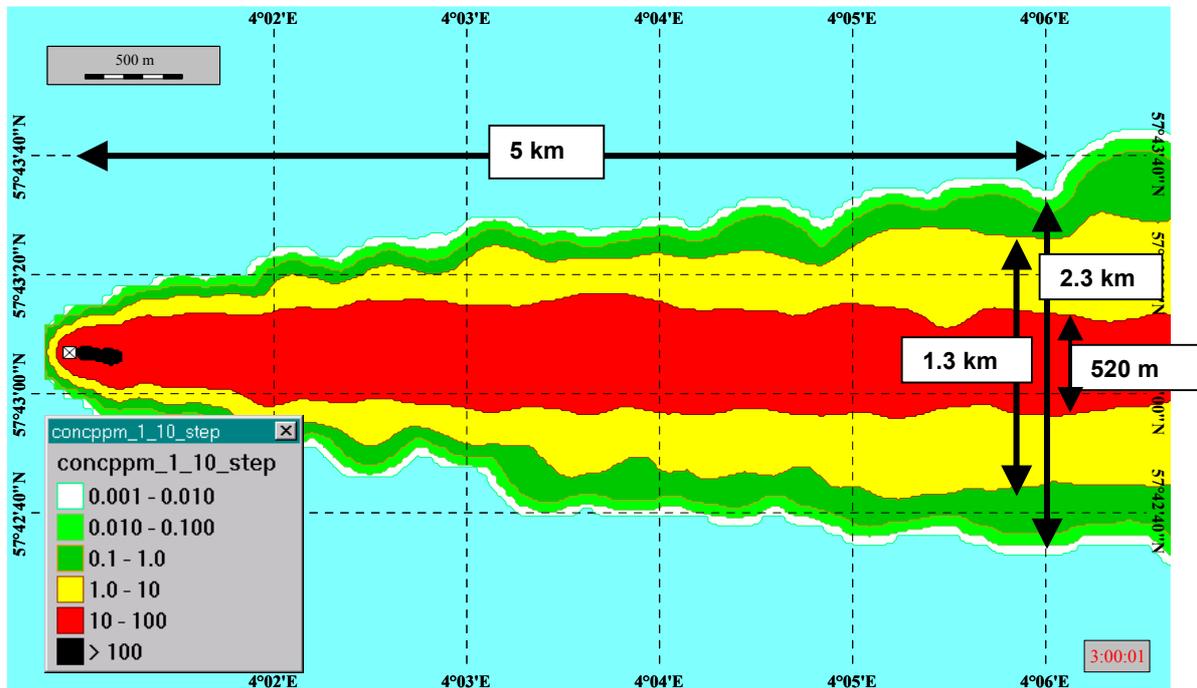


Figure 7 Numerical approximation to Equation 60, with parameters as in Figure 6. Horizontal plane through source. Dimensions are within 4% of the analytic solution. (Table 3 Table).

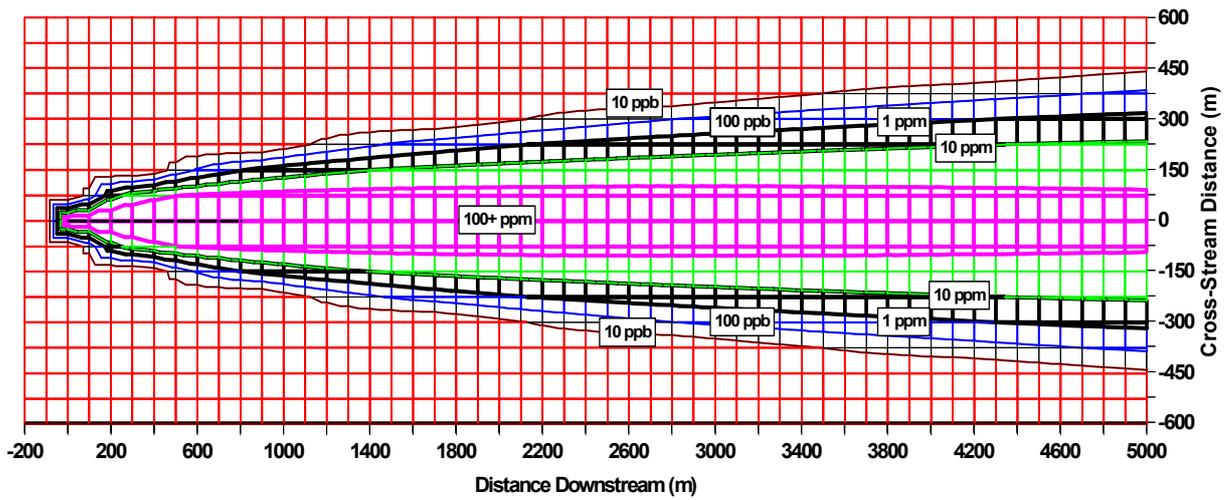


Figure 8 Analytic steady state solution for 3-dimensional, continuous release with isotropic dispersion in a steady current (Equation 60). Horizontal plane through source. Release rate is 1000 kg/s; current velocity is 0.1 m/s to the right; dispersion coefficient is $0.1 \text{ m}^2/\text{s}$.

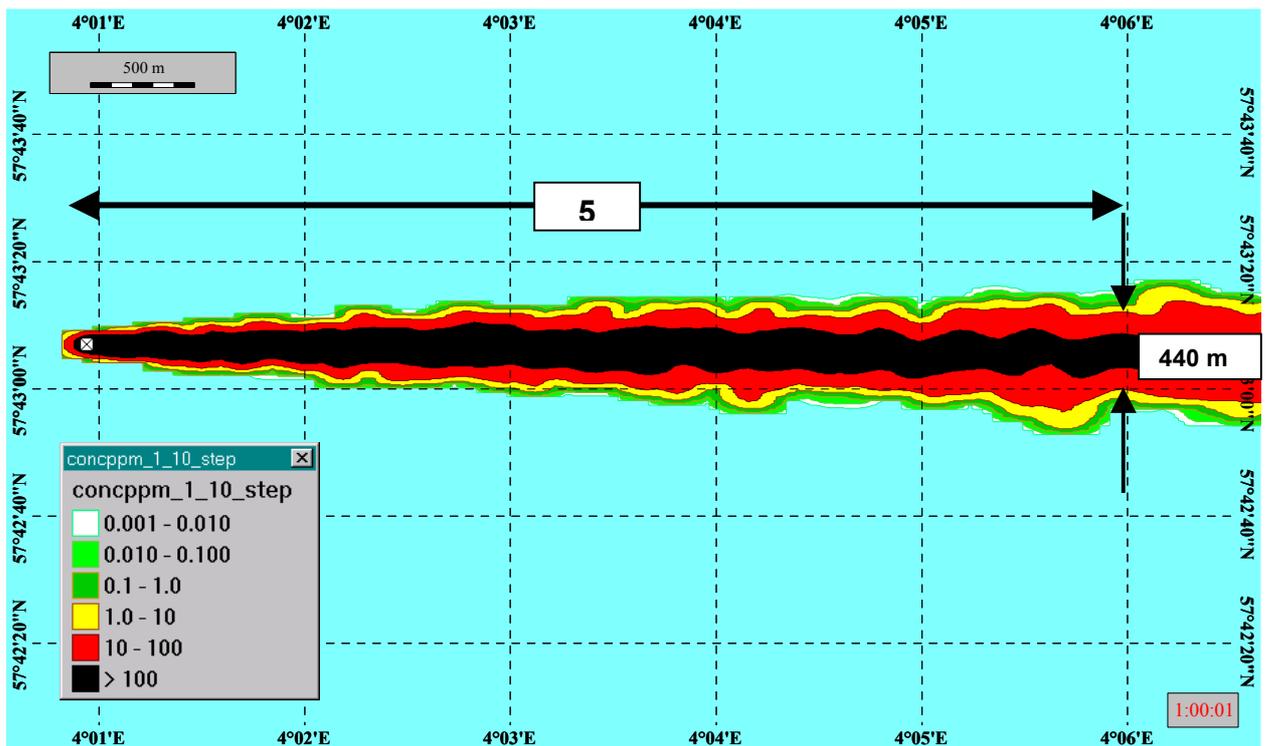


Figure 9 Numerical approximation to Equation 60, with parameters as in Figure 8. Horizontal plane through source. Dimensions are within 4% of the analytic solution

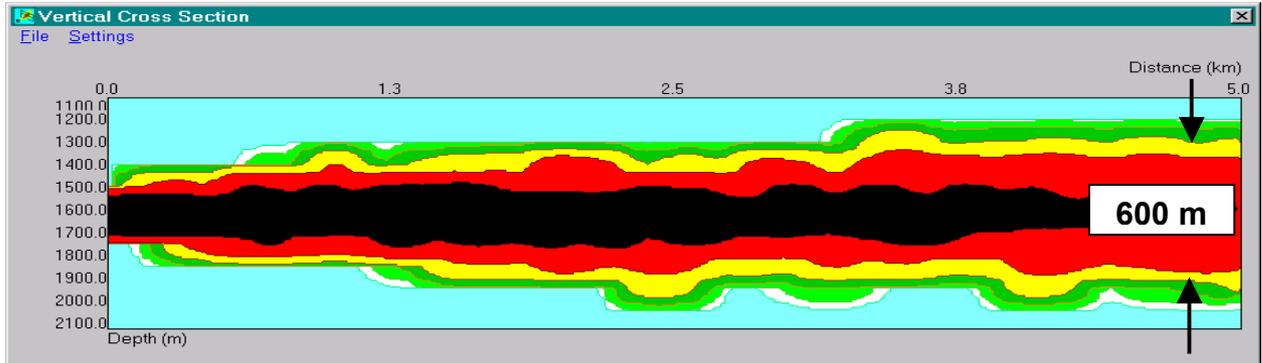


Figure 10 Numerical approximation to Equation 60, with parameters as in Figure 8. Vertical plane through source. Dimensions are compared to the analytic solution in Table 3 Table .

Table 3 Comparison of characteristic dimensions of the analytic and numerical solutions for Analytic Test 1: 3-D steady state, isotropic spreading (Equation 60).

Parameter Settings	Concentration contour width 5 km downstream (m)	Analytical Solution (m)	Numerical Solution (m)	Difference (%)
3D, K = 1 m ² /s	10 ppm contour	500	520	4 %
	1 ppm contour	1400	1360	-3 %
	10 ppb contour	2400	2300	-4 %
3D, K = 0.1 m ² /s	100 ppm	160	160	0 %
	10 ppm	450	440	-2 %
	1 ppm	620	600	-3 %

Analytic Test 2: 3-D steady-state, near-surface release, reflecting boundary, directionally variable dispersion

Here a more realistic situation is considered in which a release occurs some distance h beneath the sea surface. As before, the released substance is conservative; all removal processes are inactive. In this case we account for the boundary by superposition of a mirror image across the air-water interface, producing a reflection of mass at that boundary. In this case the solution to Equation 1 is (Sutton, 1947; Csanady, 1973):

$$C = \frac{Q}{2\pi U \sigma_y \sigma_z} \left[\exp\left(-\frac{y^2}{2\sigma_y^2} - \frac{(z-h)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{y^2}{2\sigma_y^2} - \frac{(z+h)^2}{2\sigma_z^2}\right) \right] \quad 61$$

where σ_y , σ_z are the cross-stream and vertical dispersion coefficients, and h is the depth of release.

The variances σ_y , σ_z are related to the dispersion coefficients K_y , K_z by

$$\sigma = \sqrt{2 K t} = \sqrt{2 K x / U}.$$

62

Setting the transport velocity U to 0.1 m/s, the horizontal and vertical dispersion coefficients K_y and K_z to $10 \text{ m}^2/\text{s}$ and $0.0001 \text{ m}^2/\text{s}$, and the release rate to 1000 kg/s produces the concentration contours in the horizontal plane at the release depth $h = 15 \text{ m}$ shown in Figure 11.

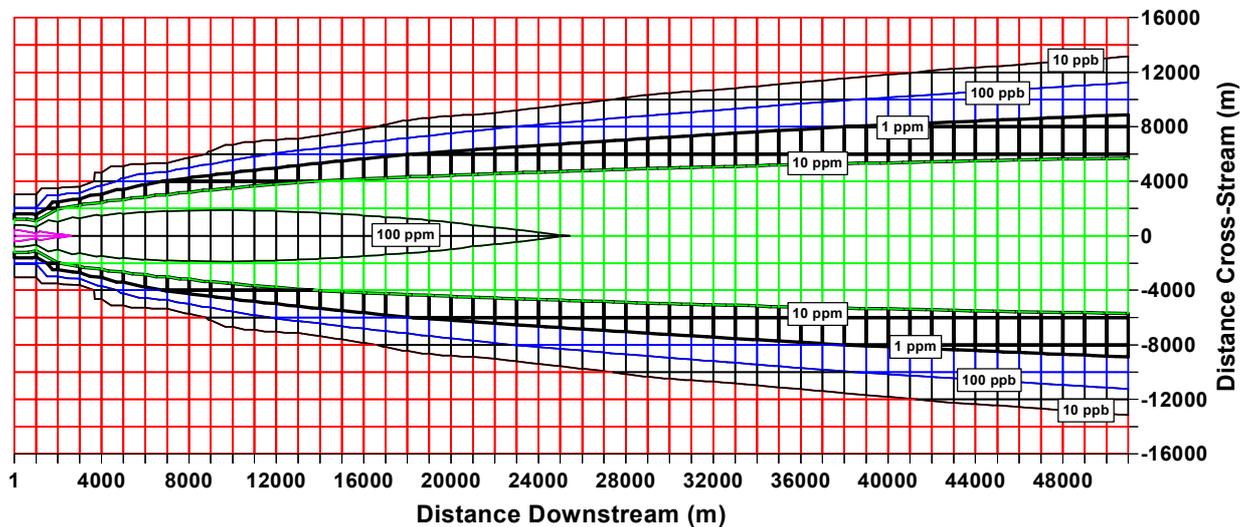


Figure 11 Horizontal plane at 15 m release level: analytic steady state solution to Equation 62. Release rate 1000 kg/s ; current velocity 0.1 m/s to the right; horizontal dispersion coefficient $10 \text{ m}^2/\text{s}$; vertical dispersion coefficient $0.0001 \text{ m}^2/\text{s}$, release depth 15 m .

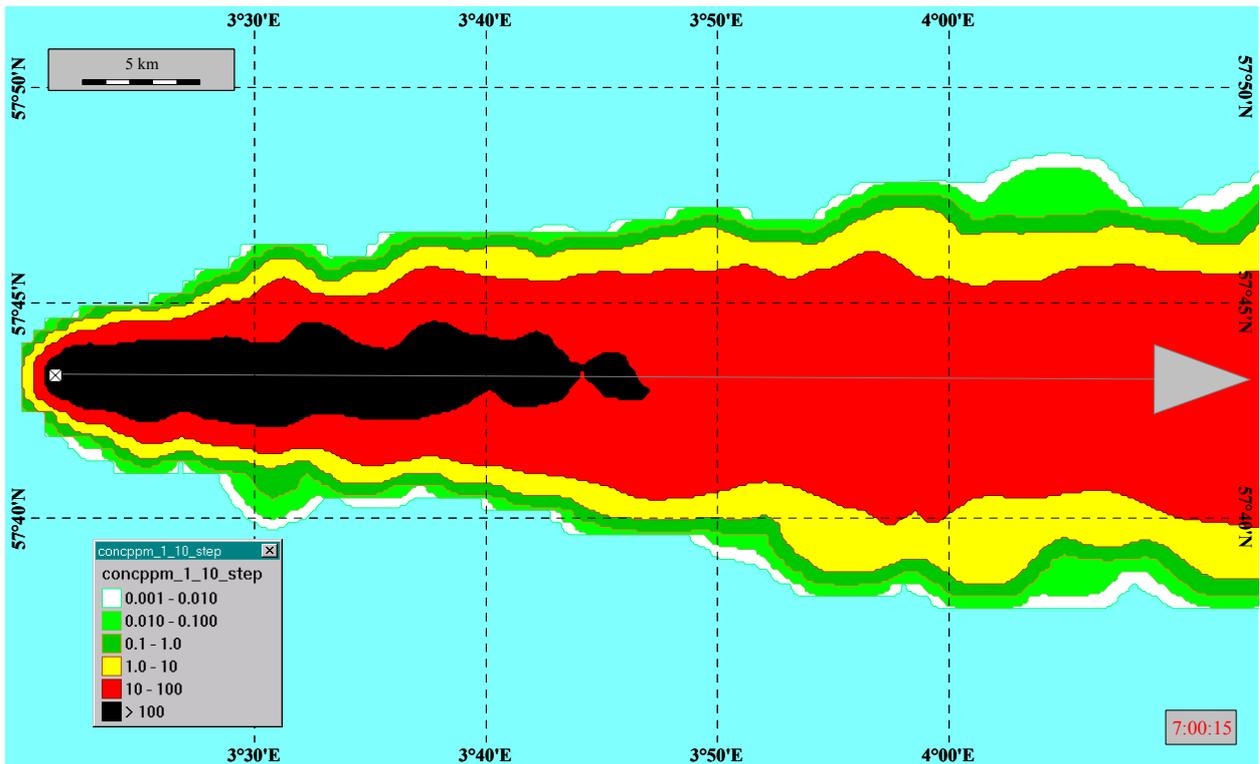


Figure 12 Numerical approximation to Equation 61, with parameters as in Figure 11. Horizontal plane through source. Dimensions are compared to the analytic solution in .

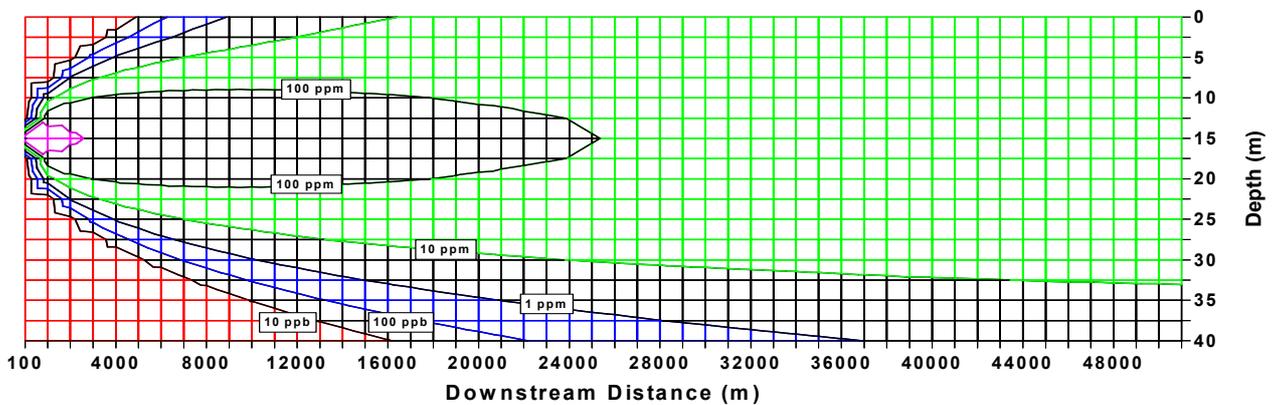


Figure 13 Vertical plane at $y = 0$ (Figure 11): analytic steady state solution for 3-dimensional, continuous release in a steady current, reflecting boundary at the air-water interface, and directionally variable dispersion coefficients. Release rate is 1000 kg/s; current velocity is 0.1 m/s to the right; horizontal dispersion coefficient is 10 m^2/s ; vertical dispersion coefficient is 0.0001 m^2/s ; release depth is 15 m.

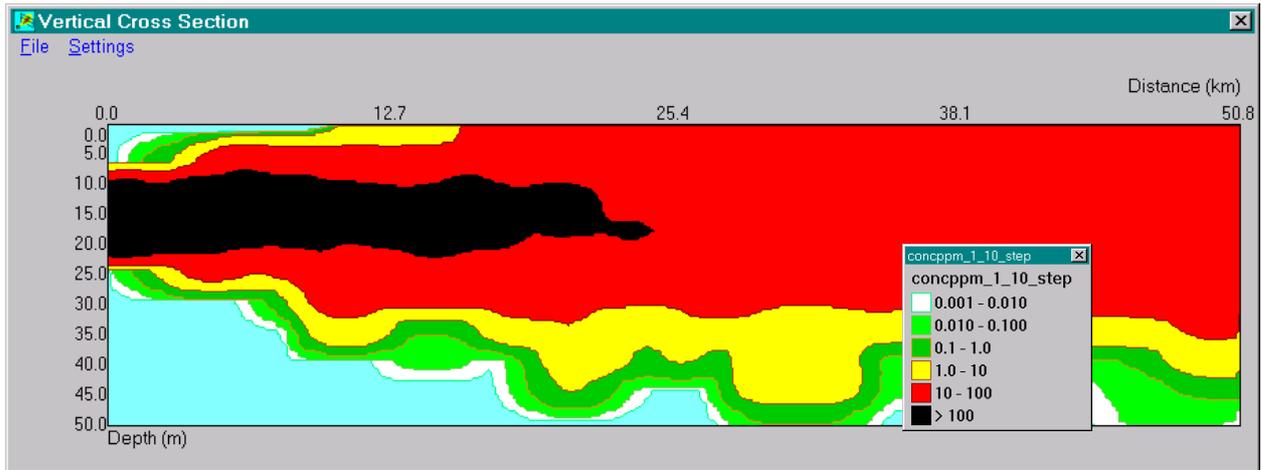


Figure 14 Numerical approximation to Equation 61, with parameters as in Figure 13. Vertical plane through source. Dimensions are compared to the analytic solution in .

Table 4 Comparison of characteristic dimensions of the analytic and numerical solutions for Analytic Test 2: Near-surface reflecting boundary, directionally variable dispersion (Equation 61).

Parameter Settings	Concentration contour measure 50 km downstream (m)	Analytical Solution (km)	Numerical Solution (km)	Difference (%)
3D, $K_y = 10 \text{ m}^2/\text{s}$, $K_z = 0.0001 \text{ m}^2/\text{s}$	width 10 ppm horizontal contour	12000	11500	-4 %
	width 1 ppm horizontal contour	18000	16600	-8 %
	width 10 ppb horizontal contour	24000	22000	-9 %
	depth 10 ppm vertical contour	33	35	6 %
	depth 1 ppm vertical contour	43	40	-8 %
	depth 10 ppb vertical contour	55	52	-6 %

Test 3: Effect of number of particles and spatial grid resolution on computed concentration fields

Here the model is set up with a constant release at 25 m depth of a fully soluble, non-degrading tracer. The release rate is 100 tons per day, and continues over 10 days. The simulation employs time-variable 3- dimensional hydrodynamics driven by wind and tides for the central North Sea, based on environmental data for May 1990 (DNMI, 1998). Figures 14 - 17 show the horizontal projection of maximum concentrations after 10 days, with a vertical profile from the release site

towards the southeast. Figures 14 - 17 result from exactly the same simulation, but with the number of particles increasing from 100 in Figure 15 to 10,000 in Figure 18.

This test demonstrates the extent to which the model retains the major features of a concentration field, even with relatively few particles. On the other hand, increasing the number of particles increases the model's ability to retain details in the field, such as the increased concentration near the source in Figures 16 and 17, using 1000 and 10,000 particles.

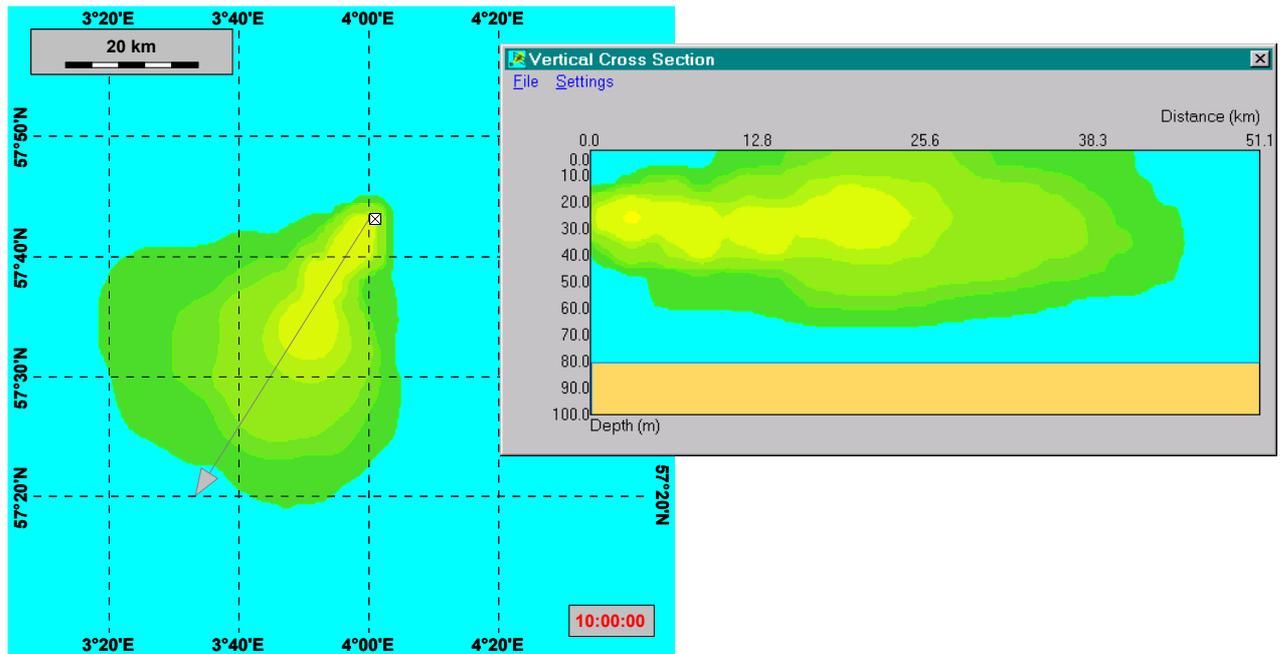


Figure 15 100 particles used in simulation: Constant release at 25 m depth of non-degrading tracer, 100 tons per day over 10 days, horizontal projection of maximum concentrations, vertical profile from release site towards southeast. Simulation uses 3D hydrodynamics driven by wind and tides (environmental data for May 1990).

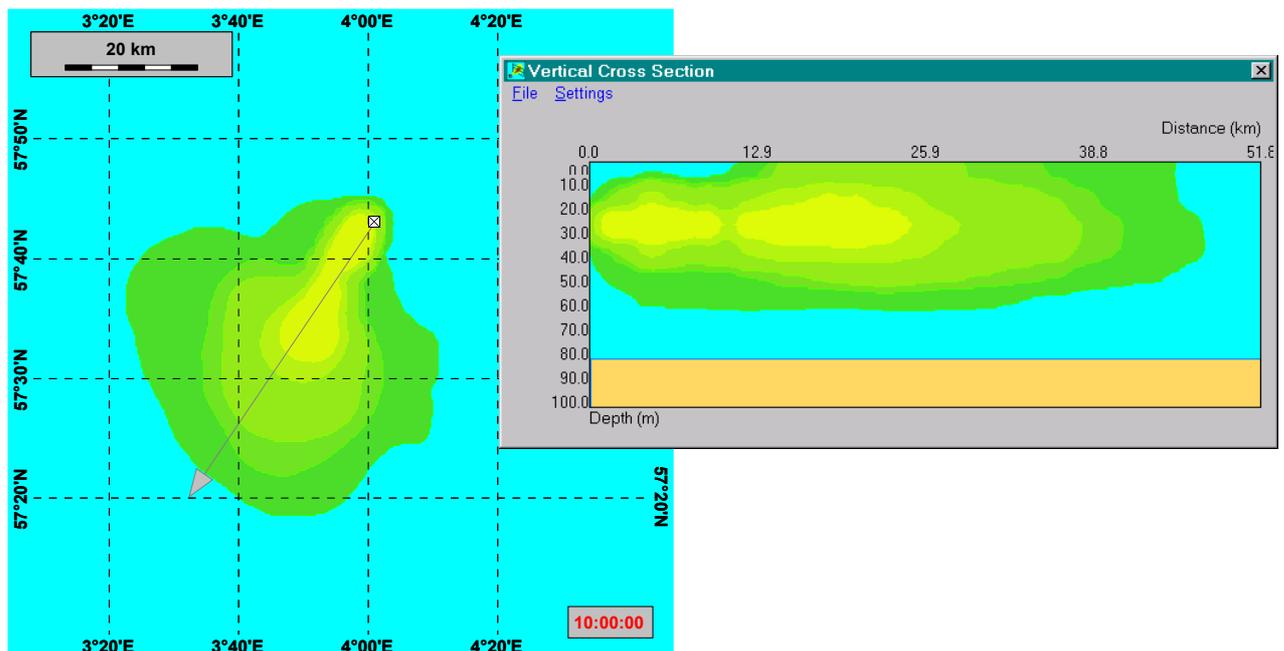


Figure 16 As in Figure 14, but 500 particles used in simulation.

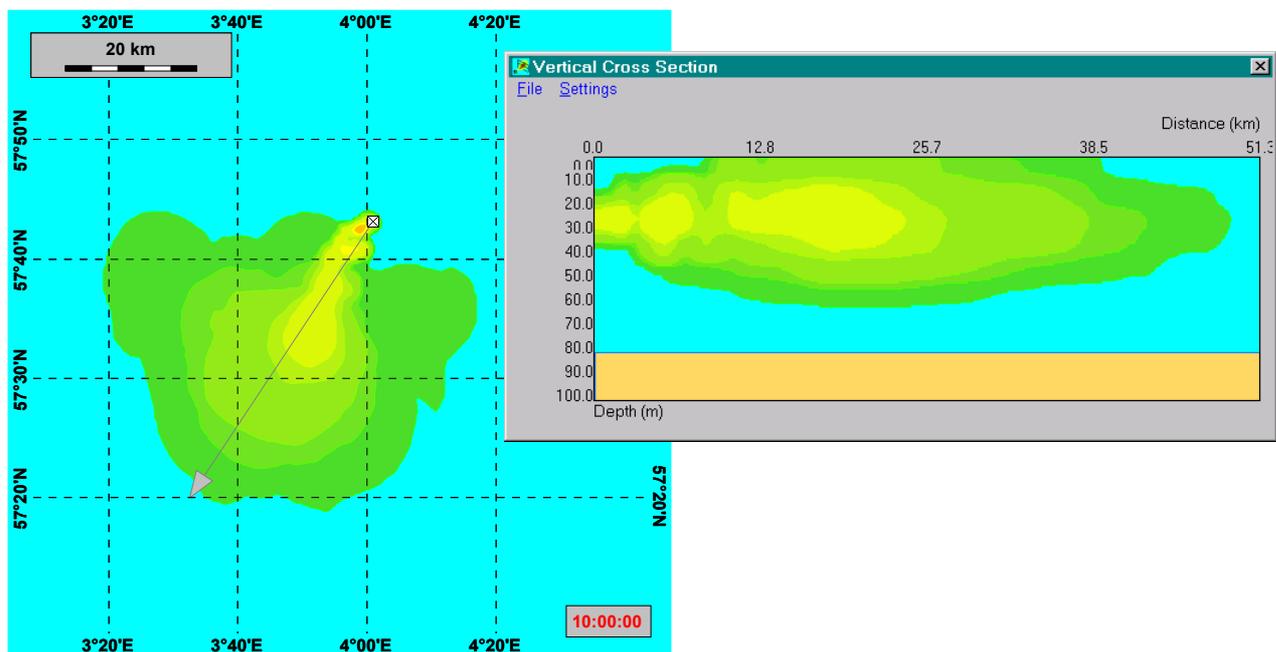


Figure 17 As in Figure 14, but 1000 particles used in simulation.

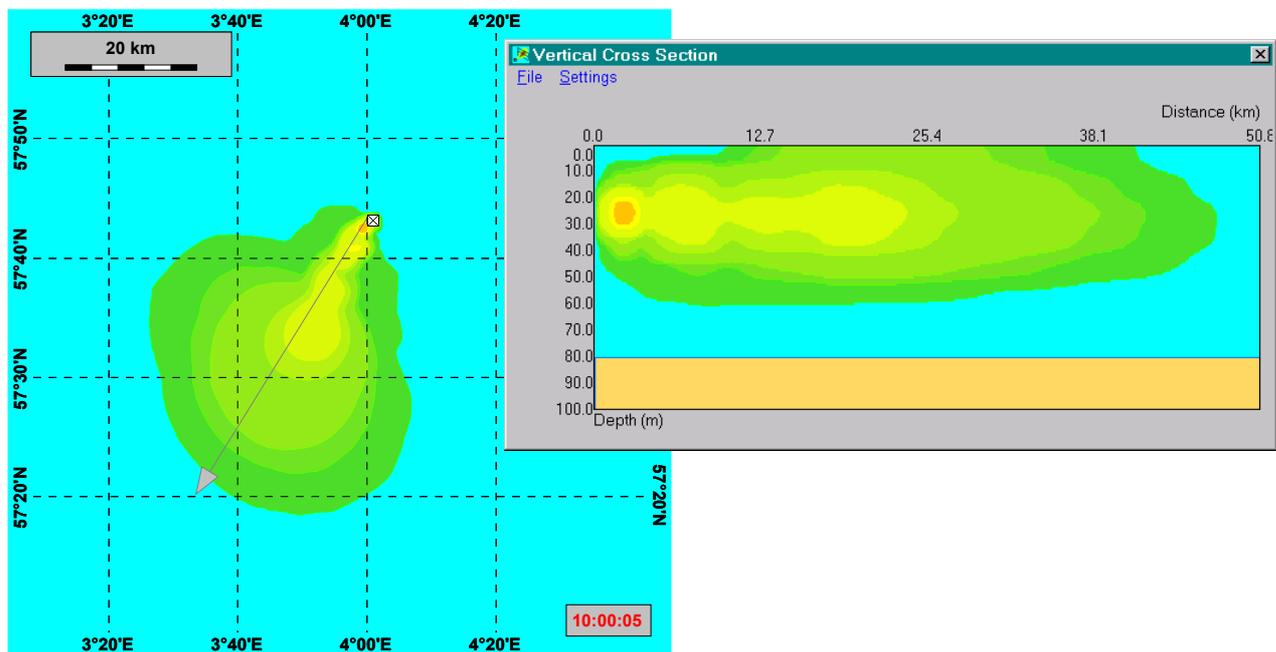


Figure 18 As in Figure 14, but 10000 particles used in simulation.

Test 4: Comparison with observations of naturally and chemically dispersed oil concentrations in the field

In 1995 a series of oil spill experiments was carried out offshore Norway (Brandvik et al, 1995). These included three nearly simultaneous surface releases of 15 m³ of stabilized Troll crude oil each. One of these three, the control or “Charlie” slick, was left untreated. Of the two others, one was sprayed with the dispersant Corexit 9500 from helicopter (the “Hotel” slick), the other from

boat (the “Bravo” slick). The helicopter treatment involved approximately 900 liters of dispersant; the boat application used about 1100 liters. Winds were on the order of 5 – 7 m/s from the west during the first day, falling to 2 – 3 m/s thereafter. Sub-surface oil sampling was carried out by

ultra-violet (UV) fluorometry, pumping water simultaneously from depths of 1, 3, and 8 meters. Concentrations were stored in real time together with the GPS position of the sampling boat.

The control slick, Charlie, was monitored for 34 hours, and had the longest drifting time of the three. The Hotel and Bravo slicks were monitored for 2 to 3 hours each. At the time of dispersant application (after 2 hours on the sea surface), the oil had the following properties:

Water content: 60%
 Emulsion viscosity: 700 cP (@ shear rate of 10 s^{-1})
 Evaporative loss: 12%
 Pour point: $-12 \text{ }^{\circ}\text{C}$
 Remaining oil volume: $\sim 12 \text{ m}^3$
 Emulsion volume: $\sim 30 \text{ m}^3$

Due to evaporation, natural dispersion, and some thin-sheen spreading, the treatable portion of the slicks was reduced by about 20% from the original oil mass, so the dispersant-to-oil treatment ratios were approximately as given in the table below.

Slick Designation	Treatment Ratio	
	Oil : Dispersant	Emulsion : Dispersant
Hotel	1 : 17	1 : 33
Bravo	1 : 14	1 : 27

Total hydrocarbon concentrations were measured by fluorometry under all three slicks. The results of one such set of measurements for each slick is shown in Figure 19.

The model was then used to simulate the helicopter dispersant action, as compared to the control slick. Time “snapshots” from the simulations of the Hotel and Charlie slicks are shown in Figures 19 and 20 respectively. From the measurements in Figure 19, we see that the maximum measured concentration under the Hotel slick was about 18 ppm, with mean values in the 1 – 10 ppm range. These values compare quite well with the simulation, Figure 20, which shows the central area with concentrations of about 5 ppm. The measurements also reflect relatively uniform concentrations down to 8 m, the lowest measurement taken. The simulations show the 1 – 5 ppm contour extending down to almost 12 m.

By comparison, the simulation of the untreated slick (Figure 21) shows maximum concentrations of 0.5 ppm, consistent with measurements under the control slick. Model results are seen to be in agreement with the observations, in both magnitude of concentration and vertical extent.

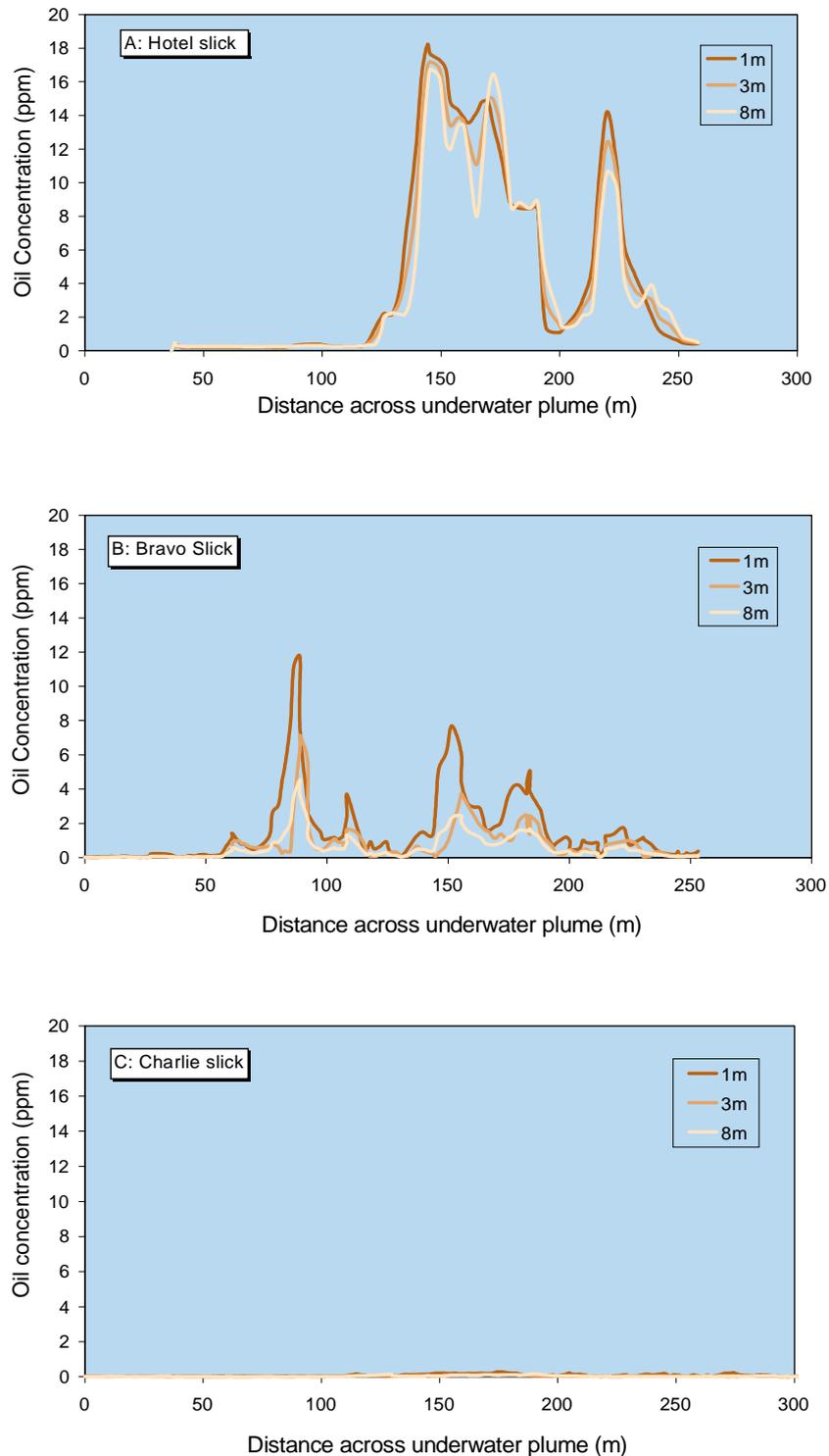


Figure 19 Total hydrocarbon concentrations measured by fluorometer 2.3 hours after slick release. (a) Application of dispersant by helicopter; (b) application of dispersant by boat, (c) without dispersant application. Maximum concentrations with dispersant application are in the range 10 to 20 ppm, and are distributed relatively evenly over at least the top 8 meters of the water column. Without dispersant application, maximum values are under 1 ppm.

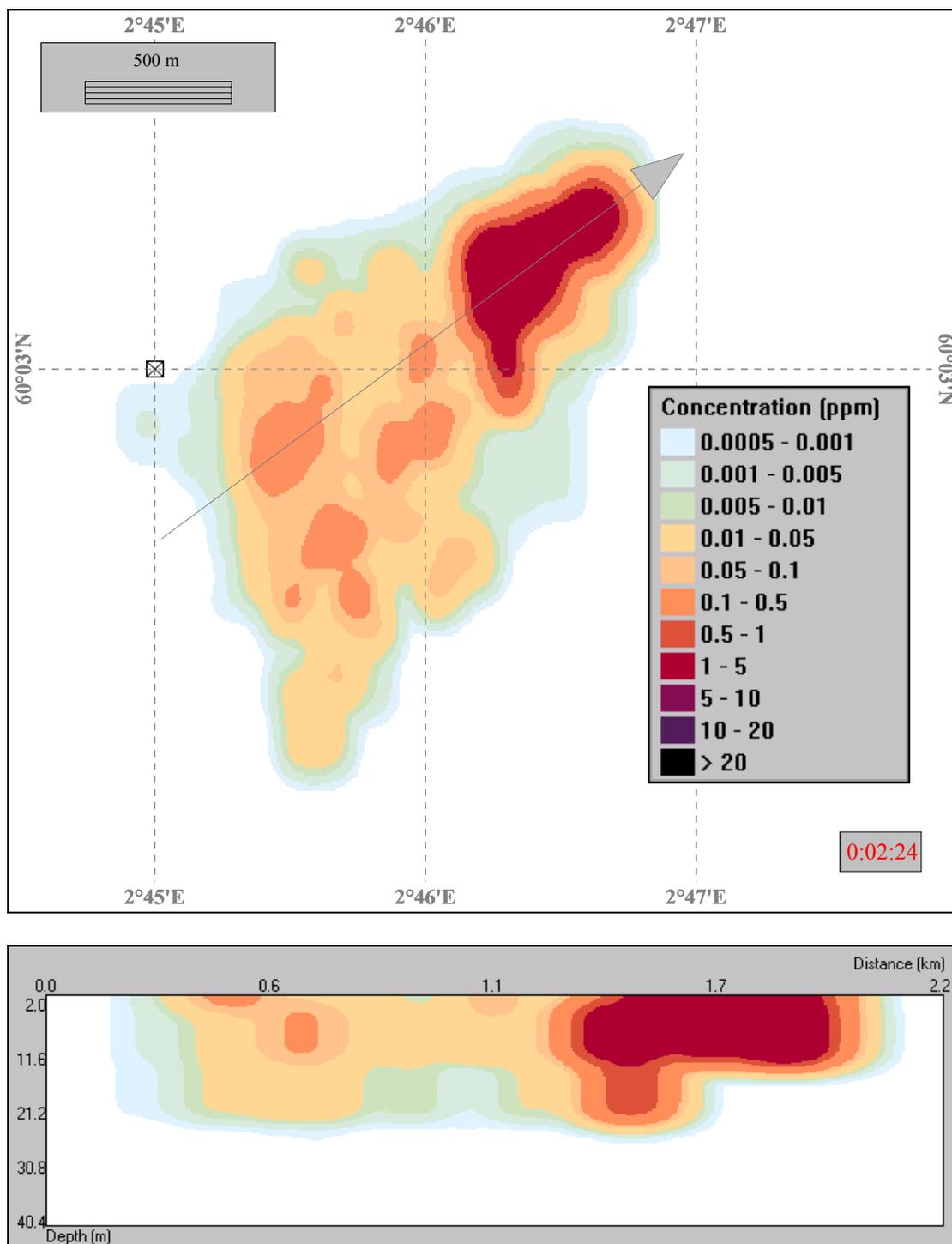


Figure 20 Modeled maximum total hydrocarbon concentrations (THC) in the top 20 meters of the water column, slick treated with dispersant by helicopter, 2.3 hours after release. The arrow in the top figure shows the orientation of the vertical section. Maximum concentrations are in the range 5 – 10 ppm, and reach down to about 12 meters.

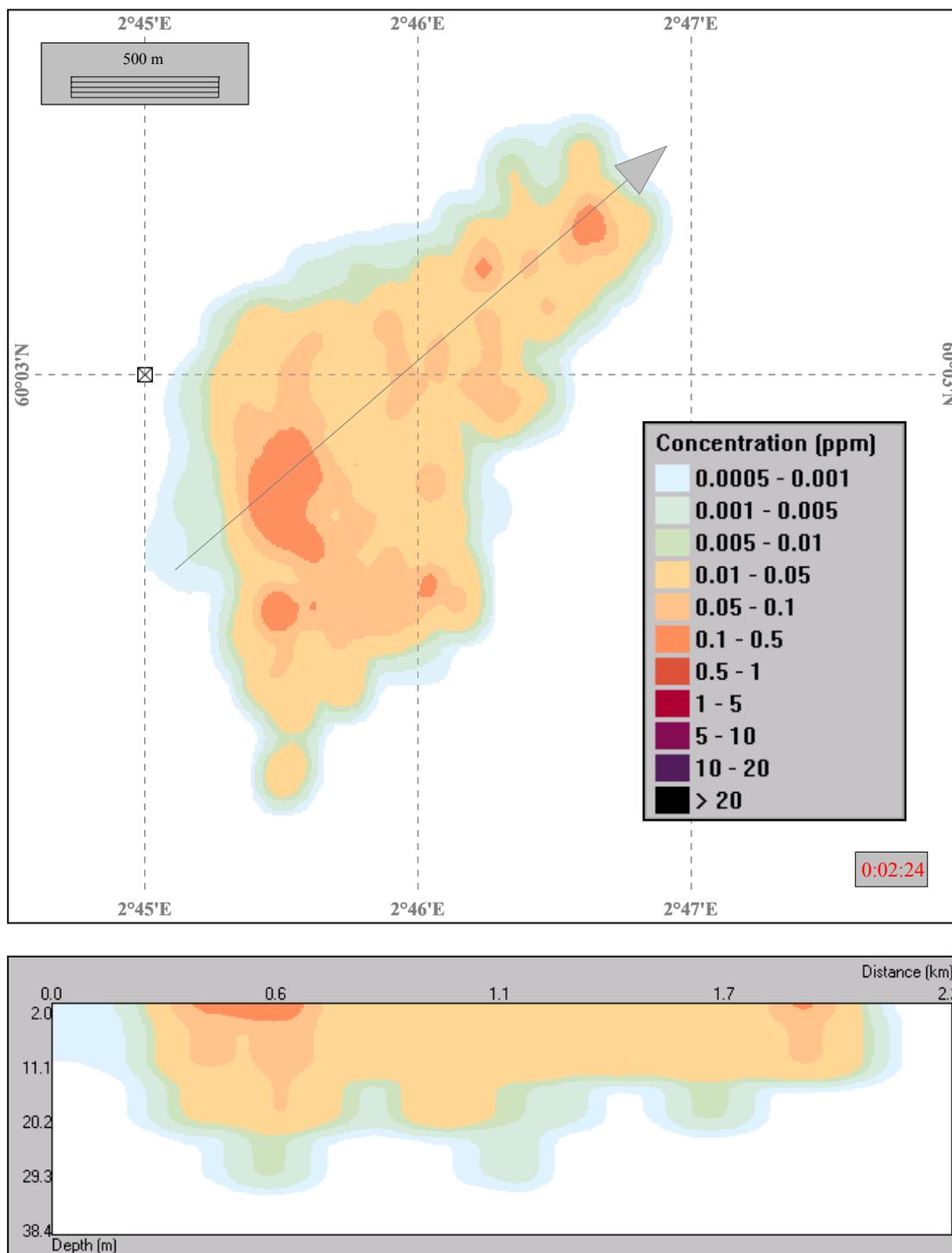


Figure 21 Same scenario as depicted in Figure 20, but without chemical dispersion. "Bird's-eye-view" of the simulated maximum total hydrocarbon concentration (THC) field 2.3 hours after start of the simulation of the control release. The lower plot shows the vertical distribution of THC along the axis of the arrow in the upper, horizontal plot. Maximum near-surface concentrations are about 0.5 ppm.

Conclusions

The Dose-related Risk and Exposure Assessment Model DREAM is described. This 3-dimensional, multiple component pollutant transport, exposure, dose, and effects software tool has been designed to support rational management of environmental risks associated with operational discharges of complex mixtures. Each component in the mixture is described by a set of physical-chemical-toxicological parameters. This paper describes the physical-chemical fates portion of the model system, and comparisons of model calculations with both analytical solutions and field measurements. These comparisons show the model to be within a few percent of the analytical solutions. The model also well reproduces observed distributions of total hydrocarbon concentrations resulting from the application of chemical dispersants to surface oil slicks. Large scale field tests of the model, reported elsewhere (Rye et al, 1998, and Johnsen et al, 1998) demonstrate the model's capability to reproduce distributions of complex mixtures from multiple offshore sources.

Exposure, uptake, depuration, and effects on fish and zooplankton are computed simultaneously with the physical-chemical transport and fates. Thus the mass balance can account for the fraction of each chemical component that is associated with biological organisms. These aspects are described in a subsequent paper.

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Appendix J

Summary of EIF Methodology

TABLE OF CONTENTS

1	Overview of Environmental Impact Factor (EIF) for Risk Assessment	1
1.1	Function of EIF	1
1.2	PEC/PNEC	3
1.3	Environmental Risk and the EIF	3
2	References	5

LIST OF FIGURES

Figure 2-1	EIF water volume = 1	4
Figure 2-2	Relation between PEC/PNEC and the fraction of potentially affected species. Based on Karman et al. (1994).....	4

LIST OF TABLES

Table 2-1	EIF weighting factors.....	2
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1 Overview of Environmental Impact Factor (EIF) for Risk Assessment

1.1 Function of EIF

The EIF (Environmental Impact Factor) has been developed as an indicator of potential environmental risk from produced water releases. The EIF is used as a relative measure of the environmental benefit achieved when alternate produced water management options are considered.

The method is very conservative and the quantified risks are therefore theoretical (see Section 2.2). An attractive feature of the EIF approach is that the method is able to discriminate among the various contributors to environmental risk. Therefore, it is possible to separate a discharge into its constituents and calculate the EIF risk contribution from each of them.

2.2 Conservative Approach

The development of the EIF methodology has been guided by the principle that areas of uncertainty should be resolved in favour of protecting the environment. The methodology is conservative in the sense of over-protecting rather than under-protecting the environment.

As such, the application of the EIF and the subsequent implementation of mitigations to reduce EIF calculated risks are in-keeping with the precautionary approach as described in Environment Canada's *Canadian Environmental Protection Act, 1999* (CEPA, 1999). Many studies on actual risks associated with produced water releases in the open ocean conclude that risks are negligible to low and restricted to the near-field. For instance, Durrell et al. (2004), later expanded in Durrell et al. (2006) and Neff et al. (2006), concluded that contaminant concentrations in caged biota and in the water column in Norway were consistently well below levels of potential concern. Authors found that field-based and modelled PAH concentrations provided comparable results, appropriately ranking concentrations and relative risk at different locations in the North Sea. However, the DREAM¹ model, on which EIF is based, consistently predicted higher risk values than were determined based on field measurements. This, they concluded, was primarily a reflection of the use of the highly conservative assumptions used in modelling. Conservatism built into the EIF and the associated DREAM model results in an exaggeration of risks. These quantified risks are used as a yardstick by which risk reduction options can be evaluated on a cost benefit basis.

Under project environmental impact assessments, actual environmental risks associated with existing produced water management strategies may be generally agreed to be negligible to low and deemed acceptable. EIF risks, which are by-their-nature expected to be higher than actual risk, are not used herein to interpret or assess risks under actual conditions. Rather EIF risks are applied on a relative basis in considering multiple produced water management improvement opportunities.

The following outlines some of the key assumptions used in the EIF. Details are provided in Section 2.3 and 2.4.

- Simulations are carried out during times when biological resources are most vulnerable, either because of sensitivity of life stages or because of low turbulent mixing and possibility of higher levels of exposure, or both. In Newfoundland, the month of June was identified as the most sensitive month, based on examination of available plankton data and discussion with authorities at Fisheries and Oceans Canada.

¹ Dose-related Risk and Effects Assessment Model

- The simulations account for potential effects of hydrocarbons and process chemicals in both dissolved and dispersed form. Possible sequestering due to adsorption to particulate matter in the water column are not included, since filter feeders will still be exposed to this fraction. Therefore, simulations are carried out with all released substances dissolved in the water column and with the processes of adsorption/dissolution partitioning to particles, and subsequent settling, de-activated in the model. Therefore, 100% of both dissolved and dispersed substances are assumed to be bioavailable.
- The EIF is defined as the maximum value over a 30-day simulation (June in Newfoundland). Although an average value would be a more robust measure, and perhaps more representative in some ways, the maximum is used regardless of the duration over which it occurs.
- Evaporation of released chemical compounds from the upper water column to the atmosphere is also de-activated in the model to adhere to the environmentally conservative principle.
- In principle, PNEC² values for each chemical compound in the discharge (see Section 2.3 for details) are obtained from the lowest EC/LC50³ or NOEC⁴ available divided by an appropriate assessment (uncertainty) factor based on the European Commission's Technical Guidance Document (TGD) on risk assessment (EC, 2003) (see Section 2.3 for details).
- An EIF of unity is defined as a water volume in which the fraction of potentially affected species is 5%. (See Section 2.4 for details). Using this cut-off value provides a conservative threshold for risk.

In addition to the above, the EIF risk scores, once calculated, are adjusted upwards for those compounds that have a small biodegradation factor combined with a large bioaccumulation factor. Details are given in Johnsen et al. (2000). A weight factor of 2 is presently applied to EIF scores for chemicals or compounds that have a biodegradation rate (BOD) lower than 60 % over 28 days, combined with unfavourable bioaccumulation properties⁵ and/or toxicity, as indicated in Table 2-1.

Table 1-1 EIF weighting factors.

	Weights		
BOD ≥ 60 %	1 if non-toxic; 2 if toxic	1 if non-toxic; 2 if toxic	1 if non-toxic; 2 if toxic
BOD < 60%	2	2	1 if non-toxic; 2 if toxic
BOD < 20 %	2	2	2
	Log Pow >5	Log Pow >3	Log Pow ≤3

Note: Toxic: EC/LC50 < 10 mg/L

The numerical model DREAM, developed by SINTEF, with financial support from Statoil, Norsk Hydro, ENI, Total, ExxonMobil, Petrobras, ConocoPhillips, and Shell, is used to calculate the EIF. DREAM is a 3-dimensional model that can account simultaneously for up to 200 chemical compounds with different release profiles from 50 or more different sources (Reed et al., 2001).

² PNEC = Predicted No Effects Concentration

³ EC50 = The concentration of a chemical expected to produce a certain effect in 50% of test organisms in a given time

³ LC50 = The concentration of the chemical that kills 50% of the test animals in a given time

⁴ NOEC = No Observable Effects Concentration

⁵ Log Pow (Log Partitioning coefficient between oil and water) is used as an indicator of bioaccumulation

1.2 PEC/PNEC

The EIF method is based on a PEC⁶/PNEC approach, in which the concentration for each compound discharged into the environment is compared to an effects concentration threshold for that compound. When the predicted (modelled) environmental concentration (PEC) is larger than the predicted no-effect concentration (PNEC), there may be a risk of negative effects on the marine environment. An outline of the EIF method is given in Johnsen et al. (2000).

The PEC is the three-dimensional and time variable concentration of a compound in the environment caused by the discharge of produced water. The PEC is calculated for all compounds that are accepted to represent a potential for harm to biota (OLF 2003).

The PNEC is the estimated lower limit for effects on biota in the receiving environment for a single compound or group of compounds. The PNEC value is derived from EC50, LC50 or NOEC values from laboratory toxicity tests. In principle, the PNEC is calculated by dividing the lowest short-term EC/LC50 or long-term NOEC value from the most sensitive species at one of three trophic levels with an appropriate assessment factor in accordance with EC (2003).

For naturally occurring compounds, a major data collection effort was performed to obtain data of sufficient reliability for determination of PNEC values. Further details on these calculations can be found in Johnsen et al. (2000) and Frost (2002).

For added chemicals, the PNEC values used are based on the Harmonized Offshore Chemical Notification Format (HOCNF) scheme. The principles for establishing PNEC values for process chemicals is presented in the EIF Computational Guidelines (OLF, 2003).

In the standardised HOCNF forms, only acute toxicity data are available for offshore chemicals. According to OSPAR standards (OSPAR, 1995), toxicity testing on offshore chemicals should be performed on marine organisms, including an alga (e.g., *Skeletonema costatum*), a crustacean (e.g., *Acartia tonsa*) and a fish larvae (e.g., *Scophthalmus maximus*). In this case, a PNEC is derived by dividing the lowest acute LC50 or EC50 concentration by a maximum assessment factor of 1000, according to OLF (2003).

Toxicity data for calculating PNEC values of the individual compounds of chemical mixtures are only rarely available. If toxicity data are available only on a whole mixture, PNEC values are determined from the toxicity of the mixture. When toxicity data are available on individual compounds of the mixture, PNEC values of the individual compounds of the mixture are preferably applied.

1.3 Environmental Risk and the EIF

The EIF for a single compound or compound group relates to the water volume where the ratio of PEC/PNEC equals or exceeds unity. An EIF of unity is defined as a water volume 100 m x 100 m x 10 m (10^5 m^3) in which the fraction of potentially affected species is 5% (Figure 2-1). For a single compound, this corresponds to a PEC/PNEC ratio equal to unity (after Karman et al., 1994, and also published in Karman and Reerink, 1997). Figure 2-2 shows the relationship between the PEC/PNEC ratio and the fraction of species potentially affected.

⁶ PEC = Predicted Environmental Concentration

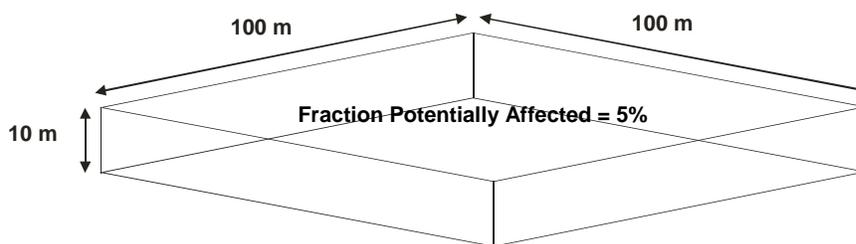


Figure 1-1 EIF water volume = 1

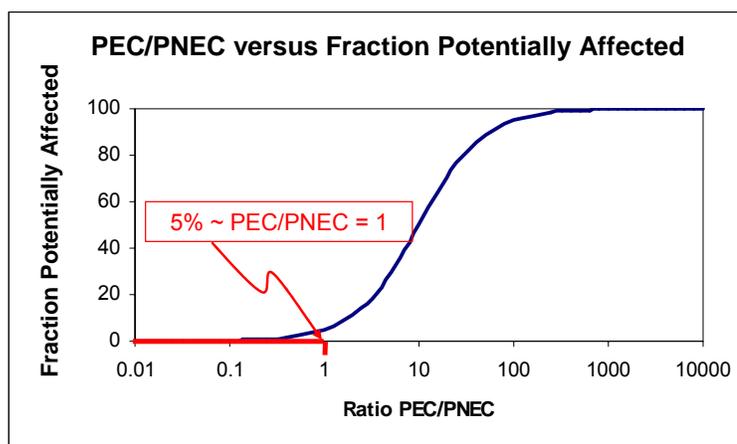


Figure 1-2 Relation between PEC/PNEC and the fraction of potentially affected species. Based on Karman et al. (1994).

The EIF method has the advantage over other risk assessment methods in that it can calculate risk contributions from a sum of chemicals and/or natural compounds in the receiving environment. Total risk is calculated from the sum of independent probabilities:

$$P(A + B) = P(A) + P(B) - P(A) * P(B) \quad (2.1)$$

where $P(A)$ is the probability of environmental risk for compound A and $P(B)$ is the probability of risk for compound B. For small risks (that is, $P(A)$ and $P(B)$ are both small), or risks from compounds that are toxicologically similar in their activity, the risks can be considered to be linearly additive, approximately. The method does not account for interactions among chemicals.

The total risk resulting from all compounds is calculated by the DREAM model in space and time within the model domain. The resultant 3-dimensional risk fields can then be viewed as a time series of risk fields. Alternatively, the risk for each point in space and time can be converted back to a nominal PEC/PNEC value. Results can also be presented as risk in percent.

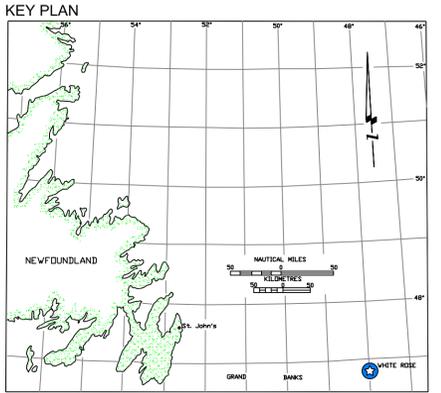
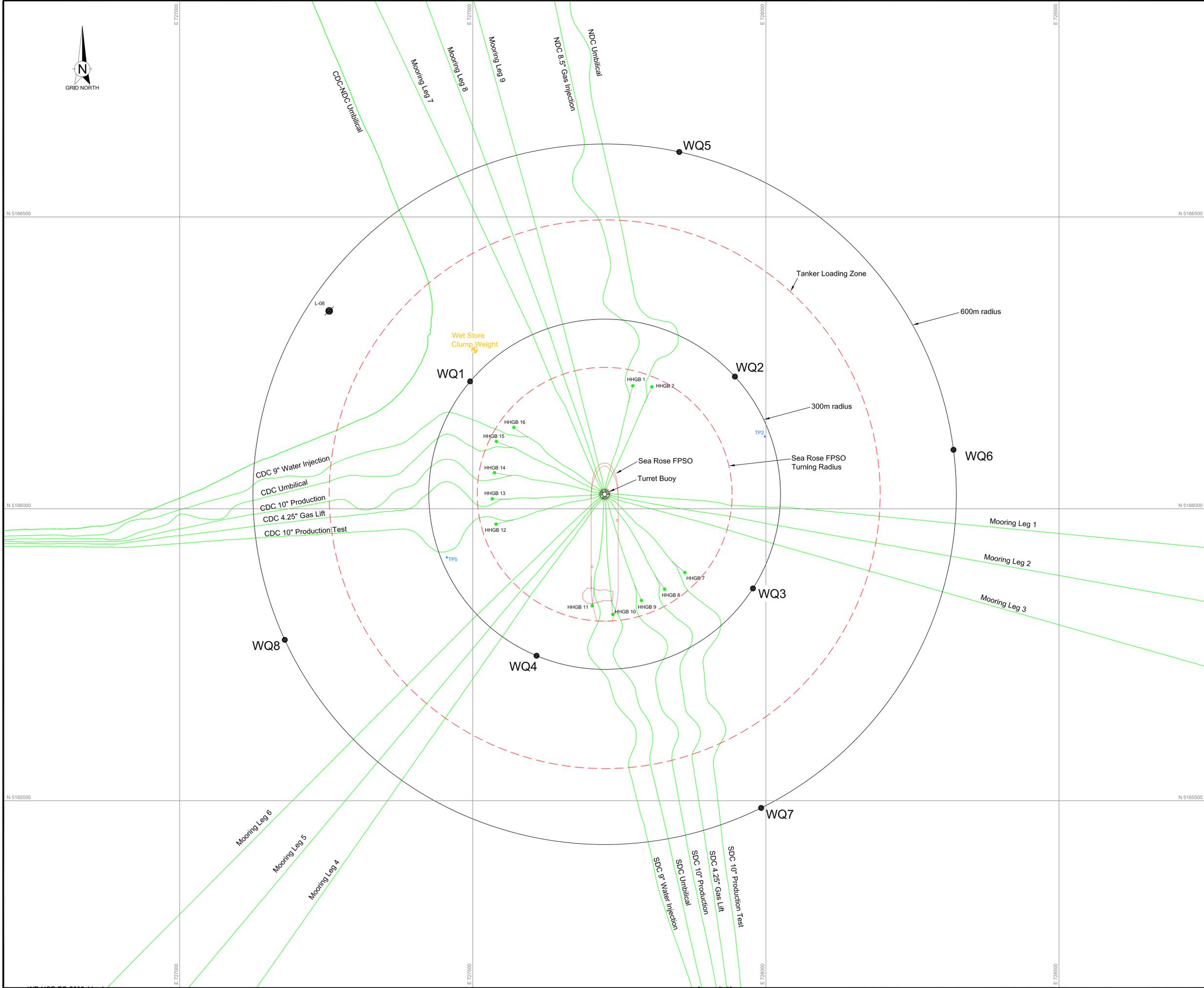
Note that the PEC/PNEC ratios for all individual compounds in the release may be less than unity, but the nominal PEC/PNEC ratio produced by the procedure described above, and representing a conglomerate value for the release, may exceed unity.

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Insert 1

Map of Near-Field Water Quality Stations and Subsea Structures around the White Rose FPSO



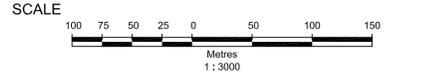
- LEGEND**
- - AS-BUILT HORIZONTAL HOLDBACK GRAVITY BASE LOCATION
 - - AS-BUILT SUBSEA ASSET
 - - WATER SAMPLING STATION
 - - ASLAIID COMPATT POSITION (FRAME ONLY)
 - - WELL (CNLOPB)

NOTE:
 TANKER LOADING ZONE AS PROVIDED BY HUSKY (470m RADIUS).
 TP POSITIONS ARE APPROXIMATE.

REFERENCE DRAWINGS			
DRAWING NO.	TITLE	REV NO.	DATE
9017SC-003-XRF-WRFLD-01-4	WHITE ROSE BASE MAP	E7	FEB. 25-10
WR-S-93-O-SB-00001-001 Rev E7			

MAP PROJECTION DETAILS
 NORTH AMERICAN DATUM 1983 (CSRS)
 GRS80 ELLIPSOID
 SEMI-MAJOR AXIS 6378137.00
 INVERSE FLATTENING 298.257222101
 6° UNIVERSAL TRANSVERSE MERCATOR
 ZONE 22 CENTRAL MERIDIAN: 51° W
 SCALE FACTOR AT C.M.: 0.9996
 FALSE EASTING: 500,000m
 FALSE NORTHING: 0m

FJG REVISION REFERENCE				
REV.	DATE	DESIGNATION	DRAWN	CHECK'D
0	25/MAR/10	INITIAL SUBMISSION	D.D.	A.C.



PREPARED BY
 Fugro Jacques GeoSurveys Inc.
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 CANADA A1B 3G2

TITLE
 WHITE ROSE WATER SAMPLING STATIONS
 MOORING AND RISER AREA

JOB NUMBER: 10031SP-003	DRAWN BY: D.D.	CHECKED BY: A.C.	REV 0
DATE: MARCH 25, 2010	FJGI DWG No: 10031SP-001-POS-TUREEM-01-0		