WhiteRose

Husky Energy

White Rose

Environmental Effects Monitoring Program

2016 (Volume 1 of 2)

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Executive Summary

The White Rose Environmental Effects Monitoring (EEM) program was designed to evaluate the environmental effects of Husky Energy's offshore oil drilling and production activities for the White Rose Development. Program design drew on the predictions and information in the White Rose Development Plan Environmental Impact Statement (EIS) and its supporting modelling studies on drill cuttings and produced water dispersion. Baseline studies to document pre-development conditions were conducted in 2000 and 2002. Those studies, combined with stakeholder and regulatory agency consultations, initiated the detailed design phase of the program. Further input on EEM program design was obtained from an expert advisory group called the White Rose Advisory Group. Beyond this, EEM results are reviewed by the regulatory community after each EEM cycle to support planning for the coming cycle. Comments from the regulatory community on the 2014 EEM program are provided in Appendix A.

The purpose of the EEM program is to assess environmental effects predictions made in the EIS and determine the area demonstrably affected by Husky Energy activities in the White Rose Field. In accordance with the design protocol, the program is updated to accommodate expansions and the establishment of new drill centres within the White Rose Field. The main components of the EEM program are sediment quality, commercial fish, and water quality.

Seabed sediments and commercial fish species from the White Rose Field have been collected in 2004, 2005, 2006, 2008, 2010, 2012, 2014, and 2016 to assess environmental effects. Sediment samples collected as part of the Sediment Quality Component of the EEM program have been processed for physical and chemical characteristics, toxicity, and an evaluation of benthic (seafloor) invertebrate communities. These three sets of measurements are collectively known as the Sediment Quality Triad. For the Commercial Fish Component of the EEM program, American plaice (a common flatfish species) and snow crab (an important commercial shellfish species), have been processed for contaminants (chemical body burden), taint and, for plaice, various health indices. A series of measurements (*e.g.*, length, weight, maturity) are also made on each species.

Seawater samples have been collected at White Rose in 2008, 2010, 2012, 2014, and 2016 and processed for chemistry and total suspended solids. The Water Quality sampling program in 2008 was preliminary, with fewer stations and variables sampled in that year than in 2010, 2012, 2014 and 2016. In addition to collection of seawater samples, the Water Quality Component of the EEM program in 2010 included sampling for sediment chemistry at Water Quality stations and a produced water modelling component to assess which constituent of produced water (the main liquid discharge from White Rose) would have a higher probability of being detected in seawater samples. The 2012 Water Quality program included seawater sampling, sediment chemistry sampling at Water Quality stations and a modelling component to assess potential concentrations of produced water constituents in sediments. Modelling was used as part of the White Rose Water Quality program to iteratively improve field sampling. The 2014 and 2016 Water Quality programs included seawater sampling and sediment chemistry sampling at Water Quality stations; there was no modelling component in the 2014 and 2016 Water Quality programs.

Figure 1 illustrates the components of the EEM program.

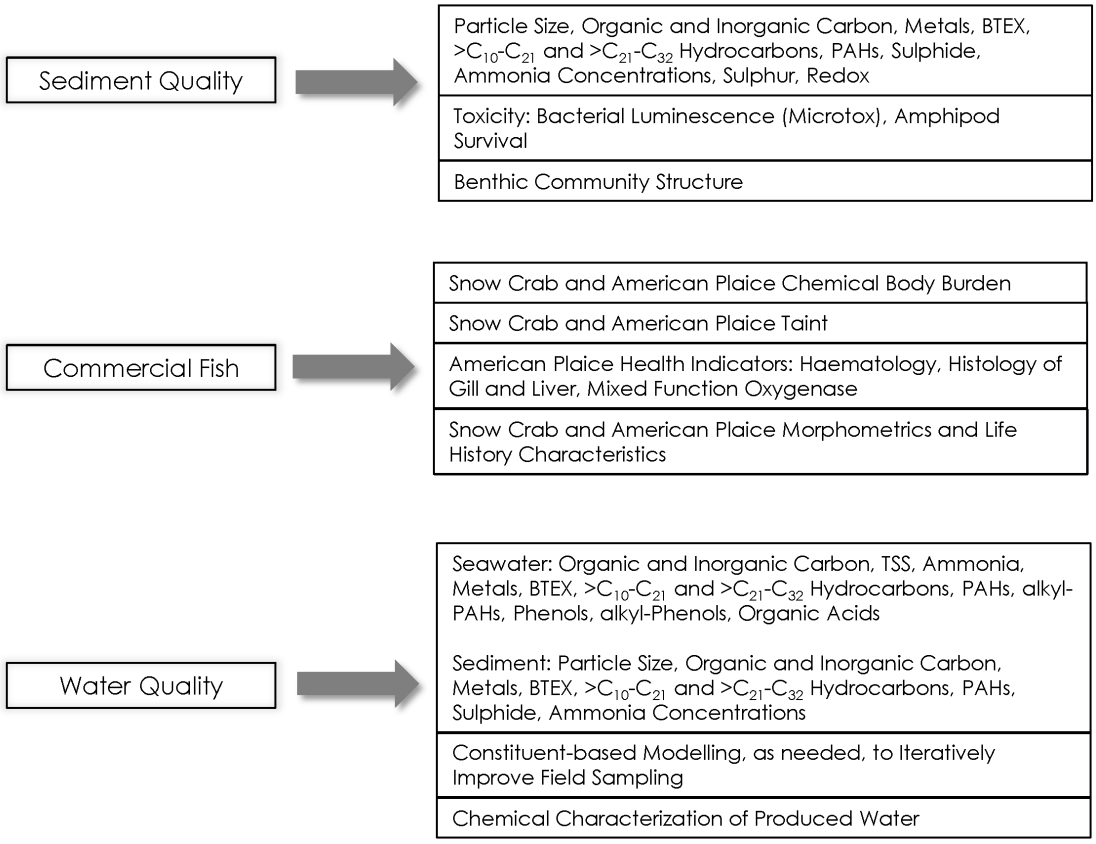

Figure 1 EEM Program Components

Notes: BTEX: Benzene, toluene, ethylbenzene, xylene.
PAH: Polycyclic aromatic hydrocarbon.
TSS: Total suspended solids.

This report provides the results from the eighth round of post-operational sampling under the program conducted in the summer (commercial fish survey) and fall (sediment and water survey) of 2016. The findings are interpreted in the context of results of previous sampling years and the baseline data collected pre-development.

Sediment Quality

In 2016, seafloor sediments were sampled for Sediment Quality Triad variables at 53 locations surrounding the Northern, Central, Southern, North Amethyst, and South White Rose Extension Drill Centres. This allowed an assessment of environmental conditions over an area of 1,200 km² around the White Rose Field.

Analysis of sediment physical and chemical characteristics showed that concentrations of drill mud hydrocarbons and barium were elevated near active drill centres and concentrations decreased with distance from drill centres, as expected. To a lesser extent, sediment lead, strontium, sulphide, sulphur, and fines content were also affected by drilling. There was no evidence of project effects on other physical or chemical parameters measured in sediments.

Maximum drill mud hydrocarbon (hydrocarbons in the $>C_{10}$-C_{21} range) and barium concentrations at White Rose in 2016 were 150 and 2,400 mg/kg, respectively. The estimated distance over which hydrocarbons concentrations were correlated with distance from active drill centres (*i.e.*, the threshold distance) extended to an average 2.7 km in 2016, less than the average of 5.8 km noted in 2014. The distance over which barium concentrations were correlated with distance from active drill centres extended to an average of 1.2 km, similar to the average of 1 km noted in 2014. In general, estimated average threshold distances for both hydrocarbons and barium were greater in earlier EEM years (2004 to 2010) than they have been in more recent years.

In 2016, project effects on sediment lead concentrations were noted to an average distance of 1.4 km from drill centres. Project-effects have been noted for lead since 2006, and threshold distances have consistently been approximately 1 km.

Project effects were also noted for strontium and sulphides, with effects weaker than in previous years. In 2016, strontium and sulphide levels were elevated to approximately 1 km from drill centres, but no precise threshold distance could be estimated. Threshold distances were detectable for strontium and sulphides in 2006, 2008 and for strontium, in 2012.

There was an indication that sediment sulphur and fines content were elevated in the immediate vicinity (0.5 km) of drill centres. These subtle effects on sulphur and fines have been noted in previous EEM years.

Sediments were generally non-toxic in 2016. Two (of 53) samples were toxic to Microtox and no station was toxic to laboratory amphipods. Sediment concentrations of drill mud hydrocarbons, barium, sulphur, and strontium were elevated at the two stations that were toxic to Microtox, and lead was also elevated relative to other stations at one of the two toxic stations. Together, these findings point to effects on Microtox at two stations[1]. No samples, including those toxic to Microtox, were toxic to laboratory amphipods; and amphipod survival was higher near drill centres; a response that does not suggest project effects. Over all eight EEM years, only six samples (of 299 samples) have been toxic to Microtox and 14 (of 299) samples have been toxic to laboratory amphipods, indicating that sediments at the White Rose Field are generally non-toxic.

As in previous years, there was evidence of project effects on total benthic invertebrate abundance and biomass, and no evidence of effects on richness. Overall effects on total abundance remain weak. In 2016, as in previous years, total abundance was reduced at some stations within 1 km of drill centres. Reductions in the number of some polychaete worm and crustacean taxa (Paraonidae, Orbiniidae, Spionidae, and Tanaidacea) were predominantly responsible for the overall decrease in abundance near drill centres. Conversely, other polychaete taxa (Cirratulidae and Pholoidae), increased in numbers near drill centres.

Of the taxa listed above, the polychaete family Paraonidae was most affected by project-related activity, with decreased numbers noted to 1 to 2 km. As was the case for drill mud hydrocarbons and barium, there was an indication that the distance over which this

[1]Only one of these stations was affected by the White Rose Development. The other station (Station 31) was predominantly affected by delineation drilling.

taxon was affected was greater in earlier EEM years (approximately 3 to 4 km from 2004 to 2008) and approximately 1 to 2.5 km from 2010 to 2016.

Biomass was reduced in the immediate vicinity (within less than 1 km) of drill centres in 2016, but effects were less spatially extensive that those noted in 2012 (1.5 km) and 2014 (5.5 km). Reductions in biomass near drill centres has been shown to be related to reduced numbers of larger echinoderms near drill centres.

After monitoring sediment quality at White Rose eight times over a period of 12 years, noted effects on sediment physical and chemical variables and benthos have varied in strength from year to year. With the addition of 2016 information, there is no indication that effects are getting greater in magnitude or in extent. The reduction in the spatial extent of effects on sediment concentrations of drill mud hydrocarbons, barium, Paraonidae abundances, and biomass, and the weaker relationship between sediment strontium and sulphide concentrations and distance to drill centres, suggests that effects may be getting more localized.

Commercial Fish

During the Summer (July) of 2016, samples of American plaice and snow crab were collected near the White Rose Field (the Study Area) and at three Reference Areas, located approximately 28 km to the southwest, northwest, and southeast of the White Rose Field. As noted above, samples were analyzed for chemical body burden and taint. In addition, analyses were also performed on American plaice for a variety of fish health indices, as outlined in Figure 1.

In 2016, there continues to be little evidence of project effects on metal and hydrocarbon concentrations in American plaice and snow crab tissues. Furthermore, results of taste tests demonstrated that edible tissues from the two species were not tainted, and indices of fish health for American plaice showed that the general health and condition of this species was similar between the Study and Reference Areas.

Overall, analyses of tissue chemistry, taste, and fish health revealed no compelling evidence of effects of project activities on commercial fish.

Water Quality

In the Fall (September) of 2016, water samples were collected in two Study Areas, the first (near-field) located 300 m from the *SeaRose* floating, production, storage, and offloading (*FPSO*) vessel and the second (mid-field) located 4 km to the southeast. Samples were also collected in two Reference Areas, located approximately 28 km to the northeast and northwest. Samples were processed for parameters listed in Figure 1.

Results indicated differences in seawater chemistry between the mid-field Study Area and remaining areas, but these differences could not be attributed to project activities. This analysis of general trends among Areas also showed no differences between the near-field Study and the Reference Areas that would point toward project effects. However, examination of individual occurrences indicated low level concentrations of some produced water constituents at three near-field (300 m) stations.

Overall, analysis of general trends in seawater chemistry does not indicate any project effects on water quality at the White Rose Field. The occurrence of produced water constituents in some samples indicates that produced water may have been detected at some stations located 300 m from the *SeaRose FPSO*, consistent with the prediction that effects of produced water would be localized near the point of discharge.

Conclusions

The following sediment quality variables were affected by the White Rose development in 2016: drill mud hydrocarbons; barium; lead; strontium; sulphides; sulphur; fines; total benthic invertebrate abundance; and biomass. Of the benthic invertebrate taxa examined, one family of polychaete worms (Paraonidae) was most affected by drilling discharge. Despite changes in sediment contamination, sediment toxicity, and benthic invertebrate responses since drilling began at White Rose in 2004, there has not been any consistent accentuation of contamination or responses. In fact, the 2016 data suggests that effects may be getting more localized.

Sediment contamination and effects on benthos noted in 2016 and in previous years have not translated into effects on the fisheries resources, as indicated by fish health assessment and taint tests. No project-related tissue contamination was noted for crab or plaice. Neither species were tainted; plaice health was similar between White Rose and more distant Reference Areas.

Although some produced water constituents may have been detected in the immediate vicinity of the *SeaRose FPSO*, overall water quality was not affected by project activity.

As there has been no continued degradation of the environment at the White Rose Field, results justify continued monitoring, without further mitigation.

Acknowledgements

Project management for the White Rose EEM program was executed by Ellen Tracy at Stantec Consulting Ltd. (St. John's, Newfoundland and Labrador). Participants in the commercial fish survey included Doug Rimmer and Sean Wilson from Stantec Consulting Ltd., and Wynnann Melvin and Matthew Osse from Oceans Ltd. (St. John's, Newfoundland and Labrador). Participants in the sediment and water survey included Doug Rimmer, Melinda Watts, Ryan Melanson, Emile Colpron, and Dan Lee from Stantec Consulting Ltd. and Adam Templeton from Oceans Ltd. Fugro Geosurveys (Jason Dawe and Devin Rideout) provided geopositional services for sediment and water collections. Benthic invertebrate sorting, identification and enumeration was led by Patricia Pocklington of Arenicola Marine (Wolfville, Nova Scotia). Chemical analyses of tissues and sediments were conducted by Maxxam Analytics (Halifax, Nova Scotia). Chemical analyses of seawater were conducted by Maxxam Analytics and RPC (Fredericton, New Brunswick). Sediment toxicity tests were conducted by petroforma inc. (St. John's, Newfoundland and Labrador). Sediment particle size analysis was conducted by Stantec Consulting Ltd. Fish and shellfish taste tests were performed at the Marine Institute of Memorial University (St. John's, Newfoundland and Labrador). Laboratory analyses for fish health indicators were supervised by Dr. Juan Perez Casanova of Oceans Ltd. Sediment quality, body burden, and fish health data were analyzed by Dr. Marc Skinner (Stantec Consulting Ltd.). Water quality data analysis was performed by Dr. Elisabeth DeBlois (Elisabeth DeBlois Inc., St. John's, Newfoundland and Labrador) and Dr. Marc Skinner. Drs Elisabeth DeBlois, Marc Skinner and Juan Perez Casanova wrote sections of the report. Technical review and consolidation of text within each report section was done by Dr. Elisabeth DeBlois. Editing and report consolidation was performed by Ellen Tracy (Stantec Consulting Ltd.). Karen Williams and Heather Ward (Stantec Consulting Ltd.) provided administrative and graphics support, respectively. Ellen Tracy, Marc Skinner and Mary Murdoch reviewed the report from a quality control perspective at Stantec Consulting Ltd. The report was prepared and finalized under the direction of David Pinsent (Husky Energy). Steve Bettles (Husky Energy) reviewed the document before final production.

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1.1 Project Setting and Field Layout

Husky Energy (Husky), with its joint-venture partner Suncor Energy, is developing and operating the White Rose Field on the Grand Banks, offshore Newfoundland. The field is approximately 360 km east-southeast of St. John's, Newfoundland and Labrador, 50 km from both the Terra Nova and Hibernia fields and 46 km from the Hebron Field (Figure 1-1). At first oil in November 2005, the White Rose Development consisted of three drill centres – the Northern, Central and Southern Drill Centres. The North Amethyst Drill Centre was excavated in 2007 and the South White Rose Extension (SWRX) Drill Centre was excavated in 2012 (Figure 1-2). Nalcor Energy is an additional partner in the North Amethyst and SWRX Drill Centres developments.

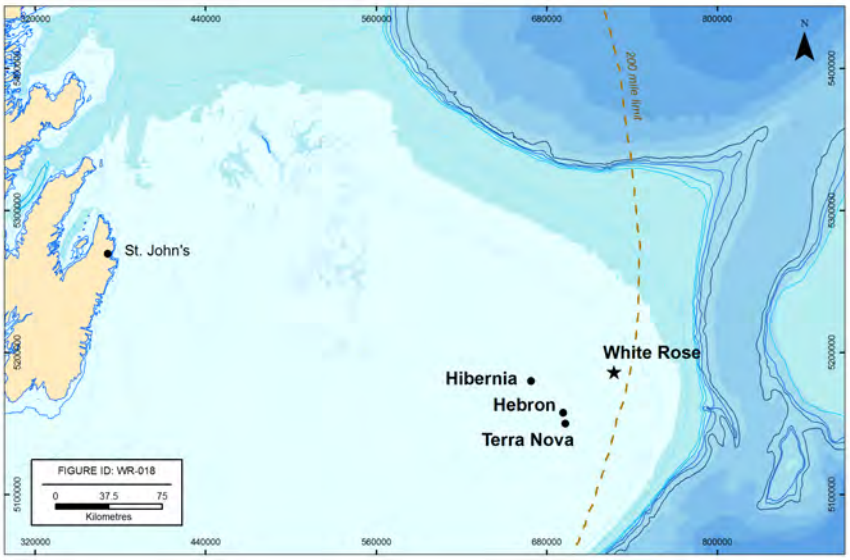

Figure 1-1 Location of the White Rose Field

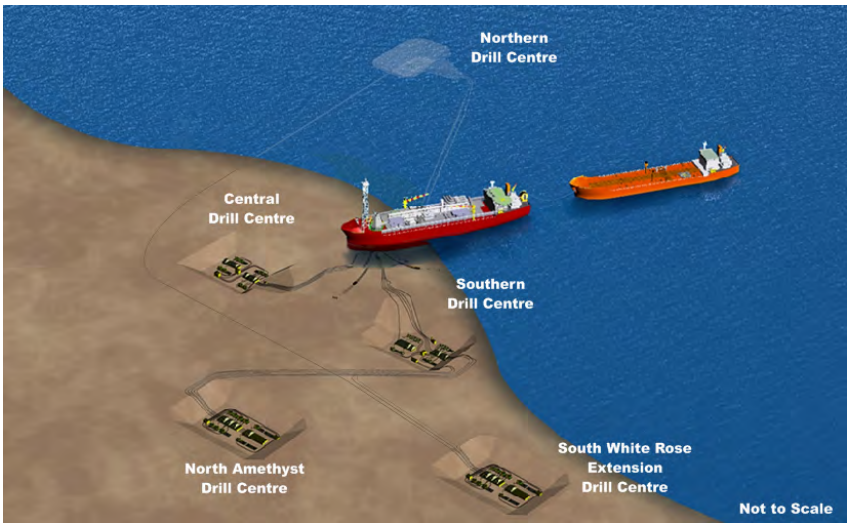

Figure 1-2 White Rose Field Layout

1.2 Project Commitments

Husky committed in its Environmental Impact Statement (EIS) (Part One of the White Rose Oilfield Comprehensive Study (Husky Oil Operations Limited 2000)) to develop and implement a comprehensive Environmental Effects Monitoring (EEM) program. This commitment was integrated into Decision 2001.01 (C-NLOPB (Canada-Newfoundland and Labrador Offshore Petroleum Board) 2001) as a condition of project approval.

Also, as noted in Condition 38 of Decision 2001.01 (Canada-Newfoundland Offshore Petroleum Board 2001), Husky committed, in its application to the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB), to make environmentally-related information available to interested parties and the general public. Husky's Environmental Protection and Compliance Monitoring Plans, prerequisites for the issuance of Operating Authorizations by the C-NLOPB, state that Husky will make the Baseline and EEM reports available to the public via Husky's corporate website.

1.3 EEM Program Design

Husky submitted an EEM program design to the C-NLOPB in May 2004, which was approved for implementation in July 2004. The design drew on information provided in the White Rose EIS (Husky Oil Operations Limited 2000), drill cuttings and produced water dispersion modelling for White Rose (Hodgins and Hodgins 2000), the White Rose Baseline Characterization program carried out in 2000 and 2002 (Husky Energy 2001, 2003), stakeholder consultations and consultations with regulatory agencies. Revised versions of the EEM program design document to accommodate the development of the North Amethyst Drill Centre were submitted to the C-NLOPB in July 2008 and, subsequently, in March 2014 to accommodate the SWRX Drill Centre and incorporate the Water Quality monitoring component.

1.4 EEM Program Objectives

The EEM program is intended to provide the primary means to determine and quantify project-induced change in the surrounding environment. Where such change occurs, the EEM program enables the evaluation of effects relative to EIS predictions and the identification of appropriate modifications to project activities.

Objectives to be met by the White Rose EEM program are:

- to estimate the zone of influence[2] of project contaminants;
- to test biological effects predictions made in the EIS;
- to provide feedback to Husky for project management decisions requiring modification of operations practices where/when necessary; and
- to provide a scientifically-defensible synthesis, analysis, and interpretation of data.

[2] The zone of influence is defined as the zone where project-related physical and chemical alterations might occur.

1.5 White Rose EIS Predictions

The White Rose EIS assessed the significance of environmental effects on Valued Ecosystem Components. Valued Ecosystem Components addressed within the context of the Husky EEM program are Fish and Fish Habitat and Commercial Fisheries (Husky Oil Operations Limited 2000). As such, predictions on physical and chemical characteristics of sediment and water, and predictions on benthos, fish, and fisheries, apply to the EEM program.

In general, development operations at White Rose were expected to have the greatest effects on near-field sediment physical and chemical characteristics through release of drill cuttings, while regular operations were expected to have the greatest effect on physical and chemical characteristics of water, through release of produced water. The zone of influence for these two waste streams, predicted from an initial modelling study for White Rose (Hodgins and Hodgins 2000), was not expected to extend beyond approximately 9 and 3 km from source for drill cuttings and produced water, respectively. Effects of other waste streams (see Section 4 for details of other waste streams associated with drilling and production) on physical and chemical characteristics of sediment and water were considered small relative to effects of drill cuttings and produced water discharge.

Effects of drill cuttings on benthos were expected to be low to high in magnitude[3] within approximately 500 m, with overall effects low in magnitude. However, direct effects to fish populations, rather than benthos (on which some fish feed), as a result of drill cuttings discharge were expected to be unlikely. Effects resulting from contaminant uptake by individual fish (including taint) were expected to range from negligible to low in magnitude and be limited to within 500 m of the point of discharge.

Effects of produced water (and other liquid waste streams) on physical and chemical characteristics of water were expected to be localized near the point of discharge. Liquid waste streams were not expected to have any effect on physical and chemical characteristics of sediment or benthos. Direct effects on adult fish were expected to be negligible.

Given predictions of effects on sediment and water quality, anticipated effects on Fish and Fish Habitat and Commercial Fisheries were assessed as not significant in the White Rose EIS (Husky Oil Operations Limited 2000). The development of the North Amethyst and SWRX Drill Centres was assessed in the New Drill Centre Construction and Operations Program Environmental Assessment (LGL 2006). Predictions in the New Drill Centre Environmental Assessment were consistent with the White Rose development EIS (Husky Oil Operations Limited 2000) in that, based on modelling, 500 m was estimated as the radius of each well's biological zone of influence (*i.e.*, potential smothering due to a minimum of 1 cm thickness of deposited cuttings and mud). Cumulative effects from new drill centre construction and operations were assessed as non-significant.

[3]Low = Affects 0 to 10 percent of individuals in the affected area; medium = affects 10 to 25 percent of individuals; high = affects more than 25 percent of individuals.

Predictions and the rankings used to assess effects are described in greater detail in project environmental assessments (Husky Oil Operations Limited 2000; LGL 2006). Further discussion on environmental assessment predictions are also provided in Section 8. For the purpose of the EEM program, testable hypotheses that draw on effects predictions were developed as part of EEM design and are discussed in Section 1.7.

1.6 EEM Program Components and Monitoring Variables

The White Rose EEM program is divided into three components: Sediment Quality, Commercial Fish, and Water Quality (Figure 1-3).

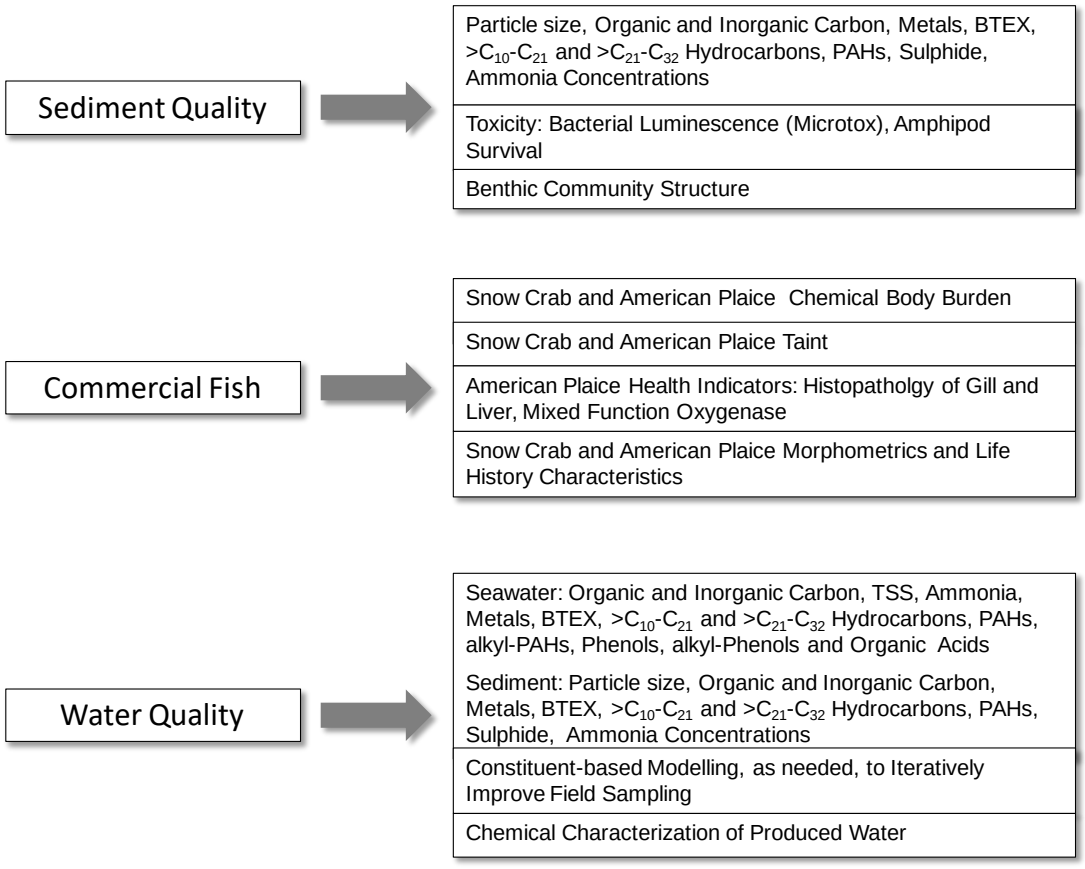

Figure 1-3 EEM Program Components

Notes: BTEX: Benzene, toluene, ethylbenzene, xylene.
PAH: Polycyclic aromatic hydrocarbon.
TSS: Total suspended solids.

Assessment of Sediment Quality includes measurement of alterations in chemical and physical characteristics, measurement of sediment toxicity and assessment of benthic community structure. These three sets of measurements are commonly known as the Sediment Quality Triad (Long and Chapman 1985; Chapman *et al.* 1987, 1991; Chapman 1992). These tests are used to assess drilling effects (Section 1.5).

Assessment of effects on Commercial Fish species includes measurement of chemical body burden, taint, morphometric and life history characteristics for snow crab (*Chionoecetes opilio*) and American plaice (*Hippoglossoides platessoides*) and measurement of various health indices for American plaice.

Assessment of Water Quality includes measurement of alteration of physical and chemical characteristics in the water column and measurement of alterations in sediment chemistry as a result of liquid discharge. Because contamination from liquid discharges from offshore installations is expected to be difficult to detect, constituent-based modelling is also undertaken, as needed, to attempt to identify constituents that would have a higher chance of being detected.

Further details on the selection of monitoring variables are provided in the White Rose EEM Program Design documents (Husky Energy 2004, 2008, 2010a, 2010b, 2014).

1.7 Monitoring Hypotheses

Monitoring, or null (H_0), hypotheses were established as part of the White Rose EEM program to assess effects predictions. Null hypotheses (H_0) will always state "no effects", even if effects have been predicted as part of the EIS. Therefore, rejection of a null hypothesis does not necessarily invalidate EIS predictions.

The following monitoring hypotheses were developed for the White Rose EEM program:

- Sediment Quality:
  - H_0: There will be no change in Sediment Quality Triad variables with distance or direction from project discharge sources over time.
- Commercial Fish:
  - $H_0(1)$: Project discharges will not result in taint of snow crab and American plaice resources sampled within the White Rose Study Area, as measured using taste panels.
  - $H_0(2)$: Project discharges will not result in adverse effects to fish health within the White Rose Study Area, as measured using histopathology and Mixed Function Oxygenase (MFO) induction[4].
- Water Quality:
  - H_0: The distribution of produced water from point of discharge, as assessed using moorings data and/or vessel-based data collection, will not differ from the predicted distribution of produced water.

[4] Haematology was removed from the list of fish health tests based on recommendations issuing from the 2014 EEM program (see Appendix A for details).

No hypotheses were developed for American plaice and snow crab chemical body burden and morphometrics and life history characteristics, as these tests were considered to be supporting tests, providing information to aid in the interpretation of results of other monitoring variables (taste tests and health).

1.8 EEM Sampling Design

Sediment samples are collected at stations in the vicinity of drill centres and at a series of stations located at varying distances from drill centres, extending to a maximum of 28 km along north-south, east-west, northwest-southeast, and northeast-southwest axes. The sediment sampling design is commonly referred to as a gradient design. This type of design assesses change in monitoring variables with distance from source.

Commercial fish are sampled near White Rose, in the vicinity of the drill centres, and normally at four distant Reference Areas located approximately 28 km to the northeast, northwest, southeast, and southwest. In 2016, sampling could not be performed in the northeast Reference Area because of intense commercial fishing activity for crab.

Water samples are collected in the vicinity of the *SeaRose* floating, production, storage and offloading (*FPSO*) vessel (at approximately 300 m), at mid-field stations located 4 km to the southeast of White Rose and in two Reference Areas located approximately 28 km to the northeast and northwest. The sampling designs for water samples and for commercial fish are control-impact designs (Green 1979). This type of design compares conditions near discharge source(s) to conditions in areas unaffected by the discharge(s).

1.8.1 Modifications to the Sediment Component

There are some differences between sediment stations sampled for baseline (2000) and for EEM programs (2004, 2005, 2006, 2008, 2010, 2012 and 2014). A total of 48 sediment stations were sampled during baseline (Figure 1-4), 56 stations were sampled for the 2004 EEM program (Figure 1-5), 44 stations were sampled for the 2005 EEM program (Figure 1-6), 59 stations were sampled in 2006 (Figure 1-7), 47 stations were sampled in 2008 (Figure 1-8), 49 stations were sampled in 2010 (Figure 1-9), 53 stations were sampled from 2012 to 2016 (Figures 1-10 and 1-11, respectively). In all, 36 stations were common to all sampling programs.

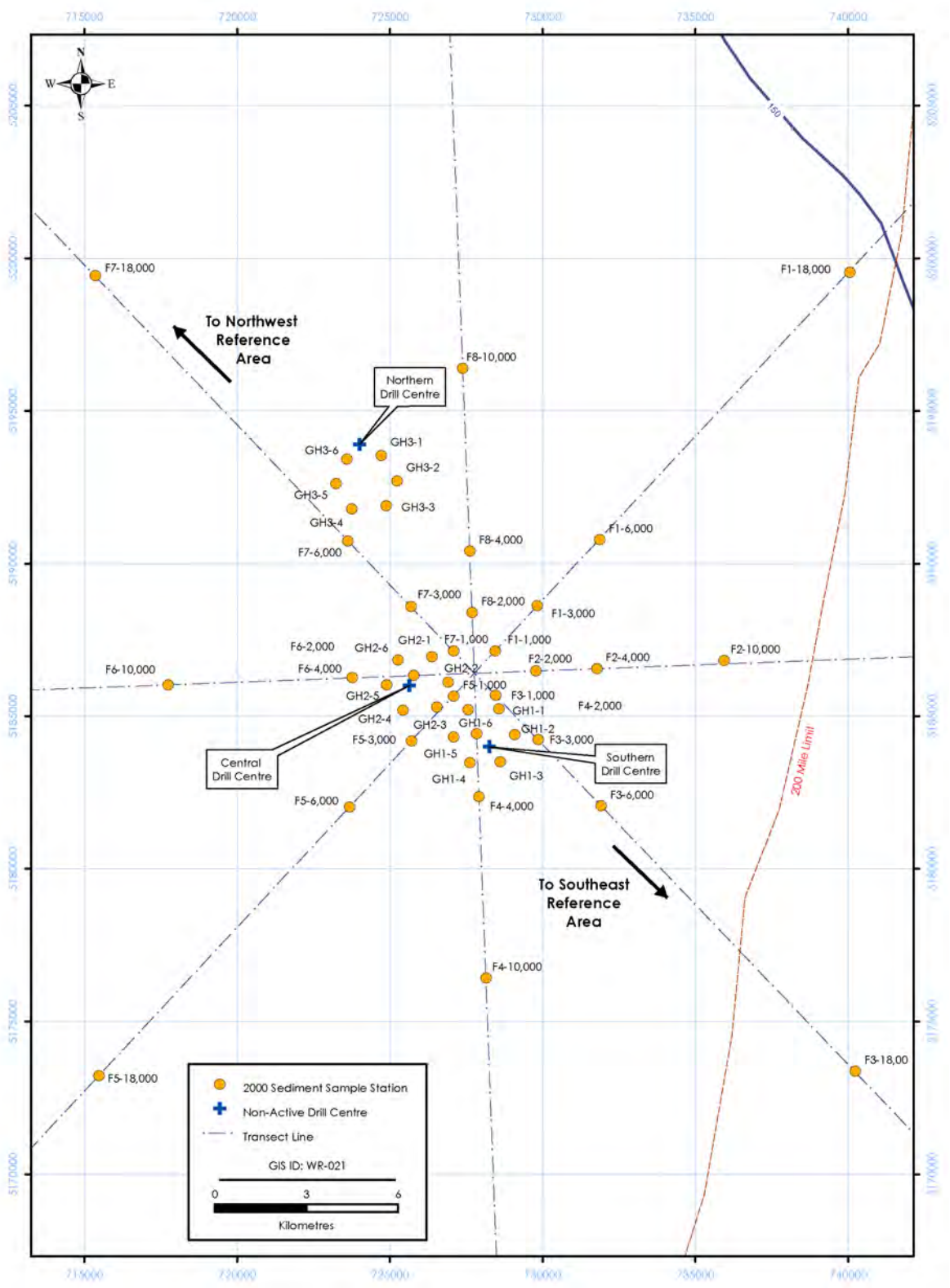

Figure 1-4 2000 Baseline Program Sediment Quality Stations

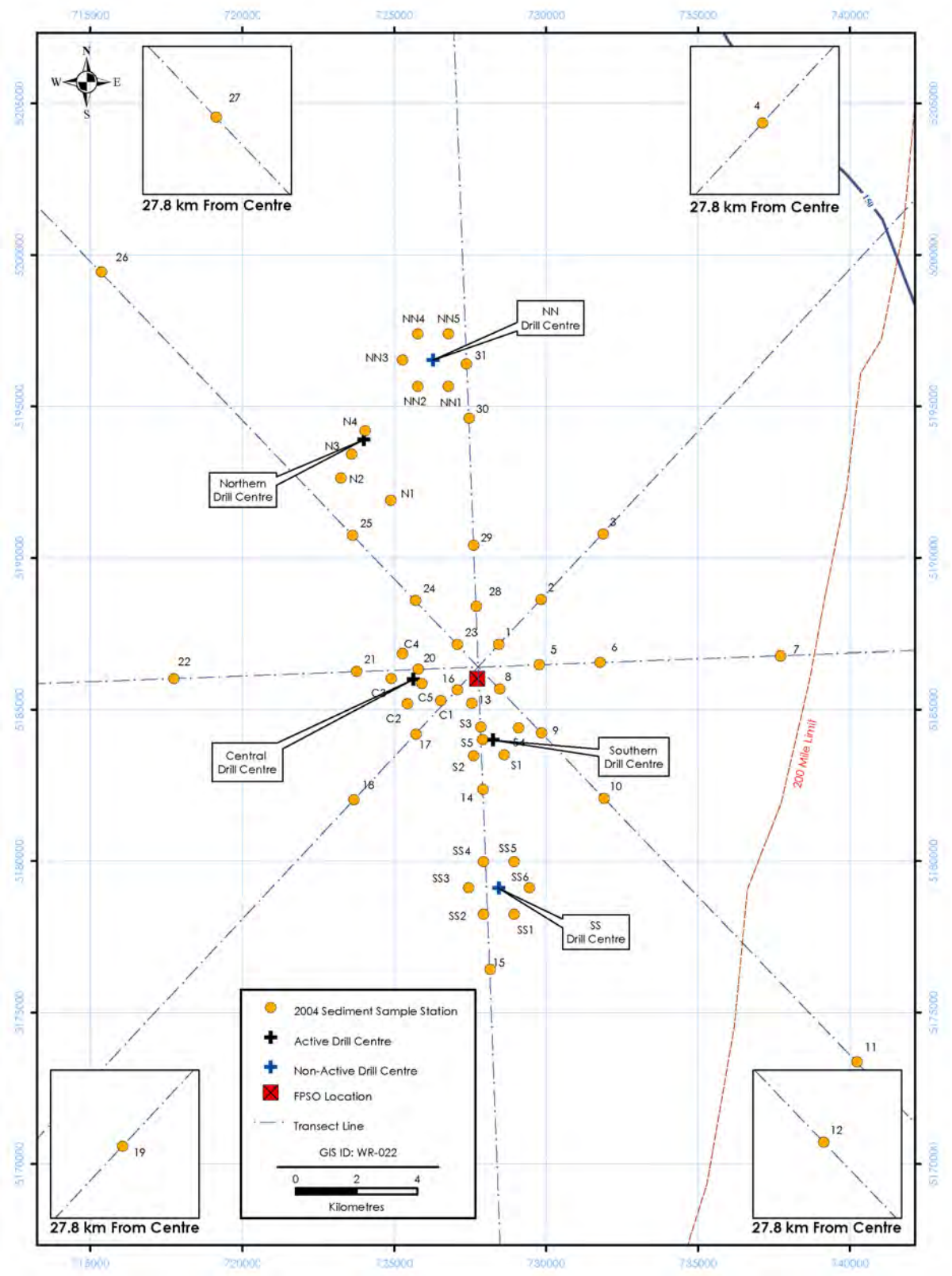

Figure 1-5 2004 EEM Program Sediment Quality Stations

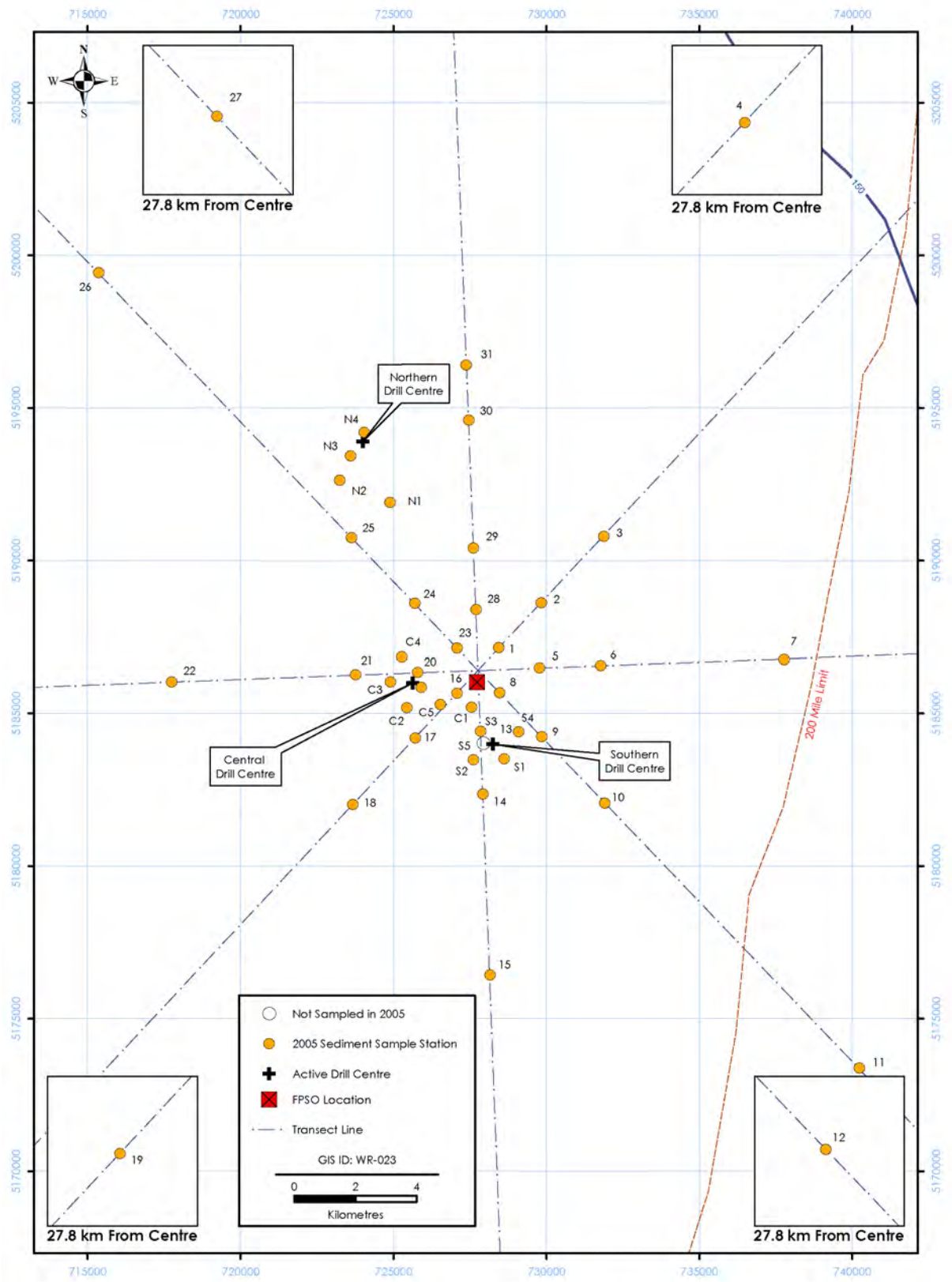

Figure 1-6 2005 EEM Program Sediment Quality Stations

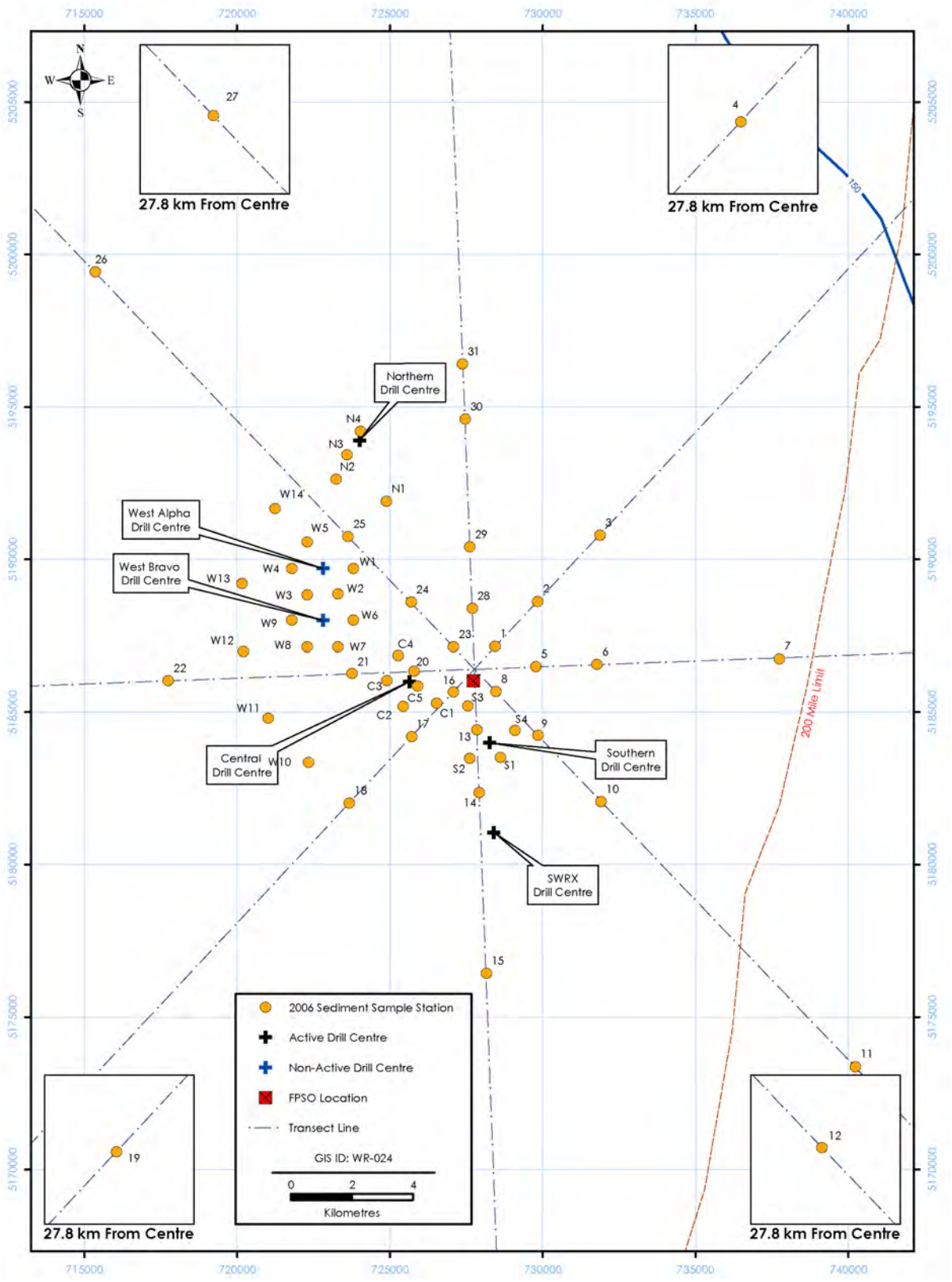

Figure 1-7 2006 EEM Program Sediment Quality Stations

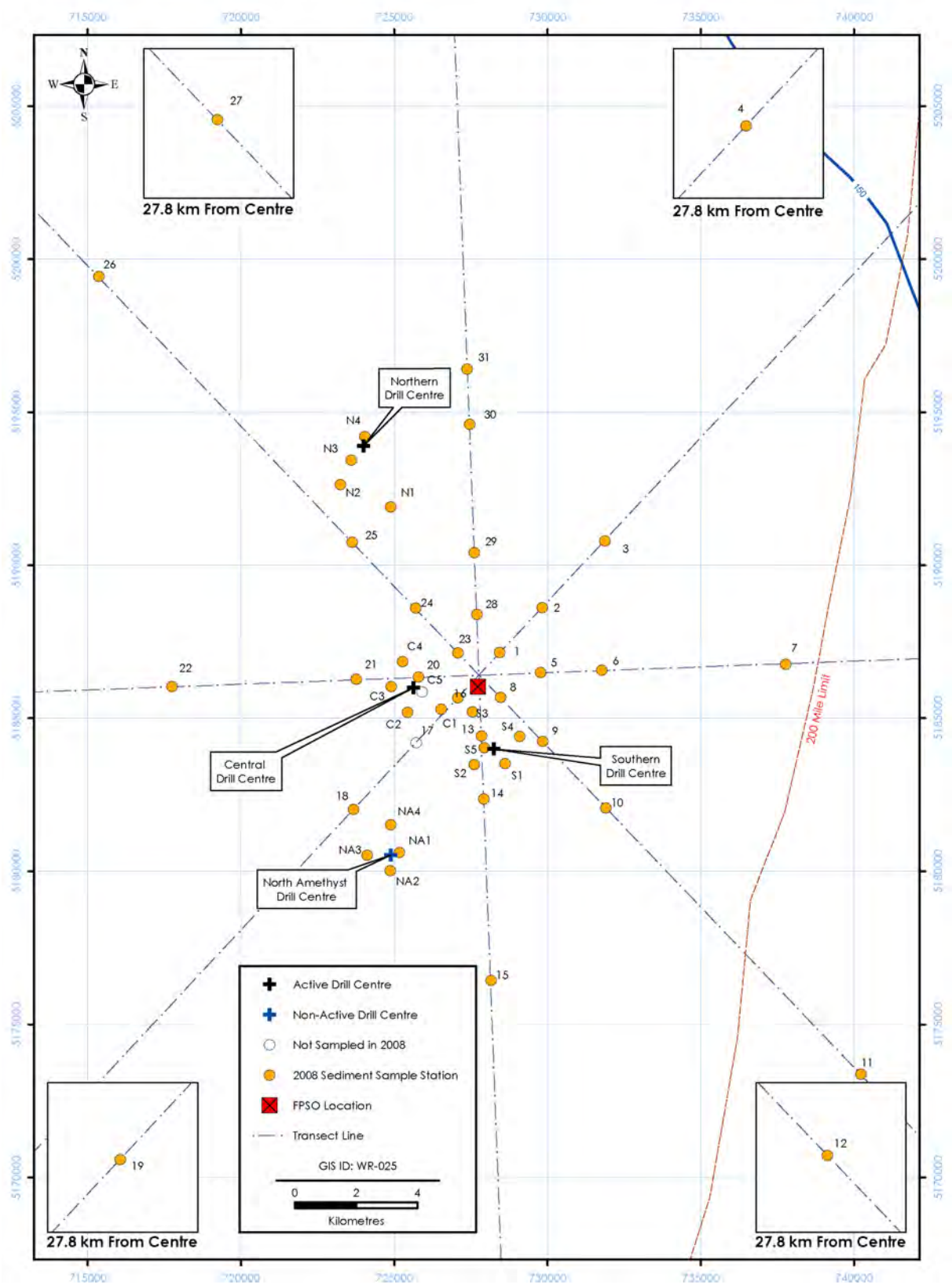

Figure 1-8 2008 EEM Program Sediment Quality Stations

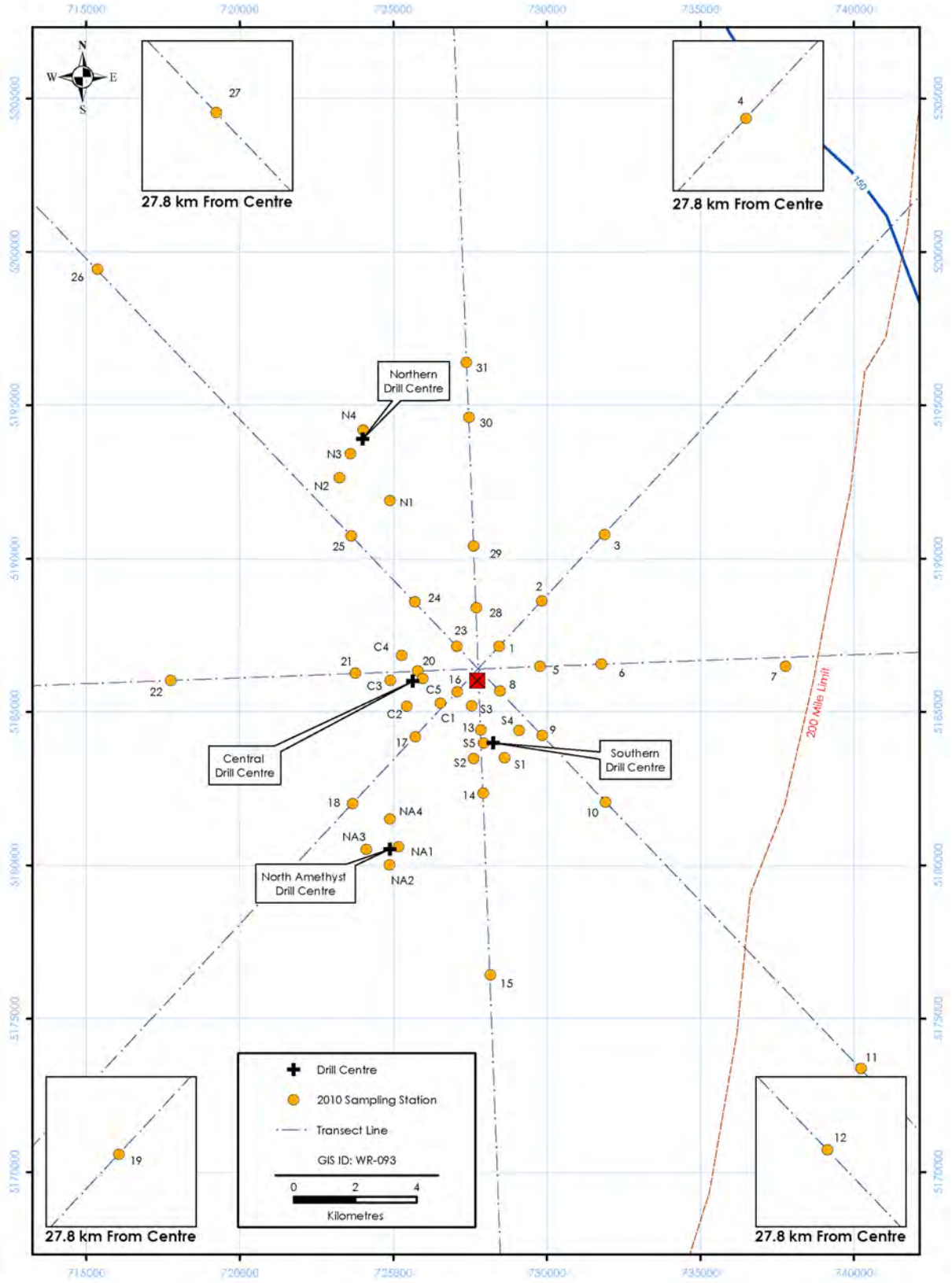

Figure 1-9 2010 EEM Program Sediment Quality Stations

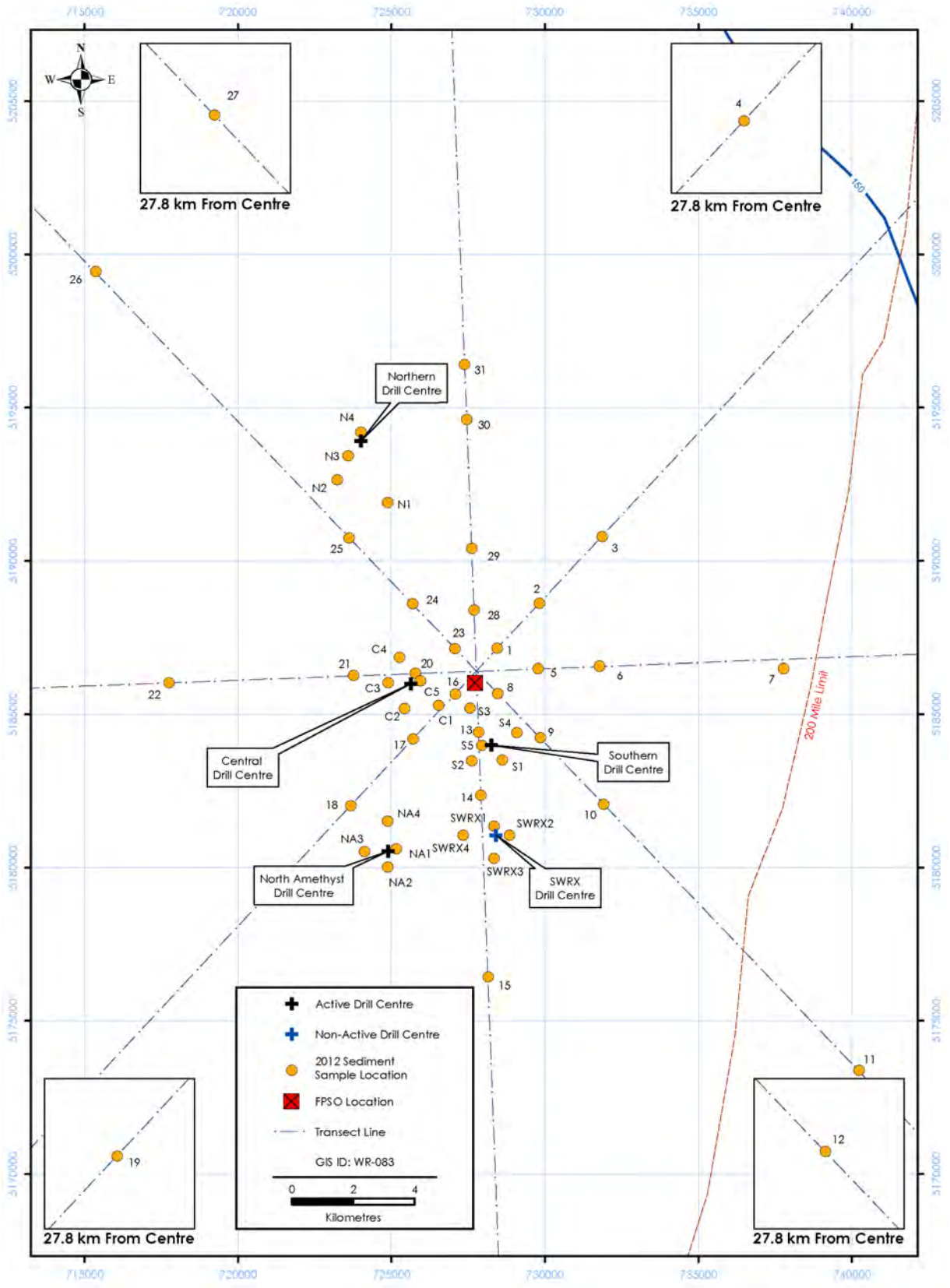

Figure 1-10 2012 EEM Program Sediment Quality Stations

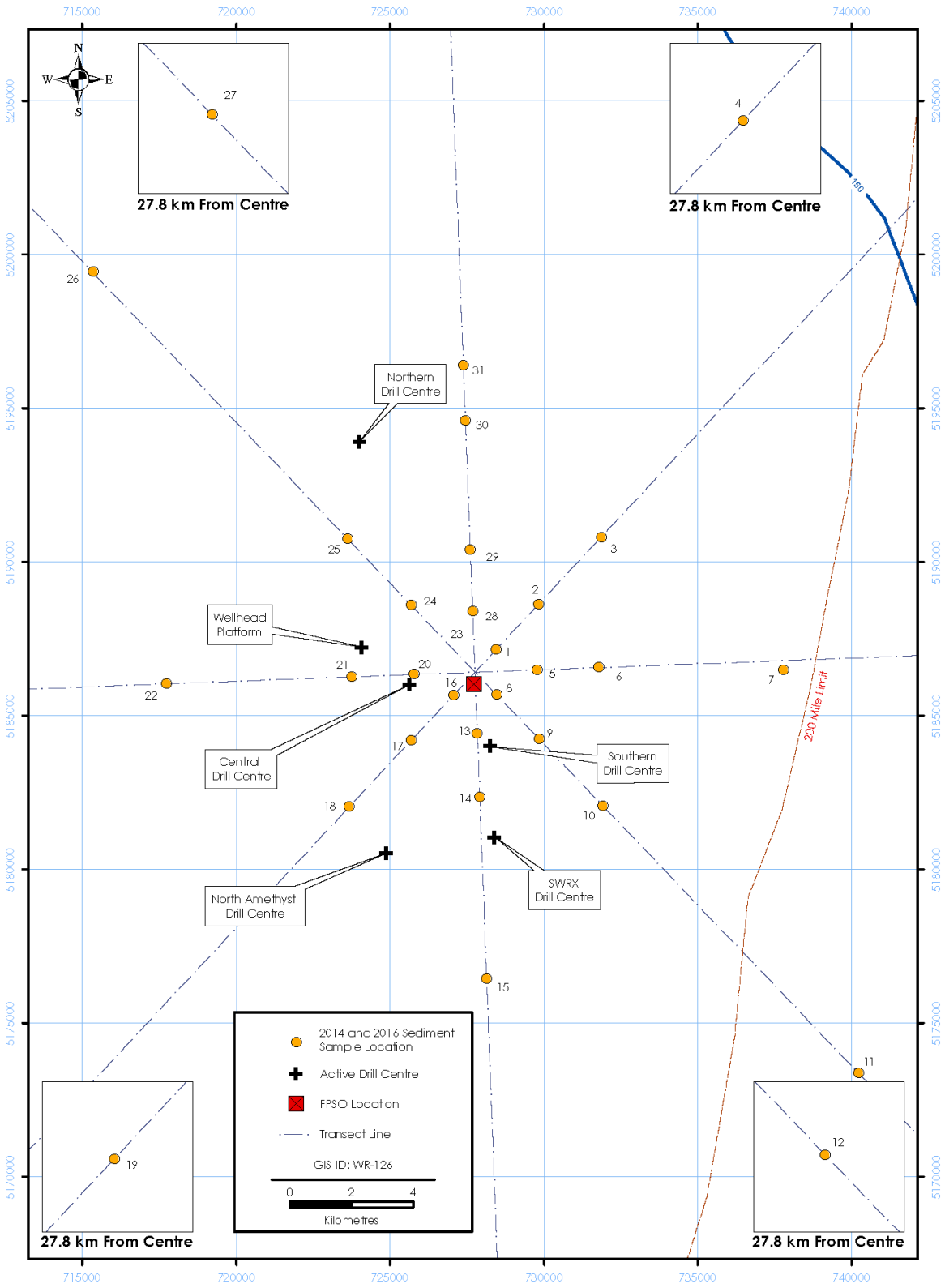

Figure 1-11 2014 and 2016 EEM Program Sediment Quality Stations

As part of EEM program design (Husky Energy 2004, 2008), seven baseline stations in the immediate vicinity of drill centres were eliminated because they were redundant. These stations were sampled during baseline because the final location of the Central, Northern and Southern Drill Centres had not been established. Two remote reference stations located 35 km south-southeast and 85 km northwest of White Rose were eliminated for the EEM programs because of their distance from the development and because sediment chemistry results from baseline sampling showed that the northwest reference station might not be comparable to other stations. Two 18-km stations were eliminated because of redundancies with other stations (see Husky Energy 2004 for details).

Original station additions for the EEM program included four reference stations at 28 km from the centre of the development, one station along the north axis at approximately 8 km from the centre of the development and three drill centre stations located approximately 300 m from each of the Northern, Central and Southern Drill Centres. However, in 2005, one of these stations (station S5) could not be sampled because of drilling activity at the Southern Drill Centre.

In 2004, six drill centre stations were sampled at 1 km from the proposed location of each of more northerly (NN) and more southerly (SS) drill centres to provide additional baseline data should drilling occur at these drill centres (see Figure 1-5). Since there are no immediate plans to drill at these drill centres, these stations were not sampled in subsequent programs. Similarly, 14 'West' stations were sampled in 2006 around the proposed location of the West-Alpha and West-Bravo Drill Centres located to the northwest of the Central Drill Centre (Figure 1-7).

In 2008, four new stations were added to the EEM program around the North Amethyst Drill Centre (Figure 1-8). These four stations, along with stations 14 and 18, were also sampled in 2007 to provide additional pre-drilling baseline information for that drill centre.

In 2010, stations NA1, NA4, C5 and 23 were moved slightly because of proximity to subsea infrastructure. NA4, 23 and C5 were relocated less than 15 m from the original locations. NA1 was relocated approximately 85 m from its original location but at the same distance from the drill centre as the original location.

In 2012, four stations were added around the SWRX Drill Centre (Figure 1-10) and stations 23, 25, C5, NA1, NA3 and N4 were moved slightly because of proximity to subsea infrastructure. All stations were moved less than 50 m from their original location.

In 2014, stations C1 and C5 were moved slightly because of proximity to subsea infrastructure. All stations were moved less than 50 m from their original location.

In 2016, stations SWRX1, SWRX2 and W-6MF were moved slightly because of proximity to subsea infrastructure. Stations W-6MF and SWRX2 were moved less than 50 m from their original location; station SWRXI was moved 106 m from its original location.

Table 1-1 provides a summary of changes between the 2000 baseline program and the 2016 EEM program for sediment, as well as station name changes that were proposed in the EEM design document to simplify reporting of results.

Table 1-1 Table of Concordance between Baseline and 2016 EEM Sediment Stations

EEM Program Station Name	Corresponding Station Name during the 2000 Baseline Program
1	F1-1,000
2	F1-3,000
3	F1-6,000
4	Not Sampled in 2000
5	F2-2,000
6	F2-4,000
7	F2-10,000
8	F3-1,000
9	F3-3,000
10	F3-6,000
11	F3-18,000
12	Not Sampled in 2000
13	F4-2,000
14	F4-4,000
15	F4-10,000
16	F5-1,000
17*****	F5-3,000
18	F5-6,000
19	Not Sampled in 2000
20	F6-2,000
21	F6-4,000
22	F6-10,000
23	F7-1,000
24	F7-3,000
25	F7-6,000
26	F7-18,000
27	Not Sampled in 2000
28	F8-2,000
29	F8-4,000
30	Not Sampled in 2000
31**	F8-10,000
C1	GH2-3
C2	GH2-4
C3	GH2-5
C4	GH2-6
*C5**	Not Sampled in 2000
N1	GH3-3
N2	GH3-5
N3	GH3-6
N4	Not Sampled in 2000
S1	GH1-3
S2	GH1-4
S3	GH1-6
S4	GH1-2
*S5***	Not Sampled in 2000
NA1	Not Sampled in 2000
NA2	Not Sampled in 2000
NA3	Not Sampled in 2000
NA4	Not Sampled in 2000
SWRX1	Not Sampled in 2000
SWRX2	Not Sampled in 2000
SWRX3	Not Sampled in 2000
SWRX4	Not Sampled in 2000

Notes:
- **Bold** – Repeated Measures Stations. *Italics* – Drill Centre Stations
- For 2000 baseline stations, only those stations retained for the EEM program are listed.
- Additional baseline stations sampled in 2004 and 2006 are not listed in the above Table; see text and figures for details.
- *Not sampled in 2008 because of drilling activity; **Although sampled in every year, station 30 is excluded from repeated-measures analysis because it is near a delineation well and, as a result, the station is a statistical outlier in analyses. *** Not sampled in 2005 because of drilling activity.

1.8.2 Modifications to the Commercial Fish Component

For American plaice and snow crab, sampling for the baseline program (2000 and 2002) occurred near White Rose and in one Reference Area located 85 km to the northwest. For the EEM program, this Reference Area was replaced with four Reference Areas located approximately 28 km northwest, northeast, southwest, and southeast of the development. Figures 1-12 to 1-19 provide transect locations for the 2004, 2005, 2006, 2008, 2010, 2012, 2014 and 2016 EEM programs, respectively. The fisheries exclusion zone was larger in 2004 than in 2005 and 2006 to accommodate possible drilling at the NN and SS Drill Centres. The zone was again increased in size in 2008 and 2010, from 2005 and 2006, to accommodate the North Amethyst Drill Centre. In 2008, heavy commercial fishing activity for crab in Reference Areas 3 and 4 precluded sampling in those areas. In 2012, the approved White Rose safety zone was used as the boundary for fishing, and that area was expanded in 2014 and 2016 to accommodate the SWRX Drill Centre. In 2016, heavy commercial fishing activity for crab in Reference Area 4 precluded sampling in that area.

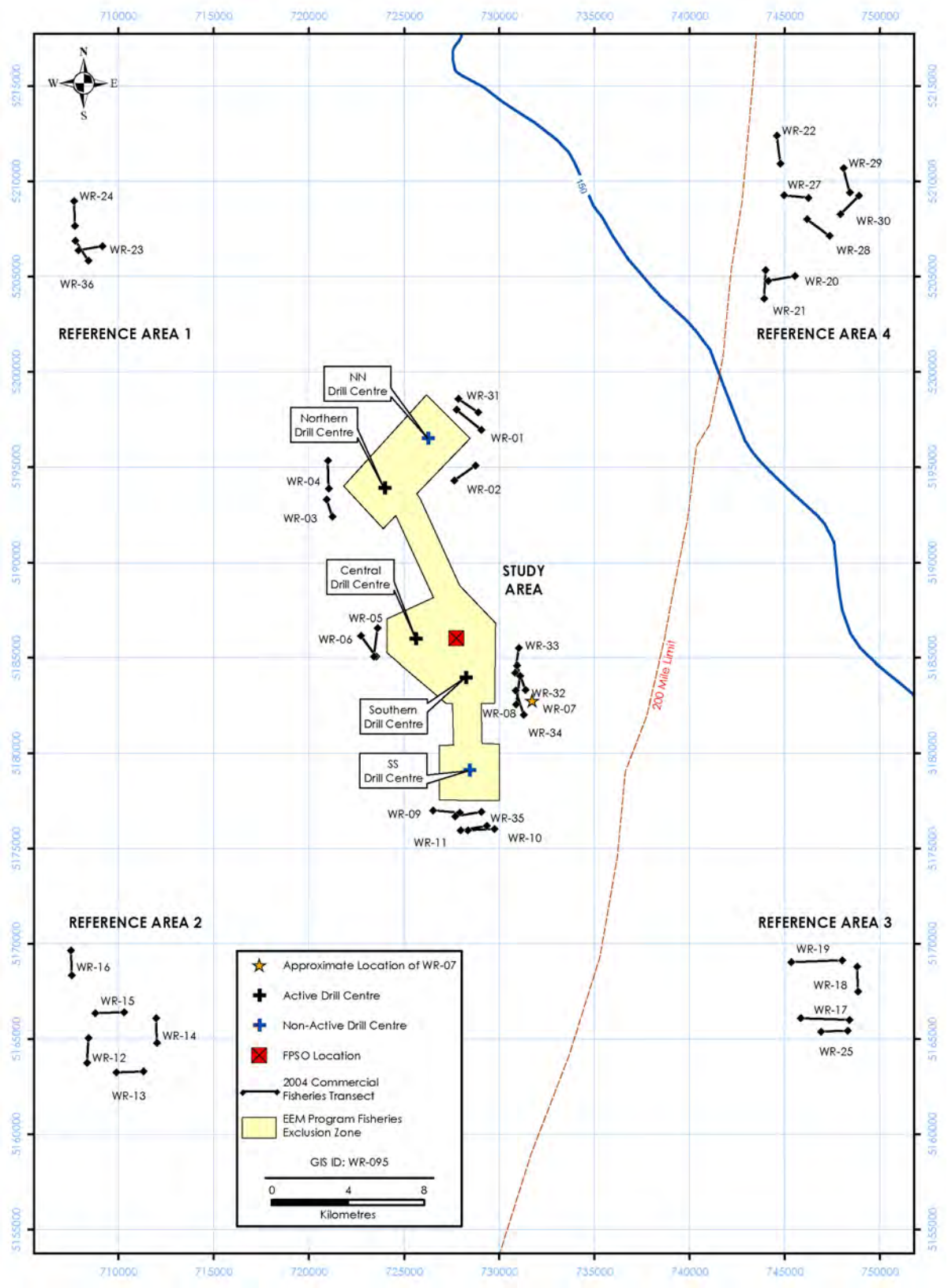

Figure 1-12 2004 EEM Program Commercial Fish Transect Locations

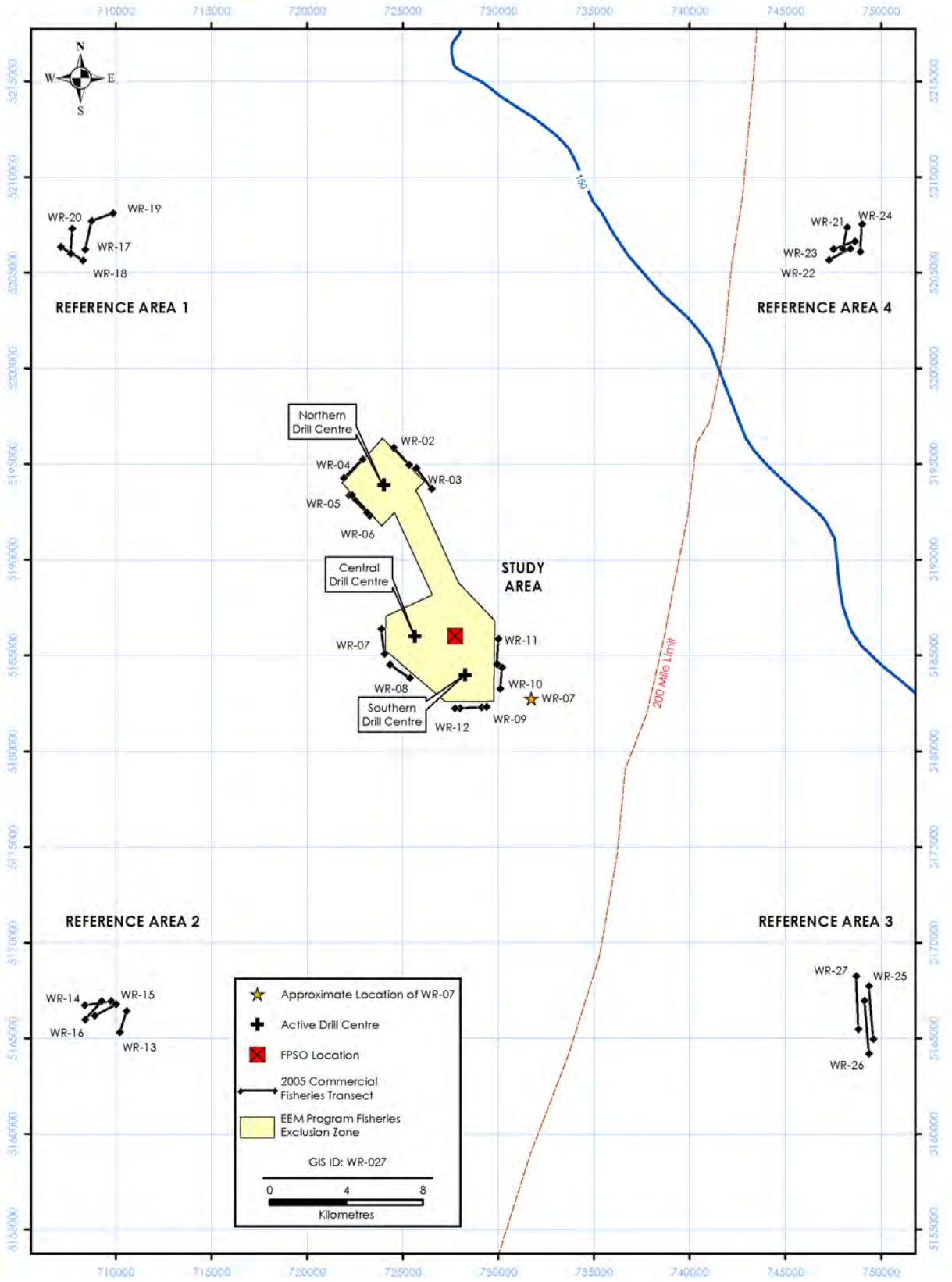

Figure 1-13 2005 EEM Program Commercial Fish Transect Locations

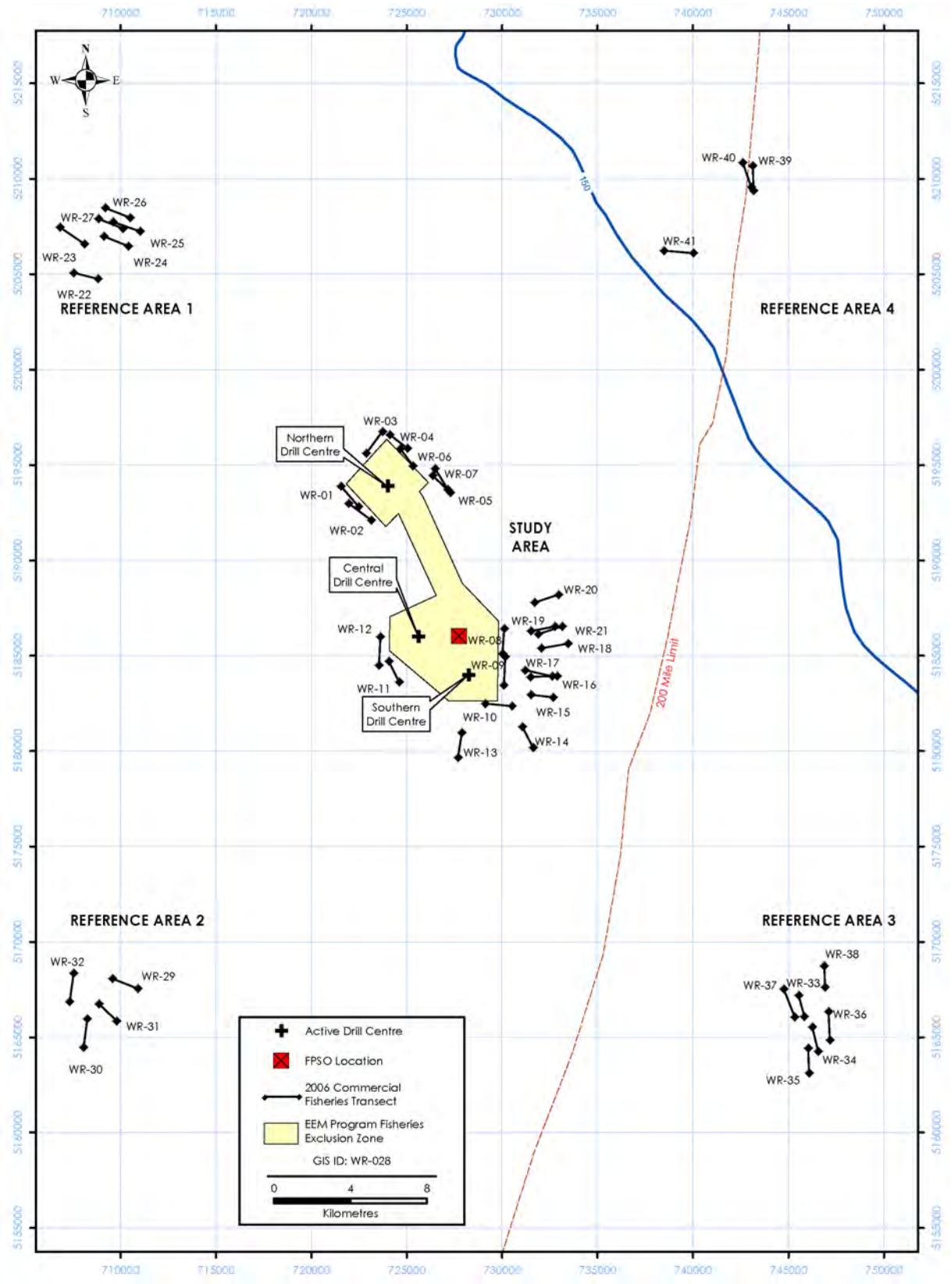

Figure 1-14 2006 EEM Program Commercial Fish Transect Locations

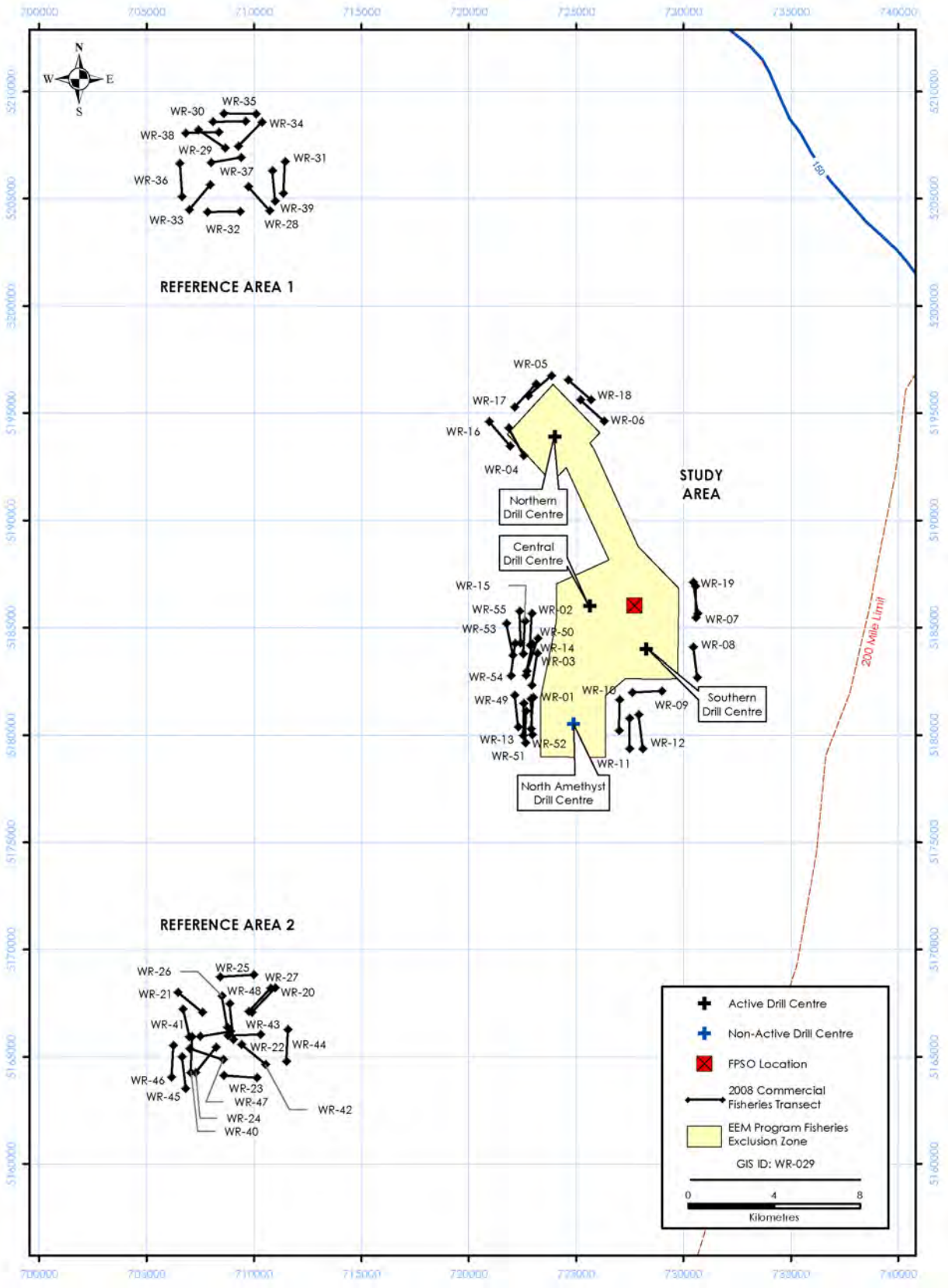

Figure 1-15 2008 EEM Program Commercial Fish Transect Locations

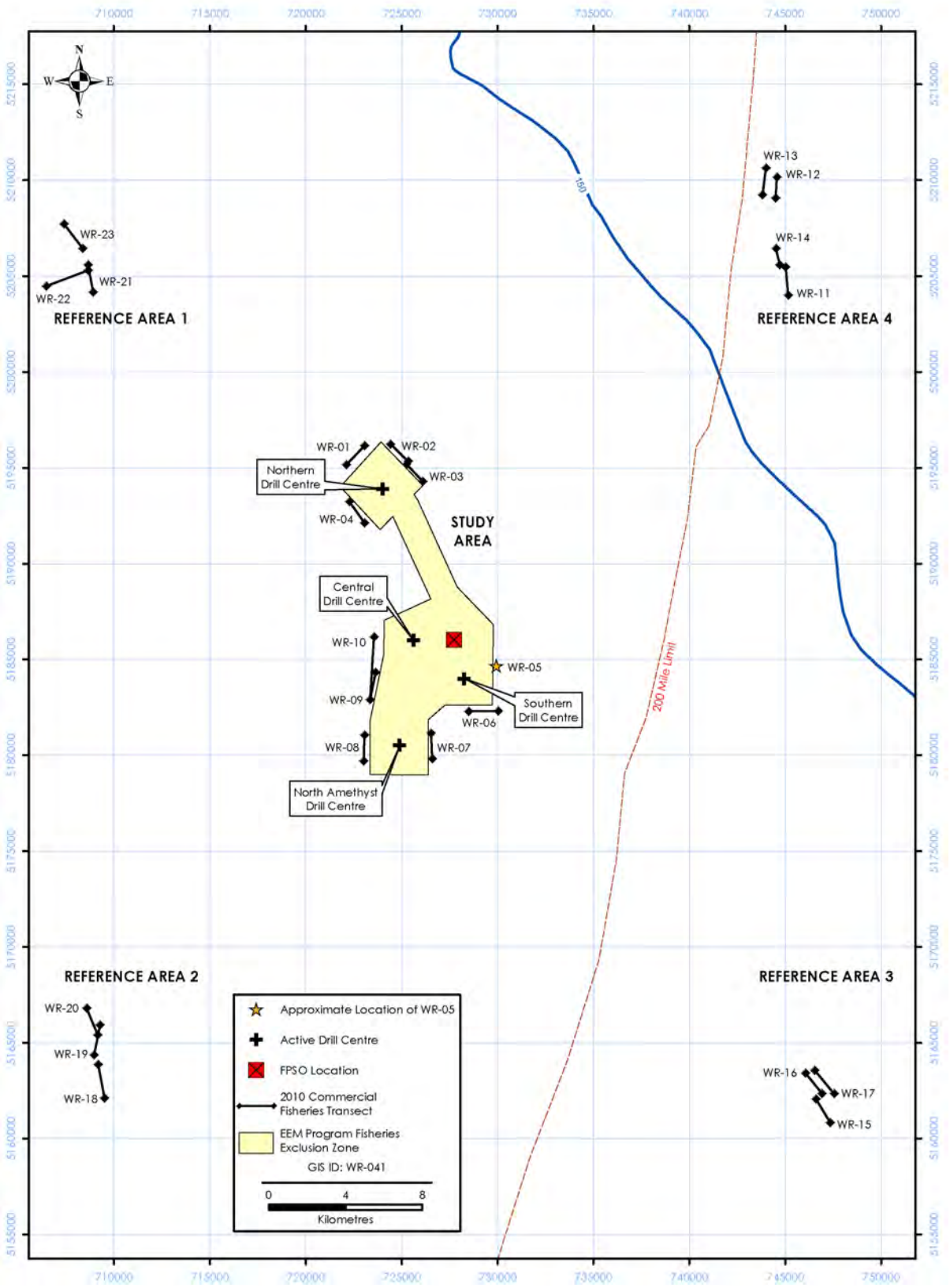

Figure 1-16 2010 EEM Program Commercial Fish Transect Locations

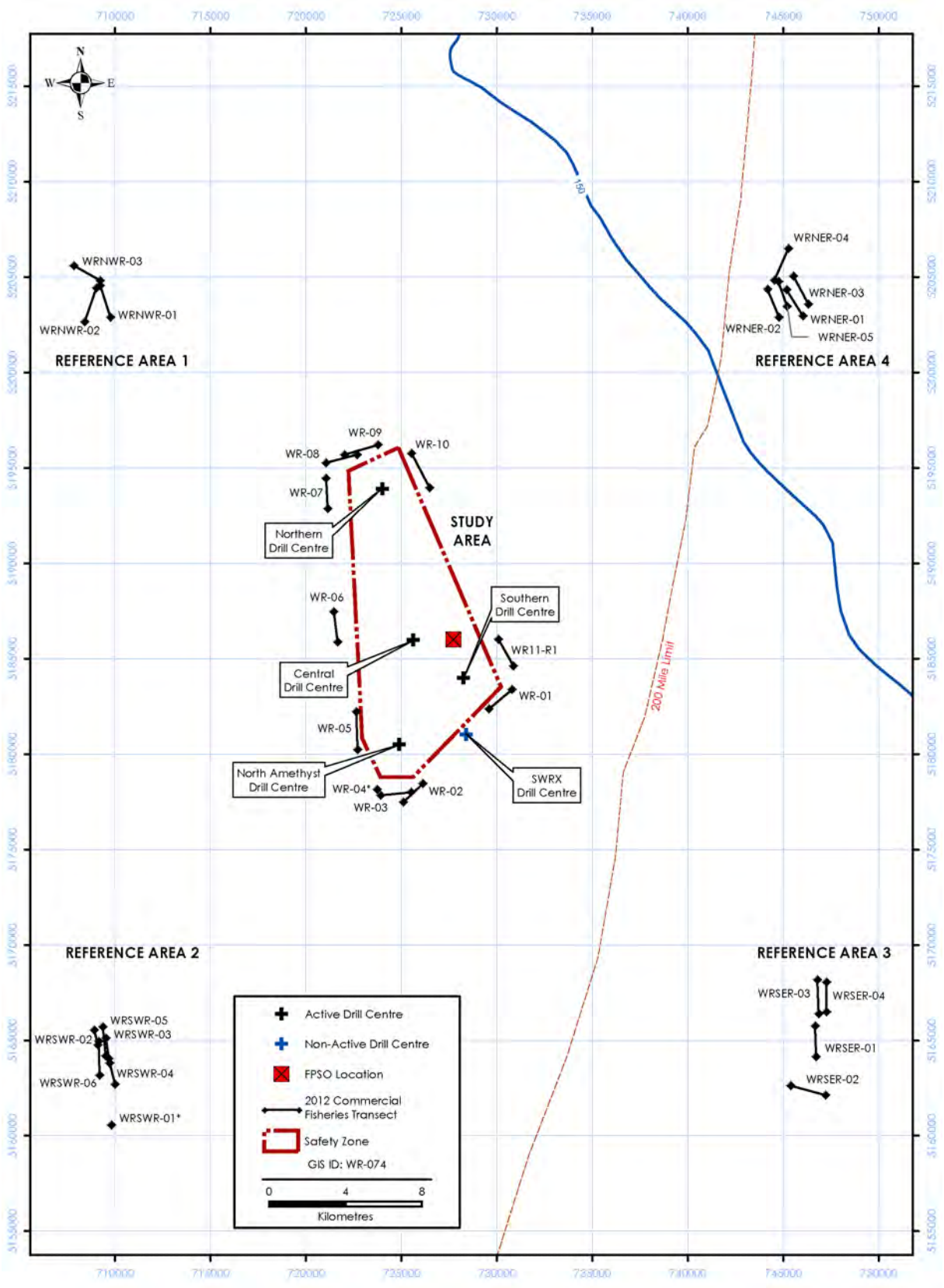

Figure 1-17 2012 EEM Program Commercial Fish Transect Locations

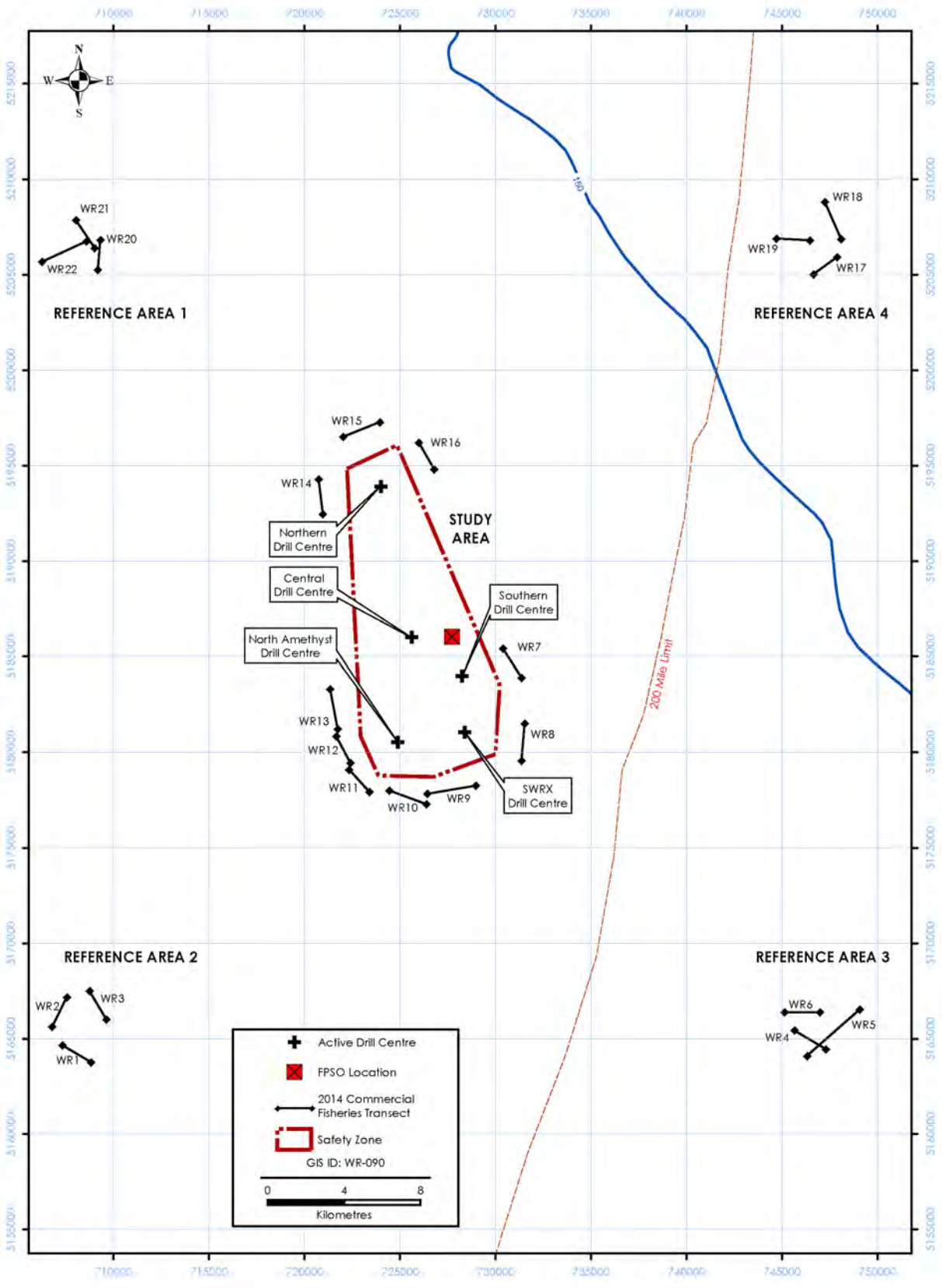

Figure 1-18 2014 EEM Program Commercial Fish Transect Locations

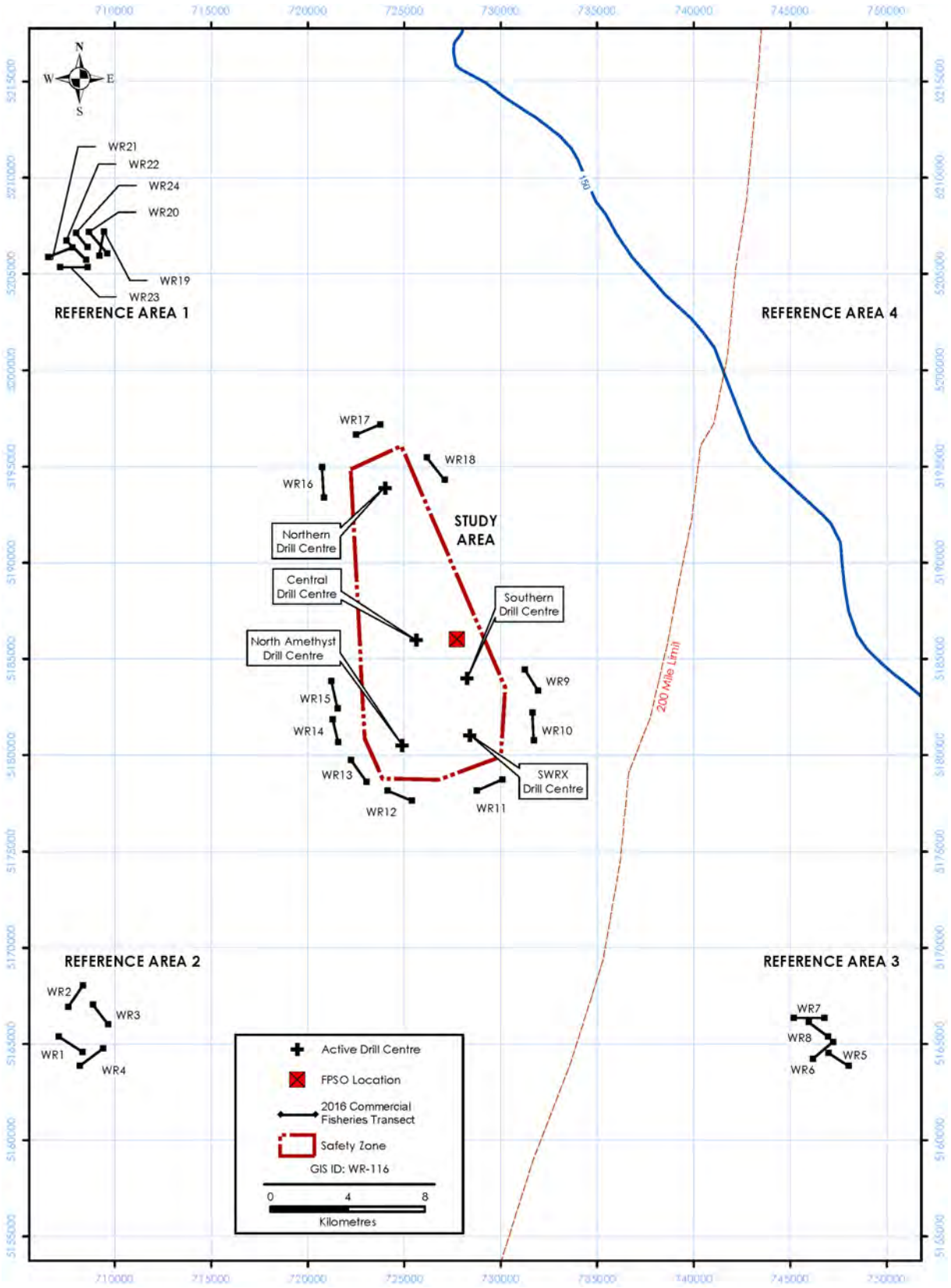

Figure 1-19 2016 EEM Program Commercial Fish Transect Locations

1.8.3 Modifications to the Water Quality Component

The Water Quality Component of the White Rose EEM targets both seawater and sediments as receiving environments for constituents from liquid discharge, predominantly produced water, from White Rose.

1.8.3.1 Seawater Samples

Water samples were collected at 13 randomly selected stations during baseline sampling in 2000 (Figure 1-20[5]). Produced water discharge began from the *SeaRose FPSO* in March 2007. A preliminary EEM water sampling program was executed in 2008, with eight stations near the *SeaRose FPSO* (the main source of liquid discharge) and one station located approximately 28 km to the northwest (Figure 1-21). A greater number of stations (18) were sampled in 2010, with 10 stations located near the *SeaRose FPSO* and eight stations located in Reference Areas to northwest and northeast (Figure 1-22). Modelling was used in the 2010 program to assess the probability of detection of produced water constituents in seawater given anticipated dilution and laboratory detection limits. The Water Quality program then was modified based on modelling, as well as field results. Sampling of radionuclides (sampled in seawater) was discontinued in 2012. Sampling of selected process chemicals in seawater was discontinued in 2014. From 2012 to 2016, five stations were sampled near the *SeaRose FPSO* in the direction of winds and currents at the time of sampling; five stations were sampled in the mid-field (4 km from the *SeaRose FPSO*) in the direction of the prevailing seasonal current; and the same eight stations sampled in Reference Areas in 2010 were again sampled (Figures 1-23 to 1-25, respectively). Since 2010, EEM water samples have been processed for a larger number of constituents and at lower detection limits than in baseline (see Section 7 and Husky Energy 2010a for details).

1.8.3.2 Sediment Samples

In 2010, stations sampled for seawater were also sampled for sediment particle size and sediment chemistry, including radionuclide concentration. Thirteen stations sampled as part of the Sediment Component of the EEM program were also sampled for radionuclide concentrations, for a total of 27 radionuclide stations.

In 2012, a modelling exercise examined the probability of detection of produced water radionuclides in sediments. Based on model results, sampling of sediment radionuclides was discontinued in 2012 (also see Section 7), but all other analyses on sediments at Water Quality stations were retained.

[5] Figure 1-20 excludes water samples collected at the two control stations sampled during baseline and subsequently excluded from the EEM sampling.

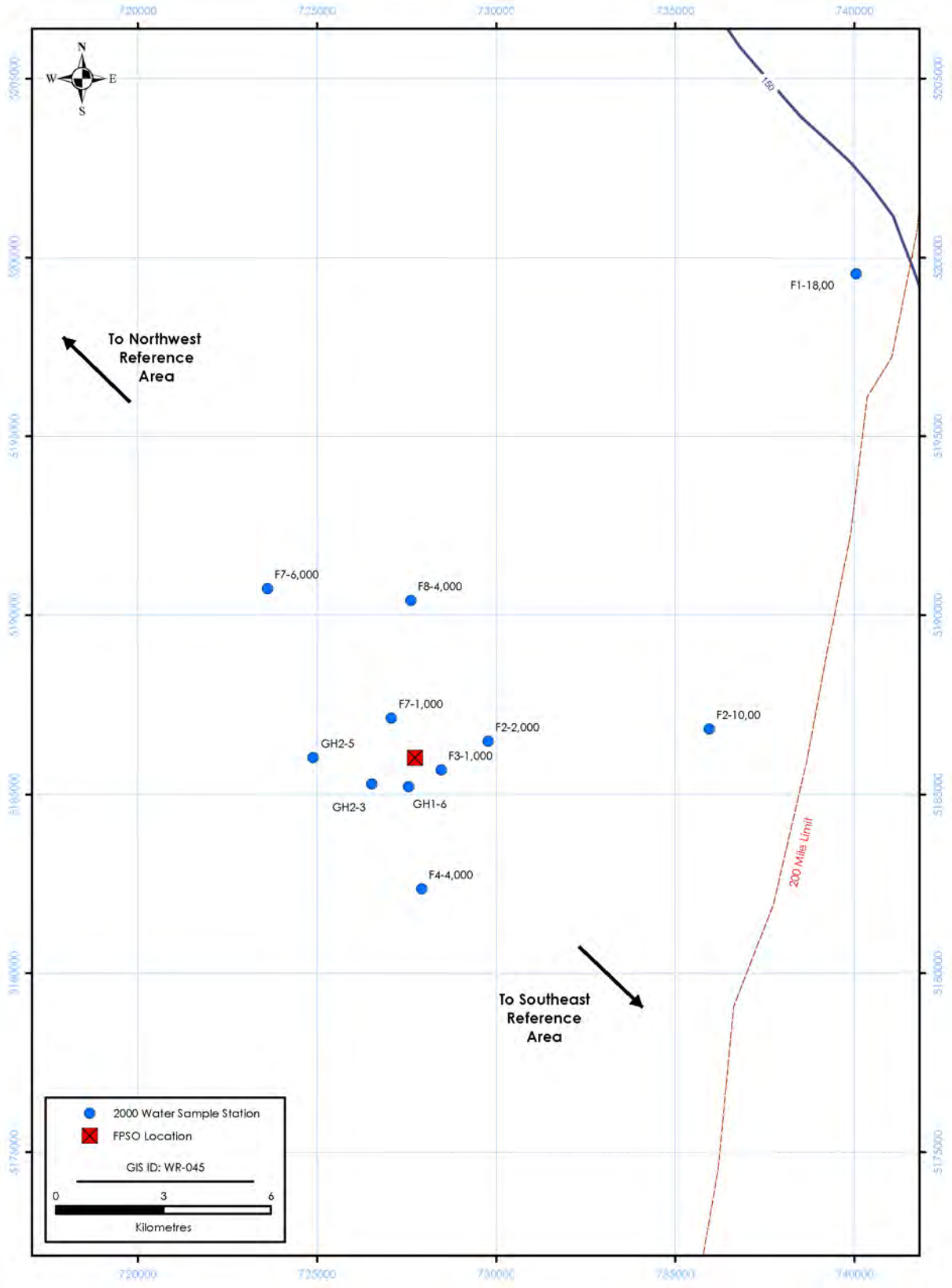

Figure 1-20 2000 Baseline Program Water Quality Stations

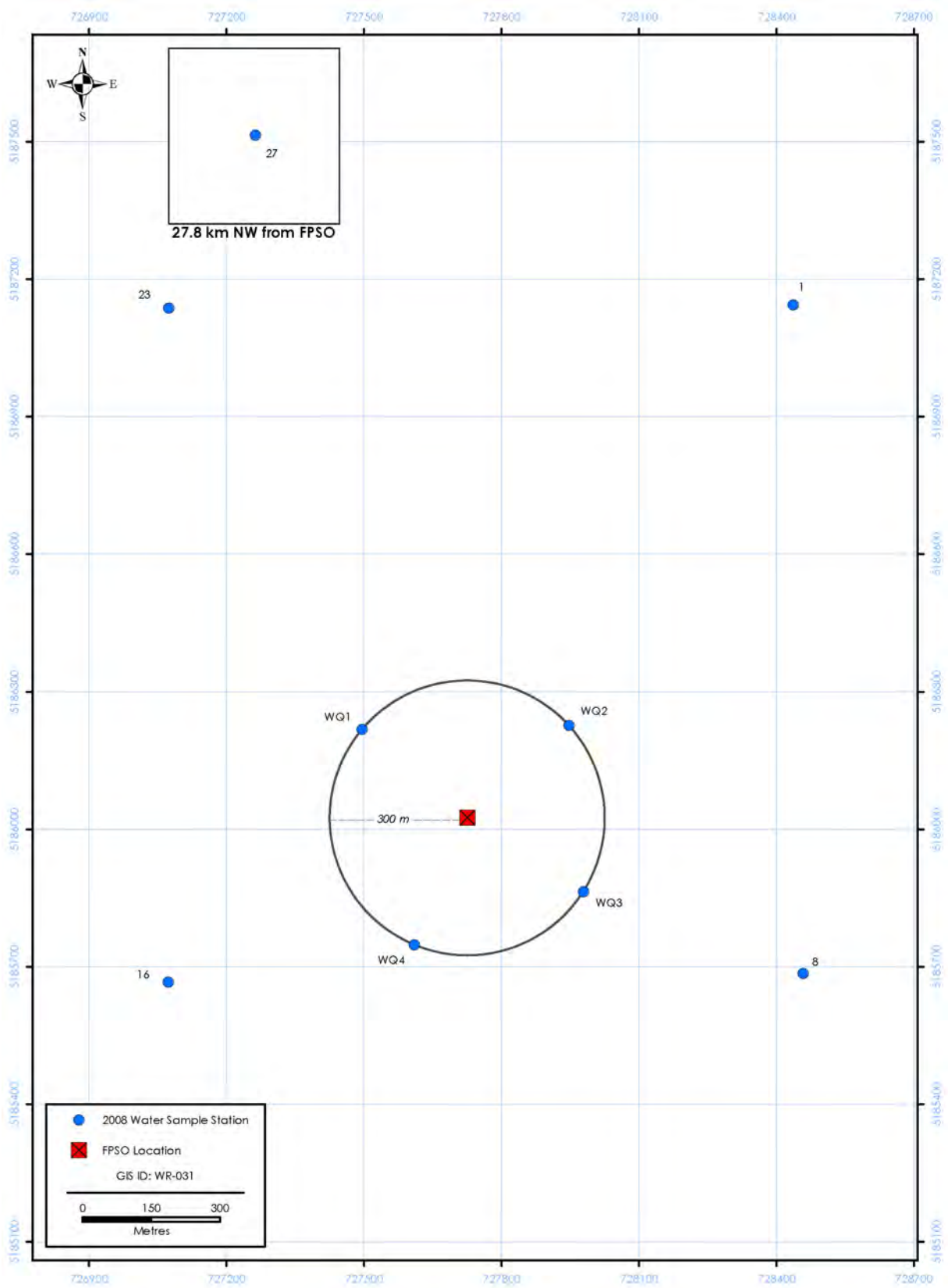

Figure 1-21 2008 EEM Program Water Quality Stations

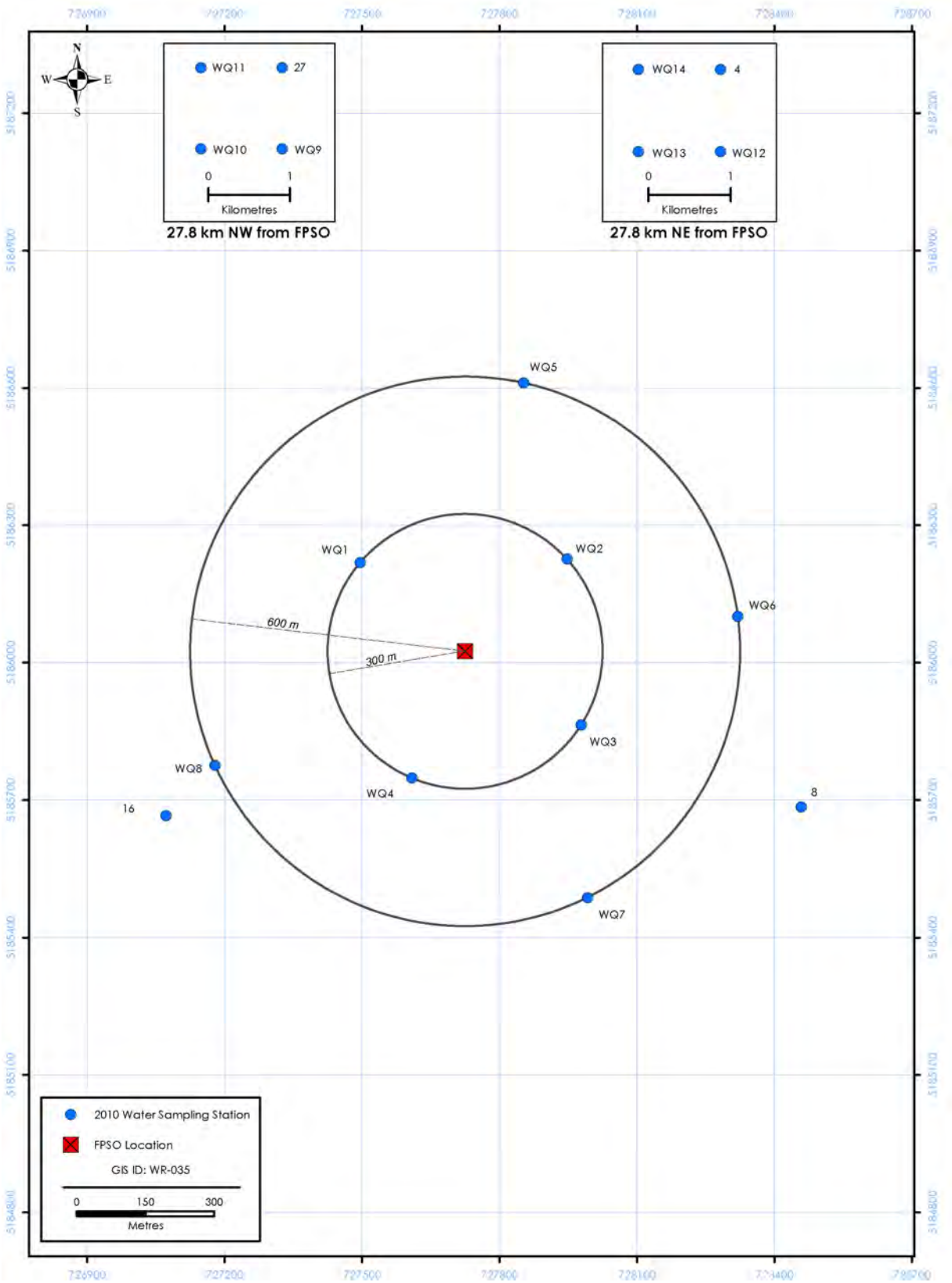

Figure 1-22 2010 EEM Program Water Quality Stations

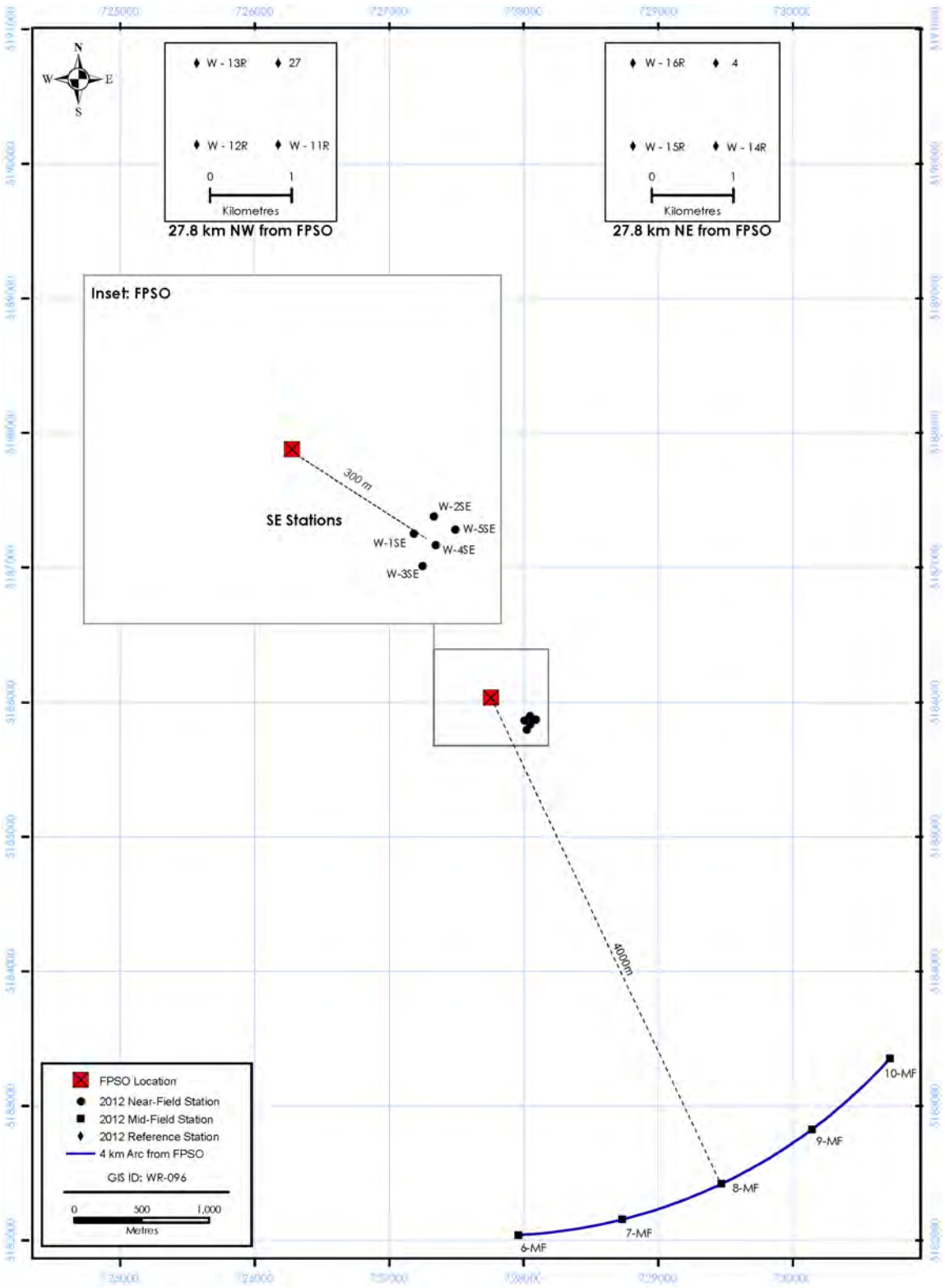

Figure 1-23 2012 EEM Program Water Quality Stations

Notes: The grey square represents an expanded view of the centre of the development. The blue line shows that mid-field stations are distributed on an arc, with each station 4,000 m from the centre of the development.

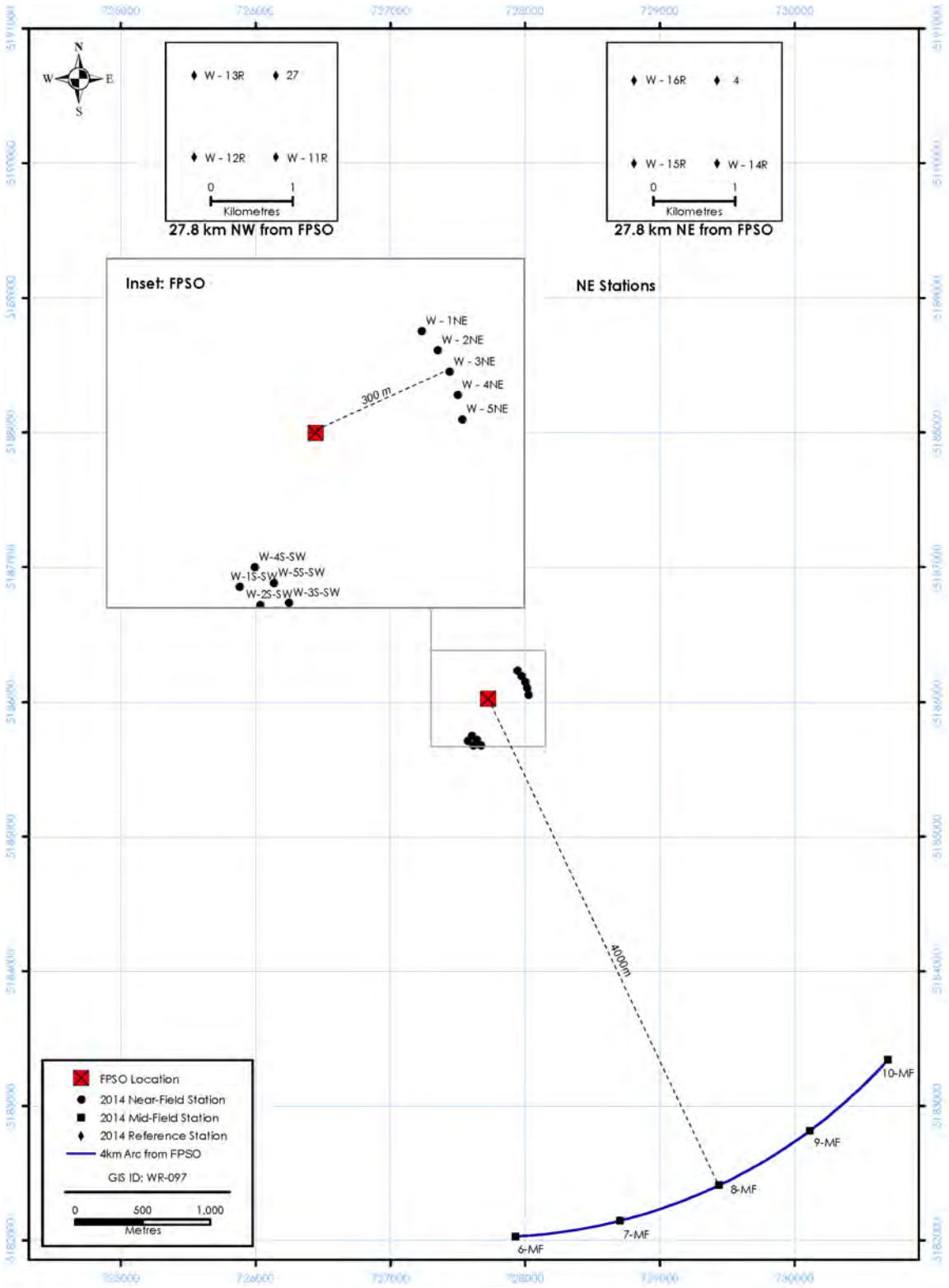

Figure 1-24 2014 EEM Program Water Quality Stations

Notes: The grey square represents an expanded view of the centre of the development. The blue line shows that mid-field stations are distributed on an arc, with each station 4,000 m from the centre of the development.

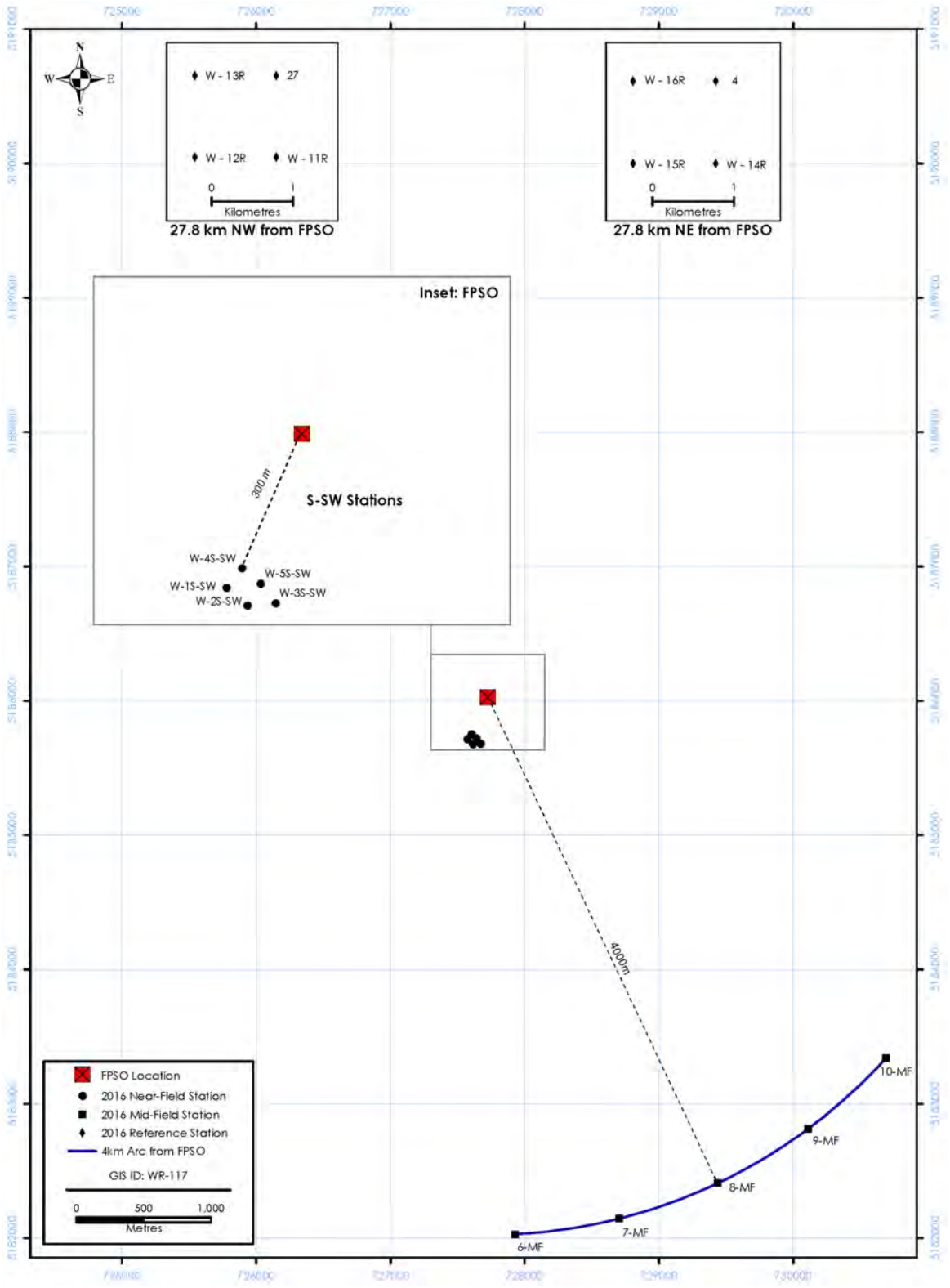

Figure 1-25 2016 EEM Program Water Quality Station

Notes: The inset square represents an expanded view of the centre of the development. The blue line shows that mid-field stations are distributed on an arc, with each station 4,000 m from the centre of the development.

2.0 Scope

This document, *White Rose Environmental Effects Monitoring Program 2016 (Volume 1)*, provides summary results, analyses, and interpretations for the White Rose 2016 EEM program. Where applicable, results from the baseline and previous EEM programs are compared to 2016 results. Since analyses of results are often highly technical, a summary of findings section is included at the end of each results section. The discussion section of the report provides interpretation of results and an overall assessment of potential project effects with respect to monitoring hypotheses (Section 1.7).

Most methods are provided in *Volume 1*. However, some more detailed methods as well as ancillary analyses are included in Appendices (*White Rose Environmental Effects Monitoring Program 2016 (Volume 2))*. Raw data and other information supporting *Volume 1* are also provided in *Volume 2*.

2.1 Background Material

The executive summary and discussion section of this document are written for a general audience. The methods and results sections assume a certain level of understanding of EEM, survey design and statistical analysis. References to statistical methods used are provided in the reference section of this document (Section 9.0). The most useful references, as well as other standard references, are provided below.

Armsworthy, S.L., P.J. Cranford and K. Lee (Editors). 2005. *Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Technologies.* Battelle Press, Columbus, OH. xvi + 631 pp.

DeBlois, E.M., J.W. Kiceniuk, M.D. Paine, B.W. Kilgour, E. Tracy, R.D. Crowley, U.P. Williams, G.G. Janes. 2014. Examination of body burden and taint for Iceland scallop (*Chlamys islandica*) and American plaice (*Hippoglossoides platessoides*) near the Terra Nova offshore oil development over ten years of drilling on the Grand Banks of Newfoundland, Canada. *Deep-Sea Research II*, 110: 65-83.

DeBlois, E.M., M.D. Paine, B.W. Kilgour, E. Tracy, R.D. Crowley, U.P. Williams and G.G. Janes. 2014. Alterations in bottom sediment physical and chemical characteristics at the Terra Nova offshore oil development over ten years of drilling on the Grand Banks of Newfoundland, Canada. *Deep-Sea Research II*, 110: 13-25.

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Environment Canada. 2002. *Biological Test Method: Reference Method for Determining the Toxicity of Sediment Using Luminescent Bacteria in a Solid-Phase Test*. Report EPS 1/RM/42. xxii + 60 pp.

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Paine, M.D., M.A. Skinner, B.W. Kilgour, E.M. DeBlois, E. Tracy. 2014. Repeated-measures regression designs and analysis for environmental effects monitoring programs. *Deep-Sea Research II*, 110: 84-91.

Quinn, G.P. and M.J. Keough. 2002. *Experimental Design and Data Analysis for Biologists*. Cambridge University Press, Cambridge, UK. 537 pp.

Schmitt, R.J. and C. W. Osenberg (Editors). 1996. *Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats.* Academic Press, San Diego, CA. 401 pp.

van Belle, G. 2002. *Statistical Rules of Thumb.* John Wiley & Sons, New York, NY. 221 pp. (more recent rules of thumb are posted at http://www.vanbelle.org).

Various Authors. 1996. *Canadian Journal of Fisheries and Aquatic Science,* Volume 53(11) (this volume provides reviews of GOOMEX studies).

Whiteway, S.A., M.D. Paine, T.A. Wells, E.M. DeBlois, B.W. Kilgour, E. Tracy, R.D. Crowley, U.P. Williams and G.G. Janes. 2014. Toxicity assessment in marine sediments for the Terra Nova environmental effects monitoring program (1997 - 2010). *Deep-Sea Research II*, 110: 26-37.

3.0 Abbreviations, Acronyms, and Units of Measure

The following abbreviations, acronyms and units of measure are used in this report.

Abbreviations	Definition
°C	degrees Celsius
#/m²	number [of organisms] per square metre
AIC	Akaike Information Criterion
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
Bq/g	Becquerel per gram
BTEX	benzene, toluene, ethylbenzene and xylenes
CCME	Canadian Council of Ministers of the Environment
cm	centimetre
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
DFO	Fisheries and Oceans Canada
DISTLM	distance-based linear model
EEM	environmental effects monitoring
EIS	Environmental Impact Statement
EPCMP	Environmental Protection and Compliance Monitoring Plan
EROD	7-ethoxyresorufin O-deethylase
FPSO	floating, production, storage and offloading vessel
g	gram
g/kg	gram per kilogram
g/m²	gram per square metre
H_0	null hypothesis
HOIMS	Husky Operational Integrity Management System
IC_{50}	50% inhibitory concentration
ISQG	Interim Sediment Quality Guidelines
kg	kilogram
km	kilometre
km²	square kilometre
L	litre
L/s	litre per second
m	metre
m²	square metre
m³	cubic metre
MFO	Mixed Function Oxygenase
mg	milligram
mg/kg	milligram per kilogram
mg/L	milligram per litre
mL	millilitre
mm	millimetre
mV	millivolts
nMDS	non-Metric Multidimensional Scaling
PAH	polycyclic aromatic hydrocarbon
PCA	Principal Component Analysis
PERMANOVA	permutational multivariate analysis of variation

Abbreviations	Definition
ppm	parts per million
QA/QC	quality assurance/quality control
SD	standard deviation
SIMPER	similarity percentage
SWRX	South White Rose Extension
TIC	total inorganic carbon
TOC	total organic carbon
TSS	total suspended solids
µg/L	microgram per litre
WRRS	White Rose Reference Station [sediment]

4.0 Project Activities

4.1 Introduction

This section reports on both drilling and production activities in the White Rose Field and summarizes the authorized discharges associated with these operations.

Husky's *Environmental Protection and Compliance Monitoring Plans* (EPCMP) describe the environmental protection measures and compliance monitoring requirements applicable to Husky's drilling- and production-related operations. The EPCMPs are prepared in alignment with the C-NLOPB's *Environmental Protection Plan Guidelines* (National Energy Board *et al.* 2011), *Offshore Waste Treatment Guidelines* (National Energy Board *et al.* 2010), *Drilling and Production Guidelines* (C-NLOPB and Canada-Nova Scotia Offshore Petroleum Board 2011) and all other applicable regulatory requirements. The EPCMP has its basis in the *Husky Operational Integrity Management System* (HOIMS), and is responsive to the C-NLOPB's regulatory approval process and other relevant regulatory requirements.

The purpose of this section is to provide context for the interpretation of the results from the EEM program.

4.2 Project Activities

Activities associated with the White Rose Development Project to date fall into five general categories:

- construction and installation operations for the original White Rose Field were completed in Fall 2005 (see Husky Energy 2006); flowlines and protective berms were installed to connect the North Amethyst Drill Centre to the Southern Drill Centre in 2009;
- A new drill centre at SWRX was excavated in 2012. In 2013, a gas injection flowline from the Northern Drill Centre was tied-in directly to the SWRX Drill Centre. In 2014, the SWRX Drill Centre was tied back to the existing production, water injection and gas lift flowlines from the North Amethyst Drill Centre and the Southern Drill Centre.
- drilling operations including development, and delineation drilling in the White Rose Field (ongoing for the foreseeable future by one or more drilling platforms);
- *SeaRose FPSO* operations (ongoing for the foreseeable future); and
- supply vessel operations (ongoing for the foreseeable future).

Production operations (*i.e.*, oil and gas production, storage and offloading to a tanker) began at the White Rose Field once hook-up, commissioning, and introduction of hydrocarbons to the *SeaRose FPSO* were completed in November of 2005. In May 2010, White Rose started producing from the North Amethyst Drill Centre. Production from the SWRX drill centre began in June, 2015. Since the last EEM in October 2014, the *SeaRose FPSO* was shut down for maintenance from August 14 to 29, 2015, and from July 1 to July 23, 2016, during which time there was no production-related discharge.

4.3 Drilling and Completions Operations

Husky uses both water-based drill muds and synthetic fluid-based drill muds in its drilling programs. Water-based drill muds are used for the upper two drill hole sections, which is riserless drilling, while synthetic fluid-based drill muds are used in deeper hole sections, especially during directional drilling operations, where drilling conditions are more difficult and hole stability is critical to safety and success.

HOIMS and Husky's *Waste Management Procedures* commit to an active program to manage the generation, reuse or recycling and disposal of waste materials generated by any of Husky's Atlantic Region offshore or onshore operations.

This is achieved through the following objectives:

- limit or minimize the waste generated from Husky's Atlantic Region operations; and
- all waste from Husky's Atlantic Region operations is handled in an environmentally responsible manner.

There are several tools currently in place to assist with the implementation of these objectives:

- White Rose Waste Management Plan;
- *SeaRose* Waste Management Procedure;
- internal reviews of waste manifesting procedures; and
- management of key contractors.

4.3.1 Drilling Mud and Completion Fluids Discharges

There was no drilling activity within the White Rose Field between October 2015 and May 2016.

Table 4-1 summarizes the volumes of drill cuttings and water-based drill muds discharged during development drilling activities by year and drill centre. The months during which drilling activities took place are also indicated.

Table 4-2 summarizes the volumes of drill cuttings and synthetic fluid-based drill muds discharged during development drilling activities by year and drill centre. The months during which drilling activities took place are also indicated.

Upon completion, a well bore needs to be cleaned of residual cuttings. This is done by flushing with "completion fluids", consisting primarily of sodium chloride or potassium formate brines. Table 4-3 summarizes the volumes of completion fluids discharged during well completions by year and drill centre. The months during which these activities took place are also indicated.

Table 4-1 Cuttings and Water-based Mud Discharges from 2003 to December 2016

Year	Drill Centre	Months with Drilling Activity												Total Cuttings Discharged (mt)	Total Muds Discharged (m^3)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
2003	Northern													N/A	N/A
	Central													N/A	N/A
	Southern													1,476	1,588
2004	Northern													682	456
	Central													655	473
	Southern													537	761
	EEM Program							F		S	S				
2005	Northern													N/A	N/A
	Central													1,748	1,674
	Southern													552	783
	EEM Program							F		S					
2006	Northern													N/A	N/A
	Central													1,749	1,282
	Southern													638	932
	EEM Program							F	S						
2007	Northern													N/A	N/A
	Central													655	867
	Southern													N/A	N/A
	Well K 03*													619	718
2008	Northern													653	726
	Central													651	985
	Southern													557	753
	EEM Program					F	F			SW					
2009	Northern													N/A	N/A
	Central													N/A	N/A
	Southern													N/A	N/A
	NADC**													1,482	1,772
2010	Northern													N/A	N/A
	Central													706	1,553
	Southern													N/A	N/A
	NADC**													1,331	2,703
	EEM Program							F			SW				
2011	Northern													N/A	N/A
	Central													649	1413
	Southern													N/A	N/A
	NADC**													1,261	2,557
2012	Northern													N/A	N/A
	Central													N/A	N/A
	Southern													459	1,285
	NADC**													512	1,596
	SWRX***													N/A	N/A
	EEM Program							F	SW						
2013	Northern													N/A	N/A
	Central													N/A	N/A
	Southern													N/A	N/A
	NADC**													1,172	6,480
	SWRX***													458	1,620
2014	Northern													N/A	N/A
	Central													N/A	N/A
	Southern													N/A	N/A
	NADC**													0	90
	SWRX***													641	3,704
	EEM Program						F				SW				

Year	Drill Centre	Months with Drilling Activity												Total Cuttings Discharged (mt)	Total Muds Discharged (m³)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
2015	Northern													N/A	N/A
	Central													N/A	N/A
	Southern													N/A	N/A
	NADC**													N/A	N/A
	SWRX***													0	1,478
2016	Northern													N/A	N/A
	Central													N/A	628
	Southern													N/A	N/A
	NADC**													584	1743
	SWRX***													865	2,056
	EEM Program							F		SW					
														1,335	1,182
														6,813	8,875
														4,219	6,102
														6,342	16,941
														1,964	8,858
														20,673	41,958

Note:
- * Well K 03 is a Delineation Well.
- ** NADC – North Amethyst Drill Centre.
- *** SRWX – South White Rose Drill Centre.
- F = Commercial Fish portion of the EEM program.
- S = Sediment Quality portion of the EEM program.
- W = Water Quality portion of the EEM program.
- mt = metric tonne
- m³ = cubic metre
- N/A = no drilling activity in that particular drill centre

Table 4-2 Cuttings and Synthetic-based Mud Discharges from 2003 to December 2016

Year	Drill Centre	Months with Drilling Activity												Total Cuttings Discharged (mt)	Total Solids Discharged (mt)	Total Base Oil Discharged (m³)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
2003	Northern													N/A	N/A	N/A
	Central													N/A	N/A	N/A
	Southern													416	957	228
2004	Northern													350	473.1	35
	Central													253	1,197	141
	Southern													1,193	3,358	512
	EEM Program							F		S	S					
2005	Northern													N/A	N/A	N/A
	Central													1,291	2,382	482
	Southern													741	1,464	157
	EEM Program							F		S						
2006	Northern													N/A	N/A	N/A
	Central													1,268	3,163	335
	Southern													1,028	1,927	185
	EEM Program							F	S							
2007	Northern													409	719.9	71
	Central													1,291	2,382	241
	Southern													N/A	N/A	N/A
	Well K 03*													437	775	65

Year	Drill Centre	Months with Drilling Activity												Total Cuttings Discharged (mt)	Total Solids Discharged (mt)	Total Base Oil Discharged (m^3)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
2008	Northern													771	1,765.6	202
	Central													483	979	88
	Southern													668	1,518	151
	EEM Program					F	F			SW						
2009	Northern													106	186	22
	Central													N/A	N/A	N/A
	Southern													N/A	N/A	N/A
	NADC**													752	1,345	117
2010	Northern													N/A	N/A	N/A
	Central													524	1,141	106
	Southern													N/A	N/A	N/A
	NADC**													1,034	3,149	223
	EEM Program							F			SW					
2011	Northern													N/A	N/A	N/A
	Central													429	1,392	101
	Southern													N/A	N/A	N/A
	NADC**													799	1,309	111
2012	Northern													N/A	N/A	N/A
	Central													N/A	N/A	N/A
	Southern													732	847	185
	NADC**													853	907	148
	SWRX***													N/A	N/A	N/A
	EEM Program							F	SW							
2013	Northern													N/A	N/A	N/A
	Central													N/A	N/A	N/A
	Southern													N/A	N/A	N/A
	NADC**													1,465	2,362	210
	SWRX***													712	1,761	160
2014	Northern													N/A	N/A	N/A
	Central													N/A	N/A	N/A
	Southern													N/A	N/A	N/A
	NADC**													814	1,459	103
	SWRX***													284	563	17
	EEM Program						F				SW					
2015	Northern													N/A	N/A	N/A
	Central													N/A	N/A	N/A
	Southern													N/A	N/A	N/A
	NADC**													N/A	N/A	N/A
	SWRX***													1,422	252.7	119
2016	Northern													N/A	N/A	N/A
	Central													637	174	47
	Southern													N/A	N/A	N/A
	NADC**													940	249	64
	SWRX***													1,541	364.8	103
	EEM Program							F		SW						
Total Discharge at Northern Drill Centre														1,636	3,144	330
Total Discharge at Central Drill Centre														6,176	12,810	1,541
Total Discharge at Southern Drill Centre														4,778	10,071	1,418
Total Discharge at NADC**														6,657	10,780	976
Total Discharge at SWRX***														3,959	2,941	399
Total Field Discharge														23,206	39,746	4,664

Notes:
- * Well K 03 is a Delineation Well.
- ** NADC – North Amethyst Drill Centre.
- *** SWRX – South White Rose Extension Drill Centre.
- F = Commercial Fish portion of the EEM program.
- S = Sediment Quality portion of the EEM program.
- W = Water Quality Portion of the EEM program.
- mt = metric tonne
- m^3 = cubic metre
- N/A = no drilling activity in that particular drill centre

Table 4-3 Completion Fluid Discharges from 2003 to December 2016

Year	Drill Centre	Months with Drilling Activity												Total Completion Fluids Discharged (m^3)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2003	Northern													N/A
	Central													N/A
	Southern													N/A
2004	Northern													N/A
	Central													N/A
	Southern													1,619
	EEM Program													
2005	Northern							F		S	S			N/A
	Central													1,015
	Southern													1,372
	EEM Program							F		S				
2006	Northern													N/A
	Central													901.1
	Southern													476
	EEM Program							F	S					
2007	Northern													150
	Central													573
	Southern													N/A
	Well K 03*													N/A
2008	Northern													N/A
	Central													186
	Southern													250
	EEM Program					F	F			SW				
2009	Northern													235
	Central													N/A
	Southern													N/A
	NADC**													29
2010	Northern													N/A
	Central													N/A
	Southern													N/A
	NADC**													2,293
	EEM Program							F			SW			
2011	Northern													N/A
	Central													673
	Southern													N/A
	NADC**													821
2012	Northern													N/A
	Central													445
	Southern													597
	NADC**													592
	SWRX***													N/A
	EEM Program							F	SW					
2013	Northern													N/A
	Central													N/A
	Southern													N/A
	NADC**													838
	SWRX***													359
2014	Northern													N/A
	Central													N/A
	Southern													N/A
	NADC**													N/A
	SWRX***													103
	EEM Program						F				SW			
2015	Northern													N/A
	Central													N/A
	Southern													N/A
	NADC**													N/A
	SWRX***													N/A

Year	Drill Centre	Months with Drilling Activity												Total Completion Fluids Discharged (m³)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2016	Northern													N/A
	Central													628.4
	Southern													N/A
	NADC**													N/A
	SWRX***													588
	EEM Program						F				SW			
Total Discharge at Northern Drill Centre														385
Total Discharge at Central Drill Centre														4,421
Total Discharge at Southern Drill Centre														4,314
Total Discharge at NADC**														4,573
Total Discharge at SWRX***														1,050
Total Field Discharge														13,527

Notes:
- * Well K 03 is a Delineation Well.
- ** NADC – North Amethyst Drill Centre.
- *** SWRX – South White Rose Extension Drill Centre.
- F = Commercial Fish portion of the EEM program.
- S = Sediment Quality portion of the EEM program.
- W = Water Quality portion of the EEM program.
- m³ = cubic metre
- N/A = no drilling activity in that particular drill centre

4.3.2 Other Discharges from Drilling Operations

Between October 2014 and September 2016, a total of 161.8 m³ of bilge water from drilling operations was discharged. All bilge water is treated in an oily water separator prior to release to reduce hydrocarbon content to 15 ppm or less in accordance with Husky's EPCMPs. In total, 4.4 kg of hydrocarbons were released to the marine environment from bilge water. Similarly, all deck drainage is collected and treated to reduce hydrocarbon content to 15 ppm or less, resulting in a total of 0.68 kg of oil discharged from 76 m³ of deck drainage.

Water and ethylene glycols are routinely discharged during function testing of a seabed blowout preventer and subsea flowline valves. In total, over the reporting period between October 2014 and September 2016, approximately 578 m³ of water and glycols have been discharged from these sources, at between 25% and 35% of total volume, approximately 173.4 m³ of which have been active ingredients.

4.4 *SeaRose FPSO* Production Operations

The primary points of hydrocarbon discharge to the marine environment from the *SeaRose FPSO* are the bilge, the slops tanks, and produced water. Bilge water on the *SeaRose FPSO* is typically directed towards the slops tanks to discharge. Slops tanks are reservoirs for collecting both rainwater (washed over the production facility from open and closed drains) and the redirected bilge water. Contents of the slops tanks undergo oil/water separation and testing prior to discharge to a level of less than 15 ppm hydrocarbon, as per Husky's *SeaRose FPSO* EPCMP. Between October 2014 and September 2016, a total of 4039 m³ of water was released from the slops tanks, representing 19.43 kg (average 1.16 ppm) of hydrocarbons to the marine environment.

Produced water is a by-product of oil production and is a combination of water entrained within the reservoir (formation) and seawater injected into the reservoir to maintain pressure. Produced water is removed from crude oil through a series of separation processes in the production train. Produced water has two regulatory limits for oil in water, as per Husky's *SeaRose FPSO* EPCMP: a 24-hour volume-weighted mean less than 44 ppm; and a volume-weighted 30-day rolling average less than 30 ppm. Between October 2014 and September 2016, 7,594,600 m^3 of produced water was released, representing 121,632 kg (average for end-of month 30-day rolling average was 15.83 ppm) of hydrocarbons to the marine environment.

Seawater is pumped aboard the *SeaRose FPSO* and is circulated around equipment as cooling water to reduce operating temperatures. To prevent biofouling within the cooling water system, the seawater is treated with chlorine and is managed such that the residual chlorine level at discharge is 1.0 ppm or less, approximately the same as drinking water. Between October 2014 and September 2016, the monthly average residual chlorine concentration prior to release was 0.29 ppm.

4.5 Supply Vessel Operations

All offshore facilities and operations are supported by Offshore Supply Vessels. Normal vessel operations involve discharge of both treated sewage and bilge water. Bilge water from vessels is treated such that it contains 15 ppm or less of dispersed oil and is released in accordance with the *International Convention for the Prevention of Pollution from Ships* (MARPOL 73/78) requirements.

5.0 Sediment Component

5.1 Methods

5.1.1 Field Collection

The Sediment Component of the 2016 EEM Program was conducted from September 2 to September 7, 2016, using the offshore supply vessel *Atlantic Kingfisher*. Sampling dates for the baseline program and EEM programs are summarized in Table 5-1. Sediment stations for the baseline and EEM programs are shown in Figures 1-4 to 1-11 (Section 1), with the 2016 station locations provided again in Figure 5-1. Differences in sampling locations among years are described in Section 1. More details on the baseline survey and the Year 1, 2, 3, 4, 5, 6, and 7 EEM programs can be found in Husky Energy (2001, 2005, 2006, 2007, 2009, 2011, 2013, 2015). Geographic coordinates and distances to drill centres for EEM stations sampled in 2016 are provided in Appendix B-1.

Table 5-1 Date of Sediment Field Programs

Trip	Date
Baseline Program	September 9 to September 19, 2000
EEM Program Year 1	September 26 to October 11, 2004
EEM Program Year 2	September 16 to September 22, 2005
EEM Program Year 3	August 14 to August 18, 2006
EEM Program Year 4	September 17 to September 21, 2008
EEM Program Year 5	October 4 to October 13, 2010
EEM Program Year 6	August 21 to August 26, 2012
EEM Program Year 7	October 31 to November 4, 2014
EEM Program Year 8	September 2 to September 7, 2016

Sediment was collected using a large-volume corer (mouth diameter = 35.6 cm, depth = 61 cm) designed to mechanically take an undisturbed sediment sample over approximately 0.1 m² (0.0995 m²) of seabed (Figures 5-2 and 5-3). Sediment oxidation/ reduction potential (redox) was measured on each sediment core before sample collection. Sediment quality stations were sampled for physical and chemical characteristics, toxicity and benthic community structure. These three sets of variables constitute the Sediment Quality Triad (see Section 1). Physical and chemical characteristics variables included particle size, total organic carbon (TOC) and total inorganic carbon (TIC), metals, benzene, toluene, ethylbenzene, and xylenes (BTEX), and $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), sulphur, sulphide, ammonia and moisture. Toxicity variables included bacterial luminescence and amphipod survival. Benthic community variables included total abundance, biomass and richness, and abundances of selected individual taxa.

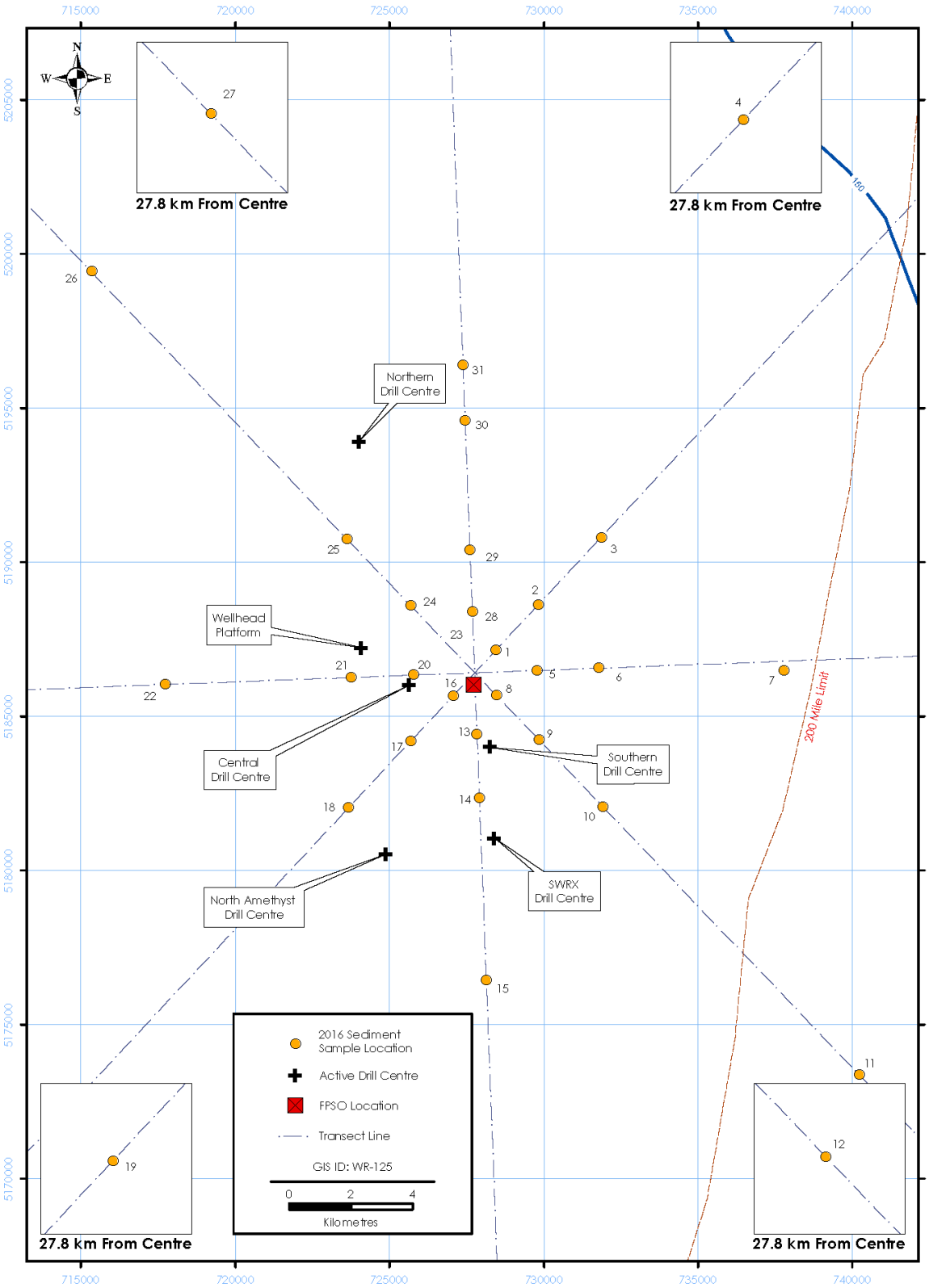

Figure 5-1 2016 Sediment Quality Triad Stations

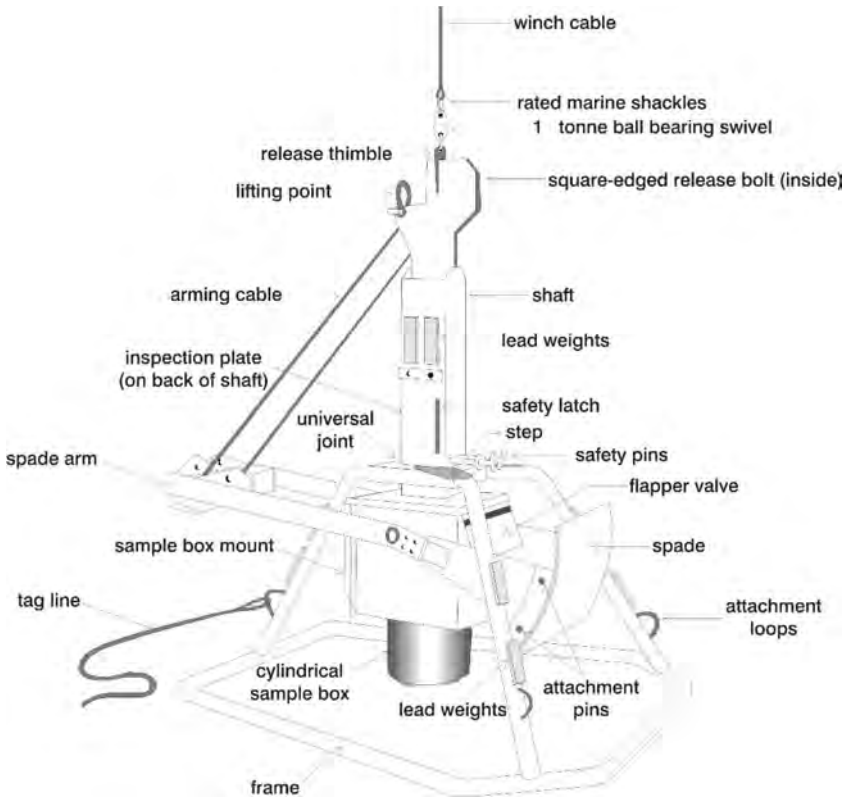

Figure 5-2 Sediment Corer Diagram

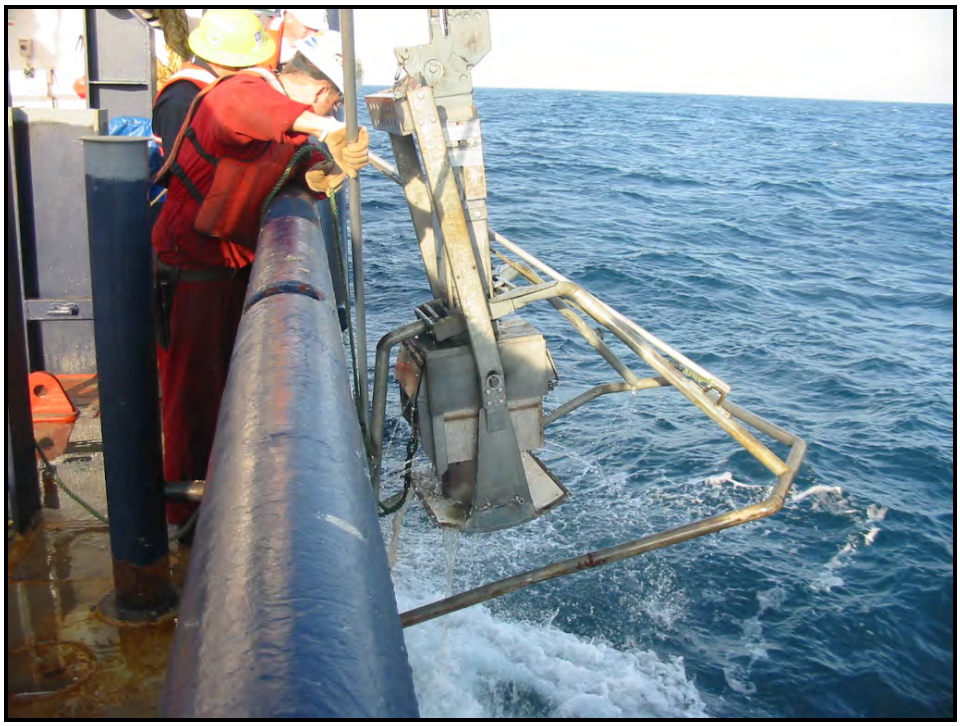

Figure 5-3 Sediment Corer

Sediment samples collected for physical and chemical analyses were a composite from the top layer of three cores per station. Sediment was sampled at the surface of the cores and at least 2 cm away from the corer walls (*i.e.*, over an area of approximately 0.078 m^2) and down to a depth of approximately 2 to 3 cm. Most samples were collected with a stainless-steel spoon and then stored in pre-labelled 120 mL or 250 mL glass jars at -20°C. Sediment samples collected for sulphide analysis were stored in a 120 mL glass jar at 4°C. Two 10 mL sediment samples for BTEX were collected by syringe and deposited into two individual vials pre-filled with 10 mL methanol (this is a new PIRI; sampling requirement that extends the sample hold time from 7 to 14 days). Sediment samples collected for toxicity analysis were taken from the top 7.5 cm of one core and stored at 4°C, in the dark, in a 4 L pail (amphipod toxicity) and a Whirl-Pak bag (bacterial luminescence). Sediment samples for benthic community structure analysis were collected from the top 15 cm of two cores and stored in two separate 11 L pails[6]. These samples were mixed with approximately 1 L of 10% buffered formalin. Benthic invertebrate counts from these two samples were later pooled for analysis.

The following Quality Assurance/Quality Control (QA/QC) protocols were implemented for collection of samples. Field duplicates were collected for sediment chemistry at stations 1, 2, 14, NA2 and SWRX1. Duplicates were collected for analysis of BTEX, $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, PAHs, metals, ammonia, sulphur, sulphides, TIC and TOC. For sample handling, core samples were immediately covered with clean, plastic-lined metal covers and moved to a working area near the laboratory facility. Sampling personnel were supplied with new latex gloves for each station. The laboratory facility and sampling tools were washed with isopropanol then rinsed with distilled water between each station to prevent cross-contamination between stations. Processed samples were transferred to cold storage within one hour of collection. Once ashore, samples to be analyzed by Maxxam were transferred to the Maxxam Laboratory in St. John's for shipment to the Maxxam laboratory in Halifax. Samples to be analyzed by petroforma, Arenicola Marine and the Stantec Materials Lab were transferred to cold storage at Stantec and then shipped to the respective laboratories. Where applicable, samples were delivered to laboratories within the prescribed sample holding time.

[6] Those chemistry samples collected from the same core as benthic community samples made up approximately 3% of the volume of sediment sampled for benthic community analysis.

5.1.2 Laboratory Analysis

5.1.2.1 Physical and Chemical Characteristics

Sediment particle size analysis was conducted by Stantec, in St. John's, Newfoundland and Labrador, following the Wentworth particle size classification scale (Table 5-2, also see Appendix B-2 for the method summary). Sediment chemistry analysis was conducted by Maxxam Analytics, in Halifax, Nova Scotia. The full suite of chemical parameters is provided in Table 5-3 along with the laboratory detection limits. Methods summaries for chemistry analyses are provided in Appendix B-3.

Table 5-2 Particle Size Classification

Size Classification (Wentworth Scale)	Size Range (mm)	PHI Scale Range
Gravel	2 to 64	-1.000 to -6.000
Sand	0.063 to 2	3.989 to -1.000
Silt	0.002 to 0.063	8.966 to 3.989
Clay	< 0.002	< 8.986

Note: - Silt + clay fractions are collectively referred to as "fines".

Table 5-3 Sediment Chemistry Variables (2000, 2004, 2005, 2006, 2008, 2010, 2012, 2014 and 2016)

Variables	Method	Laboratory Detection Limit								Units
		2000	2004	2005	2006	2008	2010/2012	2014	2016	
Hydrocarbons										
Benzene	Calculated	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	mg/kg
Toluene	Calculated	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	mg/kg
Ethylbenzene	Calculated	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	mg/kg
Xylenes	Calculated	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
C_6-C_{10}	Calculated	3	3	3	4	3	3	3	3	mg/kg
>C_{10}-C_{21}	GC/FID	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	mg/kg
>C_{21}-C_{32}	GC/FID	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	mg/kg
PAHs										
1-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
2-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
1-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
2-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Acenaphthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Acenaphthylene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benz[*a*]anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benzo[*a*]pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benzo[*b*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benzo[*ghi*]perylene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benzo[*k*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Chrysene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Dibenz[*a,h*]anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Fluorene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Naphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Perylene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Phenanthrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Carbon										
Carbon	LECO	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.5	g/kg
Organic Carbon	LECO	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.5	g/kg
Inorganic Carbon	By Diff	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.5	g/kg
Metals										
Aluminum	ICP-MS	10	10	10	10	10	10	10	10	mg/kg
Antimony	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Arsenic	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Barium	ICP-MS	5	5	5	5	5	5	5	5	mg/kg
Beryllium	ICP-MS	5	2	2	2	2	2	2	2	mg/kg
Cadmium	GFAAS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Cobalt	ICP-MS	1	1	1	1	1	1	1	1	mg/kg

Variables	Method	Laboratory Detection Limit								Units
		2000	2004	2005	2006	2008	2010/2012	2014	2016	
Copper	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Iron	ICP-MS	20	50	50	50	50	50	50	50	mg/kg
Lead	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Lithium	ICP-MS	5	2	2	2	2	2	2	2	mg/kg
Manganese	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Mercury	CVAA	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.01	mg/kg
Molybdenum	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Nickel	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Selenium	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Strontium	ICP-MS	5	5	5	5	5	5	5	5	mg/kg
Thallium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Tin	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Uranium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Vanadium	ICP-MS	2	2	2	2	2	2	2	2	mg/kg
Zinc	ICP-MS	2	5	2	5	5	5	5	5	mg/kg
Other										
Ammonia (as N)	COBAS	NA	0.25	0.3	0.3	0.3	0.3	0.3	0.3	mg/kg
Sulphide	SM4500	NA	2	0.2	0.2	0.2	0.2	0.2	0.5	mg/kg
Sulphur	LECO	NA	0.02	0.02	0.002	0.01	0.03	0.03	0.01	%
Moisture	Grav.	0.1	0.1	0.1	1	1	1	1	1	%
Radium-226	Gamma Spec.	NA	NA	NA	NA	0.02	0.02/NA	NA	NA	Bq/g
Radium-228	Gamma Spec.	NA	NA	NA	NA	0.003	0.003/NA	NA	NA	Bq/g
Lead-210	Gamma Spec.	NA	NA	NA	NA	0.01	0.01/NA	NA	NA	Bq/g

Notes:
- Total metals concentrations were assessed. Assessment of total metals concentration does not differentiate between bioavailable and non-bioavailable fractions.
- Measurement of radionucliides was discontinued in 2012 because modelling showed that the probability of detecting enrichment of these in sediments as a result of project activity at White Rose was zero.
- The laboratory detection limit is the lowest concentration that can be detected reliably within specified limits of precision and accuracy during routine laboratory operating conditions. Laboratory detection limits will vary among analytically laboratories. They may also vary from year to year if instruments are checked for precision and accuracy as part of QA/QC procedures.
- Laboratory detection limits for hydrocarbons in 2000, 2004, 2005, 2012, 2014 and 2016 were reported at one more significant digit than what is shown above. As this was not a change in detection limit but rather a change in rounding of the values, the higher of the reported detection limits (in 2006, 2008 and 2010) are used in this report.
- NA = Not Analyzed.
- GC/FID = Gas Chromatography/Flame Ionization Detection
- GC/MS = Gas Chromatography/Mass Spectrometer
- ICP-MS = Inductively Coupled Plasma/Mass Spectrometer
- CVAA = Cold Vapour Atomic Absorption

Within the hydrocarbons, BTEX are aromatic organic compounds that are detected in the C_6-C_{10} range, commonly referred to as the gasoline range. The >C_{10}-C_{21} range is referred to as the fuel range and is the range where lightweight fuels like diesel will be detected. The >C_{21}-C_{32} range is where lubricating oils (*i.e.*, motor oil and grease), crude oil and, in some cases, bunker C oil, would be detected. Hydrocarbons in all ranges include both aromatic (ring), n-alkane (straight chain) and isoalkane (branched chain) compounds. PAHs are a diverse class of organic compounds that are composed of two or more fused aromatic benzene rings.

Gas chromatography is used to assess concentrations of hydrocarbons in the C_6-C_{32} range. When complex hydrocarbon mixtures are separated by chromatography, the more unique compounds such as the n-alkanes separate as individual peaks. Isoalkanes, on the other hand, are such a diverse group with so little difference in physical characteristics that they tend not to separate into distinct peaks in the chromatogram but rather form a "hump" in the chromatogram. This hump is often referred to as the Unresolved Complex Mixture. The synthetic-based drill mud base oil (PureDrill IA35-LV) used at White Rose is a synthetic isoalkane fluid consisting of molecules ranging from >C_{10}-C_{21}. Most of the components of PureDrill IA35-LV form an Unresolved Complex Mixture that starts around the retention time of C_{11} n-alkane (2.25 min) and ends around the same time as C_{21} n-alkanes (approximately 7.4 min) (Figure 5-4). The highest peaks in a chromatogram of PureDrill IA35-LV have retention times similar to those of n-alkanes of C_{17}-C_{18} size.

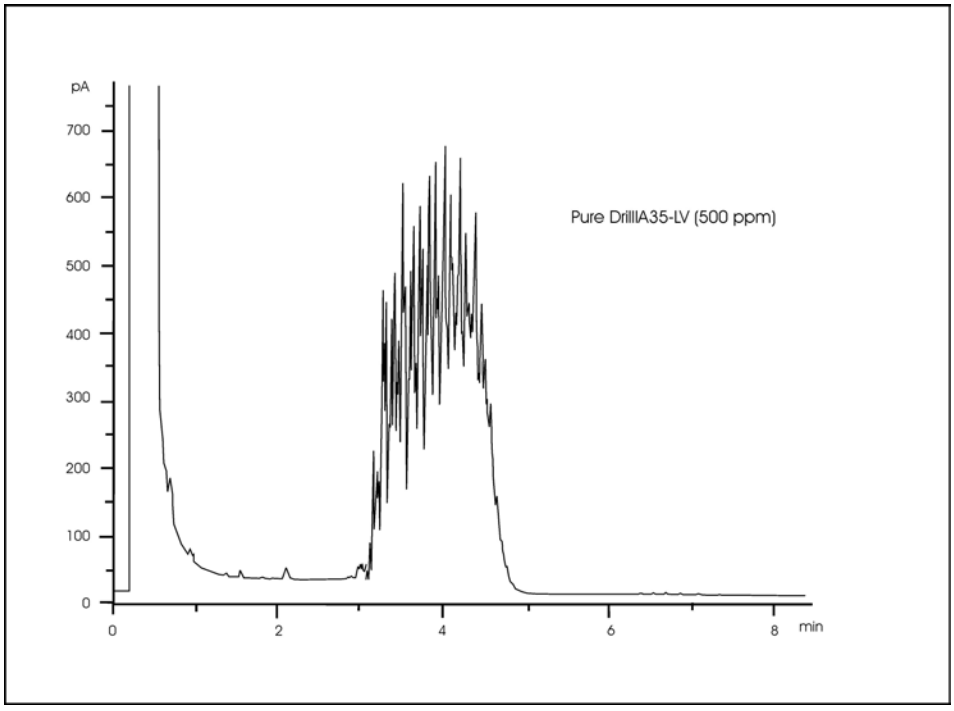

Figure 5-4 Gas Chromatogram Trace for PureDrill IA35-LV

5.1.2.2 Toxicity

Analytical Methods

Sediment toxicity analyses were conducted at petroforma inc. in St. John's, Newfoundland and Labrador. Sediment samples were examined using the amphipod

survival bioassay and the bacterial luminescence assay. Both bioassays used whole sediment as the test matrix. Tests with lethal endpoints, in this case, amphipod survival, measure survival over a defined exposure period. Tests with sublethal endpoints measure physiological functions of the test organism, such as metabolism, fertilization and growth, over a defined exposure period. Bacterial luminescence, in this case, was used as a measure of metabolism. Tests that rely on sublethal endpoints are a potential gauge of long-term effects.

Amphipod survival tests were conducted according to Environment Canada (1998) protocols and guidance from Environment Canada using the marine amphipod *Rhepoxynius abronius* collected from West Beach, Whidbey Island, Washington State (USA). *R. abronius* is a standard and widely used test species. Although it is not native to the East Coast of Canada, related species in the family Phoxocephalidae are among the more abundant amphipods in White Rose benthic invertebrate communities. Tests involved five replicate 1 L test chambers with approximately 2 cm of sediment and approximately 800 mL of overlying water (Figure 5-5).

Figure 5-5 Amphipod Survival Test

Each test container was set up with 20 test organisms and maintained for 10 days under appropriate test conditions, after which survival was recorded. An additional test container was used for water quality monitoring only. Negative control sediment was tested concurrently, since negative controls provide a baseline response against which test organisms can be compared. Negative control sediment, known to support a viable population, was obtained from the collection site for the test organisms. A positive (toxic) control in aqueous solution was tested for each batch of test organisms received. Positive controls provide a measure of precision for a particular test, and monitor seasonal and batch sensitivity to a specific toxicant.

Amphipod toxicity tests were initiated within the six weeks holding period recommended by Environment Canada (1998).

The bacterial luminescence test (Microtox) was performed with *Aliivibrio fishcheri*. This bacterium emits light as a result of normal metabolic activities. This assay was conducted according to the Environment Canada (2002) Reference Method and guidance from Environment Canada using the large volume solid phase assay. Analysis was conducted on a Model 500 Photometer with a computer interface. A geometric series of sediment concentrations was set up using Azur solid phase diluent. The actual number of concentrations was dependent on the degree of reduction in bioluminescence observed. Negative (clean) and positive (toxic) controls were run concurrently with the test samples. Reduction of light after 15 minutes was used to measure toxicity. Data interpretation for 2004, 2005, 2006, 2008, 2010, 2012, 2014 and 2016 was conducted as outlined in Environment Canada's (2002) Reference Method. Data from the 2000 (baseline) program were reexamined using the criteria outlined in Environment Canada (2002) because analyses in 2000 were conducted using earlier Environment Canada guidelines (small volume solid phase assay; Environment Canada 1992). Reinterpretation of 2000 data using Environment Canada (2002) did not alter any of the 2000 interpretations.

All Microtox tests were initiated within six weeks of sample collection, as recommended by Environment Canada (2002).

Both Environment Canada (1998) and Environment Canada (2002) require measurement of pore water pH, salinity and ammonia. However, based on recommendations from Environment Canada ensuing from discussions on the 2014 EEM report, these measurements were replaced with measurement of sediment ammonia, sulphides and redox potential.

Results Interpretation

The statistical endpoint for the amphipod toxicity test is the determination of whether the biological endpoint (percent survival) differs statistically from the control or reference sample. This endpoint was calculated using the Dunnett's Multiple Comparison Test using the CETIS computer program (©2001-2010 Tidepool Scientific, LLC). The statistical endpoint for the Microtox test is the determination of whether the biological

endpoint (bioluminescence) for the sample is significantly different from the negative control (0%), calculated as the IC_{50}[7] value.

petroforma inc. conducted amphipod toxicity tests using two separate reference samples: negative control sediment that came from the source site for the amphipods (B-7514-09, B-7537-09 and B-7549-09); and a composite sample made up of sediment from four reference stations (stations 4, 12, 19, 27). Using two reference samples to define toxicity reduces an already very low risk of false positives. Sample toxicity was assessed using standard toxicity testing statistical programs. The amphipod survival test results for sediments were considered toxic if the survival was reduced by more than 30% reduction as compared to the negative control sediment and the result was statistically significantly different from survival in the negative control sediment. Amphipod survival was also compared to White Rose Reference Station sediment (WRRS; stations 4, 12, 19 and 27). For this EEM program, the amphipod survival test results for sediments were considered toxic if survival was reduced by more than 20% as compared to WRRS sediment and the result was statistically significantly different from survival in the WRRS sediment.

Amphipod toxicity test results were then examined for the potential influence of sediment ammonia, sulphide and redox potential, as described in Appendix B-4.

The Reference Method for Determining the Toxicity of Sediment Using Luminescent Bacteria in a Solid-Phase Test (Environment Canada 2002) was also used to assess sediments. Sediments with levels of silt/clay (i.e. fines) greater than 20% are considered to be toxic if the IC_{50} is less than 1,000 mg/L as dry solids.

For any test sediment from a particular station that is comprised of less than 20% fines and that has an IC_{50} of ≥1,000 mg/L (dry weight), the IC_{50} of this sediment must be compared against a sample of “clean” reference sediment or negative control sediment (artificial or natural) with a percent fines content that does not differ by more than 30% from that of the test sediment. Based on this comparison, the test sediment is judged to have failed the sediment toxicity test if, and only if, both of the following two conditions apply:

1. its IC_{50} is more than 50% lower than that determined for the sample reference sediment or negative control sediment; and

2. the IC_{50}s for the test sediment and reference sediment or negative control sediment differ significantly.

As was the case for the amphipod tests, Microtox toxicity test results were then examined for the potential influence of sediment ammonia, sulphide and redox potential, as described in Appendix B-5.

[7] An IC_{50} (50% inhibitory concentration) is the concentration of a substance that produces 50% of the maximum possible inhibitory response to that substance.

5.1.2.3 Benthic Community Structure

All 2016 benthic invertebrate samples were provided whole to Arenicola Marine Limited (Wolfville, Nova Scotia). The two core samples collected at each station were processed separately but data were pooled for data analysis (see Section 5.1.3.3).

Sandy samples were washed through a 0.5 mm sieve. Samples with larger proportions of coarse material (gravel and shell) were elutriated and sieved by directing a high volume (1 L/s) flow of freshwater into the sample, tilting the sample bucket and catching the overflow on the sieve. This washing removed the silt/clay and finer sand fractions from the samples. The procedure was adjusted to leave coarser sediment fractions in the pail. The flow suspended the less dense organisms (*e.g.*, polychaetes) and separated small gastropods and clams which, with a suitable balance of flow in and out of the bucket, could be separated as well. Elutriation was continued until the water leaving the pail was free of organisms and when no additional heavier organisms could be seen after close examination of the sediment. Usually, larger organisms such as scallops and propeller clams were separated manually as they were found. Barnacles and sponges were scraped off rocks. With coarser sediments such as gravels, which were occasionally encountered, a 1.2 cm mesh in combination with the 0.5 mm screen was used to aid in separating the organisms. Organisms were placed in 70% alcohol after sieving.

Samples were sorted under a stereomicroscope at 6.4x magnification, with a final scan at 16x. After sorting, substrate from 10% of samples was reexamined by a different sorter to determine sorting efficiency. Efficiency levels ranging from 98.8 to 100% were achieved (*i.e.*, the first sorter recovered 98.8% to 100% of the organisms recovered by both sorters combined). Wet weight biomass (g/sample) was estimated by weighing animals to the nearest milligram at the time of sorting after blotting to remove surface water. None of the samples were subsampled.

Organisms were identified to the lowest practical taxonomic level, typically to species, using conventional literature for the groups involved (Appendix B-6). All organisms were identified by Patricia Pocklington, a specialist in marine benthic invertebrate taxonomy.

Benthic invertebrate samples from 2004 to 2016 were also processed by Arenicola Marine Limited. Benthic invertebrate samples from 2000 were processed by Pat Stewart of Envirosphere Limited. Methods and the level of taxonomy were similar to those used for the 2004 to 2016 samples (see Husky Energy 2001 for details).

5.1.3 Data Analysis

The White Rose Sediment Quality survey is based on a gradient design, with sampling locations radiating out from the general operations area defined by the Northern, Southern, Central, North Amethyst and SWRX Drill Centres. Effects during development drilling periods (since operations began; from 2004 to present) at White Rose have historically been most evident close to active drill centres and have decreased with distance away from them. The general approach for the examination of the Sediment Quality data was to confirm the presence of spatial patterns (*i.e.*, changes in response variables with distance from active drill centres) that were consistent with development

drilling effects and to identify the potential zone of influence[8] for sediment chemistry. Drill centres were considered active if any drilling had occurred there in the past.

As indicated in Husky's response to regulator comments on the 2008 EEM program (see Appendix A-1 in the 2010 EEM Program Report, Husky Energy 2011), the EEM reports now rely on both statistical analysis and visual display of information in order to assess effects. Occurrence above or below the range of values observed during baseline sampling (2000) is used to assess effects from individual drill centres. When no baseline data are available, values observed at stations greater than 10 km from drill centres since the variable began to be measured until 2014[9] are used instead.

Station 31 was excluded from all analyses of physical and chemical characteristics of sediments in from 2008 to 2016 because it is a clear outlier in terms of chemistry (hydrocarbons and barium in particular). Station 31 is located 4.2 km from the nearest development drill centre but the station is located near the site of a delineation well drilled in 2007. Station 31 was included in distance trend analyses in 2016 for laboratory toxicity test results and benthic indices, because it was not an outlier for biological measures.

5.1.3.1 Physical and Chemical Characteristics

Data were first screened to identify and exclude variables that frequently occurred below detectable concentrations. In most cases, variables with greater than 25% of test results below laboratory detection limits were not included in statistical analyses. The variables selected for detailed analysis in 2016 included $>C_{10}$-C_{21} hydrocarbons, barium, sediment particle size (% fines and % gravel), ammonia, sulphide, sulphur, TOC, redox potential and a summary measure of concentration of metals other than barium (derived from a principal component analysis (PCA) of metals data). More than 25% of results were below laboratory detection limit for both sulphide and TOC. However, these two variables were included in some statistical analyses. Also, because the metals PCA indicated that lead and strontium behaved differently from other metals, these two metals were examined separately. The rationale for selecting these variables is provided below.

Synthetic-based drill muds have elevated concentrations of $>C_{10}$-C_{21} hydrocarbons. Barium, as barium sulphate (barite), can be a constituent of both water-based and synthetic-base drill muds. Sediment particle size (particularly % fines) and TOC content could be altered by drilling activity. Water-based and synthetic-based muds and associated drill cuttings are finer than the predominantly sand substrate on the Grand Banks, and synthetic-based muds have a higher organic carbon content than natural substrates.

Percent gravel has previously been correlated with indices of benthic community structure. As in previous years, percent sand was not examined because it is strongly negatively correlated with percent gravel and, generally speaking, percent fines constitute a very small fraction of sediment particle size.

[8] The zone of influence has been defined as the zone where physical and chemical alterations might occur (see Section 1).

[9] The year 2014 is used as a cut-off because sufficient numbers are available to assess background for the variables in question and because thresholds would change from program to program if the dataset was consistently updated to include the current sample year.

Sulphur, as sulphate in barite, is also an important constituent of drill muds. Ammonia and sulphide levels are typically high, and redox levels are low, in sediments where decomposition or degradation of natural or synthetic organic matter is extensive. Ammonia and sulphides, as well as particle size, are also important confounding factors that need to be considered in the interpretation of toxicity test results (Tay *et al.* 1998); and these variables, as well as TOC, are known to affect benthic communities (Pearson and Rosenberg 1978). Metals other than barium can also be enriched in drill cuttings, albeit to a lesser extent.

Five statistical tools were used to explore the spatial variations of these selected variables as they might relate to drilling. These tools are described below.

Spearman rank correlations (Tool 1) were used to statistically test for associations between distance from the nearest active drill centre (indicated as Min D in graphics) and concentration of the subset of variables selected for detailed analysis. Correlations were assessed for all stations (n = 52 in 2016, excluding Station 31; see Section 5.1.3) and for only those stations tested in repeated-measures regression (n = 35, excluding Station 31; see Tool 5 below). The latter correlations were assessed predominantly to aid in interpretation of repeated-measures regression results. Because sample size differs between the two datasets, results of each set of analyses did at times indicate different trends over time.

Threshold models (Tool 2), including all stations (n = 52 in 2016, excluding Station 31), were constructed in order to estimate the spatial extent (threshold distance) of influence of active drill centres. Threshold models were only tested on variables that were demonstrated with Spearman rank correlations to be significantly correlated with distance from the nearest active drill centre.

The third tool (Tool 3) involved visual inspection of response variable data for all stations (n = 52 in 2016 in most cases) from 2000 to present. Scatterplots of concentration (or percent as appropriate) in relation to distance from the nearest active drill centre were produced in order to visualize the nature of the relationship with distance. Station 31 was shown on scatterplots for $>C_{10}$-C_{21} hydrocarbons and barium (*i.e.*, n = 53) since those were the variables most affected by delineation drilling near that station. Station 31 was excluded (*i.e.*, n = 52) from other scatterplots. As noted above, the station was not included in analyses.

Maps (Tool 4) of 2016 data for all stations were generated to indicate concentrations within and exceeding the variability observed in baseline (2000), or background variability (stations located at more than 10 km from drill centres) if baseline data were unavailable. These maps were used to visually assess the effects of individual drill centres on variables that were demonstrated with Spearman rank correlations to be significantly correlated with distance from the nearest active drill centre.

Repeated-measures regression (Tool 5) was used to test for spatial and temporal variation at those stations that have been repeatedly sampled since baseline (n = 35, excluding Station 31). The repeated-measures regression method was used to determine if there were changes over time both in terms of changes in mean concentration across all sampling locations (*i.e.*, an increase or decrease in concentration that is similar across all stations), or a change in the nature of the relationship between distance to the nearest active drill centre and concentration

(*i.e.*, the slope of the relationship may get steeper over time, indicating an increase in concentrations adjacent to active drill centres). For Tools 2 and 5, data were log_{10}-transformed to satisfy assumption of normality, homogeneity of variance and linearity.

5.1.3.2 Toxicity

In 2016 and in previous years, no analyses of results for bacterial luminescence toxicity tests were conducted because there were very few samples that were determined to be toxic using this test.

The relationship between amphipod survival, distance to the nearest active drill centre and the other variables brought forward for analysis were tested using Spearman rank correlations.

5.1.3.3 Benthic Community Structure

In 2016, benthic invertebrate samples from station NA2 and SWRX4 returned anomalous results with low abundances and biomass. The taxonomic laboratory reported an odour of decaying organic matter and suggested that incomplete preservation may have occurred. In the absence of elevated redox or sulphide results from chemistry analyses at these stations, it is likely that the fixative added to the samples during field collection was not completely mixed with the sediment-invertebrate sample matrix. Because of this, the biotic material in the samples decayed, producing the noted odour. Given this, samples from stations NA2 and SWRX4 were excluded from statistical analysis as procedural outliers.

Univariate Analyses

In 2016, as in previous years, benthic community structure analysis focused on three summary indices:

- total abundance (number of organisms per m^2);
- biomass (wet weight of organisms per m^2); and
- taxonomic richness (number of families per station).

Abundances of four taxa were also analyzed. These analyses were secondary to analyses of indices of benthic community structure and were performed to provide insight on the more general indices. Taxa examined were:

- Paraonidae (Polychaeta);
- Spionidae (Polychaeta);
- Tellinidae (Bivalvia); and
- Amphipoda.

Paraonidae, Spionidae and Tellinidae were the three most abundant taxa. Although Amphipoda were relatively rare, they were included in analyses of individual taxa because they are generally considered sensitive and were also reduced in abundance near active drill centres and at relatively high >C_{10}-C_{21} hydrocarbon concentrations in past years (Husky Energy 2011).

As with the sediment chemistry and amphipod toxicity results, the objective of the detailed analysis of the benthic community data was to test for evidence of effects from active drill centres. Five univariate statistical tools were used to explore the spatial variations of the selected indices of benthic community structure: Spearman rank correlations (Tool 1), threshold models (Tool 2), graphical display of data (Tool 3), maps (Tool 4), and repeated-measures regression (Tool 5). For individual taxa, only those taxa that showed significant correlations with distance from active drill centres were examined using maps.

Multivariate Analyses

As recommended in the 2014 EEM report (Husky Energy 2017), additional multivariate analyses (specifically, non-Metric Multidimentional Scaling (nMDS) were undertaken in this 2016 report. Multivariate analysis can provide additional spatio-temporal information on similarities or differences among samples/sites based on the entire data matrix (Clarke and Warwick 2001).

All multivariate statistical and graphical analyses of taxonomic abundance were based on square root-transformed Bray-Curtis similarity matrices. To assess variation in benthic infauna assemblages, permutational multivariate analysis of variance (PERMANOVA) was used by conducting 4,999 random permutations for each dataset (Anderson *et al.* 2008). The percent contribution of species or groups to the observed dissimilarity among distance groups from nearest active drill centres was determined using similarity percentage (SIMPER) analyses (Clarke and Warwick 2001). Data are presented for taxa that contributed to ≥5% of the observed dissimilarity among distance groups from nearest active drill centres.

To examine correlations between sediment physical/chemical variables and the benthic invertebrate assemblage data, step-wise distance-based linear models (DISTLM) with an Akaike Information Criterion (AIC) selection process (Anderson *et al.* 2008) were used. Prior to conducting DISTLM step-wise multivariate multiple regression analyses, sediment physical/chemical variables were $\log_{10}$-transformed and screened to identify highly correlated variables (Pearson correlation coefficients > |0.8|), which could bias model selection (Anderson *et al.* 2008). Sulphur (Pearson coefficient >0.9 with barium), strontium (Pearson coefficient >0.9 with barium), and manganese (Pearson coefficient >0.9 with iron) were removed from analyses to create a reduced model. The reduced model results were then compared to the results of the model incorporating all variables. Exclusion of the correlated variables (reduced model) did not alter the statistical interpretations; therefore, the statistical results reported are based on the full model that considered all potential variables. All multivariate statistical analyses were performed using PRIMER with PERMANOVA+ (ver. 6.1.11, PRIMER-E Ltd, Plymouth, UK).

All statistical methods are described in greater detail in Appendix B-7.

5.2 Results

5.2.1 Physical and Chemical Characteristics

Appendix B-3 provides summary statistics at Sediment Quality Triad stations for sediment physical and chemical characteristics occurring at or above the laboratory detection limit from 2000 to 2016. All variables measured on sediment are provided in Table 5-3. Toluene was detected at levels close to the laboratory detection limit at one station in 2005 and was not detected in other years. $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons have been detected in sediments since 2004, but were not detected in 2000, the baseline year. No PAHs were detected at Sediment Quality Triad stations in 2016. PAHs were only detected at Sediment Quality Triad stations in baseline (at one station) and in 2010 (at five stations), and levels were near the laboratory detection limit of 0.01 mg/kg (range 0.02 to 0.07 mg/kg; Appendix B-3). Commonly detected metals in all nine sampling years were aluminum, barium, chromium, iron, lead, manganese, strontium, uranium and vanadium.

As in previous years, sediments collected in 2016 were predominantly sand, with gravel-sized materials comprising up to 4.1% of the sediment (Table 5-4). Organic carbon content was low, with most values below the laboratory detection limit of 0.5% TOC, and a maximum of 1.1% TOC observed at station S5. Sediment percent fines *(i.e.*, silt and clay fractions combined) content was also low with an average of 1.6% and a maximum value of 3.2% at station NA1.

Table 5-4 Summary Statistics for Selected Sediment Variables (2016)

Variable	Units	ISQG	N of Cases	Minimum	Maximum	Arithmetic Mean
Aluminum	mg/kg		53	5500	11000	8425
Barium	mg/kg		53	93	2400	309
Chromium	mg/kg	52.3	53	2.8	21.0	4.7
Iron	mg/kg		53	1100	2600	1575
Lead	mg/kg	32	53	1.8	11.0	3.2
Manganese	mg/kg		53	21.0	72.0	40.5
Strontium	mg/kg		53	31.0	92.0	49.8
Uranium	mg/kg		53	0.1	0.4	0.2
Vanadium	mg/kg		53	4.0	8.6	5.3
Zinc	mg/kg	124	53	<5	6.4	NA
$>C_{10}$-C_{21}	mg/kg		53	<0.3	150	12.6
$>C_{21}$-C_{32}	mg/kg		53	0.37	3.0	0.93
Fines	%		53	1.1	3.2	1.6
Sand	%		53	93.9	98.6	97.3
Gravel	%		53	0.1	4.1	1.1
TOC	g/kg		53	<0.5	1.1	NA
Redox	mV		53	115	238	200
Ammonia	mg/kg		53	2	11	5.87
Sulphur	mg/kg		53	0.03	0.11	0.04
Sulphide	mg/kg		53	<0.5	3.6	NA
Depth	m		53	100	173	121

Note:
- For the most part, variables listed above are those that occurred frequently and/or that are brought forward for analysis in the subsequent sections. Zinc is listed because ISQG are available for the variable. Most zinc values (49 out of 53) were below laboratory detection limit in 2016.
- $>C_{10}$-C_{21} values below laboratory detection limit were set to ½ laboratory detection limit for the purpose of computing averages in this Table and for other detailed statistics.
- When more than 25% of values were below the laboratory detection limit, a mean is not calculated in this table.

Sediment concentrations of metals for which there is a sediment quality guideline were below their Interim Sediment Quality Guidelines (ISQG) (Canadian Council of Ministers of the Environment (CCME) 2001, 2015; see Table 5-4). Adverse biological effects are rarely expected to occur below ISQG (CCME 2001, 2015). Concentrations of $>C_{10}$-C_{21} hydrocarbons averaged 12.6 mg/kg and varied from below detection to 150 mg/kg, at station 20. Barium concentrations averaged 309 mg/kg, with a maximum level of 2,400 mg/kg at station NA1.

5.2.1.1 $>C_{10}$-C_{21} Hydrocarbons

As in previous years, concentrations of $>C_{10}$-C_{21} hydrocarbons in 2016 were significantly and negatively correlated (*i.e.*, decreased) with distance from the nearest active drill centre (ρ_s = -0.91, p < 0.001, All stations; ρ_s = -0.93, p < 0.001, repeated-measures stations[10]) (Figure 5-6).

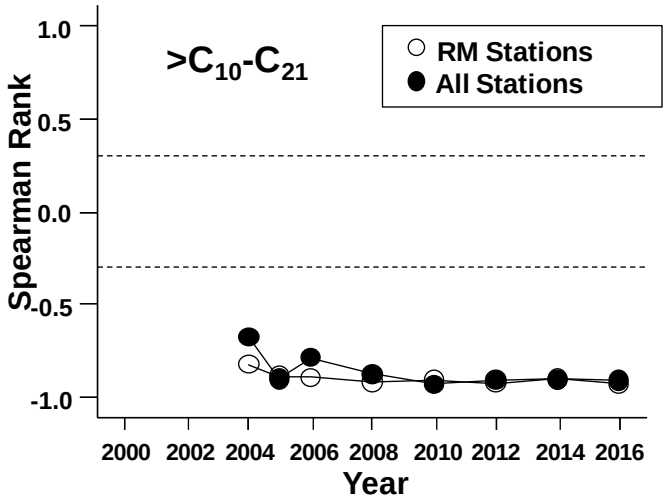

Figure 5-6 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for $>C_{10}$-C_{21} Hydrocarbons

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

[10] Refer to Table 1-1 for repeated-measures (RM) stations

A threshold model describing the relationship between concentrations of $>C_{10}$-C_{21} hydrocarbons and distance from the nearest active drill centre was significant (p < 0.001). In 2016, the threshold distance was estimated to be 2.7 km (Table 5-5). Based on confidence limits in Table 5-5, the estimated threshold in 2016 is lower than those estimated prior to 2010, and similar to estimates from more recent years. Figure 5-7 provides a graphical representation of threshold models.

Table 5-5 Results of Threshold Regressions on Distance from the Nearest Active Drill Centre for $>C_{10}$-C_{21} Hydrocarbons

Year	Threshold Distance (km)
2004	6.3 (4.1, 9.7)
2005	8.9 (4.9, 16)
2006	5.9 (4.2, 8.5)
2008	10.4 (5.2, 20.9)
2010	3.6 (2.9, 4.4)
2012	3.6 (2.6, 4.8)
2014	5.8 (3.5, 9.5)
2016	2.7 (1.9, 3.9)

Notes: - 95% confidence limits are provided in brackets.
- n = 52 in 2016 with Station 31 excluded.

As indicated in Figure 5-7, no hydrocarbons were detected in White Rose sediments during baseline sampling. As in previous EEM years, $>C_{10}$-C_{21} hydrocarbon concentrations were enriched around active drill centres in 2016 (Figures 5-7 and 5-8). $>C_{10}$-C_{21} hydrocarbons were also enriched at Station 31, located near the site of a delineation well (White Rose K-03) drilled in 2007 (Figure 5-8).

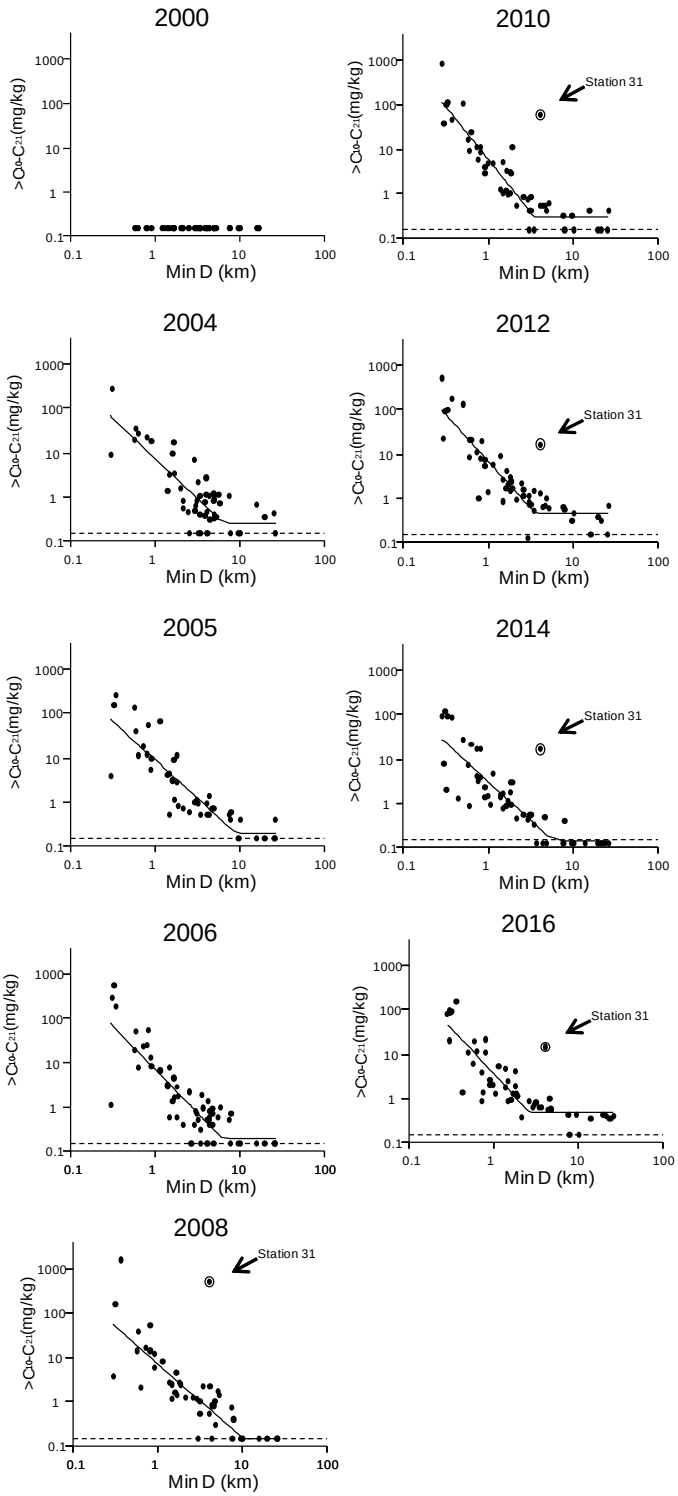

Figure 5-7 Variations in >C_{10}-C_{21} Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. The ½ of the detection limit is indicated in each graph by a horizontal dotted line (0.15 mg/kg), to indicate the levels observed in the baseline year (2000). Here and in similar figures, threshold models are plotted when these were significant.

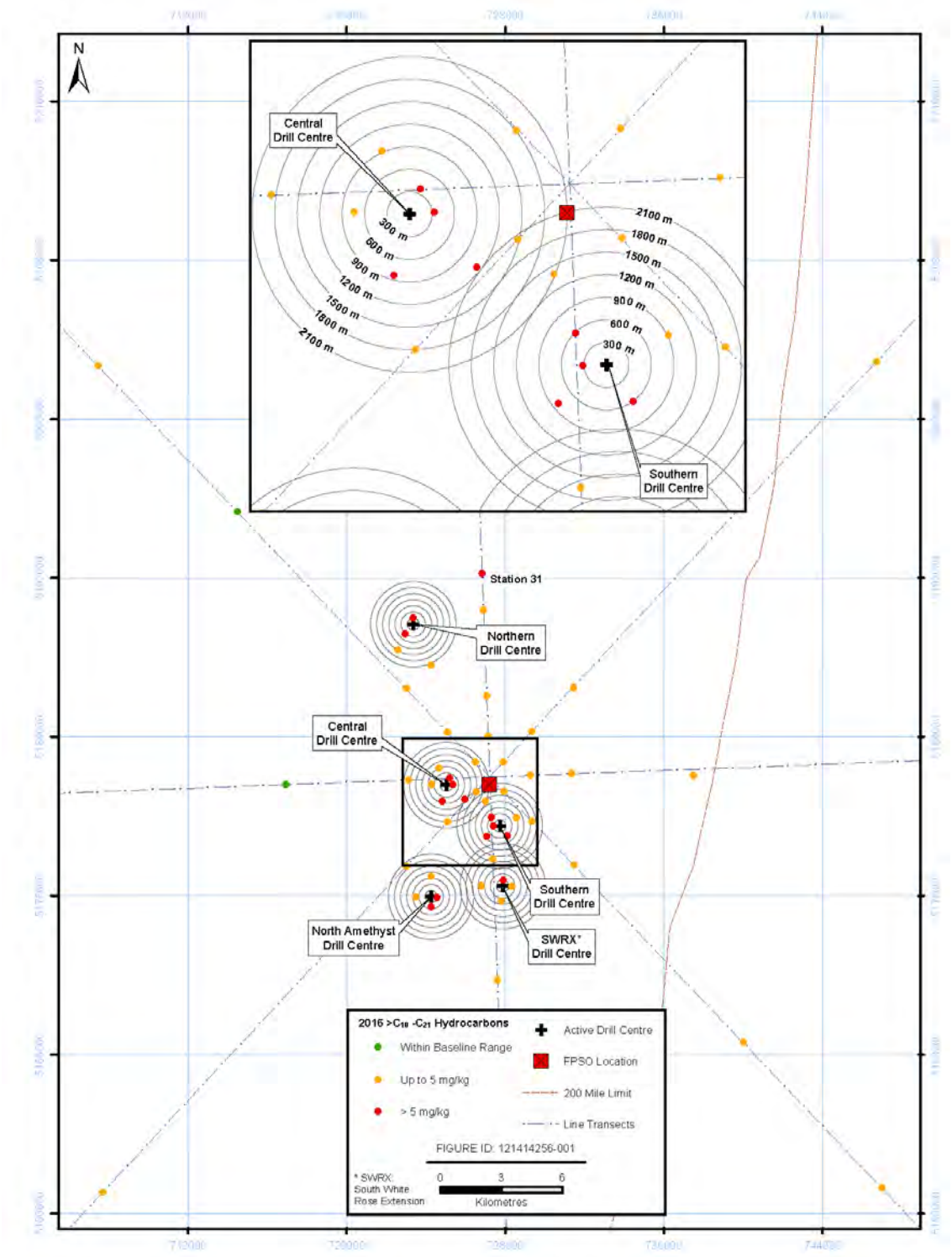

Figure 5-8 Location of Stations with >C_{10}-C_{21} Hydrocarbon Values within the Baseline Range (not detected), Stations Showing Mild Enrichment up to 5 mg/kg, and Stations with Values Greater than 5 mg/kg (2016)

Repeated-measures regression indicated no change over time in the relationship between distance and concentrations of >C_{10}-C_{21} hydrocarbons for repeated-measures stations (p = 0.831; Table 5-6), and no changes in area-wide concentrations over time (p = 0.240). This conclusion applies to the time period from 2004 to present (*i.e.*, EEM years). Concentrations of >C_{10}-C_{21} hydrocarbons were non-detectable in 2000, and generally have been at detectable concentrations since 2004 (Figures 5-7 and 5-9).

Table 5-6 Repeated-measures Regression Testing for Changes in >C_{10}-C_{21} Concentrations over Time

Trend Over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.831	0.240	NA	NA

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016. The Before to After contrast cannot be performed for >C_{10}-C_{21} hydrocarbons since all concentrations were below detection limit during baseline.

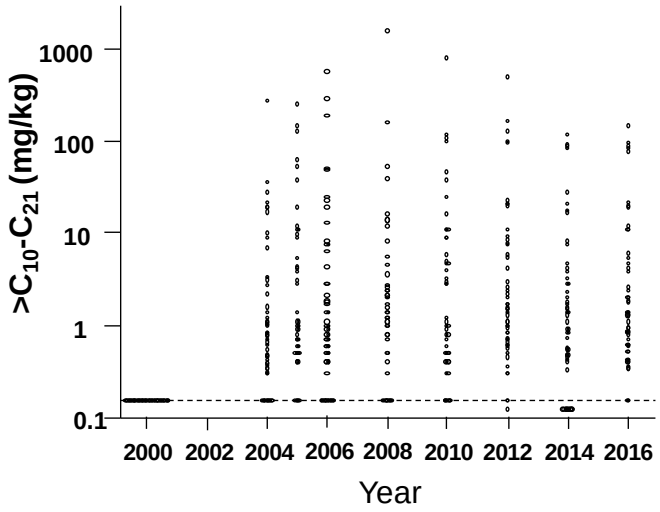

Figure 5-9 Dot Density Plot of >C_{10}-C_{21} Hydrocarbon Values by Year

Note: The horizontal dotted line indicates ½ the detection limit (0.15 mg/kg), to indicate the levels observed in the baseline year (2000).

5.2.1.2 Barium

Like >C_{10}-C_{21} hydrocarbons, barium produced a significant negative Spearman rank correlation with distance to active drill centres in 2016 (ρ_s = -0.81, p < 0.001, All stations; ρ_s = -0.88, p < 0.001, repeated-measures stations), as in previous years (Figure 5-10).

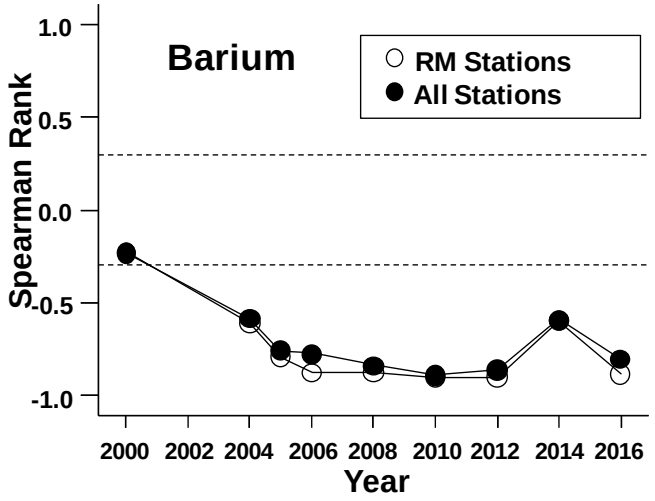

Figure 5-10 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Barium

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

The threshold model in 2016 was again significant ($p < 0.001$). The estimated threshold distance in 2016 was 1.2 km (Table 5-7). Confidence limits for 2016 overlapped with those estimated for all previous years except 2005, although there has been a tendency for threshold distances to be higher prior to 2010. Figure 5-11 provides a graphic representation of threshold models.

Table 5-7 Results of Threshold Regressions on Distance from the Nearest Active Drill Centre for Barium

Year	Threshold Distance (km)
2004	2.4 (1.6 to 3.5)
2005	3.6 (2.1 to 6.2)
2006	1.9 (1.4 to 2.6)
2008	2.4 (1.5 to 3.8)
2010	2.0 (1.6 to 2.5)
2012	1.0 (0.8 to 1.2)
2014	1.0 (0.8 to 1.4)
2016	1.2 (0.9 to 1.6)

Notes: - 95% confidence limits are provided in brackets.
- n = 52 in 2016 with Station 31 excluded.

As indicated in Figure 5-11, the “normal range” of variation for barium concentration in sediments across the sampling area was computed from the 2000 baseline data. Values in 2000 ranged between 120 and 210 mg/kg. The value 202 mg/kg (mean + 2 SDs) was used as a “benchmark” against which to judge spatial variation in the sampling area in Figures 5-11 and 5-12.

Barium was enriched to levels exceeding 202 mg/kg at some stations around the Central, North Amethyst, SWRX, Southern and Northern Drill Centres (Figure 5-12). Barium was also enriched at Station 31, located near the site of a delineation well (White Rose K-03) drilled in 2007.

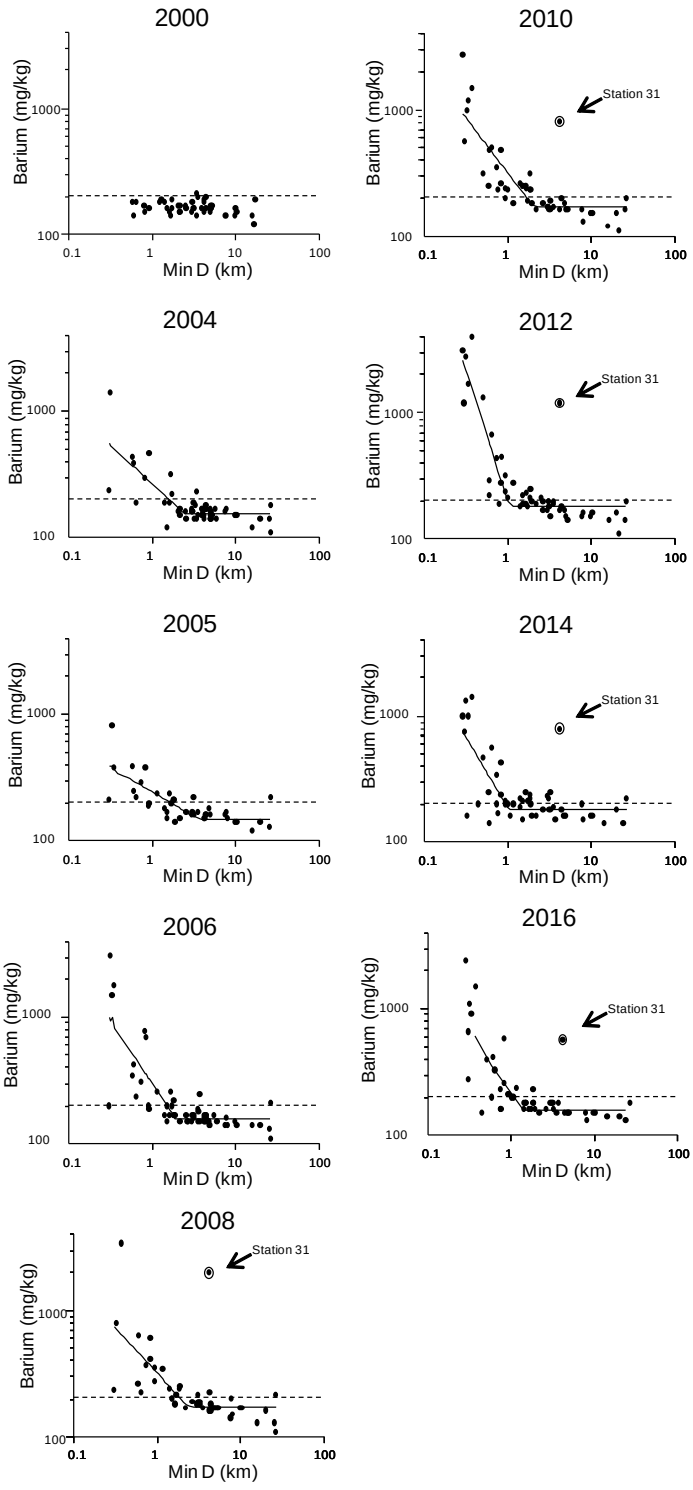

Figure 5-11 Variations in Barium Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. A concentration of 202 mg/kg is indicated in each graph by a horizontal line, based on the mean values + 2 SDs from 2000 (baseline). Here and in similar figures, threshold models are plotted when these were significant.

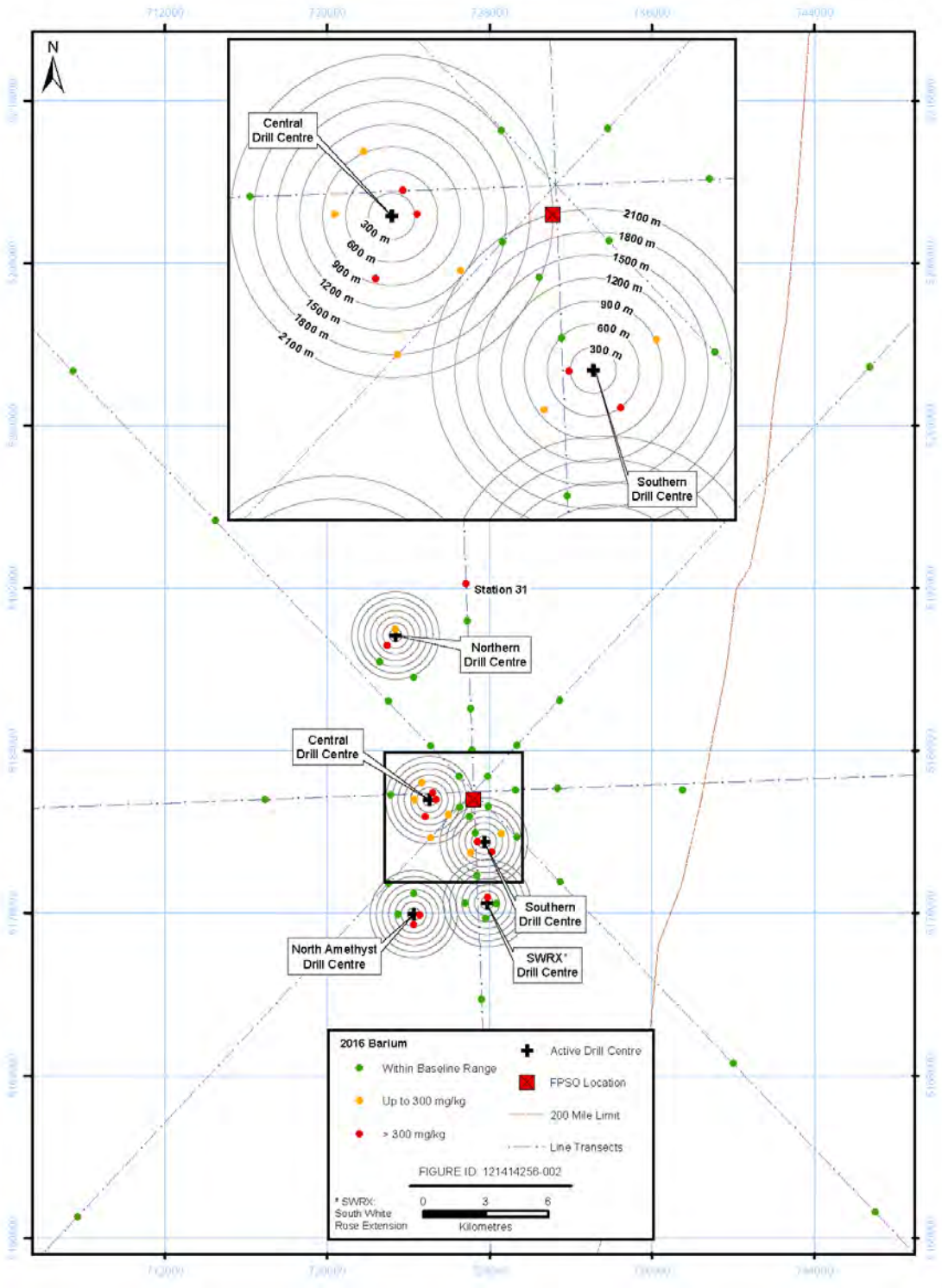

Figure 5-12 Location of Stations with Barium Levels Within the Baseline Range (up to 202 mg/kg), Stations Showing Mild Enrichment up to 300 mg/kg, and Stations with Values Greater than 300 mg/kg (2016)

Repeated-measures regression indicated no change over time in the slope of the relationship between barium concentration and distance to the nearest active drill centre in EEM years for repeated-measures stations (p = 0.157; Table 5-8). There was also no change over time in average barium concentration in EEM years (p = 0.059; also see Figure 5-13). Slopes differed from before to after drilling operations began (p < 0.001). Concentrations of barium in year 2000 averaged 168 mg/kg, with no significant correlation between barium concentrations and distance from drill centres (*e.g.*, Figure 5-10[11]). Conversely, distance correlations have been strong for barium since drilling began. Overall average barium concentrations have been higher since drilling operations began (p < 0.001; also see Figure 5-13).

Table 5-8 Repeated-measures Regression Testing for Changes in Barium Concentrations over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.157	0.059	<0.001	<0.001

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

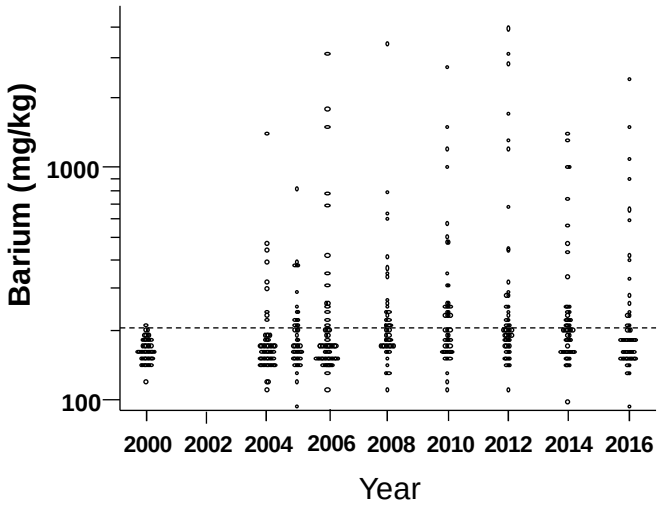

Figure 5-13 Dot Density Plot of Barium Values by Year

Note: A concentration of 202 mg/kg is indicated by a horizontal line, as based on the mean values + 2 SDs using data from the baseline year (2000).

[11] Although slopes from Spearman rank correlations (Figure 5-10 and other similar figures) are not the same as slopes from repeated-measures regression (the former is non-parametric, the latter is parametric), Figure 5-10 (and other similar figures) can often be used to better understand repeated-measures regression results.

5.2.1.3 Fines

Percent of sediment as fines (*i.e.*, silt and clay) varied between 1.1% and 3.2% across the sampling area; and the variable was not significantly correlated with distance to drill centres (ρ_s = -0.231, p > 0.05, All stations; ρ_s = -0.089, p > 0.05, repeated-measures stations) (Figure 5-14). The plot of Spearman rank correlations over time in Figure 5-14 indicates that the relation between fines and distance from the nearest active drill centre typically has not been strong.

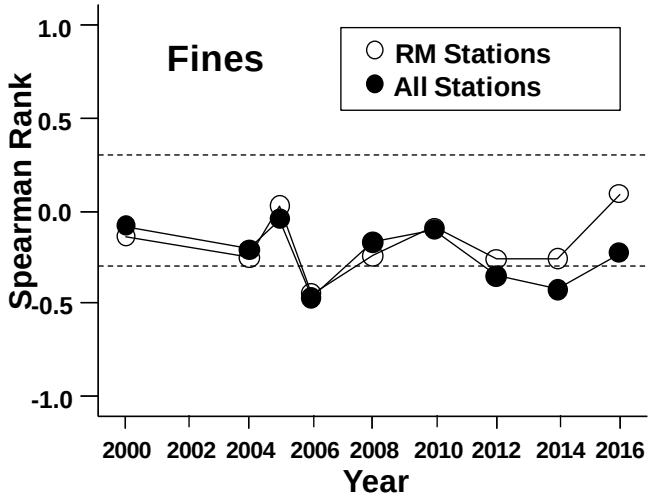

Figure 5-14 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Fines

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

Figure 5-15 provides a graphical representation of percent fines with distance from nearest active drill centres. In spite of the absence of distance trends in 2016, Figure 5-15 does indicate potential mild enrichment at stations near (within approximately 0.5 km from) drill centres. Potential enrichment near drill centres was also noted in other EEM years, particularly since 2010, and the threshold model for fines was significant in 2014 (Figure 5-15).

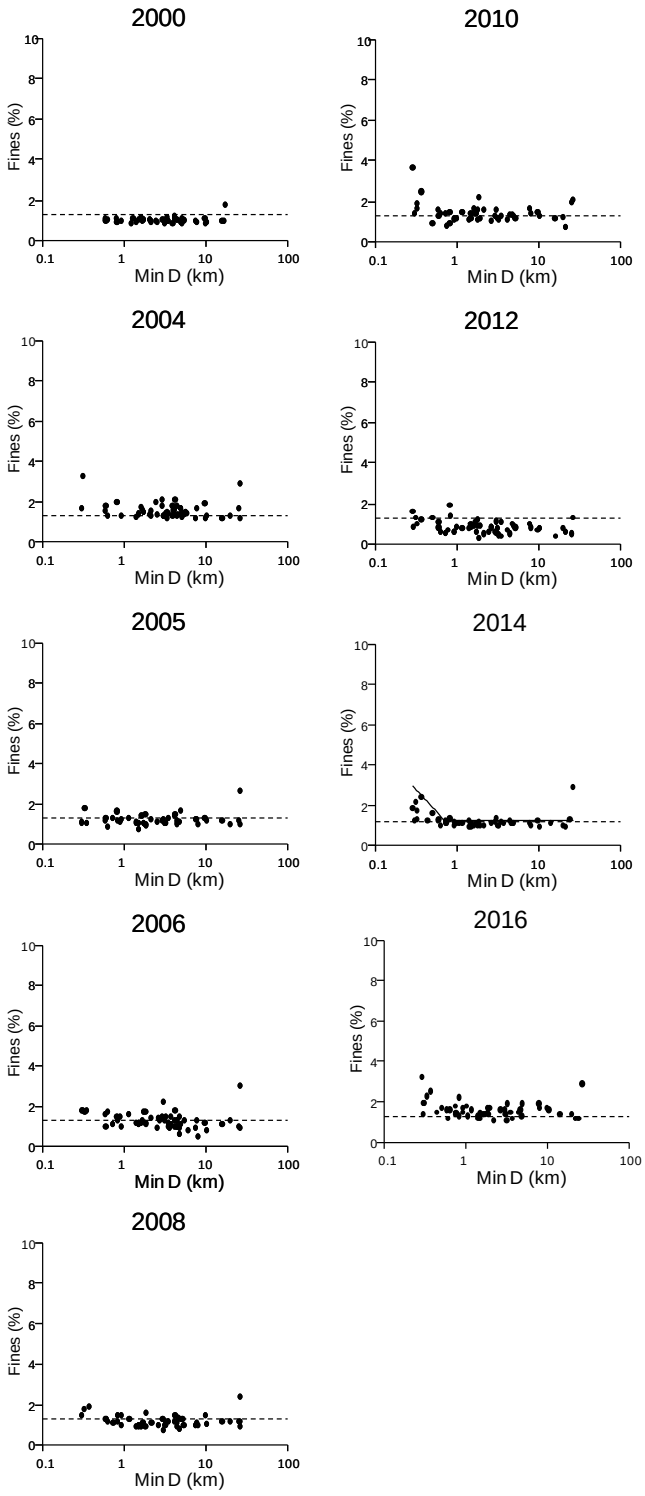

Figure 5-15 Variations in Percent Fines with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. A concentration of 1.3% is indicated in each graph by a horizontal line, based on the mean values + 2 SDs in 2000 (baseline). Here and in similar figures, threshold models are plotted when these were significant.

Repeated-measures regression (Table 5-9) indicated that there was no significant change over time in the slope of the relationship between fines and distance from the nearest active drill centre for repeated-measures stations in EEM years (p = 0.418). There were also no significant differences in slopes from before to after drilling (p = 0.088). However, there was a significant difference in percent fines across the sampling area from before to after drilling operations (p < 0.001) with fines levels generally lower before drilling began (Figure 5-16).

Table 5-9 Repeated-measures Regression Testing for Changes in Percent Fines over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.418	0.209	0.088	<0.001

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

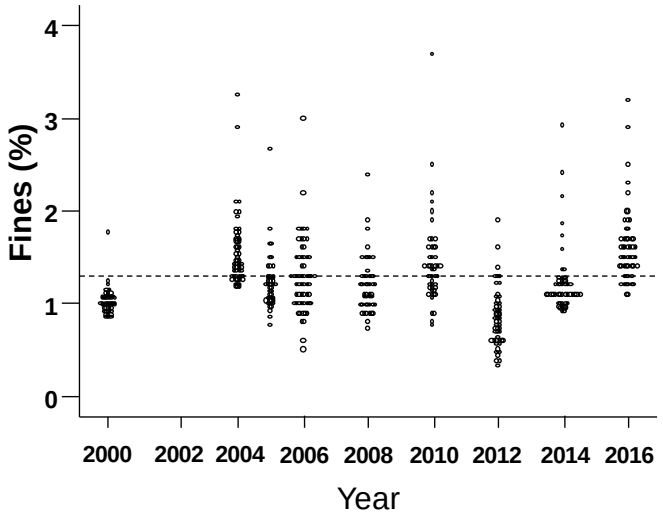

Figure 5-16 Dot Density Plot of Percent Fines by Year

Note: A concentration of 1.3% is indicated by a horizontal line, as based on the mean values + 2 SDs using data from the baseline year (2000).

Percent fines were generally at or above pre-drilling levels, except in 2012, when percent fines were generally at or below pre-drilling levels (Figure 5-15 and 5-16). Other than at stations within approximately 0.5 km from drill centres, the absence of significant linear or non-parametric trends with distance from active drill centres suggests the more general increase in 2016 is diffuse in nature and not conclusively linked to drilling activity.

5.2.1.4 Gravel

Percent of substrate as gravel varied between 0.01% and 4.10% in 2016 across the sampling area and was not significantly correlated with distance from the nearest active drill centre in 2016 (ρ_s = 0.024, p > 0.05, All stations; ρ_s = 0.218, p > 0.05, repeated-measures stations), as in previous EEM years (Figure 5-17).

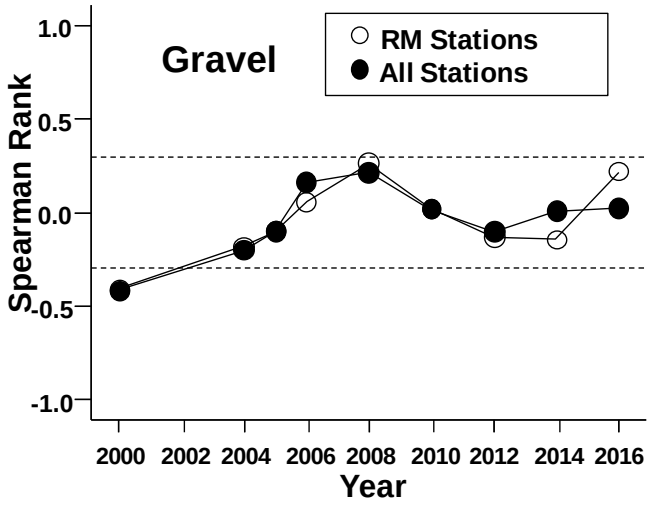

Figure 5-17 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Gravel

Note: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

Figure 5-18 provides a graphical representation of percent gravel with distance from nearest active drill centres.

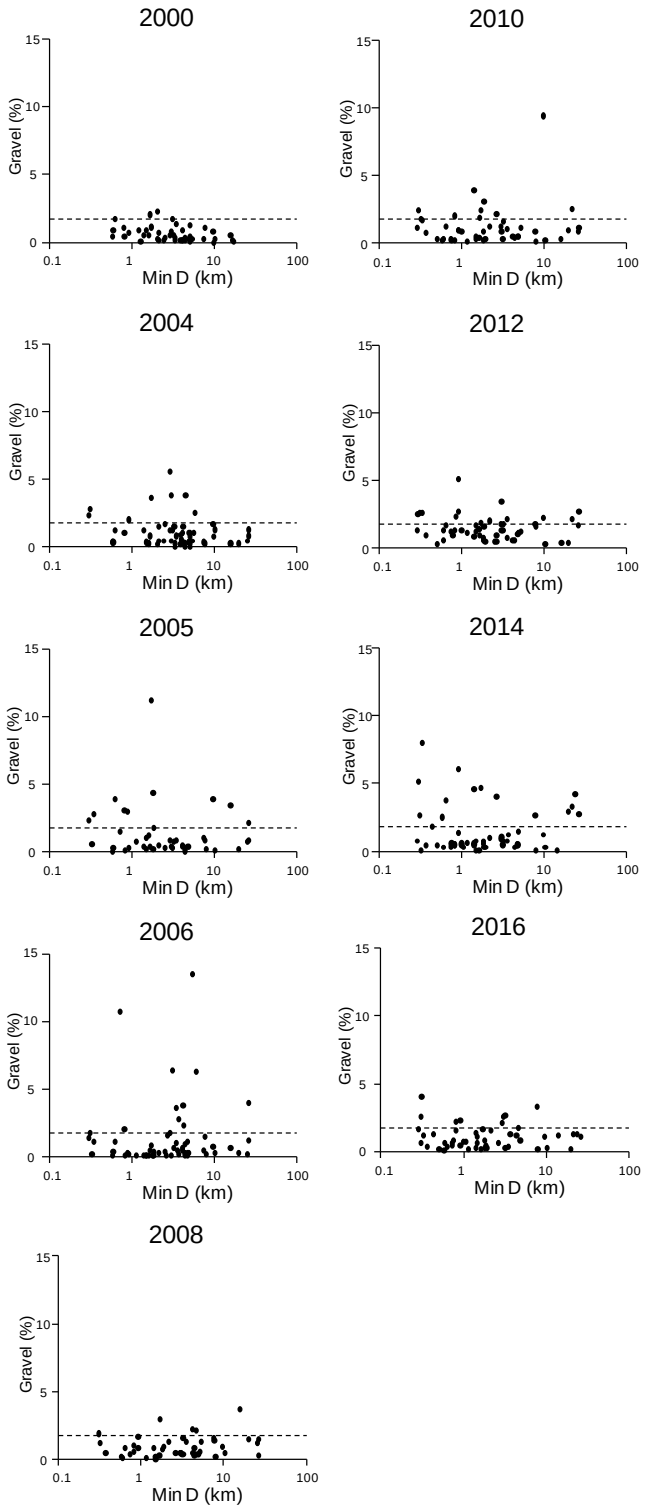

Figure 5-18 Variations in Percent Gravel with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Background levels of 1.75% are indicated based on the mean values + 2 SDs in 2000 (baseline).

Repeated-measures regression (Table 5-10) indicated no significant change in the slope of the relationship between percent gravel and distance from the nearest active drill centres in EEM years for repeated-measures stations (p = 0.504), nor did slopes vary from before to after drilling (p = 0.459). Mean percent gravel across the sampling area did not vary significantly over time in EEM years (p = 0.184). Mean percent gravel across the sampling area also did not vary significantly from before to after drilling (p = 0.255; also see Figure 5-19).

Table 5-10 Repeated-measures Regression Testing for Changes in Percent Gravel over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.504	0.184	0.459	0.255

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

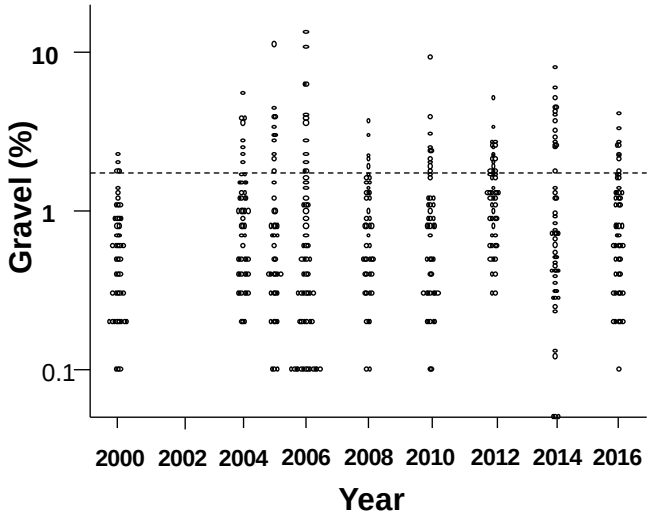

Figure 5-19 Dot Density Plot of Percent Gravel by Year

Note: Background levels of 1.75% are indicated, based on the mean values + 2 SDs in the baseline year (2000).

5.2.1.5 Total Organic Carbon

More than 80% of TOC values in 2016 were less than the laboratory detection limit of 0.5 g/kg. An increase in the detection limit for TOC from 0.2 to 0.5 g/kg in 2016[12] may have contributed to these results; although minimum sediment TOC concentrations have often been above 0.5 g/kg in previous years (*e.g.*, from 2000 to 2005, and in 2008 and 2010, Appendix B-3). Quantitative examination of variables with such a large number of values below laboratory detection limit is generally not performed in these reports. An exception is made here, given that TOC has usually been detected in most samples in

[12] The detection limit for TOC was raised from 0.2 to 0.5 mg/kg in 2016 as a result of an equipment calibration check at the analytical laboratory.

previous years, and the variable is known to influence benthic communities. Because the large number of values below detection will bias inter-annual comparisons of absolute concentrations, these comparisons are not presented. However, examinations of correlation coefficients and regression slopes of TOC versus distance to the nearest active drill centre are still valid.

TOC was not significantly correlated with distance from the nearest active drill centre in 2016 when all stations were considered (ρ_s = 0.078, p > 0.05); but the relationship was near significant when only RM stations were considered (ρ_s = 0.310, p = 0.07 (Figure 5-20). The latter suggests lower TOC values near drill centres for those stations.

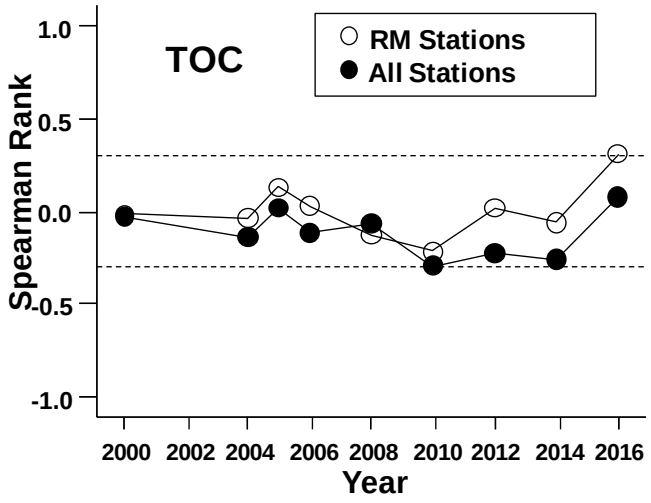

Figure 5-20 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Organic Carbon

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

The results displayed in Figure 5-21 for 2016 provide insight into the near-significant result of the Spearman rank correlation when only repeated-measures stations were included. Most samples were below the laboratory detection limit, and the majority of detectable TOC levels occurred at stations more distant from drill centres (between 1 to 10 km from drill centres; see Figure 5-21). As noted in the report for the 2014 EEM program, differences in the distribution of TOC values in 2014 were likely due to a difference in the acid used to extract carbon at petroforma in that year.

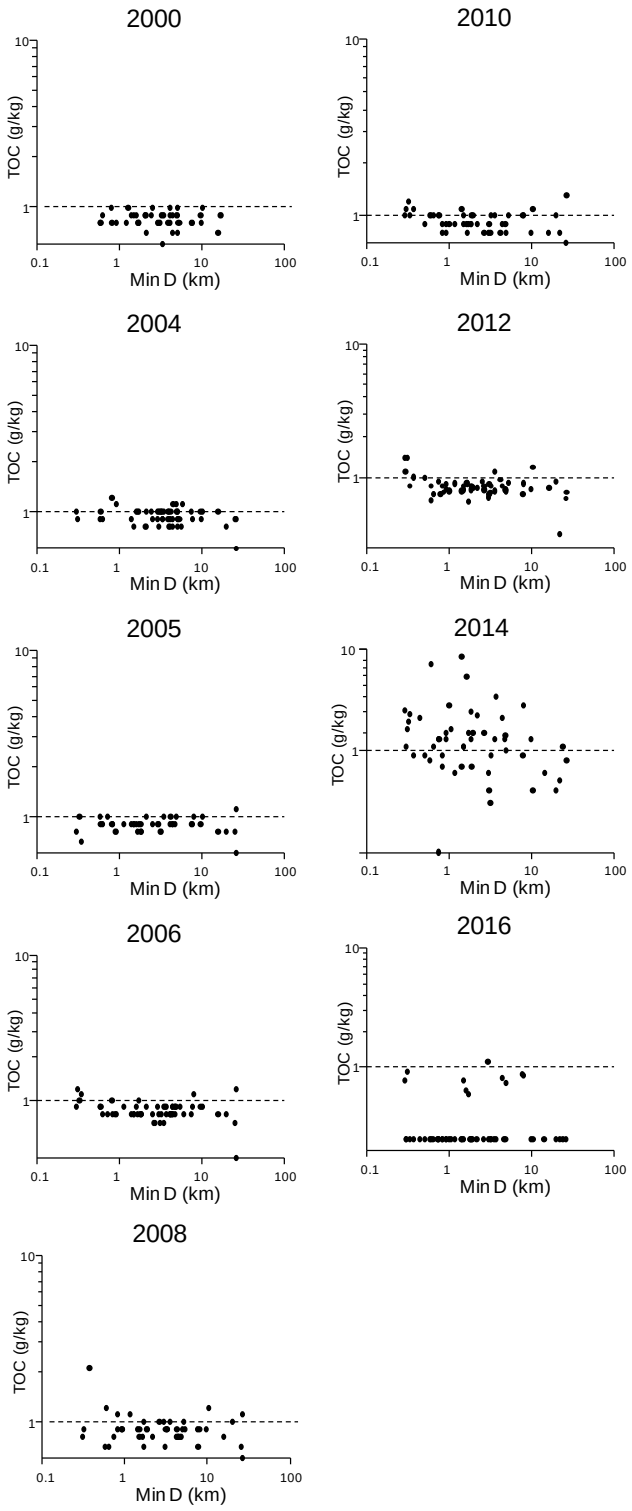

Figure 5-21 Variations in Total Organic Carbon with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. A concentration of 1 g/kg is indicated in each graph by a horizontal line, based on the mean values + 2 SDs in 2000 (baseline).

Repeated-measures regression (Table 5-11) indicated that the slope of the relationship between TOC and distance from the nearest active drill centres did not vary linearly in EEM years for repeated-measures stations (p = 0.746). There was also no change in slopes from before to after drilling (p = 0.475).

Table 5-11 Repeated-measures Regression Testing for Changes in Percent Total Organic Carbon over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.746	NA	0.475	NA

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.
- More than 80% of TOC values were below the laboratory detection limit 0.5 g/kg in 2016. As such, inter-annual comparisons of means would be biased and were excluded from analyses. Examination of regression slopes of TOC versus distance to the nearest active drill centre are still valid as they test changes in relationships as opposed to absolute concentrations.

A dot density plot of TOC values by year is provided in Figure 5-22. Only one sample in 2016 was above the baseline thresholds. TOC in 2016 and from 2000 to 2012 was estimated using the same technique by Maxxam Analytics. As noted above, TOC in 2014 was estimated using a different technique at petroforma.

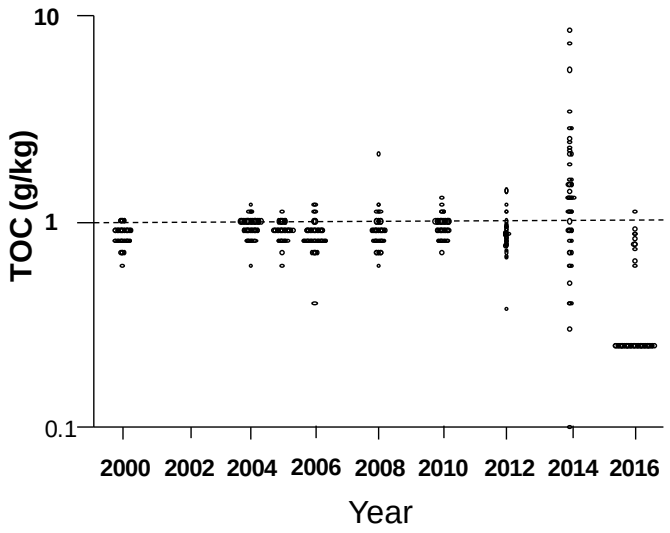

Figure 5-22 Dot Density Plot of Total Organic Carbon by Year

Note: A concentration of 1 g/kg is indicated in each graph by a horizontal line, based on the mean values + 2 SDs in the baseline year (2000).

5.2.1.6 Ammonia

Ammonia concentrations were generally less than 10 mg/kg in EEM years. The maximum value in 2016 was 11 mg/kg, observed at both stations 30 and 31. Ammonia concentrations were significantly and positively correlated (*i.e.*, increased) with distance from the nearest active drill centre in 2016 (ρ_S = 0.33, p < 0.05, All stations). Although the relationship was not significant when only repeated-measures stations were considered (ρ_S = 0.23, p > 0.05; Figure 5-23). Despite the significant correlation when all stations were considered, the threshold model was not able to estimate a reliable threshold. However, a weak but significant bivariate regression with Min D was detected (r^2 = 0.126, p = 0.01, Appendix B-7, Table 3-3) with ammonia concentrations increasing, rather than decreasing, with increasing distance from the nearest drill centre. The relationship between ammonia concentrations and distance to the nearest active drill centre was generally weak and not readily apparent in Figure 5-24.

Ammonia concentrations did not exceed the background range in 2016 (Figures 5-25 and 5-26)[13]. Repeated-measures regression (Table 5-12) indicated that there was no change in the slope of the relationship between ammonia and distance in EEM years for repeated-measures stations (p = 0.566), but there was significant change over time in average concentrations across the sampling area (p < 0.001, Table 5-12). Concentrations generally decreased over time (Figure 5-26).

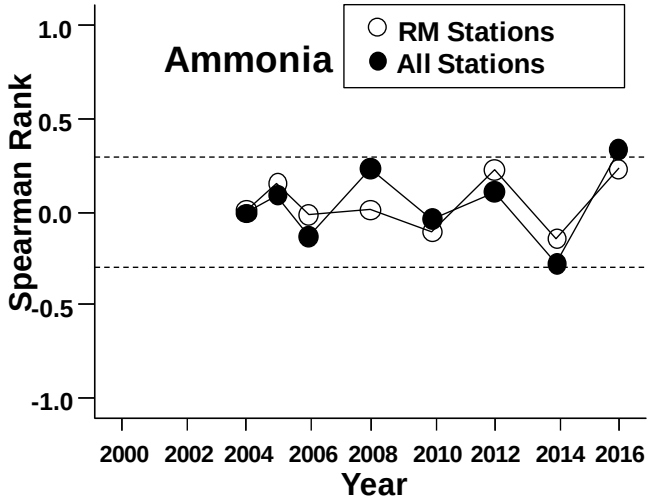

Figure 5-23 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Ammonia

Notes: Station 31 was excluded. n = 52 for All Stations n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.
Ammonia was not measured in the 2000 baseline survey.

[13] Ammonia was not sampled in baseline. An ammonia concentration of 12.2 mg/kg was used as an estimate of the upper level of the background range. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (n = 43).

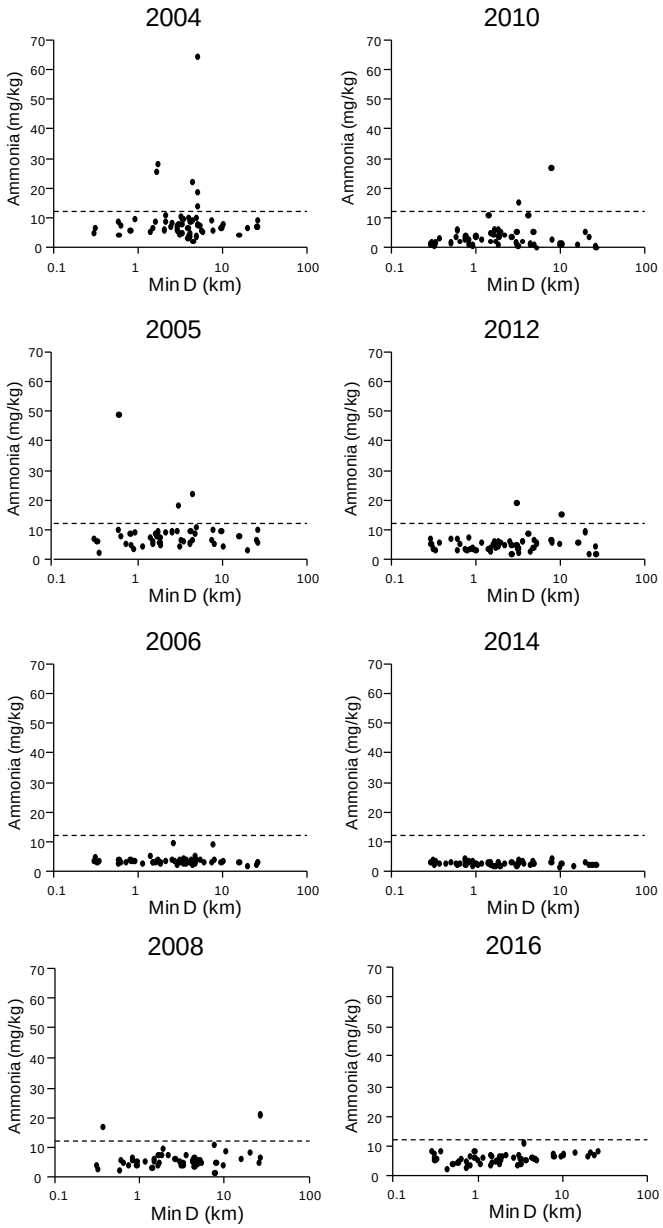

Figure 5-24 Variations in Ammonia Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre. Ammonia was not measured the 2000 baseline survey. An ammonia concentration of 12.2 mg/kg was used as an estimate of the upper level of the background range. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (*n* = 43).

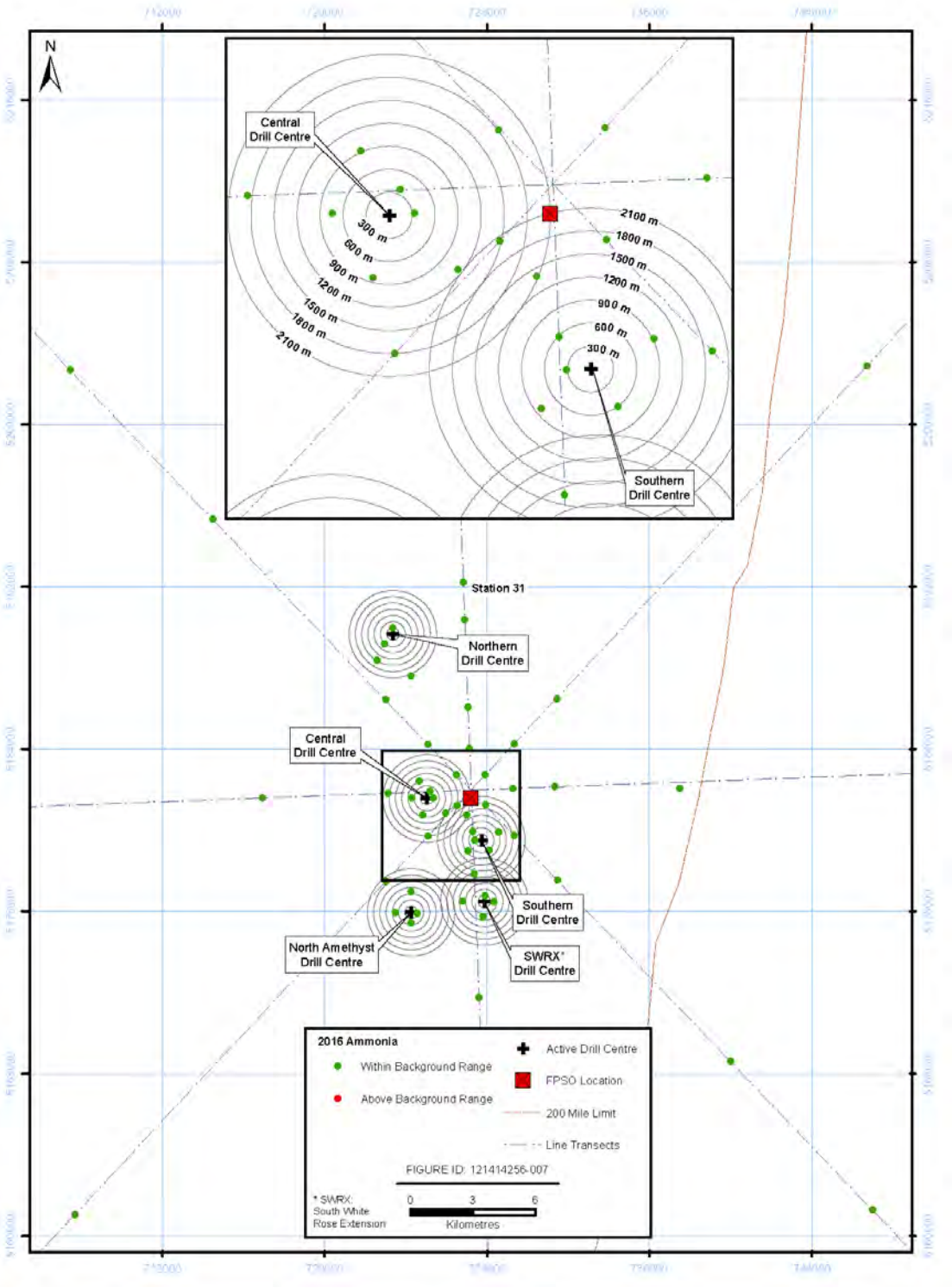

Figure 5-25 Location of Stations with Ammonia Concentrations (2016) Within and Above the Background Range

An ammonia concentration of 12.2 mg/kg was used as an estimate of the upper limit of the background range. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (*n* = 43).

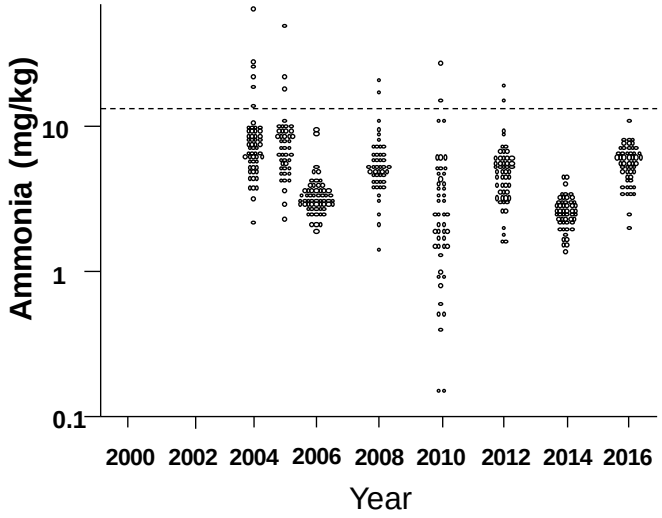

Figure 5-26 Dot Density Plot of Ammonia Concentrations by Year

Note: A concentration of 12.2 mg/kg is indicated by a horizontal line, based on the mean values + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (*n* = 43).

Table 5-12 Repeated-measures Regression Testing for Changes in Ammonia Concentrations over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.566	<0.001	NA	NA

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016. The Before and After contrast cannot be tested for ammonia because it was not measured in baseline.

5.2.1.7 Sulphide

In 2016, 53% of sulphide values were below the laboratory detection limit. As was the case for TOC, an increase in detection limit from 0.2 to 0.5 mg/kg in 2016[14] may have contributed to these results. In spite of the large number of values below laboratory detection limit, sulphide results are examined here because distance effects have been noted in the past and the variable is known to influence toxicity test results and benthic communities. As was the case for TOC, the large number of values below detection will bias inter-annual comparisons of absolute concentrations. Therefore, these comparisons are not presented. However, examinations of correlation coefficients and regression slopes versus distance to the nearest active drill centre are still valid.

Sulphide concentrations were related to distance to the nearest drill centre when all stations were considered (ρ_s = -0.401, p < 0.01), but correlations were not significant when only repeated-measures stations were considered (ρ_s = -0.065, p >0.05) (Figure 5-27).

[14] The detection limit for sulphide was raised from 0.2 to 0.5 mg/kg in 2016 as a result of an equipment calibration check at the analytical laboratory.

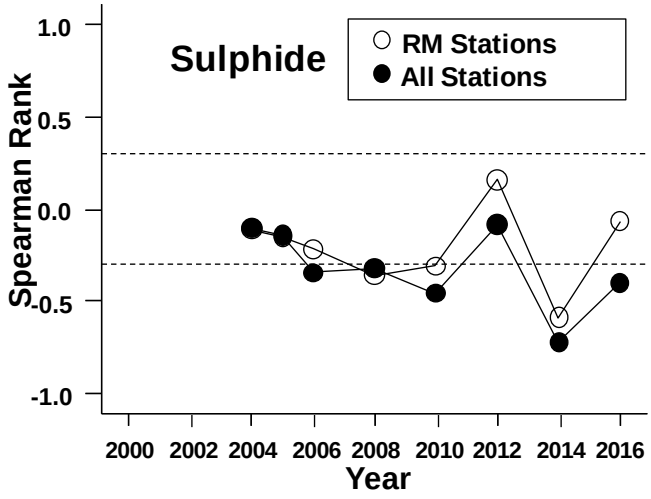

Figure 5-27 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Sulphide

Notes: Station 31 was excluded. *n* = 52 for All Stations *n* = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year. Significance from specific statistical tests are reported in text.
Sulphide was not measured in the 2000 baseline survey.

Figure 5-28 provides a graphical representation of sulphide concentrations with distance from nearest active drill centres. Due to the high percentage of samples below detection limits, no attempt was made to fit a threshold model. Threshold models were significant for sulphides in 2006 and 2008. In 2016, sulphides appear to be elevated within approximately 1 km from drill centres, which is generally consistent with results observed in most years since 2006 (Figure 5-28).

Sulphide levels were elevated above background levels around the Central, North Amethyst, SWRX and Southern Drill Centres in 2016 (Figure 5-29).

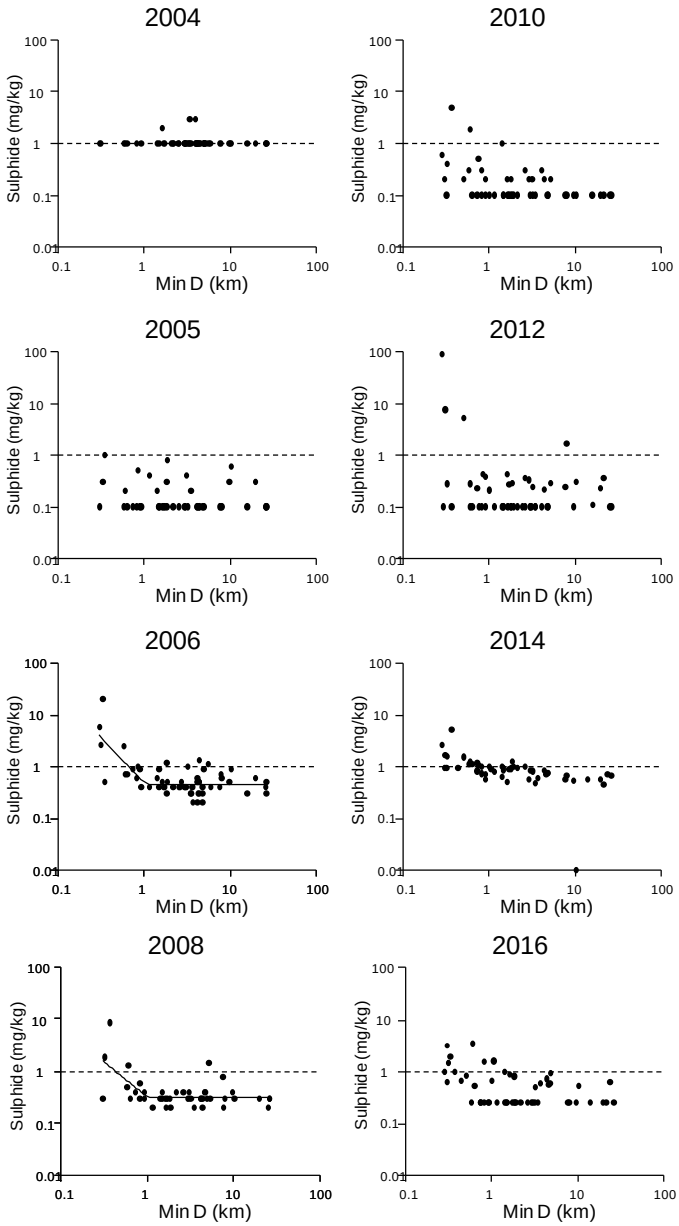

Figure 5-28 Variations in Sulphide with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre. Sulphide was not measured in the 2004 baseline survey. A sulphide concentration of 0.98 mg/kg was used as an estimate of the upper limit of the background range. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2000 to 2014 (*n* = 43). Here and in similar figures, threshold models are plotted when these were significant.

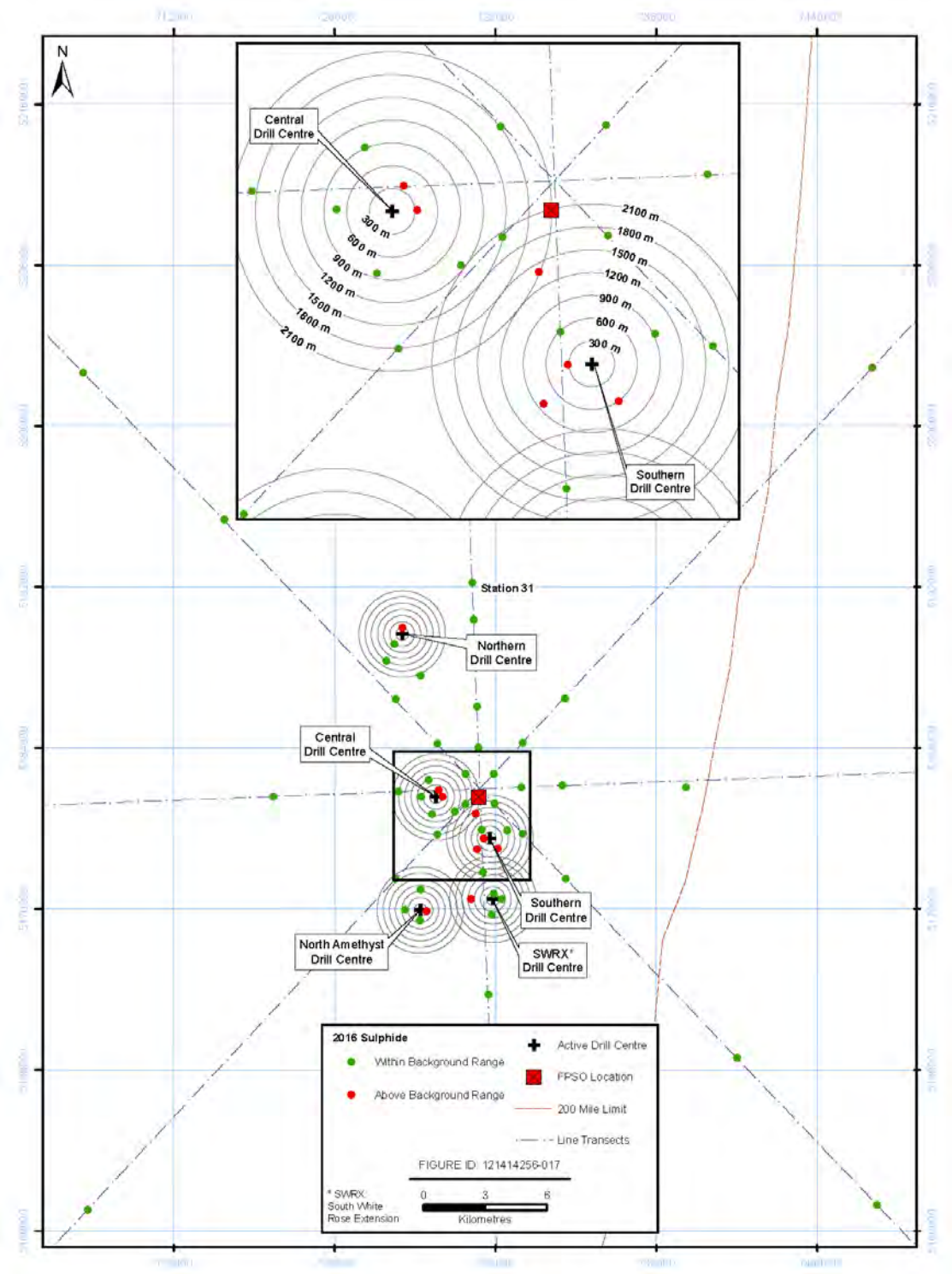

Figure 5-29 Location of Stations with Sulphide Concentrations (2016) Within and Above the Background Range

A sulphide concentration of 0.98 mg/kg was used as an estimate of the upper limit of the background range. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (n = 43).

Repeated-measures regression (Table 5-13) indicated that there was significant change in the slope relationship between sulphide concentrations and distance in EEM years for repeated-measures stations (p = 0.001). For these stations, there was no relationship between sulphide concentrations and distance in 2005, 2006, 2012 and 2016. Slopes were significant and negative in 2008, 2010 and 2014 (Figure 5-27).

Table 5-13 Repeated-measures Regression Testing for Changes in Sulphide Concentrations over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.001	NA	NA	NA

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016. The Before to After contrast cannot be performed for sulphides because these were not measured during baseline.
- In 2016, 53% of sulphide values were below the laboratory detection limit. As such, inter-annual comparisons of means would be biased and were excluded from analyses. Examination of regression slopes of sulphide concentration versus distance to the nearest active drill centre are still valid as they test changes in relationships as opposed to absolute concentrations.

A dot density plot of sulphide values by year is provided in Figure 5-30.

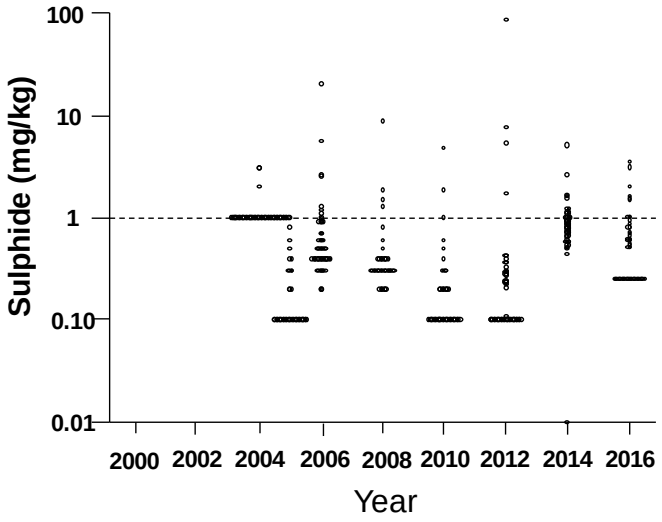

Figure 5-30 Dot Density Plot of Sulphide Concentrations by Year

Note: Sulphide was not measured in baseline. A concentration of 0.98 mg/kg is indicated in each graph by a horizontal line, based on the mean values + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (n = 43).

5.2.1.8 Sulphur

Sulphur and distance to the nearest active drill centre were significantly and negatively correlated when all stations were considered (ρ_s = -0.472, p < 0.001), but the correlation was not significant when only repeated-measures stations were considered (ρ_s = -0.304, p > 0.05) (Figure 5-31). Despite the significant correlation with all stations included, the threshold model was not able to estimate a reliable threshold. However, a significant bivariate regression with Min D was detected (r^2 = 0.259, p < 0.001, Appendix B-7, Table 3-4) with sulphur concentrations decreasing with increasing distance from the nearest drill centre (see Figure 5-32). Sulphur was elevated near the Central, North Amethyst, SWRX and Southern Drill Centres, and at Station 31 (Figure 5-33).

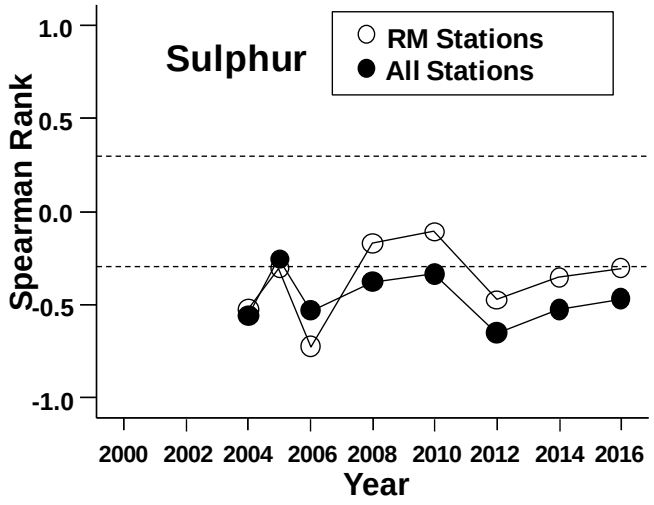

Figure 5-31 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Sulphur

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

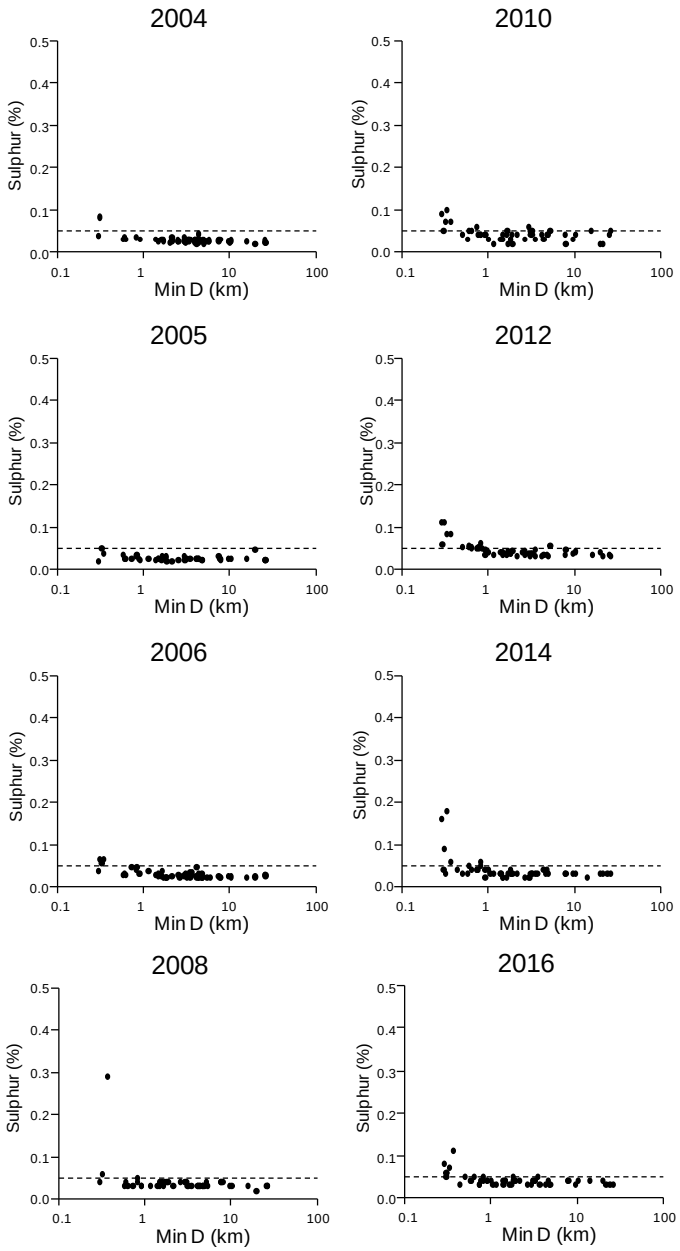

Figure 5-32 Variations in Sulphur Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Note: Min D = distance (km) to the nearest active drill centre. Sulphur was not measured in the 2004 baseline survey. A concentration of 0.05%, representing the upper limit of the background range, is indicated in each graph by a horizontal line. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2000 to 2014 (*n* = 43).

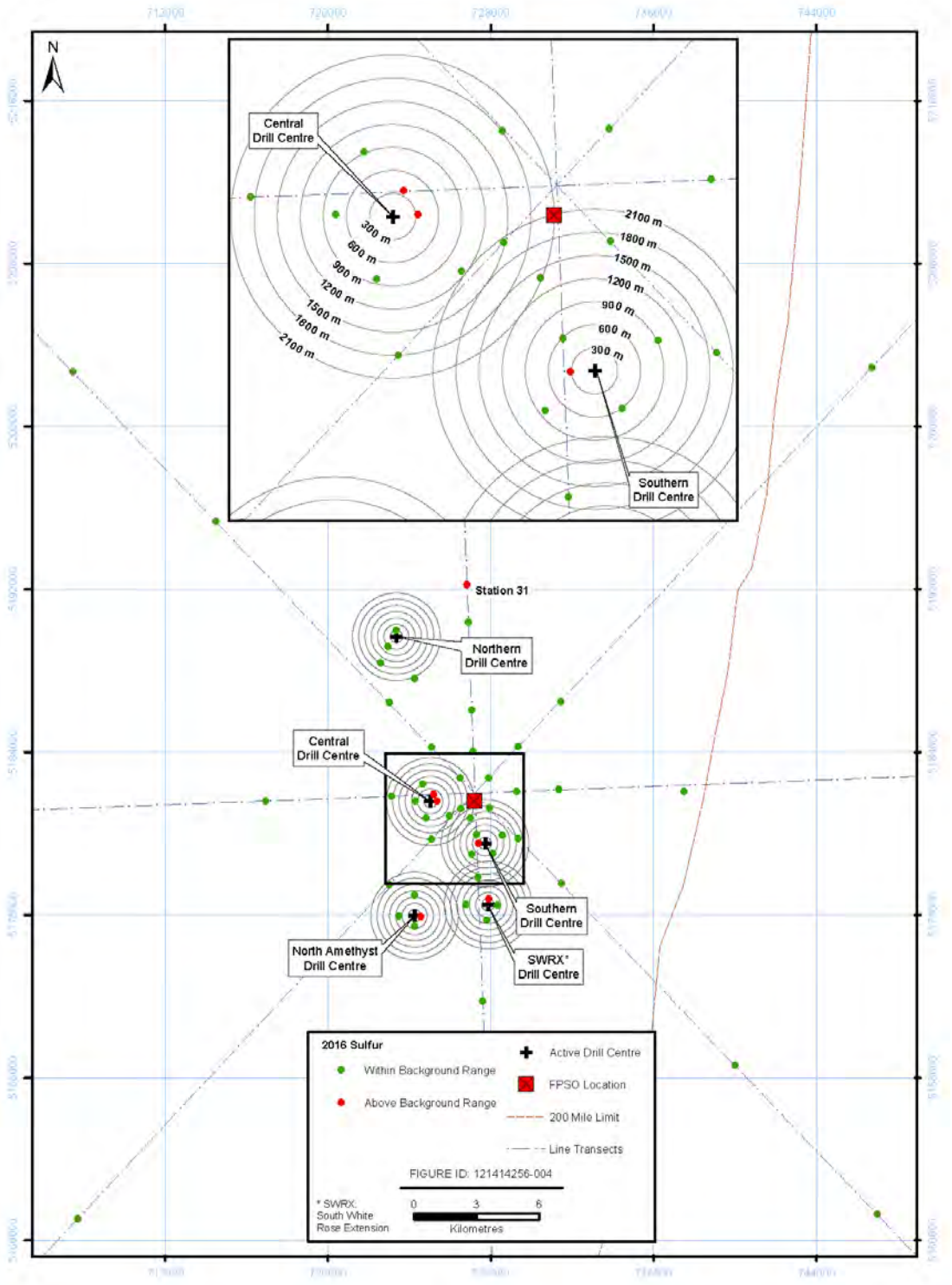

Figure 5-33 Location of Stations with Sulphur (2016) Within and Above the Background Range

A sulphur concentration of 0.05% was used as an estimate of the upper limit of the background range. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (*n* = 43).

Repeated-measures regression (Table 5-14) indicated that there was no change in the slope of the relationship between sulphur and distance from active drill centres in EEM years for repeated-measures stations (p = 0.525). There was a significant linear change in average sulphur concentrations in the overall sampling area (p < 0.001). The dot density graph of percent sulphur (Figure 5-34) illustrates that mean values in sediments have been higher from 2008 to 2016 than in prior years.

Table 5-14 Repeated-measures Regression Testing for Changes in Sulphur Concentrations over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.525	<0.001	NA	NA

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016. The Before to After contrast cannot be performed for sulphur because sulphur was not measured in baseline.

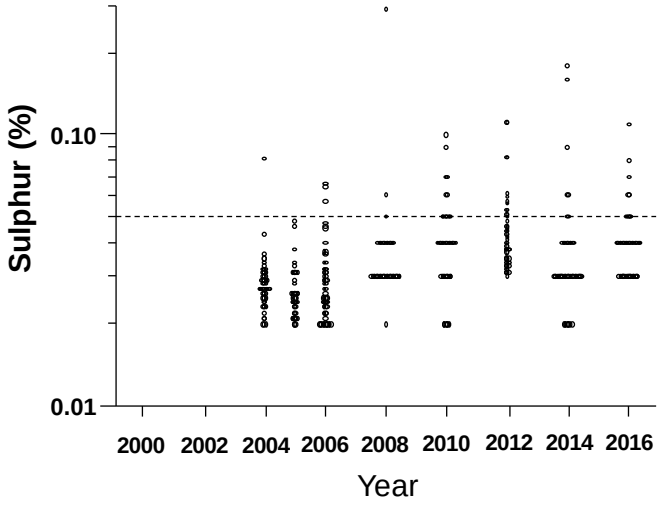

Figure 5-34 Dot Density Plot of Sulphur Concentrations by Year

Note: A concentration of 0.05% is indicated in each graph by a horizontal line, based on the mean values + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (n = 43).

5.2.1.9 Metals Other than Barium

Analysis of sediment chemistry data in previous years has demonstrated that metal concentrations co-vary (increase and decrease in concentration together). Rather than analyze the spatial-temporal variations of individual metals, one option, since the metals co-vary, is to produce a proxy variable that reflects the increasing and decreasing concentrations of metals. A PCA was carried out to produce a proxy variable that summarized general variations in metals concentrations among stations and years.

The PCA of the concentrations (log_{10}-transformed) of metals other than barium produced two strong axes (*i.e.*, proxy variables) (Table 5-15). All of the metals were strongly

associated with the first PCA axis, and all with the same sign, indicating that metals all increased or decreased in concentration in approximately the same way. Concentrations of strontium and lead were also strongly correlated with the second PCA axis, indicating that those metals, independently of the others, covaried in relation to other factors. Scores on the first PCA axis were used as the proxy variable (Metals PC1) summarizing variations in metals concentrations in subsequent analyses. Lead and strontium, which correlated strongly with the second PCA axis, were analyzed separately.

Table 5-15 Principal Component Analysis Component Loadings (Correlations) of Metals Concentrations

Variable	Principal Component	
	1	2
Aluminum	**0.79**	0.154
Chromium	**0.635**	-0.221
Iron	**0.899**	-0.32
Lead	**0.570**	**0.728**
Manganese	**0.837**	-0.411
Strontium	**0.739**	**0.605**
Uranium	**0.675**	0.005
Vanadium	**0.820**	-0.262
Percent Variance Explained	56.7	16.4

Notes: - $|r| \geq 0.6$ in **bold.** $n = 52$, with Station 31 excluded.

Metals PC1

Metals PC1 scores were not correlated with distance from the nearest active drill centre in 2016 (ρ_s = -0.161, $p > 0.05$, All stations; ρ_s = -0.145, $p > 0.05$, repeated-measures stations; Figure 5-35).

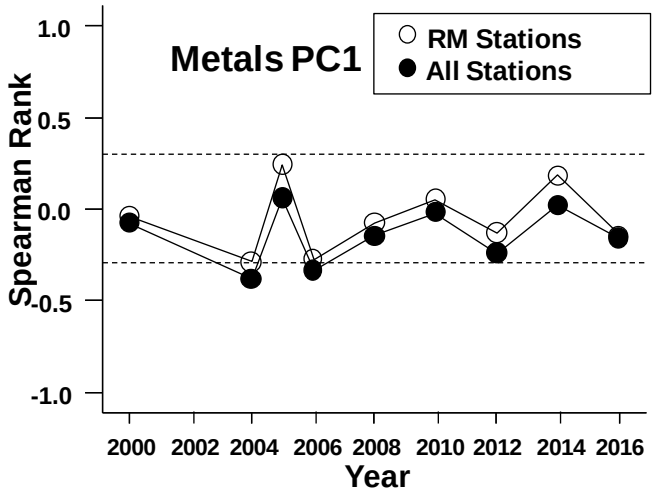

Figure 5-35 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Metals PC1

Notes: Station 31 was excluded. $n = 52$ for All Stations $n = 35$ for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year. Significance from statistical tests are reported in text.

Figure 5-36 provides a graphical representation of Metals PC1 scores with distance from active drill centres.

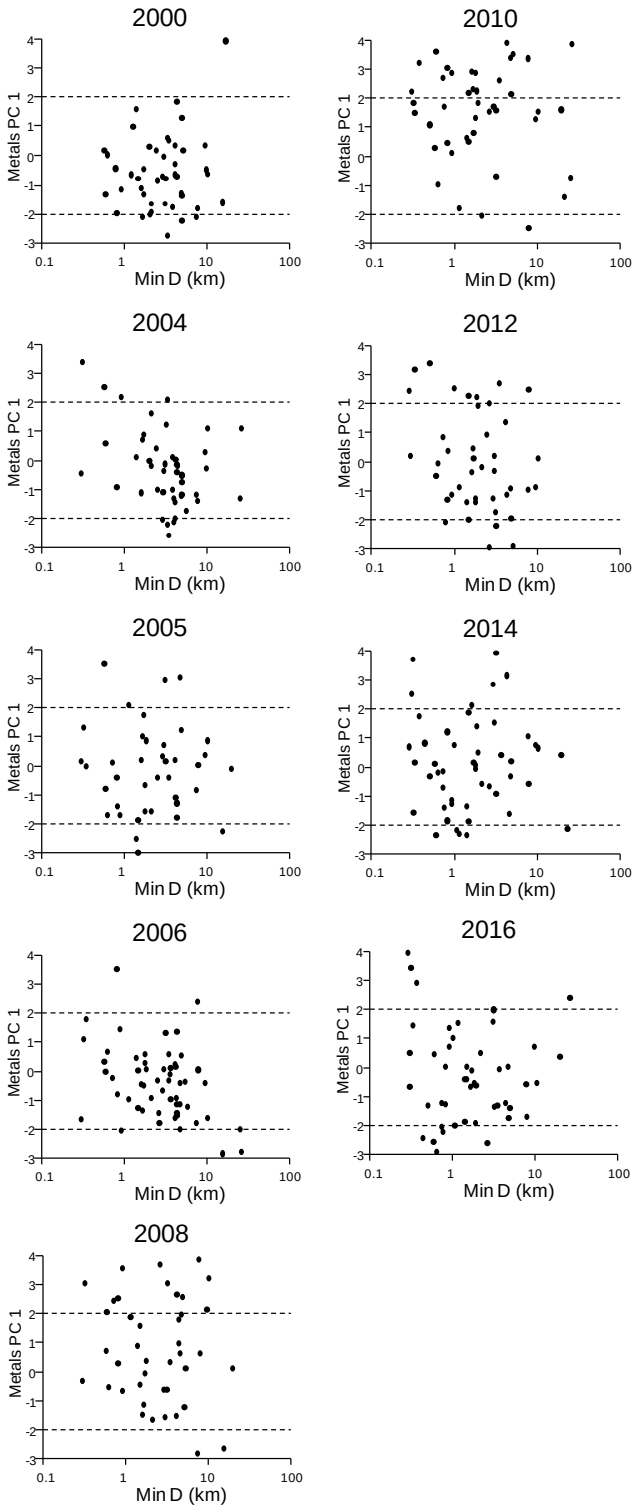

Figure 5-36 Variations in Metals PC1 Scores with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Background PC1 scores (-2 and 2) are indicated by a horizontal line, based on the mean values ± 2 SDs using data from 2000.

Repeated-measures regression (Table 5-16) indicated that there was no change in the slope of the relationship between Metals PC1 scores and distance to the nearest active drill centre in EEM years for repeated-measures stations (p = 0.539), and no change in slope from before to after drilling began (p = 0.498). There were also no significant variations in the average PC1 axis scores in the overall sampling area (p = 0.383), and no difference from before drilling to after drilling began (p = 0.560).

Table 5-16 Repeated-measures Regression Testing for Changes in Metals PC1 scores over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.539	0.383	0.498	0.560

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

The dot density graph of scores (Figure 5-37) further illustrated that Metals PC1 scores were consistent across years, with scores in 2016 mostly within the baseline range of variation for scores in 2000.

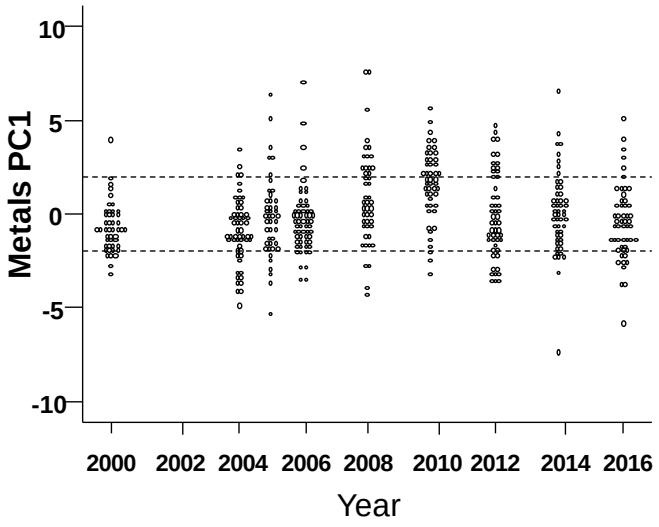

Figure 5-37 Dot Density Plot of Metals PC1 Scores by Year

Note: Background PC1 scores are indicated by a horizontal line, based on the mean values ± 2 SDs using data from the baseline year (2000).

Lead

Lead concentrations in sediments were negatively correlated with distance to the nearest active drill centre in 2016 when all stations were considered (ρ_s = -0.282, p < 0.05), but the correlation was not significant when only repeated-measures stations were considered (ρ_s = -0.294, p > 0.05) (Figure 5-38). A threshold distance explained significant variation in distance relationships from 2006 to 2016 (Appendix B-7), with threshold distances typically near 1 km (Table 5-17). The relationship between lead concentrations and Min D is illustrated in Figure 5-39. In 2016, lead was enriched around the Central, North Amethyst and Southern Drill Centres (Figure 5-40).

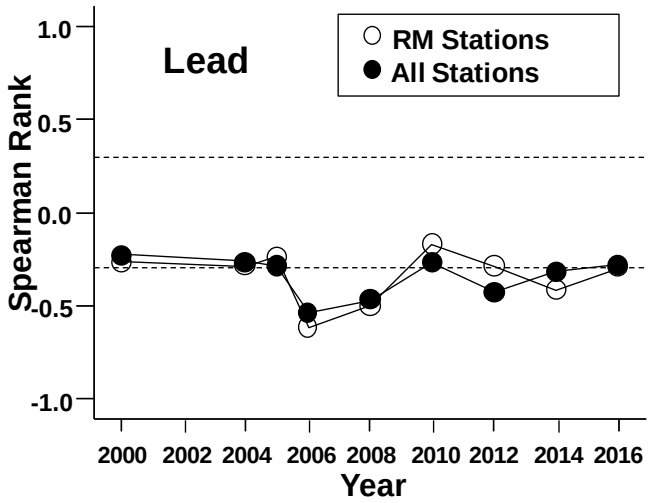

Figure 5-38 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Lead

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

Table 5-17 Results of Threshold Regressions on Distance from the Nearest Active Drill Centre for Lead

Year	Threshold Distance (km)
2004	No threshold
2005	No threshold
2006	1.5 (1.0, 2.3)
2008	1.1 (0.7, 1.7)
2010	0.9 (0.6, 1.4)
2012	0.6 (0.5, 0.8)
2014	0.6 (0.4, 1.0)
2016	1.4 (0.3, 6.1)

Notes: - 95% confidence limits are provided in brackets.
- n = 52 in 2016 with Station 31 excluded.

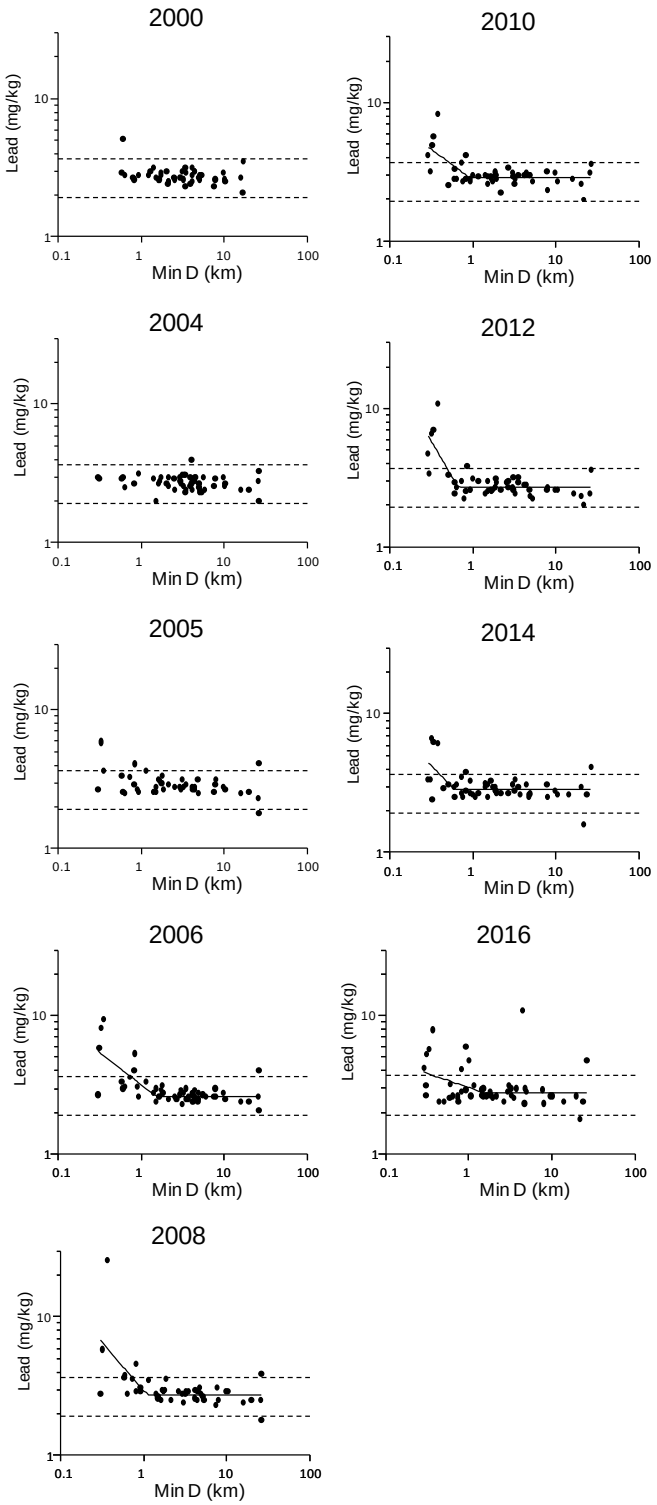

Figure 5-39 Variations in Lead with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Background concentrations of 2.1 and 3.7 mg/kg are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline), respectively. Here and in similar figures, threshold models are plotted when these were significant.

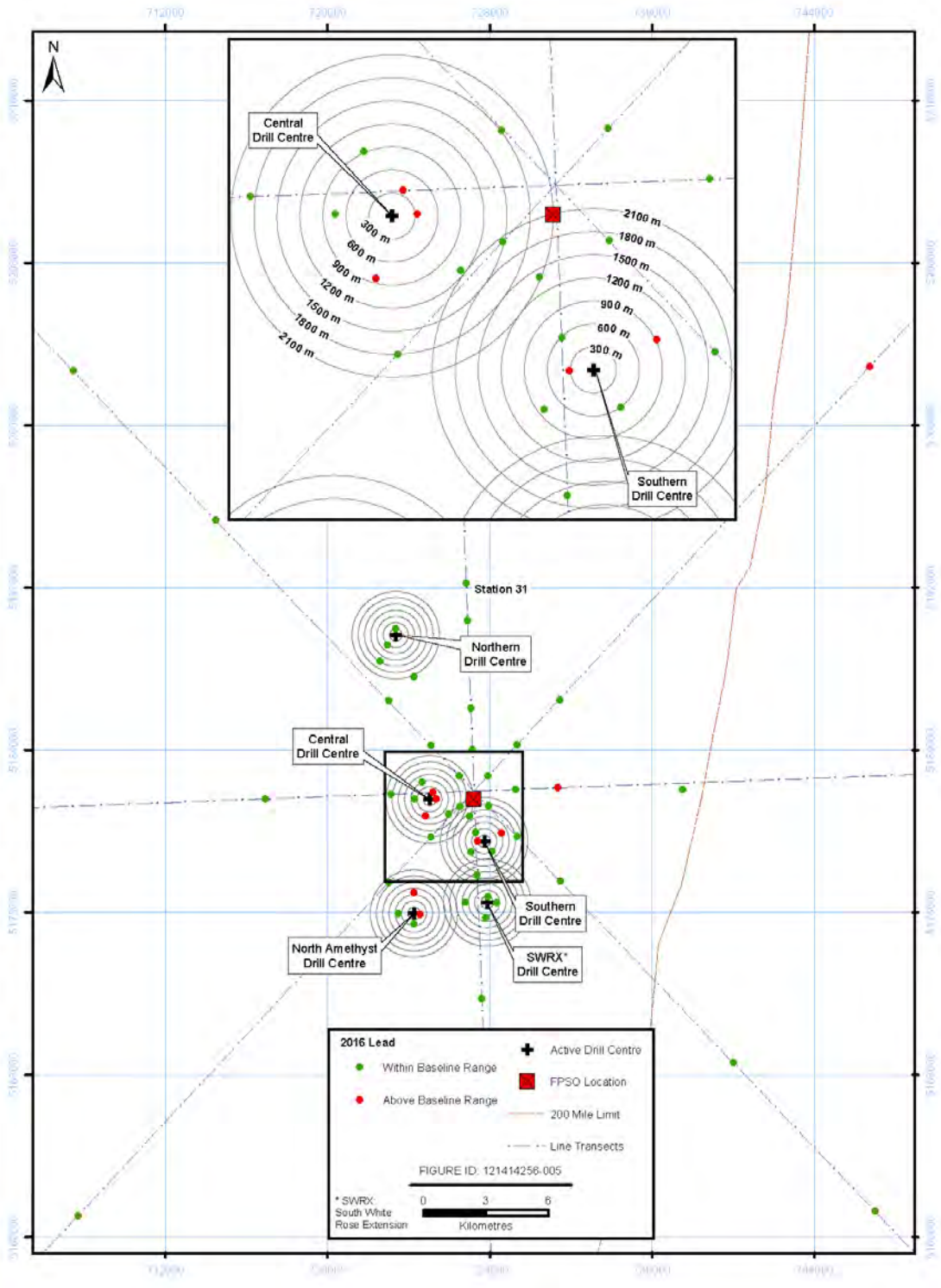

Figure 5-40 Location of Stations with Lead (2016) Within and Above the Baseline Range

Repeated-measures regression (Table 5-18) indicated that there was no change in the slope of the relationship between lead concentration in sediment and distance to the nearest active drill centre in EEM years for repeated-measures stations (p = 0.205), and no change in slope from before to after drilling began (p = 0.118). There was also no change in average lead concentration in the overall sampling area during active drilling (p = 0.065), but average lead concentration did vary significantly from before to after drilling began (p = 0.037). The central tendency for lead concentrations remained relatively similar from survey to survey but, in EEM years, there was a larger number of stations (near active drill centres) that had high concentrations of lead (Figure 5-41).

Table 5-18 Repeated-measures Regression Testing for Changes in Lead over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.205	0.065	0.118	0.037

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

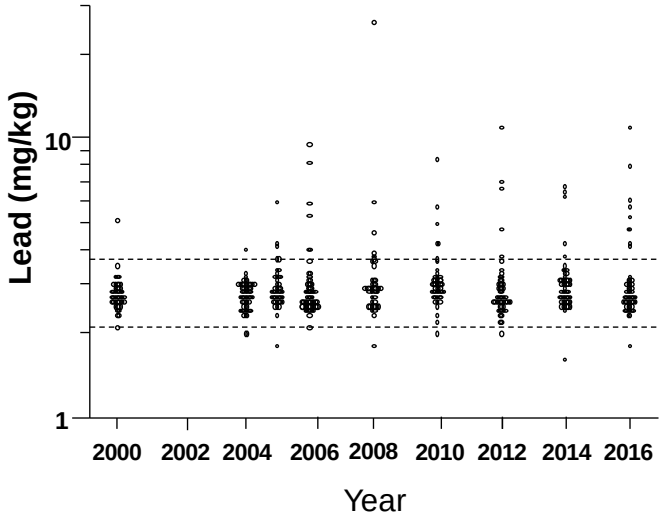

Figure 5-41 Dot Density Plot of Lead by Year

Note: Background concentrations of 2.1 and 3.7 mg/kg are indicated by the horizontal lines, based on the mean value ± 2 SDs using data from 2000.

Strontium

Strontium concentrations in sediments were significantly and negatively correlated with distance to the nearest active drill centre in 2016 (ρ_s = -0.459, p < 0.001, All stations; ρ_s = -0.456, p < 0.01, repeated-measures stations) (Figure 5-42). Despite these significant correlations, the threshold model was not able to estimate a reliable threshold. However, a significant bivariate regression with Min D was detected (r^2 = 0.274, p < 0.001, Appendix B-7, Table 3-4) with strontium concentrations decreasing with increasing distance from the nearest drill centre. Thresholds for strontium were detected in 2006, 2008 and 2012 (Figure 5-43). In 2016, strontium was enriched around the Central, North Amethyst, SWRX, and Southern Drill Centres; strontium was also enriched at Station 31 (Figure 5-44).

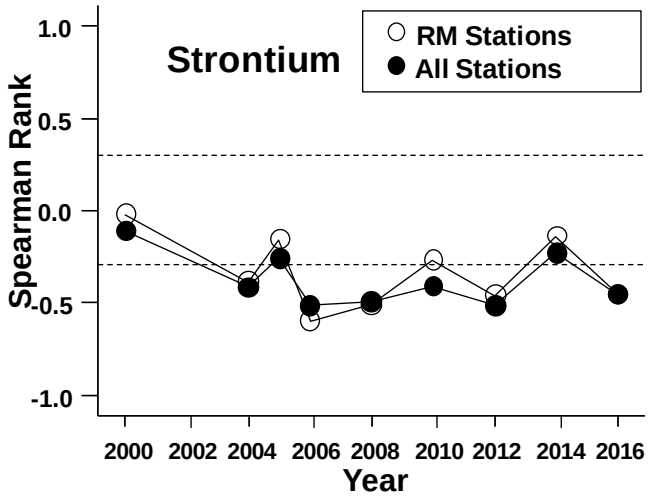

Figure 5-42 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Strontium

Notes: Station 31 was excluded. n = 52 for All Stations n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

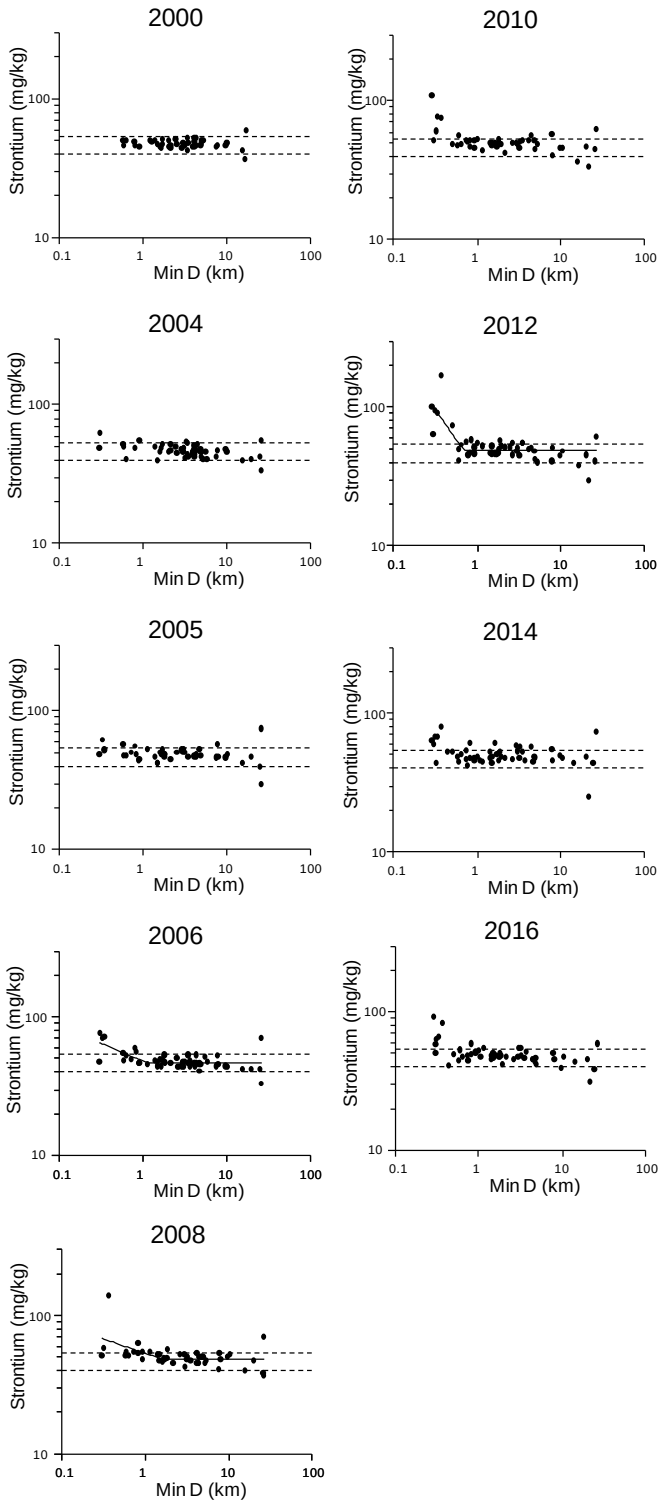

Figure 5-43 Variations in Strontium with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Background concentrations of 40 and 54 mg/kg are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline), respectively. Here and in similar figures, threshold models are plotted when these were significant.

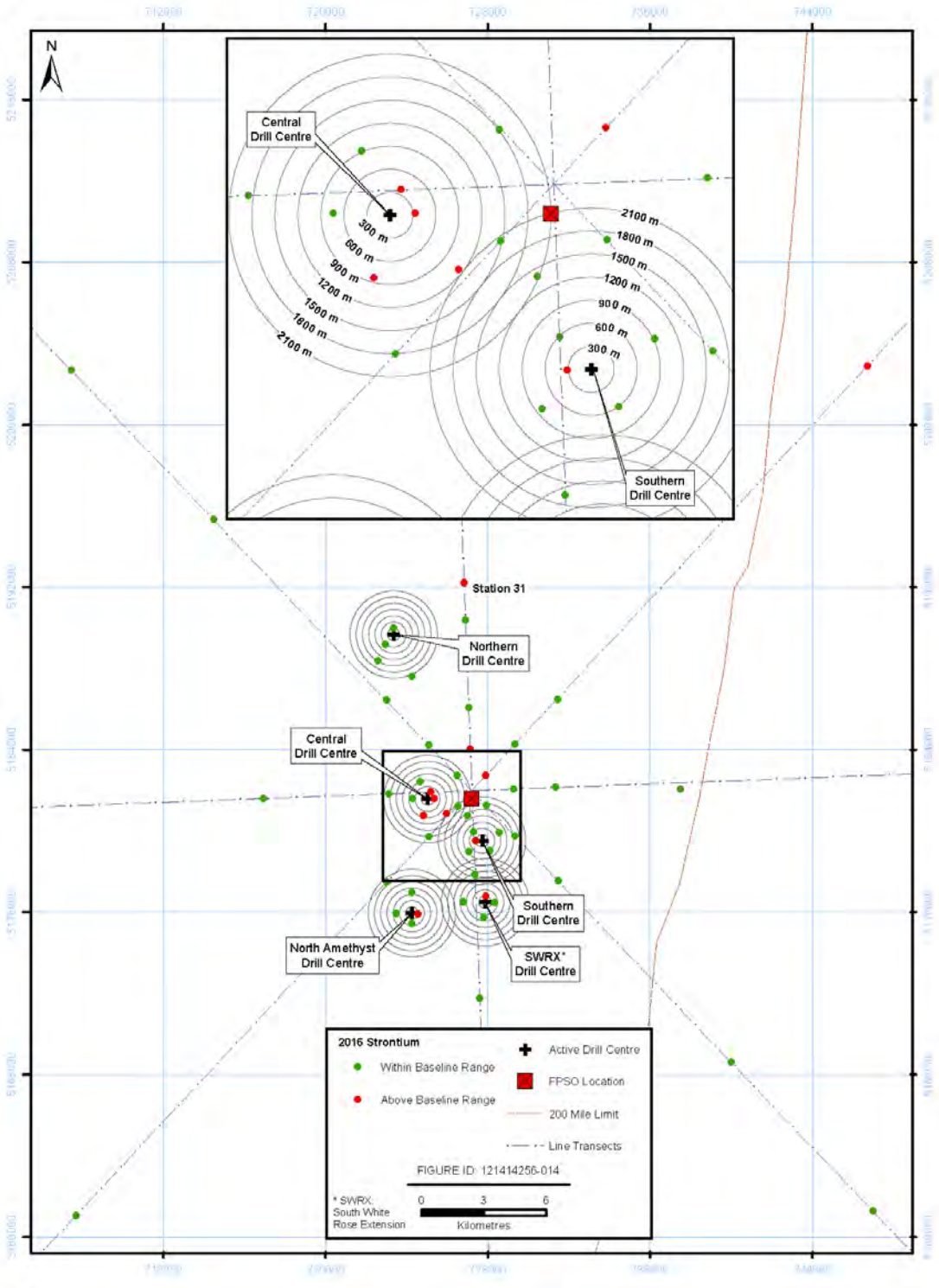

Figure 5-44 Location of Stations with Strontium (2016) Within and Above the Baseline Range

Repeated-measures regression (Table 5-19) indicated no change in the slope of the relationship between strontium concentration and distance to the nearest active drill centre in EEM years for repeated-measures stations (p = 0.070). However, slopes did vary significantly from before to after drilling (p = 0.008). Slopes were generally steeper in EEM years (*e.g.*, Figures 5-42 and 5-43). Overall strontium concentration in the sampling area varied in EEM years (p = 0.034, Figure 5-45)), and was generally higher in EEM years than in baseline (p = 0.001, Figure 5-45). Figure 5-45 illustrates that the central tendency for strontium concentrations remained similar from survey to survey but, in EEM years, there was a larger number of stations (near active drill centres) that had high concentrations of strontium.

Table 5-19 Repeated-measures Regression Testing for Changes in Strontium over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.070	0.034	0.008	0.001

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

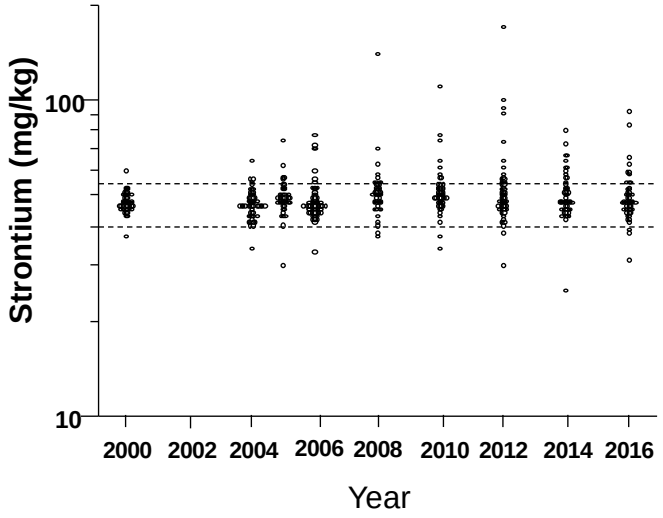

Figure 5-45 Dot Density Plot of Strontium by Year

Note: Background concentrations of 40 and 54 mg/kg are indicated by the horizontal lines, based on the mean value ± 2 SDs using data from 2000.

5.2.1.10 Redox Potential

Redox potential varied between 115 and 238 mV in 2016, and was significantly and negatively correlated (*i.e.*, decreased) with distance from the nearest active drill centre (ρ_S = -0.401, p < 0.01, All stations; ρ_S = -0.403, p < 0.05, repeated-measures stations) (Figure 5-46). The threshold model was not able to estimate a reliable threshold. However, a significant bivariate regression with Min D was detected (r^2 = 0.393, p < 0.001, Appendix B-7, Table 3-4) with redox potential decreasing with increasing distance from the nearest drill centre (also see Figure 5-47).

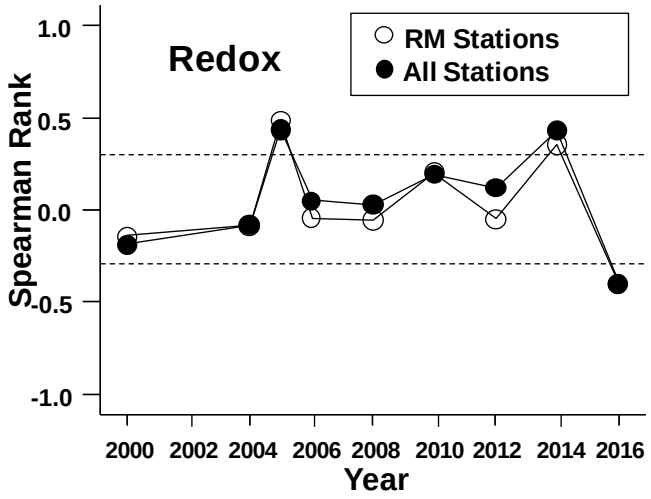

Figure 5-46 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Redox Potential

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

In 2016, many samples had redox potential values below the baseline range (209 and 299 mV; Figures 5-47 and 5-48); and the lowest redox potential readings were observed at the most distant stations (Figure 5-47).

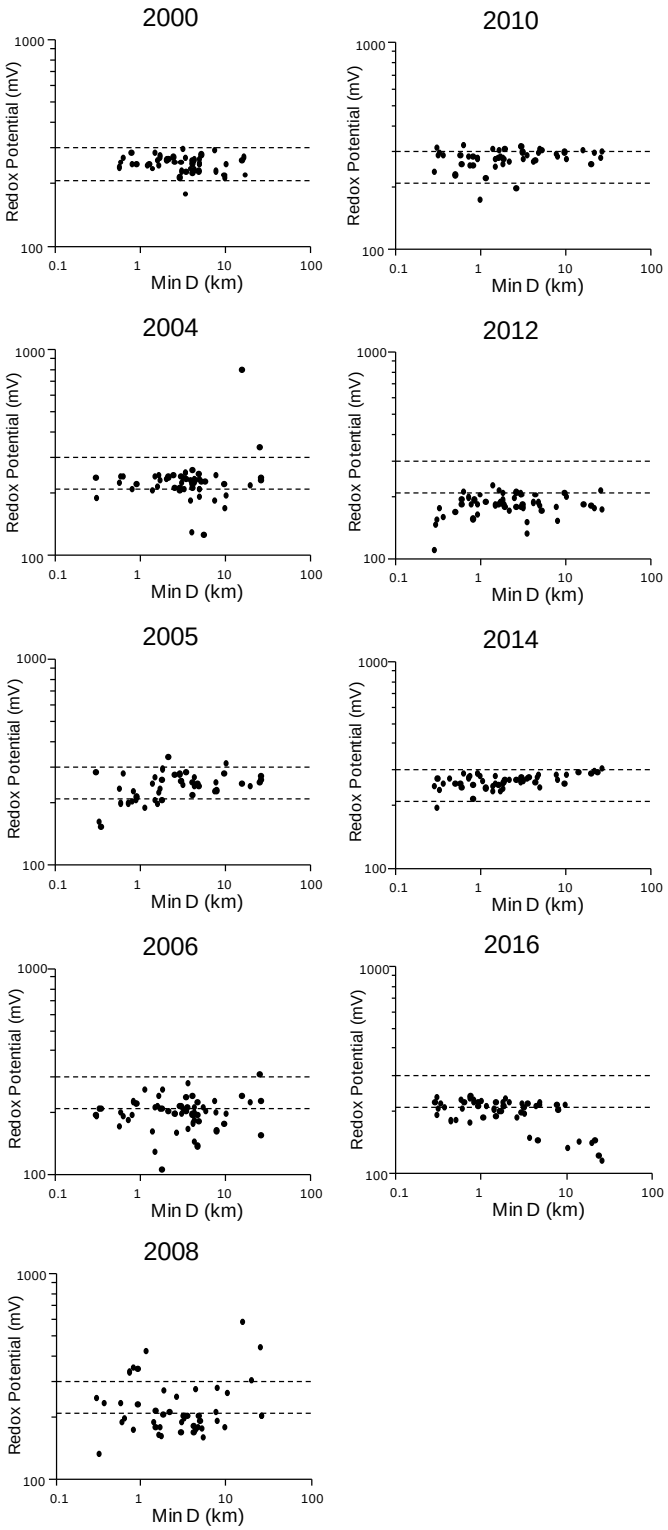

Figure 5-47 Variations in Redox Potential with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Background redox potential levels are indicated by a horizontal line, based on the mean values ± 2 SDs (209 and 299 mV) using data from 2000.

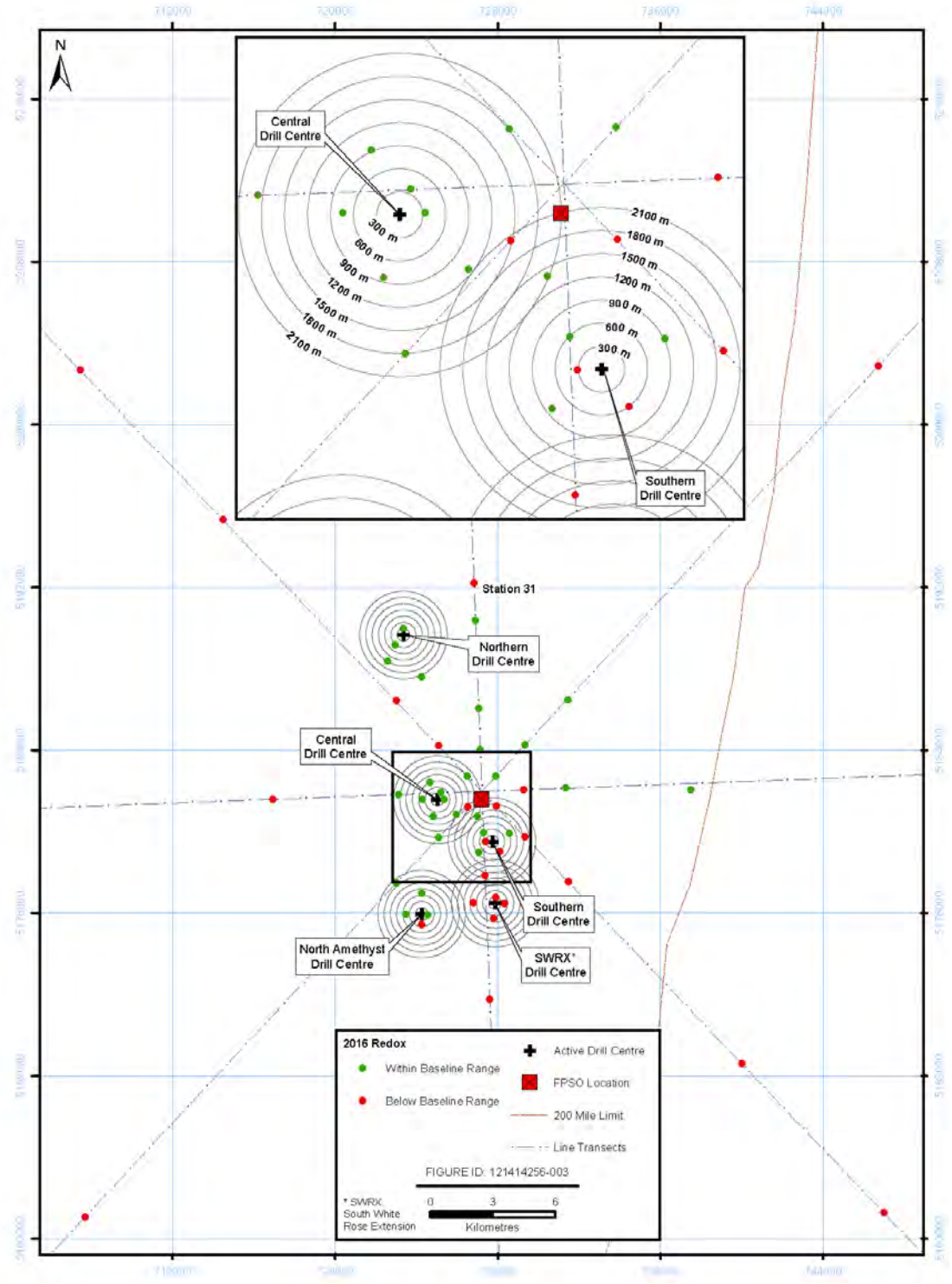

Figure 5-48 Location of Stations with Redox Potential (2016) Within and Above the Baseline Range

Repeated-measures regression (Table 5-22) demonstrated that the slope of the relationship between redox potential in sediment and distance to the nearest active drill centre varied in EEM years (p = 0.004; also see Figure 5-46); but there was no change in EEM years in mean redox potential across the sampling area (p = 0.303). However, there was a significant change in mean redox potential from before to after drilling (p = 0.001), with redox potential often lower in EEM years (*e.g.*, 2006, 2012 and 2016; Figure 5-49). Although redox potential has varied with time, all sediments since baseline have been oxic (>100 mV).

Table 5-20 Repeated-measures Regression Testing for Changes in Redox Potential over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.004	0.303	0.765	0.001

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

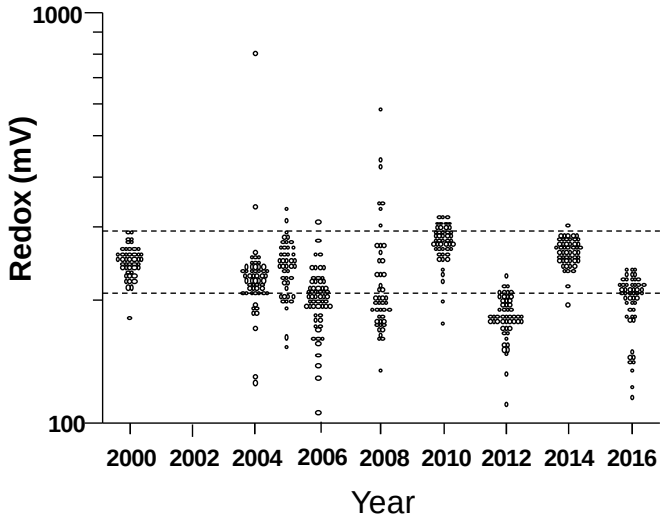

Figure 5-49 Dot Density Plot of Redox Potential by Year

Note: Background concentrations of 209 and 299 mV are indicated by the horizontal lines, based on the mean value ± 2 SDs using data from 2000.

5.2.2 Toxicity

In 2016, two samples, from stations 20 and 31, were toxic to Microtox. Examination of sediment ammonia and sulphide levels, and sediment redox potential in the laboratory at the time of testing in 2016 indicated that these variables were within the tolerance and application limits for the Microtox test (Appendix B-5). Chemistry data from field samples indicated that $>C_{10}$-C_{21} hydrocarbons, barium, sulphur, and strontium were elevated at these two stations. Lead was also elevated at Station 20 (see maps in Section 5.2.1). For comparison, a single toxic sample, from station C5, was noted in 2010. Three samples, from stations 19, N1, and N2, were toxic in 2014.

No samples were considered toxic to laboratory amphipods in 2016. Examination of sediment ammonia and sulphide levels, and sediment redox potential in the laboratory at the time of testing in 2016 indicated that these variables were within the tolerance and application limits for the amphipod test. Full results for amphipod toxicity for 2016 are provided in Appendix B-4. In previous years, no samples were toxic to laboratory amphipods in 2000, 2004 and 2010; sediment from three stations were toxic in 2006; sediment from eight stations were toxic in 2008; sediment from one station was toxic in 2012; and sediment from two stations were toxic in 2014.

Percent amphipod survival in 2016 was significantly correlated with sediment ammonia concentrations ($p < 0.05$) and distance from nearest active drill centre ($p < 0.01$); Table 5-21). Correlations were negative, indicating higher survival in samples collected near drill centres, but lower survival in samples with higher ammonia concentrations. No significant correlations were noted for the remaining variables.

Table 5-21 Spearman Rank Correlations (ρ_s) Between Amphipod Survival *versus* Distance from the Nearest Active Drill Centre and Sediment Physical and Chemical Characteristics (2016)

Variable	Spearman Rank Correlation (ρ_s) with Amphipod Survival
Distance from nearest active drill centre	-0.372**
$>C_{10}$–C_{21} hydrocarbons	0.223
Barium	0.179
% Fines	-0.144
% Gravel	-0.041
TOC	-0.137
Metals PC1	0.046
Lead	0.065
Strontium	0.05
Ammonia	-0.344*
Sulphur	-0.030
Redox	-0.018

Notes: - *$p \leq 0.05$; **$p \leq 0.01$.
- n = 53 stations.

The 2016 data, and toxicity data from prior years, suggest little change over time. Variation in amphipod survival was somewhat higher in 2005, 2006 and 2008, and was similar in 2016 to what was observed in 2000 (baseline), 2004, 2010, 2012, and 2014 (Figure 5-50).

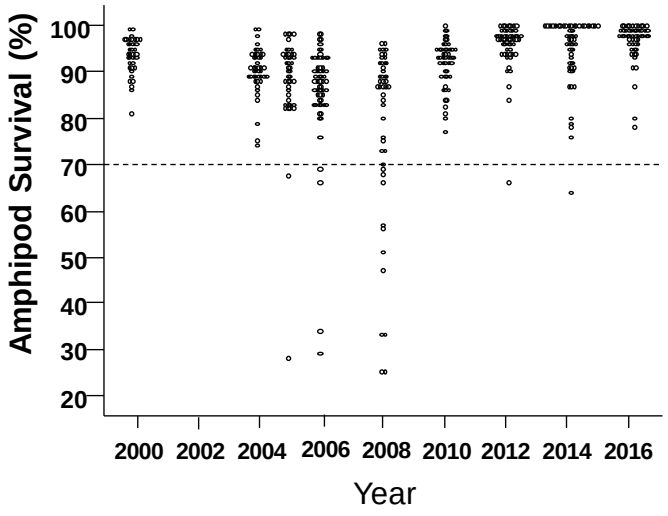

Figure 5-50 Dot Density Plot of Laboratory Amphipod Survival by Year

Note: The horizontal line denotes 70% survival. Values above 70% indicate a non-toxic response.

5.2.3 Benthic Community Structure

5.2.3.1 General Composition

Raw data for benthic community structure in 2016 are provided in Appendix B-6. A total of 243 taxa, from 80 families, were identified from 106 samples collected from 53 stations in 2016. As in prior years, Polychaeta were numerically dominant, accounting for 82% of total numbers, while Bivalvia (9%), Amphipoda (3%) and Tanaidacea (3%) were sub-dominant numerically, and Cnidaria, Gastropoda, Cumacea, Decapoda, Echinodermata, and Hemichordata were found in trace numbers (1% or less).

5.2.3.2 Univariate Analyses

Total Abundance

In 2016, total abundance of all benthic invertebrates varied between approximately 85 organisms per m² to over 5,800 per m² across the sampling area. The relationship between total abundance and distance from the nearest active drill centre was significant in 2016 when all stations were considered (ρ_s = 0.456, p < 0.001); but the relationship was not significant when only repeated-measures stations were considered (ρ_s = 0.287, p > 0.05) (Figure 5-51).

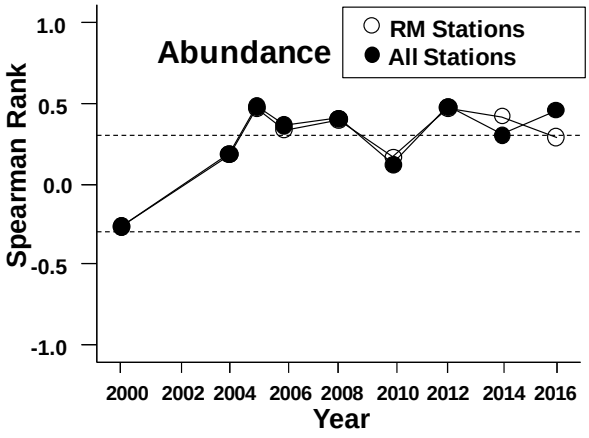

Figure 5-51 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Benthic Abundance

Notes: Stations NA2 and SWRX4 were excluded. n = 51 for All Stations. n = 36 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

Significant distance relationships for all stations were also noted in 2005, 2006, 2008, 2012 and 2014 (Figure 5-51). While the data did not allow for precise estimation of a threshold (Appendix B-7), a significant bivariate regression with Min D was detected (r^2 = 0.457, p < 0.001, Appendix B-7, Table 3-4), with total abundance increasing with increasing distance from the nearest drill centre.

The relationships between total abundance and distance to the nearest active drill centre since 2000 are illustrated in Figure 5-52. As indicated in the figure, the “normal range” of variation for total abundance across the sampling area was computed from the 2000 baseline data. Values in 2000 ranged between 1,885 and 6,776 individuals per m². Those values were also used as “benchmarks” against which to judge spatial variations in the sampling area in 2016 (Figure 5-53), as well as variations over time (Figure 5-54).

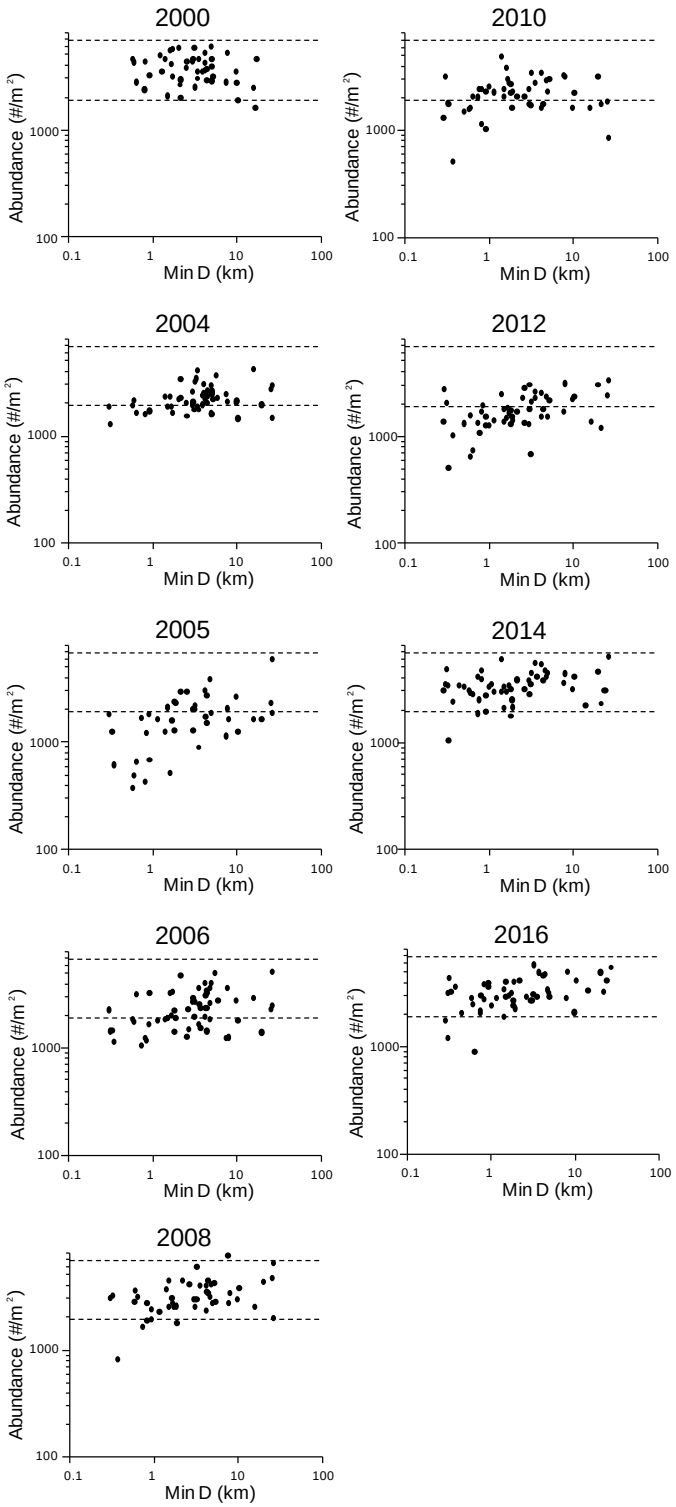

Figure 5-52 Variation in Total Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 1,885 and 6,776 individuals per m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

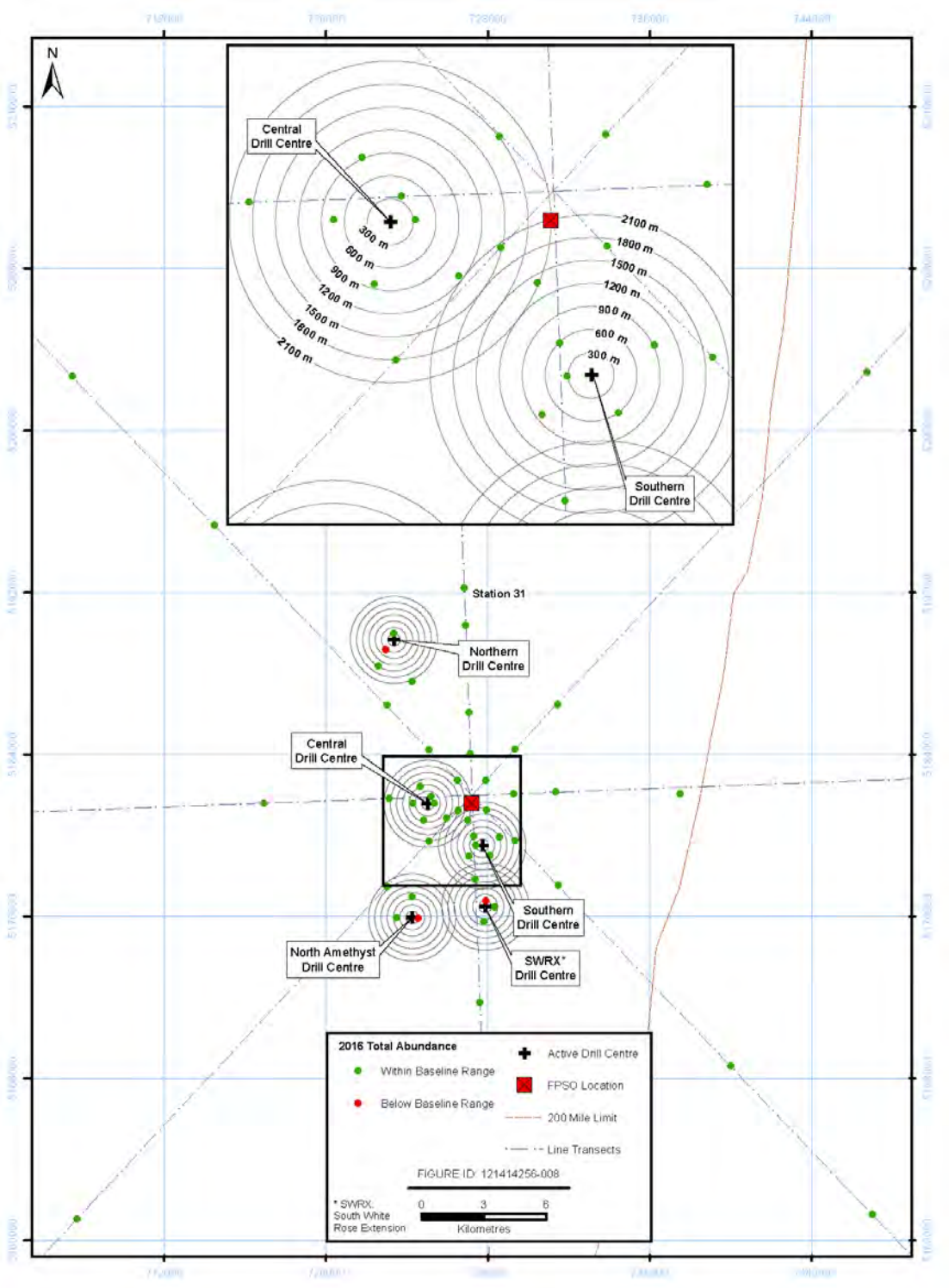

Figure 5-53 Location of Stations with Total Abundance Values Within and Below the Baseline Range (2016)

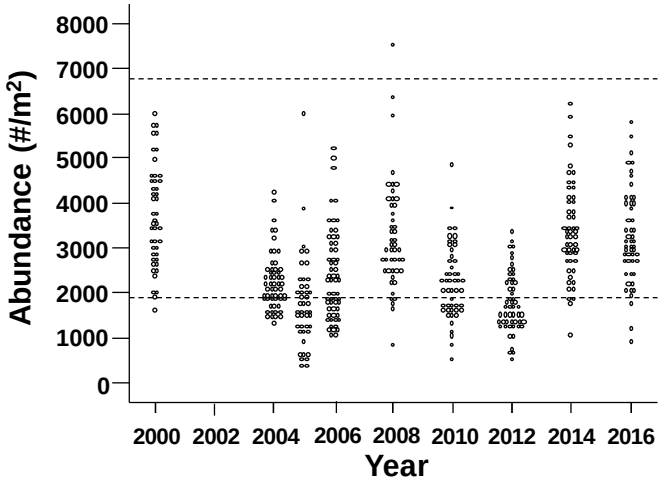

Figure 5-54 Dot Density Plot of Total Benthic Abundance by Year

Note: Values of 1,885 and 6,776 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

In 2016, three stations (excluding NA2 and SWRX4[15]) had abundances lower than the baseline range (Figure 5-53); one near the North Amethyst and SWRX Drill Centres, respectively, and one near the Northern Drill Centre. Overall, abundance in 2016 fell below the baseline range at 6% of stations (excluding NA2 and SWRX4). Overall abundance also fell below baseline range at 6% of stations in 2014, and it fell below baseline at 8% to 64% of stations in EEM years prior to 2014.

Repeated-measures regression (Table 5-22) demonstrated that the relationship between abundance and distance from nearest active drill centre did not vary over time in EEM years for repeated-measures stations (p = 0.364); but the relationship did vary from before to after drilling (p = 0.002). There was no distance trend before drilling; distance trends generally became positive, with lower abundance near drill centres after drilling began. There was also a decreasing trend in overall numbers in EEM years (p < 0.001) and between Before to After drilling (p < 0.001), although that trend reversed in 2014 with the abundance in almost all samples in both 2014 and 2016 at levels comparable to baseline (Figure 5-54).

Table 5-22 Repeated-measures Regression Testing for Changes in Total Benthic Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.364	<0.001	0.002	<0.001

Notes:
- Values are probabilities.
- n = 36.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

[15] Stations NA2 and SWRX4 were excluded from analysis because of incomplete preservation of the samples. See Section 5.1.3.3.

Total Biomass

In 2016, total biomass varied from approximately 12 to 902 g/m² within 500 m of active drill centres and from 592 to 1,157 g/m² at stations more than 10 km from drill centres. Variations in total biomass were significantly related to distance from active drill centres in 2016 (ρ_s = 0.575, p < 0.001, All stations; ρ_s = 0.409, p < 0.05, repeated-measures stations; (Figure 5-55). Similar to abundance, the data did not allow for precise estimation of a threshold (Appendix B-7), but a significant bivariate regression with Min D was detected (r^2 = 0.261, p < 0.001, Appendix B-7, Table 3-4), with biomass increasing with increasing distance from the nearest drill centre. A threshold could be estimated for biomass in 2012 and 2014 (Figure 5-56).

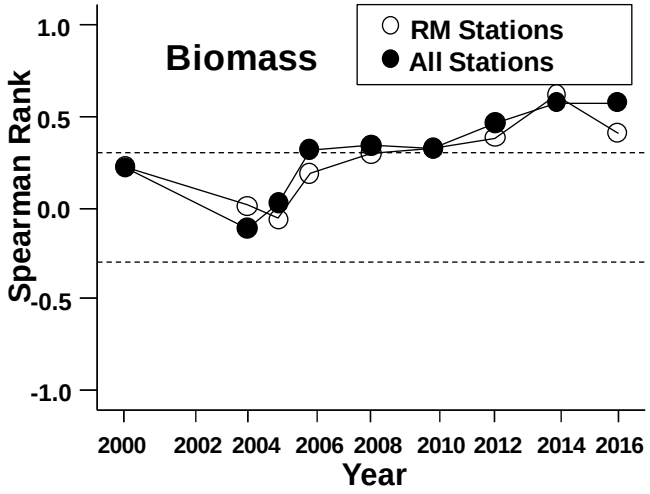

Figure 5-55 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Benthic Biomass

Notes: Stations NA2 and SWRX4 were excluded. n = 51 for All Stations. n = 36 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

As indicated in Figure 5-56, the "normal range" of variation for total biomass across the sampling area was computed from the 2000 baseline data. Values ranged between 367 and 1,400 g/m² in 2000 (*i.e.*, mean from year 2000 ± 2 SDs). Those values also were used to judge spatial variation in the sampling area in 2016 (Figure 5-57) and over time (Figure 5-58).

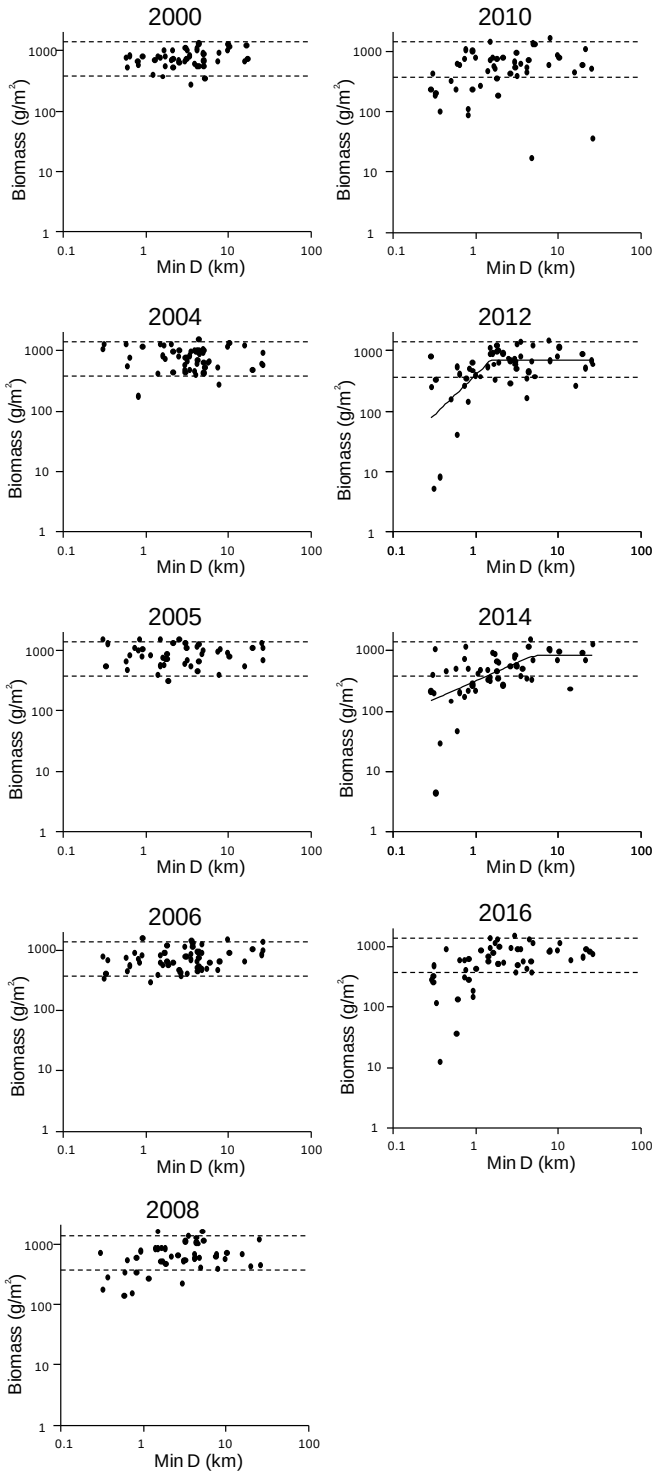

Figure 5-56 Variation in Total Benthic Biomass (g/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 367 and 1,400 g per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline), Here and in similar figures, threshold models are plotted when these were significant.

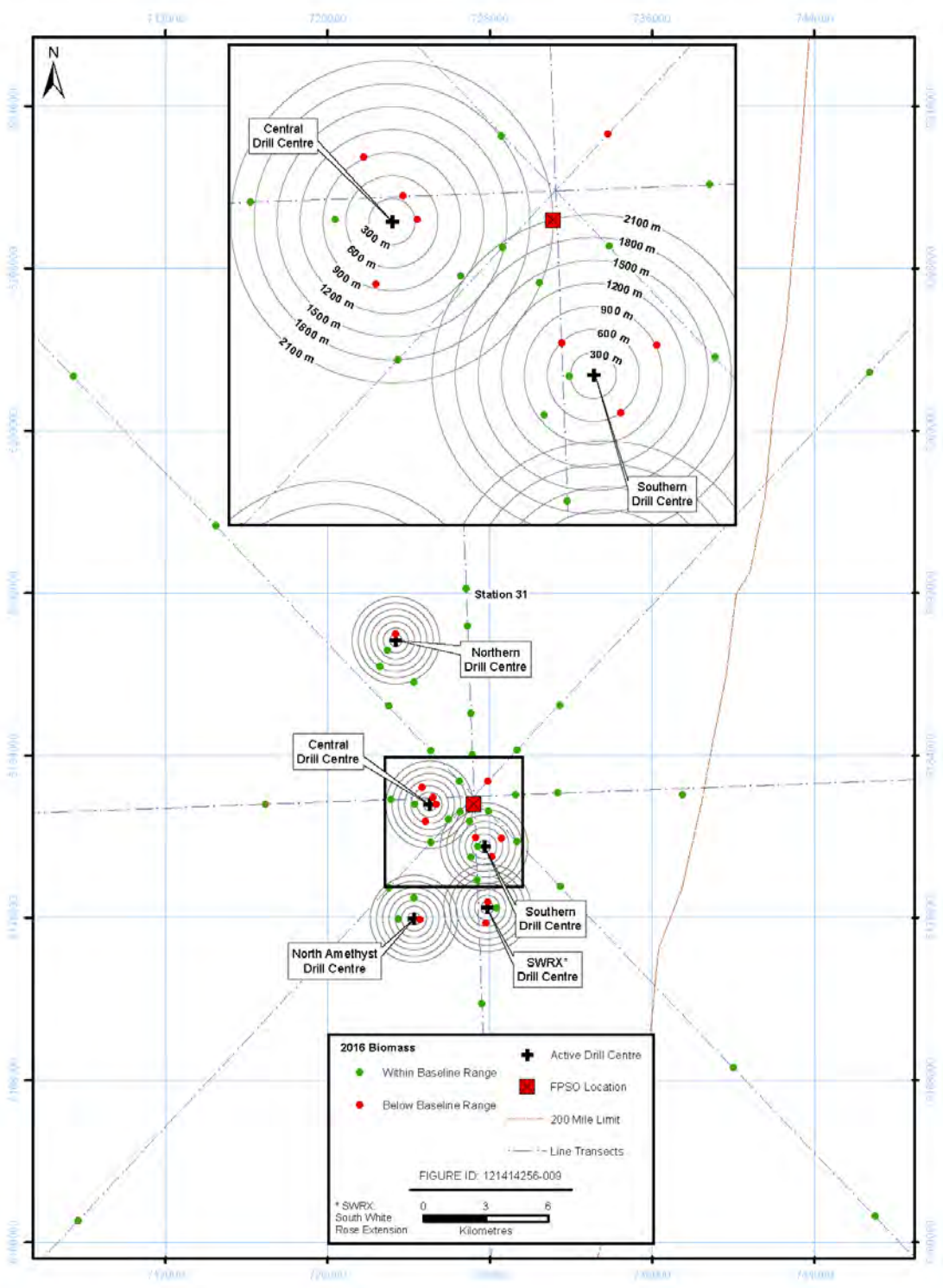

Figure 5-57 Location of Stations with Total Biomass Values Within and Below the Baseline Range (2016)

Biomass was reduced to below the baseline range near all drill centres (Figure 5-57). Overall, benthic biomass in 2016 fell below the baseline range at 27% of stations (excluding NA2 and SWRX4[16]), as compared to 40% in 2014 and 2% to 29% in EEM years prior to 2014.

Repeated-measures regression (Table 5-23) indicated that there was a significant linear trend over time in the slope of the distance relationship for biomass for repeated-measures stations, becoming increasingly positive over time (p = 0.002), as well as a significant difference in the slope of the relationship from before to after drilling (p = 0.047). Mean biomass was greater before drilling than during drilling (p < 0.001; Figure 5-58). Mean biomass also varied among EEM years (p < 0.001), with relatively higher biomass prior to 2008 (Figure 5-64).

Table 5-23 Repeated-measures Regression Testing for Changes in Total Benthic Biomass over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.002	<0.001	0.047	<0.001

Notes:
- Values are probabilities.
- n = 36.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

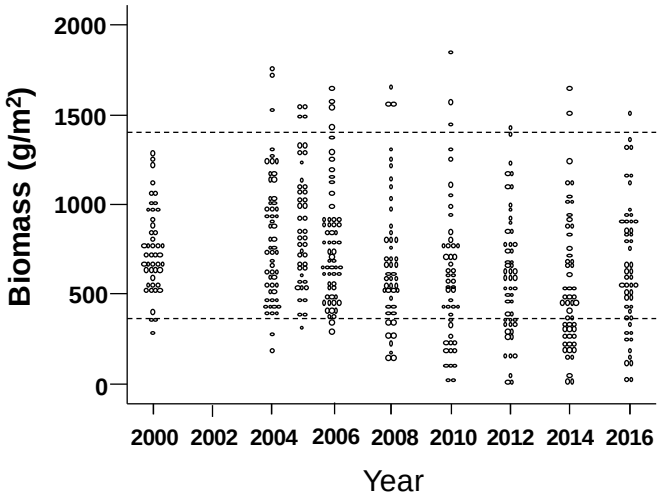

Figure 5-58 Dot Density Plot of Total Benthic Biomass by Year

Note: Values of 367 and 1,400 g per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

[16] Stations NA2 and SWRX4 were excluded from analysis because of incomplete preservation of the samples. See Section 5.1.3.3.

As indicated in the 2012 and 2014 EEM reports (the first years when effects on biomass were noted), reductions in biomass near drill centres are related, in part, to reductions in the number of larger echinoderms. In 2016, the two stations with the lowest biomass (stations 13 and 20) had approximately one-third as many echinoderms as other stations (mean = 9 versus 33 echinoderms/m^2).

Richness

Number of families per station (*i.e.*, richness) varied between 26 and 47 in 2016, compared to the baseline range of between 21 to 38 families. Richness was not significantly correlated with distance to the nearest active drill centre in 2016 (ρ_S = 0.208, p > 0.05, All stations; ρ_S = 0.062, p > 0.05, repeated-measures stations), or in other years (Figure 5-59). Figures 5-60 and 5-61 provide graphical representations of the relationship between richness and distance to active drill centres. In 2016, richness was not reduced at any drill centre (Figure 5-61).

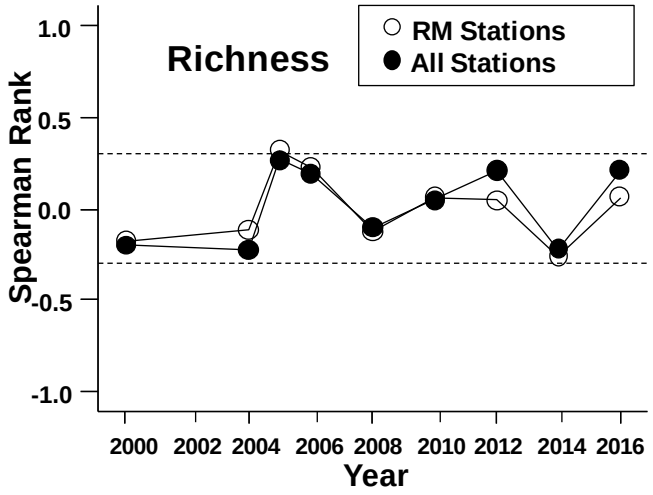

Figure 5-59 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Taxa Richness

Notes: Stations NA2 and SWRX4 were excluded. n = 51 for All Stations. n = 36 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

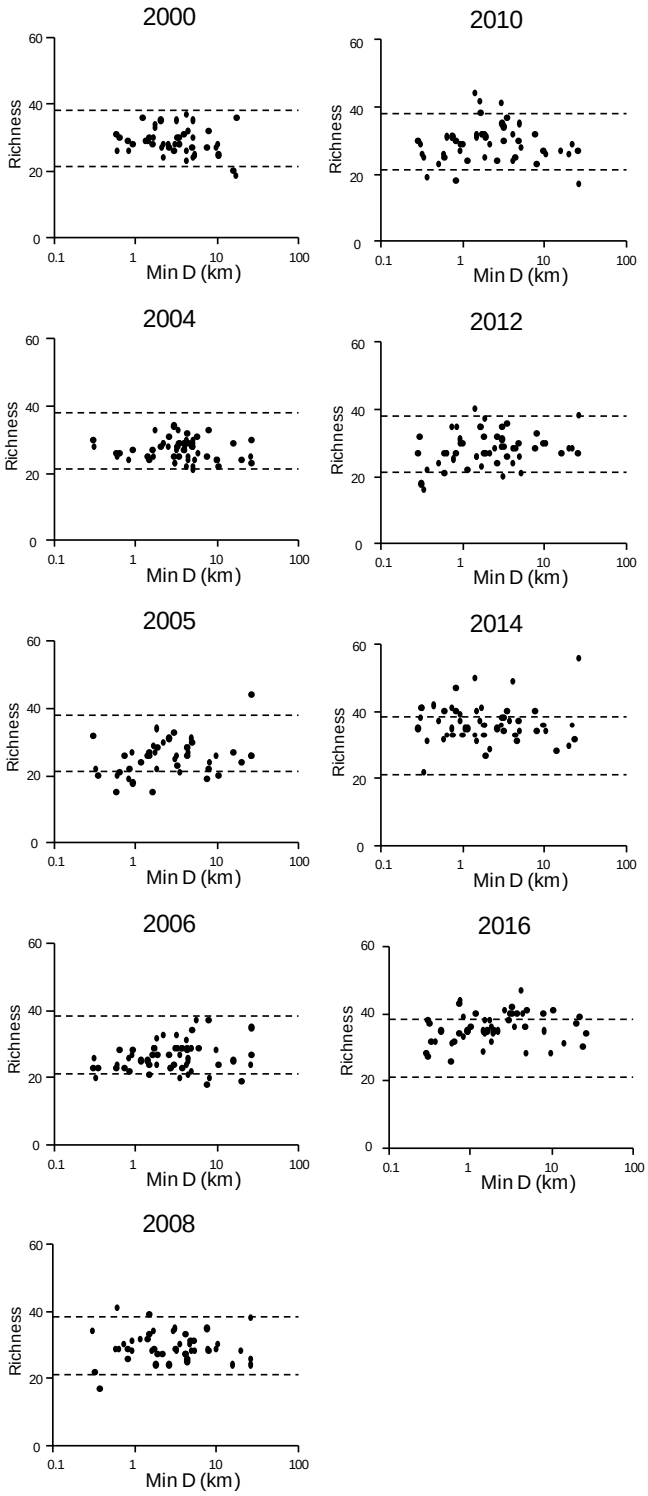

Figure 5-60 Variation in Taxa Richness with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values for number of families (22 to 38) are indicated by a horizontal line, based on the mean values ± 2 SDs using data from 2000.

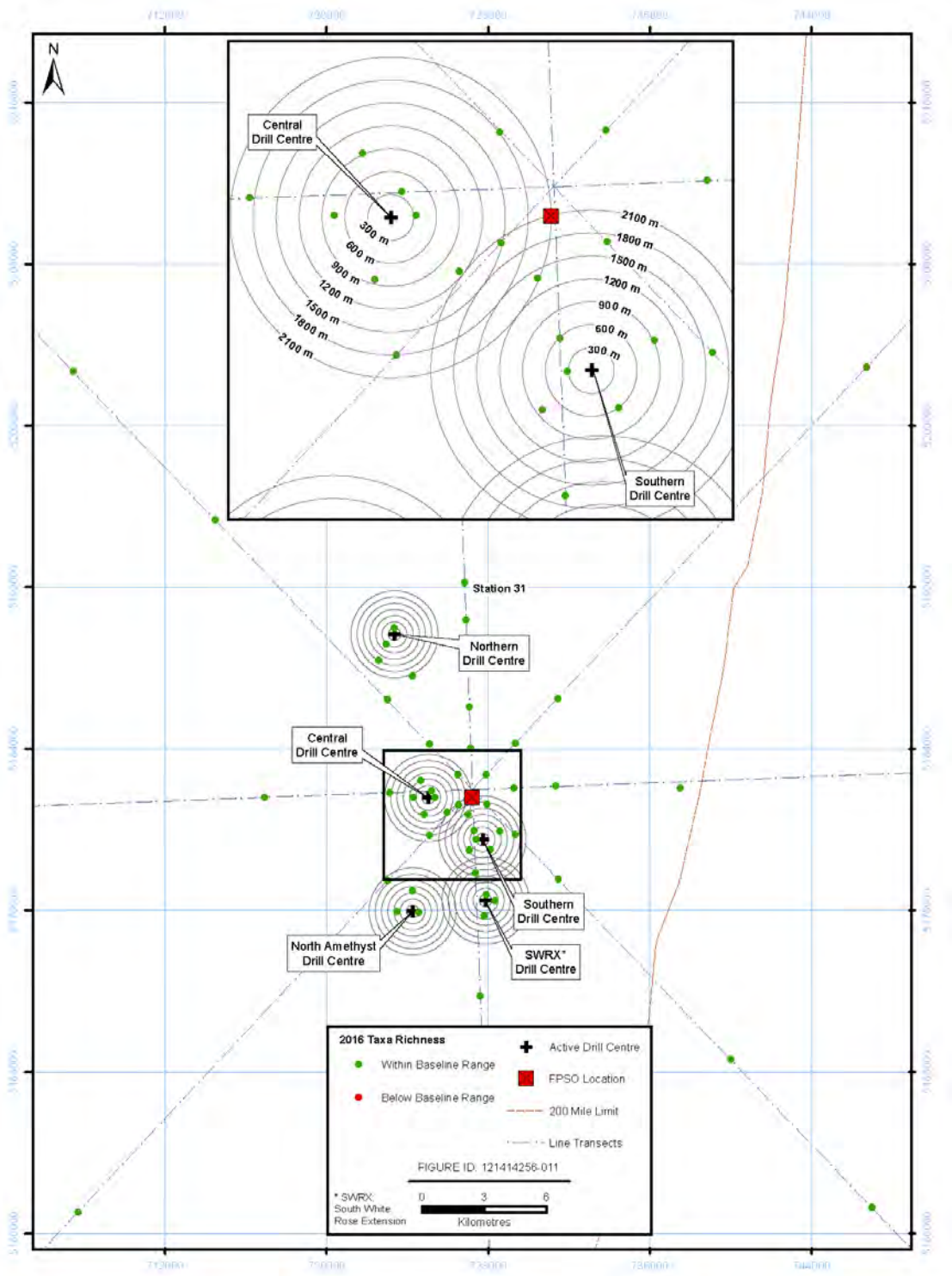

Figure 5-61 Location of Stations with Richness Values Within and Below the Baseline Range (2016)

Repeated-measures regression (Table 5-24) indicated that the slope of the relationship between number of families and distance from the nearest active drill centre has not varied over time in EEM years for repeated-measures stations (p = 0.1699). The relationship also has not changed significantly from before to after drilling (p = 0.084). There was a significant trend (increase; p < 0.001; see Figure 5-62) in number of families in EEM years. However, the number of families did not differ significantly between EEM years and the baseline year (p = 0.281; see Figure 5-68).

Table 5-24 Repeated-measures Regression Testing for Changes in Taxa Richness over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.169	<0.001	0.084	0.281

Notes:
- Values are probabilities.
- n = 36.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

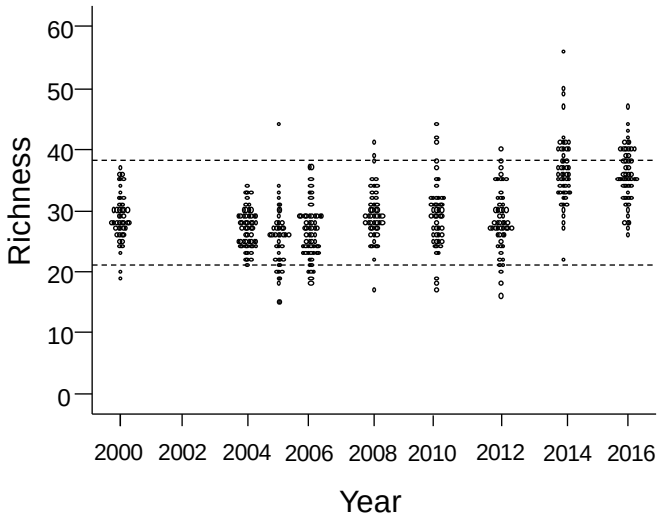

Figure 5-62 Dot Density Plot of Taxa Richness by Year

Note: Values for number of families (22 to 38) are indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

Results indicate that there has been no reduction in the number of families (richness) in the sampling area and, in fact, there has been an increase in richness since 2005, with the greatest increase noted in the 2014 and 2016 surveys.

Paraonidae Abundance

Paraonidae abundances have been strongly related to distance from active drill centres (Figure 5-63), with abundances lower near drill centres in most EEM years and in 2016 (ρ_s = 0.822, p < 0.001, All stations; (ρ_s = 0.782, p < 0.001, repeated-measures stations). Threshold models were significant for Paraonidae abundance for all years from 2004 to 2016 (Table 5-25). Threshold distances have been somewhat variable (1.2 km in 2016 to 4.1 km in 2004) but confidence limits have generally overlapped (Table 5-25).

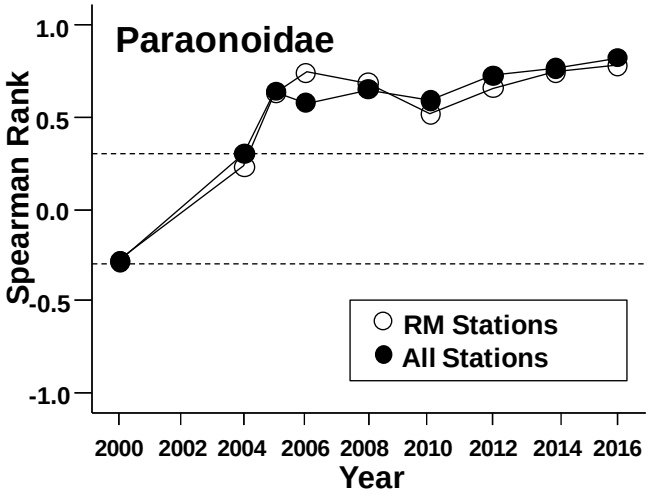

Figure 5-63 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Paraonidae Abundances

Notes: Stations NA2 and SWRX4 were excluded. n = 51 for All Stations. n = 36 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

Table 5-25 Threshold Distances Computed from Threshold Regressions on Distance from the Nearest Active Drill Centre for Paraonidae Abundance

Year	Threshold Distance (km)
2004	4.1 (2.0 to 8.6)
2005	2.6 (1.5 to 4.5)
2006	2.8 (1.9 to 4.2)
2008	3.8 (2.1 to 6.9)
2010	1.6 (1.0 to 2.7)
2012	2.5 (1.5, 4.3)
2014	1.5 (0.5 to 3.0)
2016	1.2 (0.6 to 2.1)

Note: - 95% confidence limits are provided in brackets.

Figure 5-64 provides a graphical representation of the relationship between Paraonidae abundance and distance to active drill centres. As indicated in the figure, the “normal range” of variation for Paraonidae abundance across the sampling area was computed from the 2000 baseline data. Values ranged from 130 to 1,671 per m² in 2000. The lower range of 130 individuals per m² was used as a “benchmark” against which to judge spatial variations in the sampling area in 2016 (Figure 5-65) as well as variations over time (Figure 5-66).

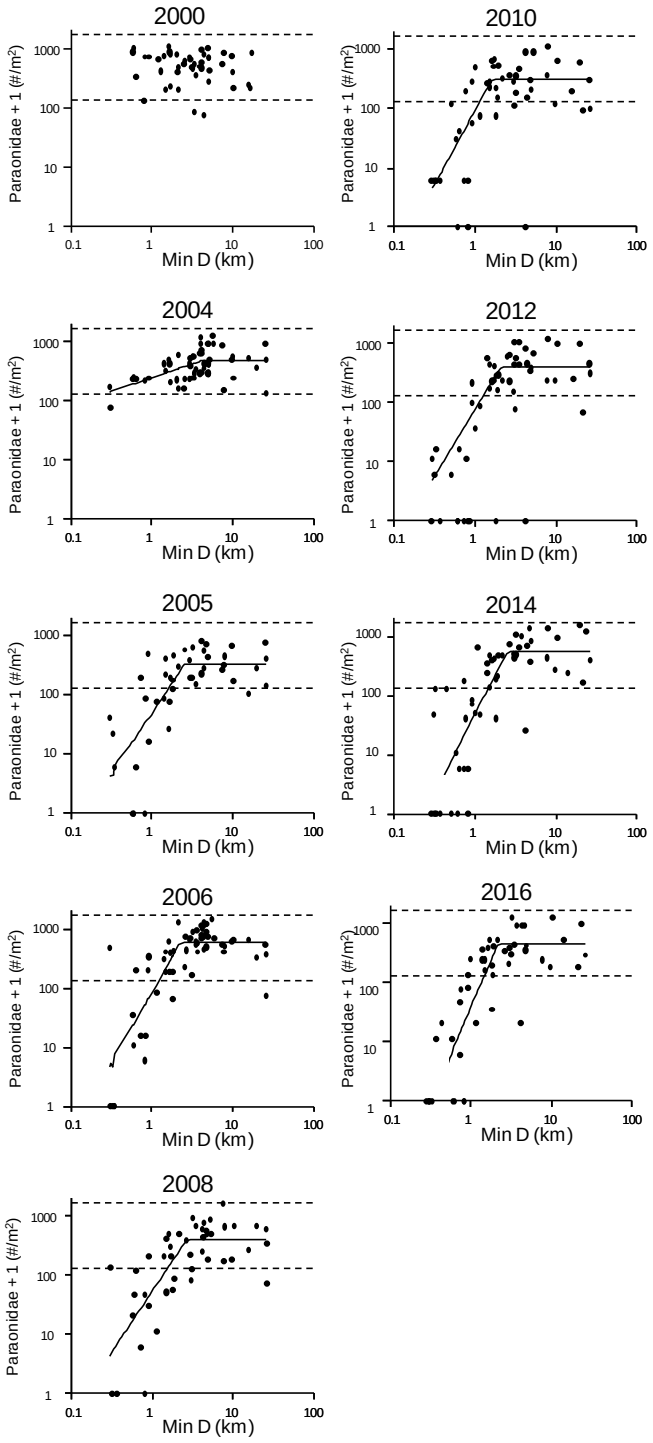

Figure 5-64 Variation in Paraonidae Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 130 and 1,671 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline). Here and in similar figures, threshold models are plotted when these were significant.

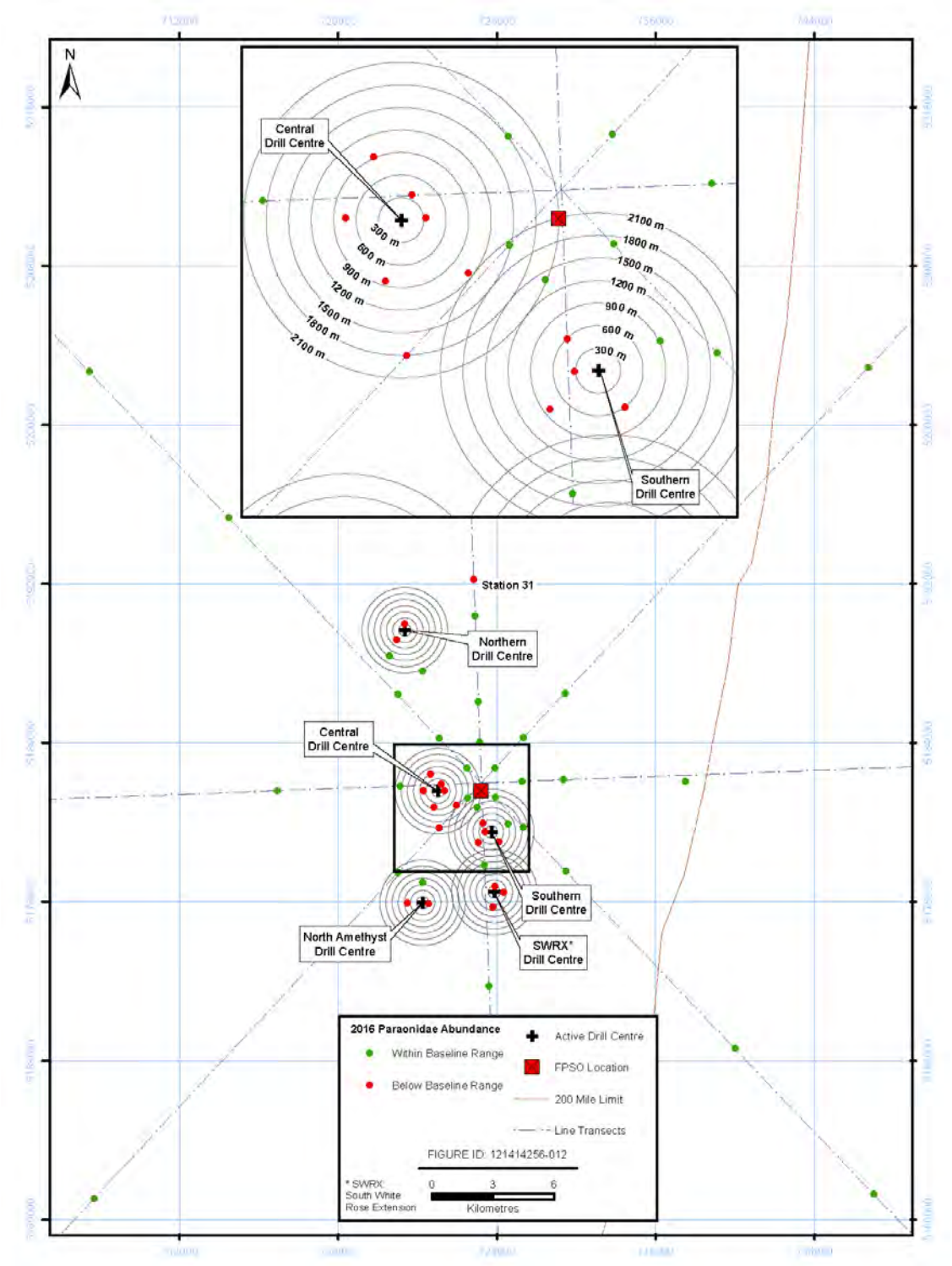

Figure 5-65 Location of Stations with Paraonidae Abundance Values Within and Below the Baseline Range (2016)

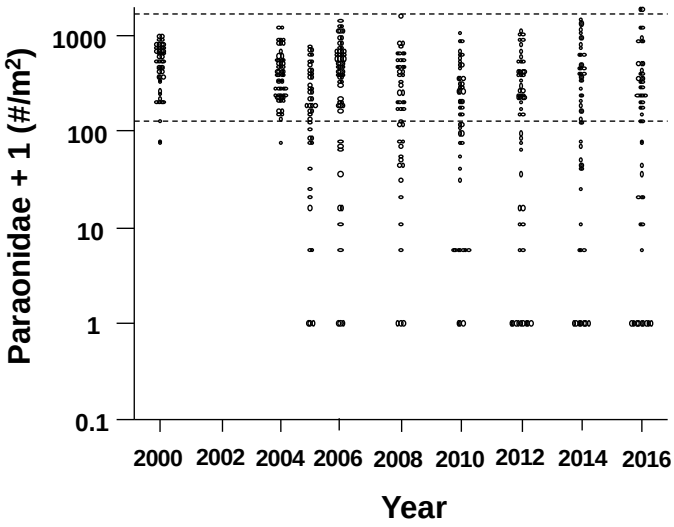

Figure 5-66 Dot Density Plot of Paraonidae Abundance by Year

Note: Values of 130 and 1,671 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

Paraonidae abundances were reduced at several stations around all drill centres in 2016 (Figure 5-65). Paraonidae abundances were also reduced at Station 31, near the site of delineation drilling in 2007. Overall, Paraonidae abundance in 2016 fell below the baseline range at 37% of stations (excluding NA2 and SWRX4[17]), as compared to 45% in 2014 and 2% to 38 % in EEM years prior to 2014.

Repeated-measures regression (Table 5-26) indicated there was a significant linear trend over time in the slope of the relationship between distance and Paraonidae abundance in EEM years for repeated-measures stations (increase in the slope, $p < 0.001$; also see Figure 5-63). There was also a difference in the slope from before to after drilling (higher slope in EEM years, $p < 0.001$); a linear decrease over time in mean Paraonidae abundances in EEM years ($p < 0.001$); and overall lower numbers of Paraonidae from before to after drilling ($p < 0.001$), with effects caused by the low abundances near active drill centres (*e.g.*, Figure 5-66).

Table 5-26 Repeated-measures Regression Testing for Changes in Paraonidae Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
<0.001	<0.001	<0.001	<0.001

Notes:
- Values are probabilities.
- $n = 36$.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

[17] Stations NA2 and SWRX4 were excluded from analysis because of incomplete preservation of the samples. See Section 5.1.3.3.

Spionidae Abundance

Spionidae abundances varied between 285 and 2,230 individuals per m², averaging just over 1,200 per m² in 2016. Variation in abundances of Spionidae polychaetes in 2016 was uncorrelated with distance to the nearest active drill centre (ρ_s = 0.177, p > 0.05, All stations; ρ_s = -0.034, p > 0.05, repeated-measures stations) (Figure 5-67). Figure 5-68 provides a graphical representation of the relationship between Spionidae abundance and distance to active drill centres. The baseline range of Spionidae abundances was between 640 and 2,700 per m². Abundances of Spionidae in 2016 were below the lower limit of baseline at only 12% of stations. Spionidae abundance fell below the baseline range at 8% of stations in 2014 and at 4% to 59% of stations in EEM years prior to 2014 (also see Figure 5-69).

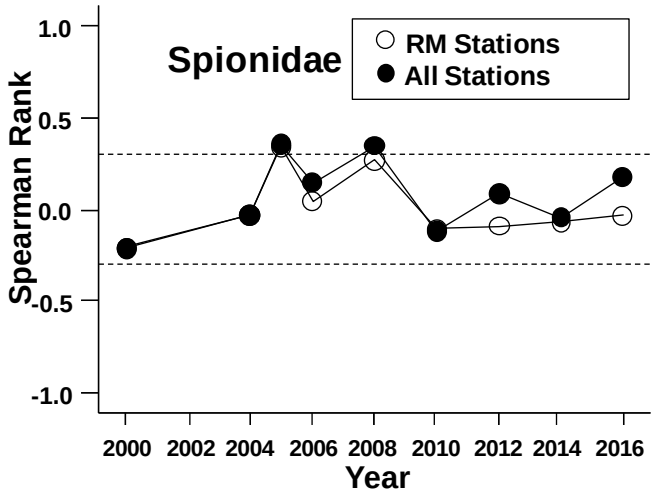

Figure 5-67 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Spionidae Abundances

Notes: Stations NA2 and SWRX4 were excluded. n = 51 for All Stations. n = 36 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

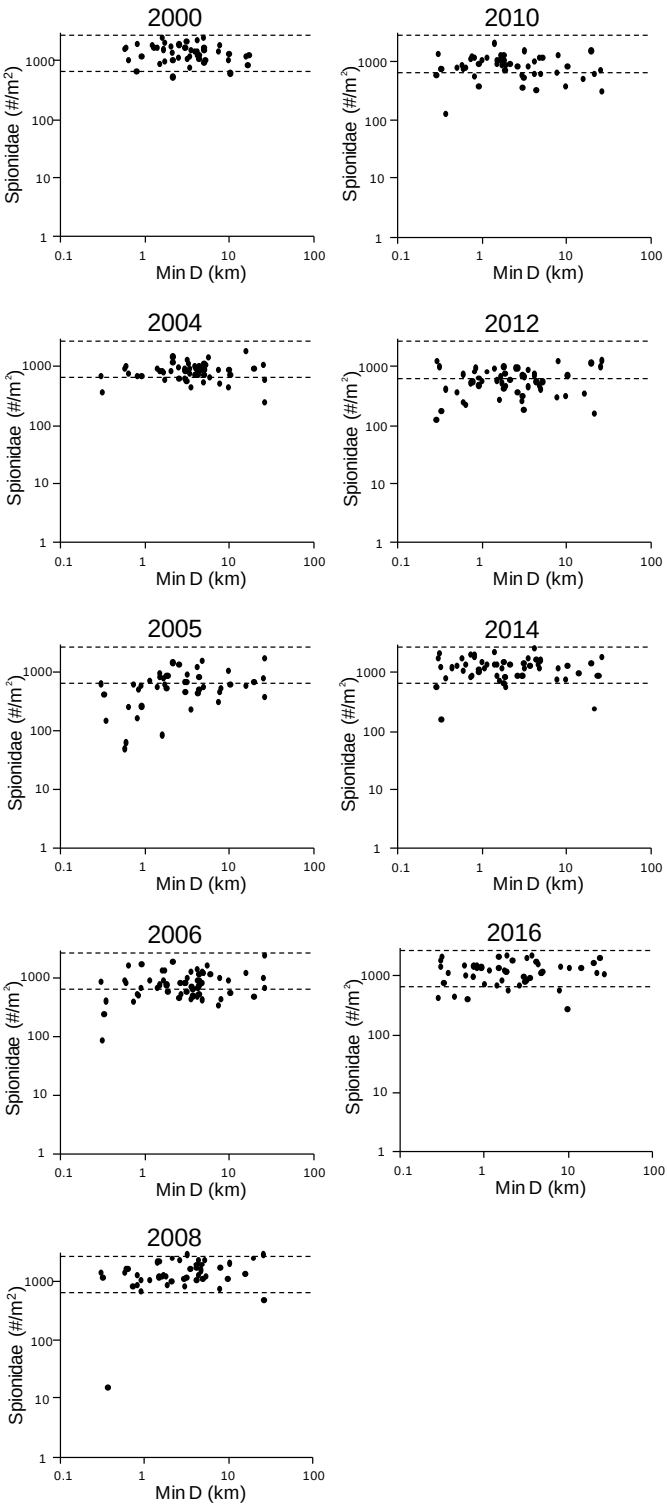

Figure 5-68 Variation in Spionidae Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 640 and 2,700 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

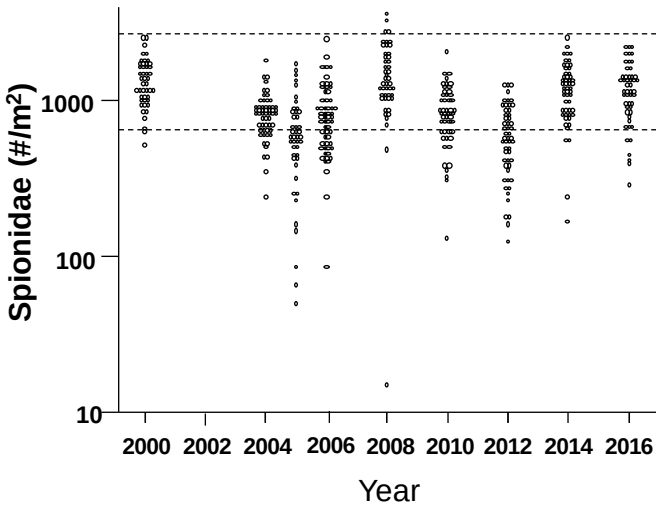

Figure 5-69 Dot Density Plot of Spionidae Abundance by Year

Note: Values of 640 and 2,700 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

Repeated-measures regression (Table 5-27) indicated a significant change in the slope of the relationship between Spionidae abundance and distance from the nearest active drill centre in EEM years for repeated-measured stations (p = 0.020), yet no difference in slope from before to after active drilling operations (p = 0.223). Slopes in earlier EEM years were more positive; slopes since 2010 have been similar to baseline (*e.g.*, Figures 5-67 and 5-68). There was a difference in mean Spionidae abundance across the sampling area from before to after active drilling (p = 0.002) that appears to have been driven by reduced abundances in 2005, 2010 and 2012 (Figure 5-69). These same reductions combined with the relative increase in abundances in 2014 were likely the drivers for the significant difference in mean abundances in EEM years (p < 0.001; see Figure 5-69).

Table 5-27 Repeated-measures Regression Testing for Changes in Spionidae Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.020	<0.001	0.223	0.002

Notes:
- Values are probabilities.
- n = 36.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

Tellinidae Abundance

Tellinidae abundances varied between 45 and 810 individuals per m², with an area-wide average of approximately 285 per m² in 2016. The correlation between Tellinidae abundance and distance to active drill centres was significant from 2008 to 2014 when only repeated-measures stations were considered (Figure 5-70). In 2016, the relationship was also significant when all stations were considered (2016: ρ_s = 0.276, p = 0.048, All stations; ρ_s = 0.565, p < 0.001, repeated-measures stations (Figure 5-70). However, the data did not allow for precise estimation of a threshold, nor was the bivariate regression with Min D significant (r^2 = 0.033, p > 0.05, Appendix B-7, Table 3-4).

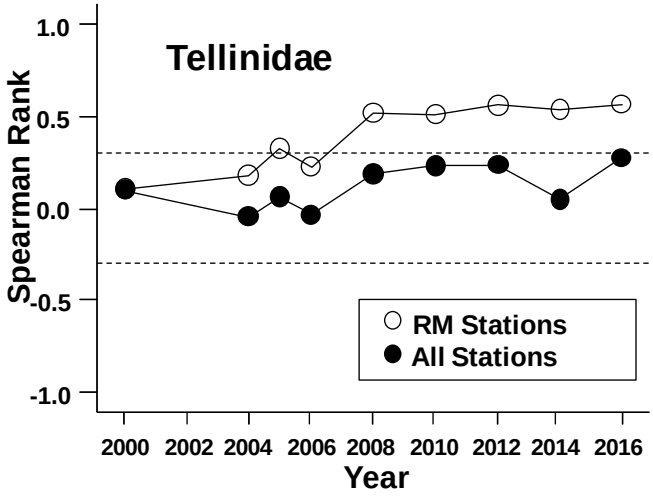

Figure 5-70 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Tellinidae Abundance

Notes: Stations NA2 and SWRX4 were excluded. n = 51 for All Stations. n = 36 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

Figure 5-71 provides a graphical representation of the relationship between Tellinidae abundance and distance to active drill centres. As indicated in the figure, the "normal range" of variation for Tellinidae abundance across the sampling area was computed from the 2000 baseline data. Values ranged from 151 and 1,303 per m² in 2000. The lower range of 151 individuals per m² was used as a "benchmark" against which to judge spatial variations in the sampling area in 2016 (Figure 5-72) as well as variations over time (Figure 5-73).

Tellinidae abundances were reduced at a number of stations in the centre of the White Rose development, although the association with specific drill centres was not as clear as it was for other variables (Figure 5-72). Tellinidae abundances were also reduced near the Northern Drill Centre. Approximately 30% of all stations had Tellinidae abundances in 2016 that were below the lower baseline value of 151 per m², compared to 6% in 2014 and 9% to 58 % in EEM years prior to 2014 (Figure 5-73).

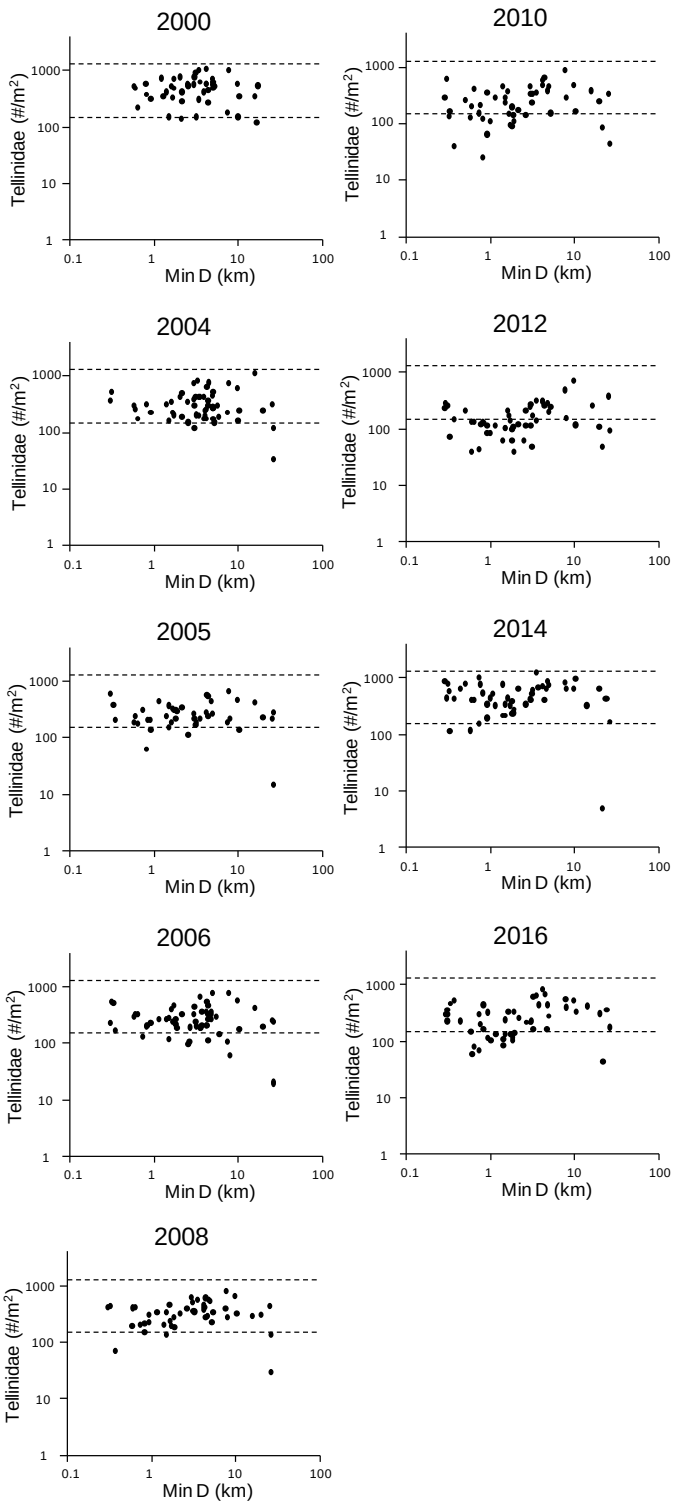

Figure 5-71 Variation in Tellinidae Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 151 and 1,303 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

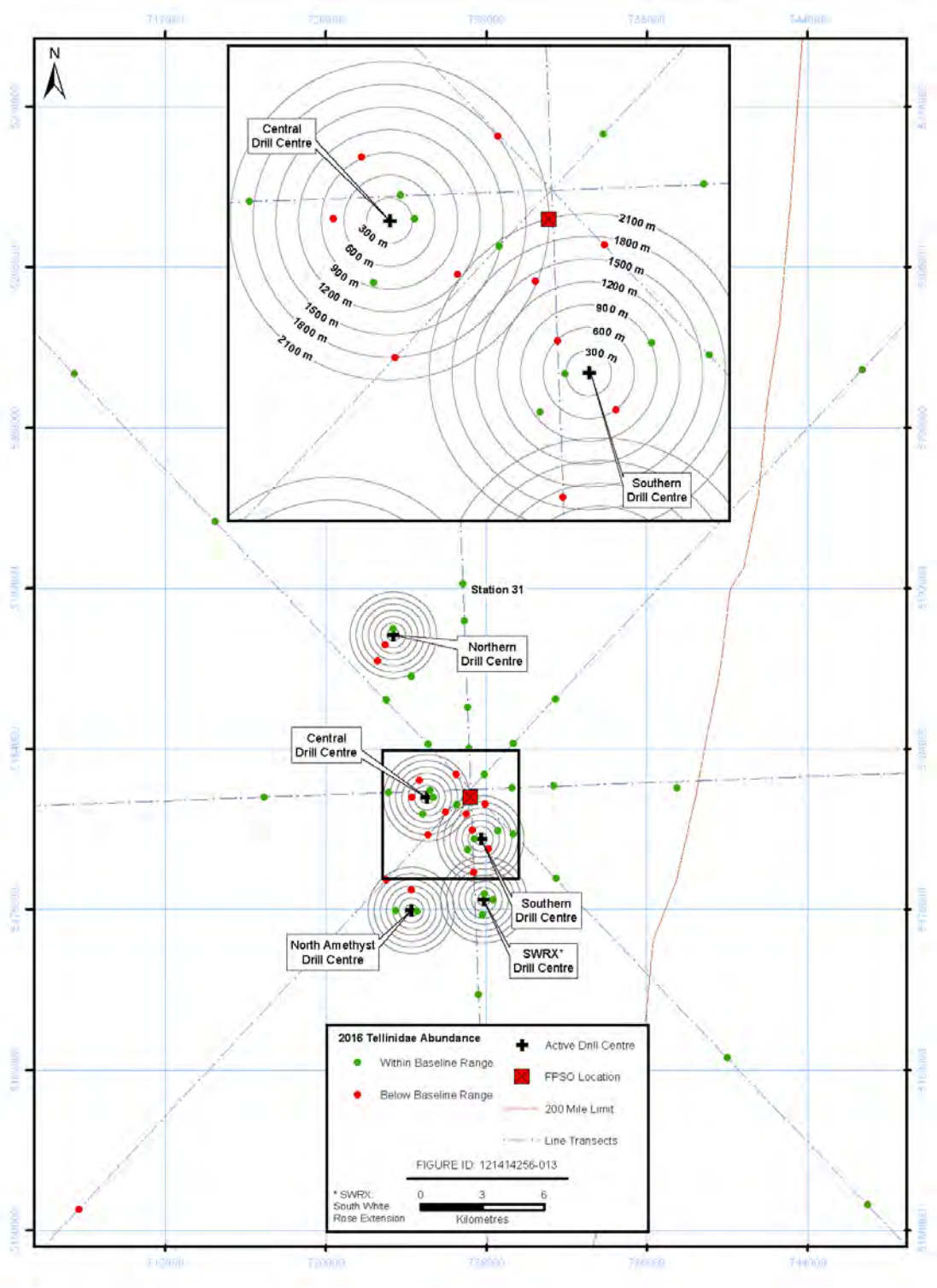

Figure 5-72 Location of Stations with Tellinidae Abundance Values Within and Below the Baseline Range (2016)

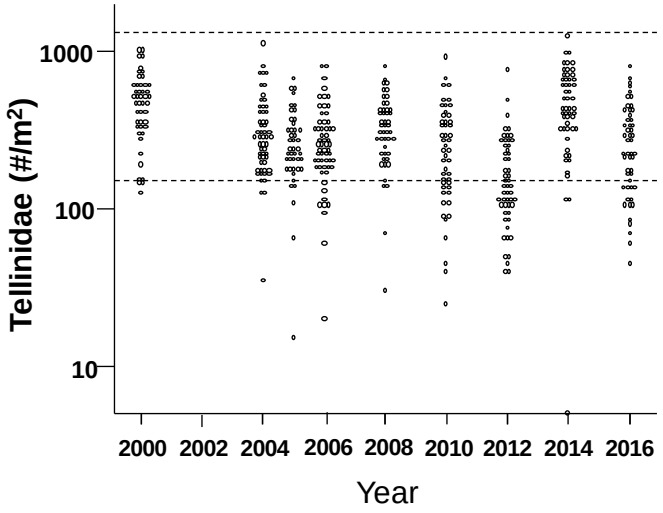

Figure 5-73 Dot Density Plot of Tellinidae Abundance by Year

Note: Values of 151 and 1,303 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

Repeated-measures regression (Table 5-28) indicated that the slope of the relationship between Tellinidae abundance and distance to the nearest active drill centre was different between EEM years and baseline for repeated-measures stations (p = 0.003), yet the slope of the relationship did not significantly vary during EEM years (p = 0.095). Mean numbers of Tellinidae varied significantly over time in EEM years (p < 0.001). There was also a significant difference between baseline and EEM years (p = 0.001), with numbers generally lower in EEM years (Figure 5-73).

Table 5-28 Repeated-measures Regression Testing for Changes in Tellinidae Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.095	<0.001	0.003	<0.001

Notes:
- Values are probabilities.
- n = 36.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

Amphipod Abundance

Amphidod abundances varied between 25 and 480 individuals per m², with an area-wide average of approximately 97 per m² in 2016. In 2016, amphipod abundance was not correlated with distance to nearest active drill centre (ρ_s = 0.051, p > 0.05, All stations; ρ_s = -0.152, p > 0.05, repeated-measures stations; Figure 5-74).

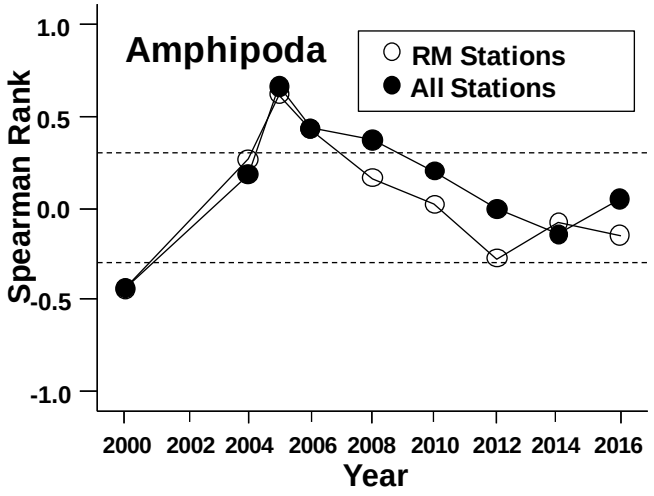

Figure 5-74 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Amphipoda Abundance

Notes: Stations NA2 and SWRX4 were excluded. *n* = 51 for All Stations. *n* = 36 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year. Significance from specific statistical tests are reported in text.

Figure 5-75 provides a graphical representation of the relationship between amphipod abundance and distance to active drill centres. As indicated in the figure, the "normal range" of variation for amphipod abundance across the sampling area was computed from the 2000 baseline data. Values ranged from 44 to 313 per m^2 in 2000. The lower range of 44 individuals per m^2 was used as a "benchmark" against which to variations over time (Figure 5-76).

In 2016, 10% of stations had amphipod abundances below the lower benchmark of 44 per m^3, as compared to 15% in 2014 (Figure 5-76). In earlier years, amphipod abundances have been below the lower baseline benchmark at more stations than in either 2014 or 2016; from 2004 to 2012, 30% to 45% of stations were below the lower baseline benchmark.

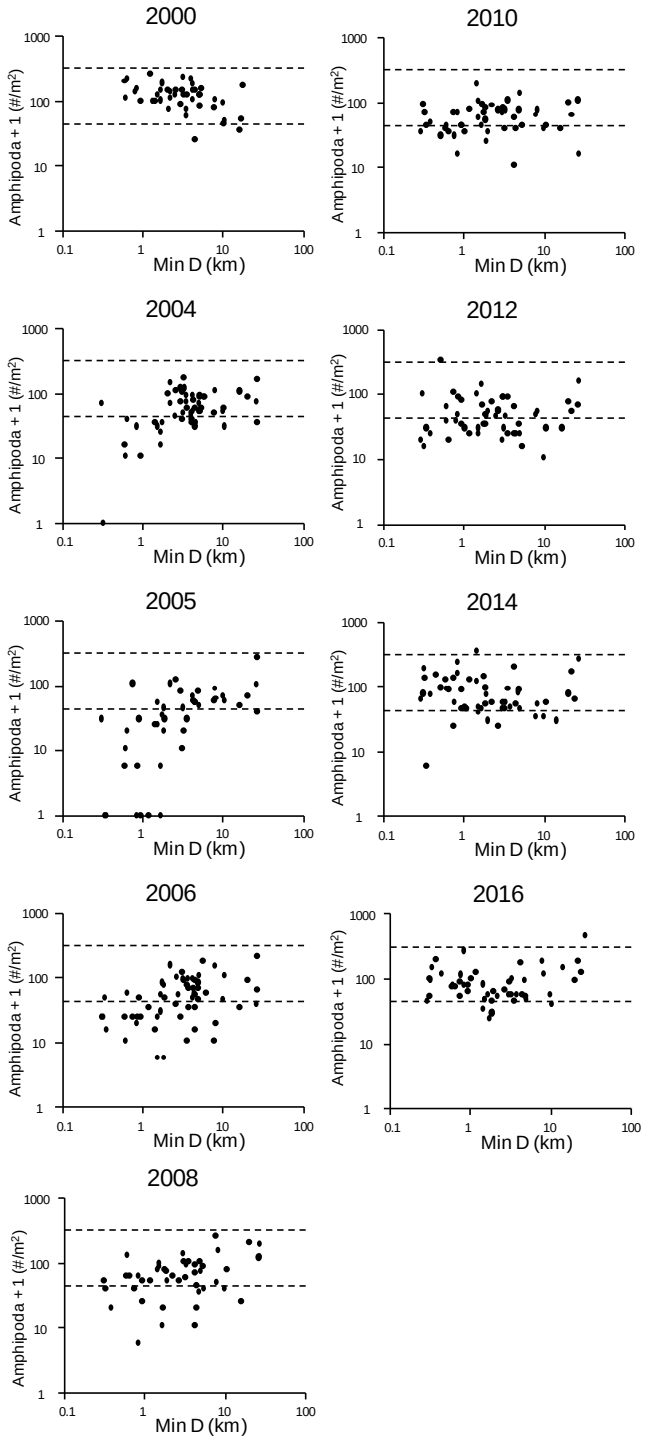

Figure 5-75 Variation in Amphipoda Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 44 and 313 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

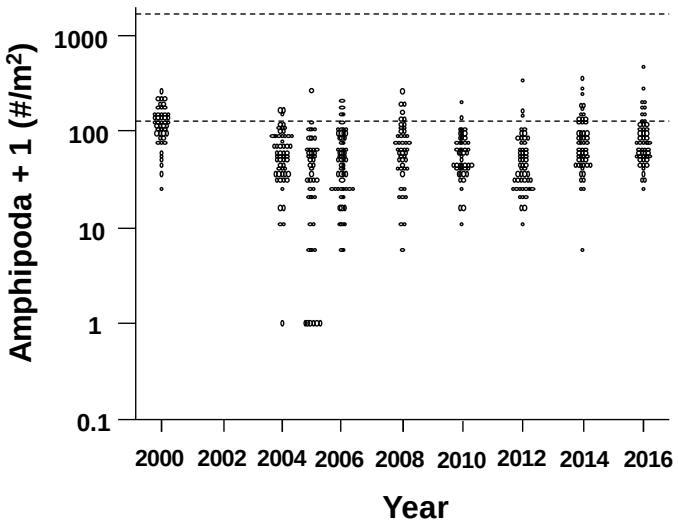

Figure 5-76 Dot Density Plot of Amphipoda Abundance by Year

Note: Values of 44 and 313 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

Repeated-measures regression indicated that slopes of the relationship between amphipod abundance and distance to the nearest drill centre varied linearly in EEM years ($p < 0.001$; a decrease in strength, see Figure 5-73), and from before to after drilling ($p < 0.001$, Table 5-29) for repeated-measures stations. The slope of the distance relationship was modestly negative during in baseline (see Figure 5-74), and tended to be more positive in most EEM years, reflecting somewhat reduced numbers of amphipods near drill centres. The linear change in slopes over time in EEM years indicates that effects near drill centres (if any) decreased over time. There were significant variations in mean abundance over time ($p < 0.001$ for both mean Terms), with numbers generally lower in EEM years, and with numbers in 2014 and 2016 showing recent increases (Figure 5-75).

Table 5-29 Repeated-measures Regression Testing for Changes in Amphipoda Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
<0.001	<0.001	<0.001	< 0.001

Notes:
- Values are probabilities.
- $n = 36$.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2016).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2016.

Correlations Between Univariate Measures of Benthic Community Structure and Environmental Descriptors

In 2016, none of the indices of benthic community composition were significantly related to percent gravel or Metals PC1, and richness was not significantly related to any environmental descriptor (Table 5-30). However, total abundance decreased with increasing sediment concentrations of $>C_{10}$-C_{21} hydrocarbons and sediment redox potential. Biomass decreased with increasing sediment $>C_{10}$-C_{21} hydrocarbon, barium,

lead, strontium and sulphur concentrations. Biomass was also affected by water depth, with higher biomass at deeper stations.

Of the individual taxa, Paraonidae abundance decreased with increasing sediment $>C_{10}$-C_{21} hydrocarbon, barium, lead, strontium and sulphur concentrations and increasing sediment redox potential. Correlations with redox potential for both total abundance and Paraonidae abundance could be an spurious, resulting from lower redox potential at stations more distant from drill centres in 2016 (*i.e.*, a negative correlation between distance from drill centres and redox). In 2014, Paraonidae abundance increased with increasing redox potential. Of remaining taxa, Tellinidae abundance decreased and Amphipoda abundance increased with increasing sediment fine content. None of the benthos variables were related to laboratory amphipod survival.

Table 5-30 Spearman Rank Correlations (ρ_S) of Indices of Benthic Community Composition with Environmental Descriptors (2016)

Environmental Descriptor	Index of Invertebrate Community Composition						
	Total Abundance	Biomass	Richness	Paraonidae Abundance	Spionidae Abundance	Tellinidae Abundance	Amphipoda Abundance
% Fines	0.002	-0.204	0.162	-0.270	-0.195	-0.296*	0.294*
% Gravel	0.164	-0.151	0.225	-0.061	0.133	0.228	0.170
$>C_{10}$-C_{21}	**-0.342*** **	**-0.552*** **	-0.086	**-0.825*** **	-0.021	-0.235	0.070
Barium	-0.251	**-0.548*** **	0.047	**-0.799*** **	0.003	-0.187	0.071
Metals PC1	0.077	-0.200	0.233	-0.200	-0.090	0.047	0.088
Lead	0.062	-0.348*	0.246	-0.346*	0.042	0.104	0.047
Strontium	0.034	**-0.465*** **	0.204	**-0.471*** **	0.041	0.058	0.158
Sulphur	-0.017	-0.447**	-0.190	-0.421**	0.108	0.171	0.119
Redox Potential	-0.367**	-0.260	-0.011	-0.417**	-0.151	-0.144	-0.089
Laboratory Amphipod survival	-0.145	-0.152	-0.144	-0.105	0.075	-0.260	-0.165
Water Depth	0.042	0.376**	0.125	0.219	-0.046	0.213	-0.080

Notes: - *p < 0.05; **p < 0.01; ***p < 0.001 (**in bold**).
- TOC and sulphides were excluded from the above comparisons because too many values were below laboratory detection limit.
- n = 51 with stations NA2 and SWRX4 excluded.
- Correlations with redox potential for both total abundance and Paraonidae abundance could be an artifact of lower redox potential at stations more distant from drill centres in 2016 (*i.e.*, a negative correlation between distance from drill centres and redox).

5.2.3.3 Multivariate Analyses

Significant differences in benthic invertebrate community structure (*i.e.*, taxa abundance) relative to distance from nearest active drill centres were detected among samples collected during 2016 sampling (PERMANOVA Pseudo-$F_{5,45}$ = 5.64; P(perm) < 0.001, Table 3-5, Appendix B-7).

Specifically, station groups less than 500 m, 500 to 1,000 m, and 1,000 to 2,000 m from active drill centres were significantly different from other groups (Figure 5-77; P(perm) < 0.05, Table 3-4, Appendix B-7), while stations at more than 2,000 m were statistically indistinguishable.

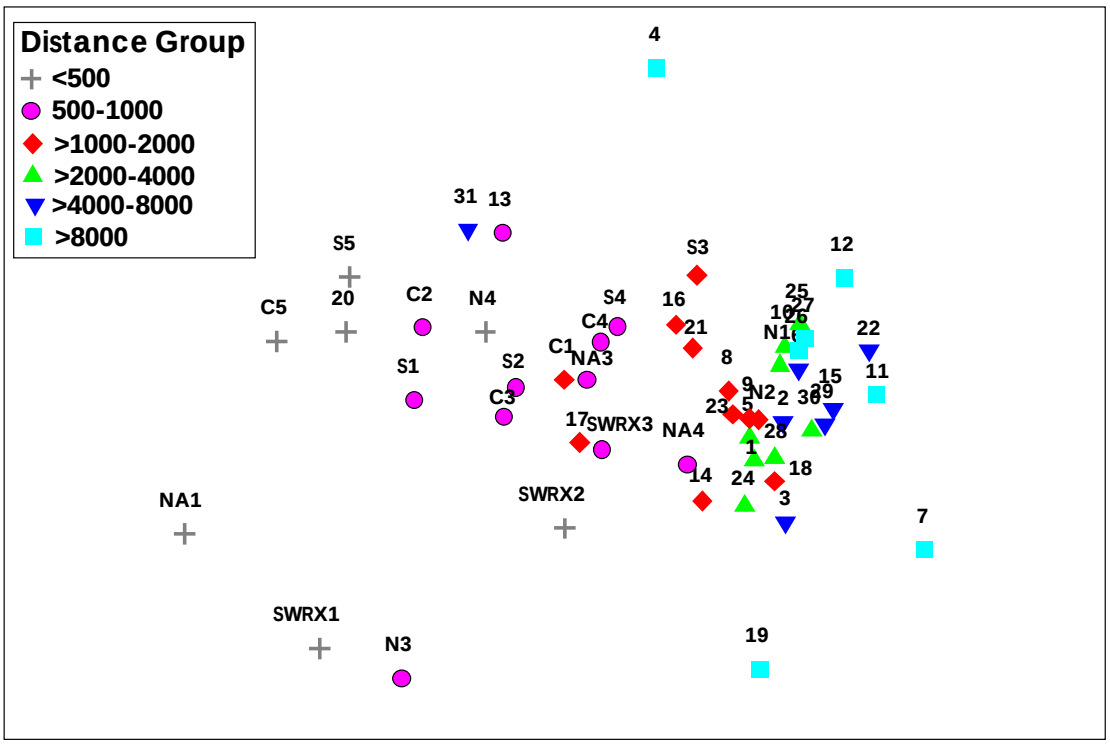

Figure 5-77 nMDS Scatterplot Based on Bray-Curtis Similarities of Benthic Infauna Assemblage Matrix Sampled in 2016 Grouped by Distance

Notes: *n* = 51 with stations NA2 and SWRX4 excluded.
Stress = 0.14. Stress values are a measure of goodness-of-fit between the calculated similarity values and the distance between sample points. Stress values <0.1 have no real prospect for misinterpretation while values >0.2 are close to being arbitrarily placed and should be interpreted with a high degree of caution (Clarke and Warwick 2001).

Further multivariate analyses detected significant relationships between the benthic community structure and sediment physical and chemical variables. When sediment physical and chemical variables were considered sequentially using step-wise multivariate multiple regression (distance-based linear models; DISTLM), the resulting model explained 50% of the variation in the benthic assemblages (Table 5-31). The individual sediment physical and chemical variable contributing most to this variation was >C_{10}-C_{21} hydrocarbons (31%). The subsequent addition of the variables (in order of cumulative contribution to cumulative r^2) barium, uranium, iron, redox potential and percent fines significantly improved the model. The remaining variables (depth, percent gravel, percent sand, ammonia, or sediment concentrations of aluminum, chromium, lead, manganese, strontium, sulphur, vanadium, or zinc) did not significantly improve the multivariate model[18].

[18] TOC and sulphides were not included in these analyses because too many values were below laboratory detection limit in 2016. Distance to the nearest active drill centre was also not included as it is an aggregate variable (*i.e.*, Min D, in and of itself, can not affect benthic community).

Table 5-31 Results of DISTLM Multivariate Multiple Stepwise Regression of Predictor Variables on Bray-Curtis Similarities of Benthic Infauna Assemblage Matrix

Variable	*P*	Sequential Proportion of Variance Explained	Cumulative r^2
$>C_{10}$-C_{21}	**<0.001*** **	0.306	0.306
Barium	**<0.001*** **	0.055	0.361
Uranium	0.036*	0.023	0.443
Iron	0.029*	0.024	0.467
Redox	0.011*	0.028	0.474
% Fines	0.018*	0.026	0.499

Notes: - *p < 0.05; **p < 0.01; ***p < 0.001 (**in bold**).
- n = 51 with stations NA2, and SWRX4 excluded.
- Further model diagnostics and graphics on the relationship between benthic community structure and selected variables are provided in Appendix B-7.

Ten taxa contributed to a total of 60% of the variation in community structure between samples within 500 m of the nearest active drill centre and those greater than 8,000 m away, as determined by SIMPER analyses. The polychaete family Paraonidae (13.2%) was most influential, followed by Tanaidacea crustaceans (6.3%). The remaining taxa that contributed to 5% or more of the observed differences between these two distance groups were from the polychaete families (in order of decreasing influence): Cirratulidae; Orbiniidae; Spionidae; and Pholoidae (contributing from 5.6% to 6.2% of the variation). The mean abundance of Paraonidae within 500 m of the nearest active drill centre was 1.19 individuals per m² versus 650 individuals per m² at stations greater than 8,000 m away (Table 5-32). Similar trends of increasing abundance with distance from drill centres for these two distance groupings were noted for the remaining taxa, with the exception of Cirratulidae and Pholoidae polychaetes. Cirratulidae polychaetes were approximately three-fold greater in abundance and Pholoidae polychaetes were approximately 150-fold greater in abundance at stations closest to drill centres. Pholoidae polychaetes were virtually absent from stations greater than 8,000 m from the nearest active drill centre, with densities of 0.8 individuals per m².

Table 5-32 Mean Abundance of Key Benthic Infauna Taxa by Distance Group

Distance Groups	*n*	Mean Abundance (individuals per m²)					
		Paraonidae	Tanaidacea	Cirratulidae	Orbiniidae	Spionidae	Pholoidae
<500	7	1.19	3.31	175	0.20	933	127
500 to 1,000	11	26.7	32.5	208	21.8	1169	48.3
>1,000 to 2,000	11	216	83.4	95.5	186	1229	7.51
>2,000 to 4,000	8	502	154	9.06	464	1225	4.84
>4,000 to 8,000	6	696	240	7.4	400	1149	2.72
>8,000	7	650	166	55.5	117	1204	0.81

Notes: - n = 50, with stations 31, NA2, and SWRX4 excluded.

5.3 Summary of Results

5.3.1 Whole-Field Response

Hydrocarbons in the $>C_{10}$-C_{21} range and barium in sediments were clearly influenced by drilling operations in 2016, with concentrations elevated up to estimated threshold distances of 2.7 km and 1.2 km from the nearest active drill centre, respectively. Significant threshold distances (*i.e.*, the distance at which values return to background values) have been detected in all sampling years for $>C_{10}$-C_{21} hydrocarbons and barium since drilling began. The threshold distance for $>C_{10}$-C_{21} hydrocarbons has varied from 5.9 to 10.4 km from 2004 to 2008, and from 2.7 to 5.8 km from 2010 to 2016. The

threshold distances for barium also tended to be greater in earlier EEM years; 2 to 3.6 km from 2004 to 2010 versus approximately 1 km since 2012.

Sediment lead concentrations also exhibited a threshold relationship in 2016, with levels elevated to 1.4 km from drill centres. Elevated levels of lead to approximately 1 km of drill centres have been noted since 2006.

Remaining sediment chemical and physical characteristics showed either no or only subtle project-related alterations. Strontium and sulphide levels were elevated to approximately 1 km from drill centres in 2016. Threshold relationships have been significant for these two variables in 2006, 2008 and, for strontium, in 2012, but they were not significant in 2016. There was an indication that sediment sulphur and fines content were elevated in the immediate vicinity of (0.5 km from) drill centres, as in some previous EEM years.

There was no evidence of project-related alterations for sediment gravel and redox potential, ammonia, TOC and metals other than barium, lead and strontium.

Sediments were generally non-toxic in 2016. Two samples, from stations 20 and 31, were toxic to Microtox and no samples were toxic to laboratory amphipods. Sediment concentrations of $>C_{10}$-C_{21} hydrocarbons, barium, sulphur and strontium were elevated at the two stations that were toxic to Microtox. Lead was also elevated at station 20.

Amphipod survival was higher near drill centres than at stations further away; a response that would not suggest project-effects. Survival did decrease with increasing sediment ammonia concentration. However, since there was no evidence that ammonia was affected by project activity, this association more likely is natural.

As in previous years, there was evidence of project effects on total benthic abundances and biomass, and there was no evidence of effects on richness. Univariate analysis of abundances of individual taxa provided evidence of project effects on Paraonidae. Multivariate analyses of 2016 data confirmed that Paraonidae was the taxon most affected by project activity, and also indicated potential project-effects on Tanaidacea, Cirratulidae, Orbiniidae, Spionidae and Pholoidae.

As in previous years, the relationship between total benthic abundance and distance to active drill centres was relatively weak, with no threshold distance for effects. In 2016, total abundance ranged from approximately 1,215 to 4,405 individuals per m^2 within 500 m of active drill centres and from 3,270 to 5,470 individuals per m^2 at station more than 10 km from drill centres.

The relationship between total biomass and distance from active drill centres was somewhat comparable to those observed in 2012 and 2014; however, threshold distances for effects on biomass were significant in 2012 and 2014, and were not significant in 2016. Total biomass varied from approximately 12 to 902 g/m^2 within 500 m of active drill centres and from 592 to 1,157 g/m^2 at stations more than 10 km from drill centres.

Paraonidae abundance has been strongly related to distance from active drill centres, with threshold distances significant in every EEM year. The threshold distance for Paraonidae in 2016 was estimated at 1.2 km. As was the case for $>C_{10}$-C_{21}

hydrocarbons and barium, there was an indication that threshold distances were larger in early EEM years (approximately 3 to 4 km from 2004 to 2008) and approximately 1 to 2.5 km from 2010 to 2016. In 2016, Paraonidae abundance ranged from 0 to 20 individuals per m² within 500 m of active drill centres and from 180 to 1,945 individuals per m² at stations more than 10 km from drill centres.

Univariate analysis indicated that total benthic abundances, benthic biomass and abundances of Paraonidae were correlated to concentrations of $>C_{10}$-C_{21} hydrocarbons. Total abundances and biomass, and abundances of Paraonidae were lower in sediments with high concentrations of $>C_{10}$-C_{21} hydrocarbons. Higher concentrations of barium, sulphur and strontium also co-occurred with lower biomass and lower abundances of Paraonidae. Since sulphur and strontium concentrations were highly correlated with sediment concentrations of barium, the correlation between these two variables and biomass and Paraonidae abundances could be spurious[19]. Multivariate analysis confirmed correlations between sediment $>C_{10}$-C_{21} hydrocarbons and barium concentrations and benthic community structure and, to a lesser extent, also identified changes in community structure with varying sediment uranium and iron concentrations, and sediment redox potential and fines content.

5.3.2 Effects of Individual Drill Centres

Maps of response variables outside the baseline (2000) or background (>10 m from nearest active drill centre) range were used to qualitatively assess the spatial distribution of effects around each drill centre, with a focus on benthic invertebrate responses. Only drill centre stations (*i.e.*, stations labelled with a drill centre prefix) were considered in this exercise

Total abundance in 2016 was reduced below the baseline range at one station within 0.3 km of each the North Amethyst and the SWRX Drill Centres; and at one station within 0.6 km of the Northern Drill Centre.

Total benthic biomass in 2016 was below the baseline range at one to four stations around each of the Central, North Amethyst, SWRX, Southern and Northern Drill Centres. Stations with reduced biomass extended to approximately 0.9 km around the Central, SWRX and Southern Drill Centres; and to approximately 0.3 km around the North Amethyst and Northern Drill Centres.

Paraonidae abundances in 2016 were also reduced below the baseline range at a number of stations around drill centres. Abundances were reduced to approximately 1.8 km around the Central Drill Centre; approximately 0.9 km around the North Amethyst, SWRX and Southern Drill Centres; and approximately 0.6 km around the Northern Drill Centre. In 2016, the estimated threshold distance of 1.2 km generally agrees with the estimate of the zone of effects from examination of the maps.

Overall, 2016 data suggest that the majority of effects on benthos are limited to 1 to 2 km of drill centres. This is supported by the 2016 multivariate assessment, which showed that stations beyond 2 km of drill centres were indistinguishable from each other.

[19] Sulphur, strontium, and barium all occur naturally and correlations among sediment chemistry variables are the norm. Beyond this, evidence of project effects for all three variables has been noted in some EEM years. Therefore, correlations reflect natural variability, project effects, or a combination.

In terms of magnitude of effect in 2016, and examining only the stations nearest the drill centres, mean barium concentrations were highest around the North Amethyst Drill Centre (Table 5-33). Mean $>C_{10}$-C_{21} hydrocarbon concentrations were similar (approximately 25 mg/kg) around most drill centres, but were lower (8 mg/kg) around the Northern Drill Centre. The maximum for barium (2,400 mg/kg) occurred at station NA1, located approximately 300 m from the North Amethyst Drill Centre. The maximum for $>C_{10}$-C_{21} hydrocarbons (96 m/kg) occurred at station SWRX1, located approximately 300 m from the SWRX Drill Centre; although the concentrations at stations C5 (89 mg/kg), S5 (86 mg/kg) and NA1 (77 mg/kg) were also relatively high.

Total benthic invertebrate abundance was reduced to less than 75% of the baseline range at one station around each of the Northern and SWRX Drill Centres. Biomass was reduced to less than 75% of the baseline range at two stations around the Central and Southern Drill Centres, and one station around the Northern Drill Centre. Richness was not reduced at any station. Paraonidae abundance was reduced to less than 75% of the baseline range of all stations around the Central Drill Centre, and two to three stations around remaining drill centres.

Table 5-33 Values at Drill Centre Stations for Selected Variables

Station	Distance to Drill Centre (km)	Barium (mg/kg)	$>C_{10}$-C_{21} (mg/kg)	Fines (%)	Abundance (#/m²)	Biomass (g/m²)	Richness	Paraonidae (#/m²)
Central Drill Centre								
C1	1.14	240	5.4	1.6	2840	842	40	20
C2	0.83	590	22	2.2	3870	284	39	0
C3	0.74	230	3.9	1.4	2195	593	43	5
C4	0.92	210	2	1.7	3650	145	35	80
C5	0.33	900	89	2.3	3250	113	32	0
Mean	**0.79**	**434**	**24.5**	**1.8**	**3161**	**395**	**38**	**21**
Range		**210 to 900**	**2 to 89**	**1.4 to 2.4**	**2,95 to 3870**	**113 to 842**	**32 to 43**	**0 to 80**
Northern Drill Centre								
N1	2.18	150	0.36	1.1	4140	546	35	525
N2	1.49	180	0.88	1.5	2940	1362	34	240
N3	0.63	330	12	1.6	900	599	32	0
N4	0.3	280	20	2	3200	248	38	0
Mean	**1.2**	**235**	**8.3**	**1.6**	**2795**	**688.75**	**35**	**191**
Range		**150 to 330**	**0.36 to 20**	**1.1 to 2**	**900 to 4140**	**248 to 1362**	**32 to 38**	**0 to 525**
North Amethyst Drill Centre								
NA1	0.29	2400	77	3.2	1755	275	28	0
NA2	0.5	400	11	1.7	NA	NA	NA	NA
NA3	0.76	160	1.4	1.5	3030	402	44	75
NA4	1	200	2	1.8	2445	428	36	250
Mean	**0.64**	**790**	**22.9**	**2.1**	**2410**	**368**	**36**	**201**
Range		**160 to 2400**	**2 to 77**	**1.5 to 3.2**	**1755 to 3030**	**275 to 428**	**28 to 44**	**0 to 250**
Southern Drill Centre								
S1	0.6	420	19	1.2	2475	134	31	0
S2	0.83	260	11	1.3	2795	625	33	0
S3	1.4	160	1.8	1.3	3425	565	35	365
S4	0.92	210	2.6	1.5	4000	180	35	130
S5	0.31	1100	86	2	4405	478	37	0
Mean	**0.81**	**430**	**24.1**	**1.5**	**3420**	**396**	**34**	**99**
Range		**160 to 1100**	**2.6 to 86**	**1.2 to 2**	**2475 to 4405**	**134 to 625**	**31 to 37**	**0 to 365**
SWRX Drill Centre								
SWRX1	0.3	660	96	1.4	1215	326	27	0
SWRX2	0.44	150	1.4	1.5	2050	902	35	20
SWRX3	0.74	160	0.84	1.8	2075	300	34	45
SWRX4	1.06	200	1.3	1.3	NA	NA	NA	NA
Mean	**0.64**	**293**	**25**	**1.5**	**1780**	**509**	**32**	**22**
Range		**150 to 660**	**1.3 to 96**	**1.3 to 1.8**	**1215 to 2075**	**300 to 902**	**27 to 35**	**0 to 45**

Notes:
- Benthos data are unavailable for stations NA2 and SWRX4 because samples were incompletely preserved.
- Shading indicates values 75% below the baseline range for benthic invertebrates. Based on this threshold, cut-off levels for total abundance, biomass and Paraonidae abundance are 1,413 #/m², 275 g/m² and 97 #/m², respectively.

6.0 Commercial Fish Component

6.1 Methods

6.1.1 Field Collection

American plaice (plaice) and snow crab (crab) were collected on-board the commercial trawler *M/V Kinguk* between July 11 and July 15, 2016. Collection dates for the baseline program and subsequent EEM programs, and tests performed on collected specimens, are shown in Table 6-1.

Table 6-1 Field Trip Dates

Trip	Collections/Tests	Date
2000 Baseline Program	Study Area crab for body burden analysis; Study and Reference Area plaice for body burden and taste analysis; Study Area plaice for health analysis.	July 4 to July 10, 2000
2002 Baseline Program	Reference Area crab for body burden analysis; Study and Reference Area crab for taste analysis; Reference Area plaice for health analysis.	June 24 to July 10, 2002
2004 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 10 to July 18, 2004
2005 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 8 to July 13, 2005
2006 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 11 to July 20, 2006
2008 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	May 26 to June 2, 2008
2010 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 2 to July 5, 2010
2012 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 8 to July 10, 2012
2014 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	June 26 to June 28, 2014
2016 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 11 to July 15, 2016

Notes: - Since the location of Reference Areas sampled from 2004 to 2016 differs from locations sampled in 2000 and 2002, data from Reference Areas collected during baseline cannot be compared to EEM Reference Area data (see Husky Energy 2004 for details).

Details on the collection and processing of 2000, 2002, 2004, 2005, 2006, 2008, 2010, 2012 and 2014 samples are presented in Husky Energy (2001, 2003, 2005, 2006, 2007, 2009, 2011, 2013, 2015). Sampling for the 2016 program was conducted under an experimental fishing license (NL3606-16). A total of 100 plaice and 120 crab from the White Rose Study Area were retained from 10 transects for analysis in 2016. A total of 145 plaice and 137 crab were retained from 14 transects in Reference Areas. Plaice and crab that were not retained were released with as little damage as possible. No species at risk were reported from any of the trawls. Location of transects are provided in Figure 6-1 and Appendix C-1[20]. In 2016, sampling in Reference Area 4 was not possible because of intense commercial fishing activity in that area for crab. Therefore, additional transects were performed in Reference Area 1 to provide the necessary number and weight of plaice and crab for use in this EEM program.

[20] Trawl by-catch data are no longer provided in Appendix C-1 for comparison with previous years (2000 to 2008) because a commercial trawl has been used since 2010. This results in substantially less by-catch than the previous DFO Campelen trawl.

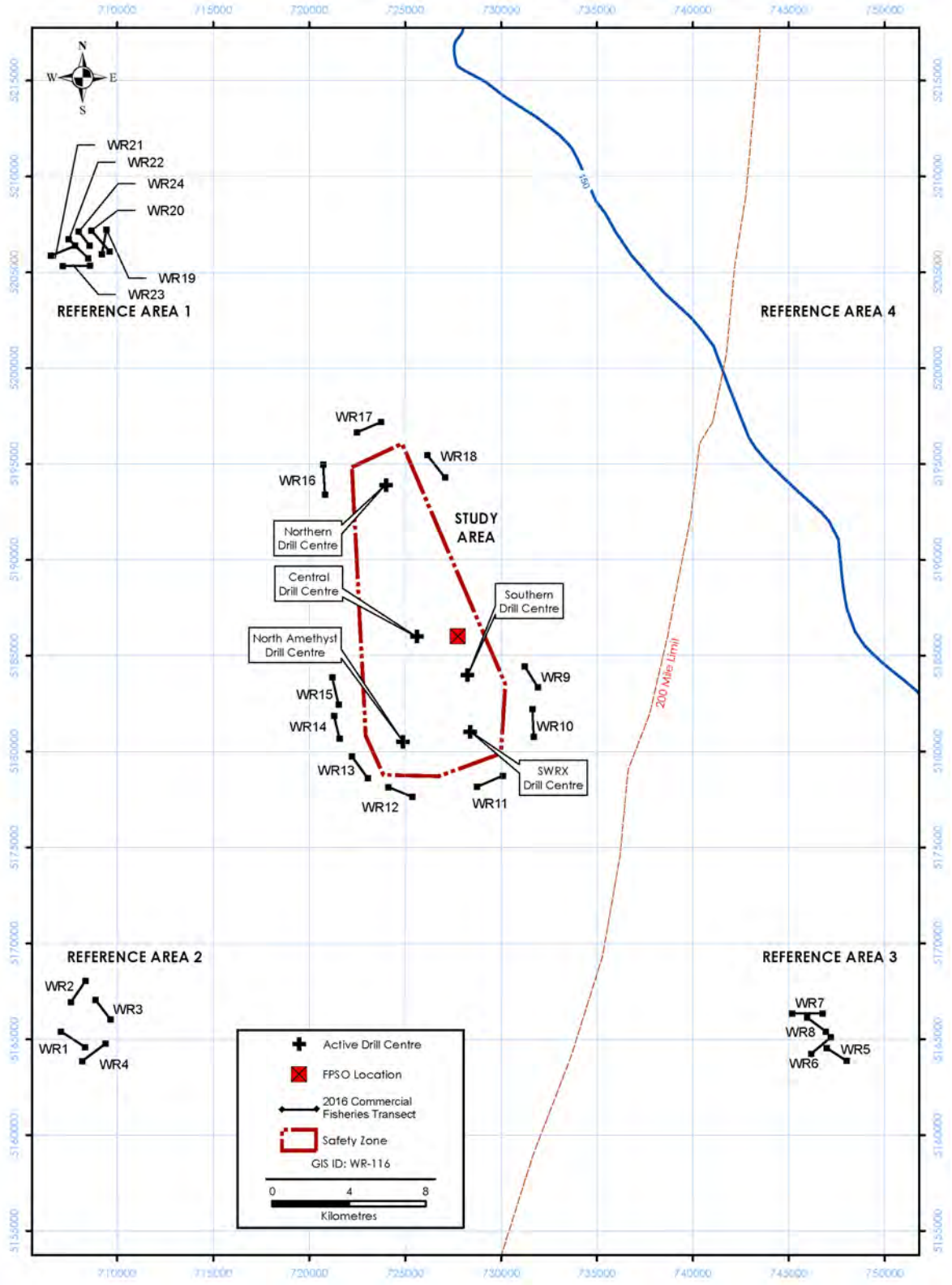

Figure 6-1 2016 EEM Program Transect Locations

Preliminary processing of samples was done on-board the vessel by technical staff. Plaice and crab that had suffered obvious trawl damage were discarded. Only plaice larger than 300 mm in length and crab larger than 60 mm in carapace width were retained for analysis. Tissue samples for subsequent taste analysis at shore (*i.e.*, top fillet for plaice and left legs for crab) were frozen at -20°C. For body burden analysis, bottom fillets and liver (left half only) for plaice and right legs for crab were frozen at -20°C. For fish health analysis, gill, liver (right half) and otolith samples from plaice were preserved (see below). Additional measurements on plaice included fish length, weight (whole and gutted), sex and maturity stage, liver weight, and gonad weight. For crab, measurements included carapace width, shell condition (see Appendix C-1 for shell condition indices), sex and chela height.

The following procedures were used for collection of fish health indicator samples. Each fish was assessed visually for parasites and/or abnormalities on the skin and fins or on internal organs (liver, gonads, digestive tract, musculature, and spleen) under the general framework of Autopsy-Based Condition Assessment described by Goede and Barton (1990). Fish were dissected and sex and maturity stage were determined by visual examination according to procedures used by DFO in the Newfoundland Region (see Annex A, Appendix C-3). The first gill arch on the right/top side of the fish was removed and placed in 10% buffered formalin for histological processing. The entire liver was excised and bisected. A 3 to 5 mm-thick slice was cut from the centre portion of the right half of the liver (along the longitudinal axis) and placed in 10% buffered formalin for histological processing. The remainder of the right half was frozen on dry ice until return to port, where it was placed in a -65°C freezer for mixed function oxygenase (MFO) analysis. A pair of otoliths was removed for ageing. Throughout the dissection process, any internal parasites and/or abnormal tissues were recorded and preserved in 10% buffered formalin for subsequent identification.

6.1.1.1 Sampling Quality Assurance/Quality Control

The following sampling QA/QC protocols were implemented to reduce the potential for introducing contamination to samples from the vessel, handling, other transects. For each transect, the top deck of the survey vessel was washed with degreaser then flushed with seawater. The fishing deck and chute leading to the processing facilities were flushed continuously with clean seawater during the survey. All measuring instruments and work surfaces were washed with mild soap and water, disinfected with isopropyl alcohol, then rinsed with distilled water prior to the start of each transect. Sampling personnel wore new latex gloves for each transect. Processed samples were transferred to a -20°C freezer within one hour of collection where applicable. Additional QA/QC measures also included use of trained and experienced technical staff, and use of calibrated equipment for taking weight and length measurements.

6.1.2 Laboratory Analysis

6.1.2.1 Allocation of Samples

Plaice were used for body burden analysis, taste tests and fish health assessment. Plaice bottom fillets and liver tissues were composited to generate 10 individual body burden samples for fillet and liver for the Study Area and 12 composites for the Reference Areas. When sufficient tissue was available, tissue from individual fish was archived for subsequent body burden on individuals if warranted by results of health

analyses. Top fillets from a subset of fish used in body burden analysis were used in taste analysis. In this test, fish fillets selected from the Study Area and the Reference Areas were allocated to the triangle test and the hedonic scaling test (see Section 6.1.2.3 for details on taste tests) and then randomly assigned to panelists. Fish health analyses, by design, were conducted on individual fish rather than composite or randomly assigned samples (see Table 6-2).

Table 6-2 Plaice Selected for Body Burden, Taste and Health Analyses (2016)

Transect No.	Area	No. of Fish Retained	Body Burden Composites # (Fillet or Liver)	Taste Test (wt. (g) of Top Fillets)	Fish Health (No. of Fish)
WR9	Study Area	10	13 (10 fish)	200	6
WR10	Study Area	10	14 (10 fish)	205	6
WR11	Study Area	10	15 (10 fish)	239	6
WR12	Study Area	10	16 (10 fish)	253	6
WR13	Study Area	10	17(10 fish)	227	6
WR14	Study Area	10	18 (10 fish)	248	6
WR15	Study Area	10	19 (10 fish)	236	6
WR16	Study Area	10	20 (10 fish)	278	6
WR17	Study Area	10	21 (10 fish)	207	6
WR18	Study Area	10	22 (10 fish)	261	6
Study Area Total		**100**	**10**	**2,354**	**60**
WR19	Reference Area 1	10	1 (10 fish)	813	10
WR20	Reference Area 1	15	2 (15 fish)		10
WR21	Reference Area 1	15	3 (15 fish)		10
WR22	Reference Area 1	15	4 (15 fish)		10
WR23	Reference Area 1	15	5 (15 fish)		10
WR24	Reference Area 1	15	6 (15 fish)		10
WR1	Reference Area 2	10	7 (10 fish)	770	10
WR2	Reference Area 2	10	8 (10 fish)		10
WR3	Reference Area 2	10	9 (10 fish)		10
WR5	Reference Area 3	10	10 (10 fish)	793	10
WR6	Reference Area 3	10	11 (10 fish)		10
WR7	Reference Area 3	10	12 (10 fish)		10
Reference Area Total		**145**	**12**	**2,379**	**120**

Note: - A much as feasible, tissue weights for taste tests were selected to generate relatively constant weights over all composites within the Study Area or over each of the Reference Areas.

Crab were used for body burden and taste analyses. Only hard shell crab were tested. Tissue from right legs was composited to generate 10 body burden samples for the Study Area and 12 composite samples for the Reference Areas (see Table 6-3). Left leg tissue was used in taste analysis. In this test, leg tissue selected from the Study Area and the Reference Areas was allocated to the triangle test and the hedonic scaling test and then randomly assigned to panelists (see Section 6.1.2.3 for details on taste tests).

Table 6-3 Crab Selected for Body Burden and Taste Analysis (2016)

Transect No.	Area	No. of Crab	Body Burden Composites (Right Legs)	Taste Tests (wt. (g) of Crab, Left Legs)
WR9	Study Area	12	Crab 13 (12 crab)	988
WR10	Study Area	10	Crab 14 (10 crab)	605
WR11	Study Area	17	Crab 15 (17 (crab)	822
WR12	Study Area	12	Crab 16 (12 crab)	740
WR13	Study Area	12	Crab 17 (12 crab)	671
WR14	Study Area	11	Crab 18 (11 crab)	674
WR15	Study Area	10	Crab 19 (10 crab)	1,100
WR16	Study Area	12	Crab 20 (12 crab)	1,054
WR17	Study Area	12	Crab 21 (12 crab)	1,080
WR18	Study Area	12	Crab 22 (12 crab)	1,450
Study Area Total		**120**	**10**	**9,184**
WR19	Reference Area 1	12	Crab 1 (12 crab)	2,986
WR20	Reference Area 1	12	Crab 2 (12 crab)	
WR21	Reference Area 1	11	Crab 3 (11 crab)	
WR22	Reference Area 1	12	Crab 4 (12 crab)	
WR23	Reference Area 1	12	Crab 5 (12 crab)	
WR24	Reference Area 1	12	Crab 6 (12 crab)	
WR1 & WR4	Reference Area 2	12	Crab 7 (12 crab)	2,703
WR2	Reference Area 2	14	Crab 8 (14 crab)	
WR3	Reference Area 2	10	Crab 9 (10 crab)	
WR5 & WR6	Reference Area 3	12	Crab 10 (12 crab)	3,510
WR7	Reference Area 3	9	Crab 11 (9 crab)	
WR8	Reference Area 3	9	Crab 12 (9 crab)	
Reference Area Total		**137**	**12**	**9,199**

Note: - A much as feasible, tissue weights for taste tests were selected to generate relatively constant weights over all composites within the Study Area or over each of the Reference Areas.

6.1.2.2 Body Burden

Samples of plaice fillet and liver as well as crab legs were delivered frozen to Maxxam Analytics (Halifax, Nova Scotia) and processed for the variables listed in Table 6-4. Analytical methods for these tests are provided in Appendix C-2.

Table 6-4 Body Burden Variables (2000, 2002, 2004, 2005, 2006, 2008, 2010, 2012, 2014 and 2016)

Variables	Method	Laboratory Detection Limits							Units
		2000	2002	2004 & 2005	2006	2008, 2010 & 2012	2014	2016	
Hydrocarbons									
>C_{10}-C_{21}	GC/FID	15	15	15	15	15	15	15	mg/kg
>C_{21}-C_{32}	GC/FID	15	15	15	15	15	15	15	mg/kg
PAHs									
1-Chloronaphthalene	GC/MS	NA	NA	0.05	0.05	0.05	0.05	0.05	mg/kg
2-Chloronaphthalene	GC/MS	NA	NA	0.05	0.05	0.05	0.05	0.05[1]	mg/kg
1-Methylnaphthalene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
2-Methylnaphthalene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthylene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Anthracene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benz[*a*]anthracene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*a*]pyrene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*b*]fluoranthene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg

Variables	Method	Laboratory Detection Limits							Units
		2000	2002	2004 & 2005	2006	2008, 2010 & 2012	2014	2016	
Benzo[*ghi*]perylene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*k*]fluoranthene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Chrysene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Dibenz[*a,h*]anthracene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluoranthene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluorene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05[2]	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Naphthalene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Perylene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Phenanthrene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Pyrene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Metals									
Aluminum	ICP-MS	2.5	2.5	2.5	2.5	2.5	2.5	2.5	mg/kg
Antimony	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.35	0.5	mg/kg
Arsenic	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Barium	ICP-MS	1.5	1.5	1.5	1.5	1.5	1.5	1.5	mg/kg
Beryllium	ICP-MS	1.5	1.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Boron	ICP-MS	1.5	1.5	1.5	1.5	1.5	1.5	1.5	mg/kg
Cadmium	ICP-MS	0.08	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Cobalt	ICP-MS	0.2	0.2	0.2	0.2	0.2	0.2	0.2	mg/kg
Copper	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Iron	ICP-MS	5	5	15	15	15	0.1	15	mg/kg
Lead	ICP-MS	0.18	0.18	0.18	0.18	0.18	0.25	0.18	mg/kg
Lithium	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Manganese	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Mercury	CVAA	0.01	0.01	0.01	0.01	0.01	0.01	0.01	mg/kg
Molybdenum	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Nickel	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.1	0.5	mg/kg
Selenium	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Silver	ICP-MS	0.12	0.12	0.12	0.12	0.12	0.1	0.12	mg/kg
Strontium	ICP-MS	1.5	1.5	1.5	1.5	1.5	0.15	1.5	mg/kg
Thallium	ICP-MS	0.02	0.02	0.02	0.02	0.02	0.02	0.02	mg/kg
Tin	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Uranium	ICP-MS	0.02	0.02	0.02	0.02	0.02	0.10	0.02	mg/kg
Vanadium	ICP-MS	0.5	0.5	0.5	0.5	0.5	1.0	0.5	mg/kg
Zinc	ICP-MS	0.5	0.5	0.5	1.5	1.5	0.5	1.5	mg/kg
Other									
Percent Lipids/Crude Fat	AOAC922.06	0.1	0.5	0.5	0.5	0.5	0.5	0.5	%
Moisture	Gravimetry	0.1	0.1	0.1	0.1	1	0.10	1	%

Notes:
- NA = Not Analyzed.
- GC/FID = Gas Chromatography/Flame Ionization Detection.
- GC/MS = Gas Chromatography/Mass Spectrometer.
- ICP-MS = Inductively Coupled Plasma/Mass Spectrometer.
- CVAA = Cold Vapour Atomic Absorption.
- [1] RDL elevated to between 0.12 and 0.22 mg/kg in some liver samples due to matrix/co-extractive interference (see Appendix C-2 for details).
- [2] RDL elevated to between 0.12 and 3 mg/kg in some liver samples due to matrix/co-extractive interference (see Appendix C-2 for details).

6.1.2.3 Taste Tests

Plaice and crab samples were delivered frozen to the Marine Institute of Memorial University for sensory evaluation, using triangle and hedonic scaling taste test procedures (after Botta 1994). Since no procedures have been established to compare multiple Reference Areas to one Study Area, samples were selected from each of the sampled Reference Areas to generate one set of Reference Area samples to be compared to Study Area samples.

Frozen plaice samples were thawed for 24 hours at 2°C, removed from plastic bags and homogenized in a food processor. Samples were allocated to either the triangle taste test or the hedonic scaling test. Samples were enclosed in individual aluminum foil packets (Figure 6-2), labelled with a predetermined random three-digit code and cooked in a convection oven at 82°C for 11 minutes. Samples were then served in glass cups at approximately 35°C.

Figure 6-2 Plaice Taste Test Preparations

Frozen crab samples were cooked, shucked of meat, and stored overnight at 4°C. All meat was homogenized in a food processor and allocated to either the triangle taste test or the hedonic scaling test. Crab was served to taste panelists in glass cups at room temperature.

Each panel included 24 panelists who were provided with score sheets (Figures 6-3 and 6-4) and briefed on the presentation of samples prior to taste tests. Panelists were instructed that samples were being tested for uncharacteristic odour or taste and that grit, cartilage and texture should not be considered in their assessment. Panelists were also instructed not to communicate with each other and to leave immediately upon completion of the taste tests.

For the triangle test, panelists were presented with a three-sample set (triangle) and asked to identify the sample that was different from the others. Half of the panelists received sets composed of two samples from Treatment A (Study Area) and one from Treatment B (Reference Areas). The other panelists received sets composed of one sample from Treatment A and two from Treatment B. There were six possible orders in

which the samples were presented to panelists, after Botta (1994): ABB, AAB, ABA, BAA, BBA, and BAB.

QUESTIONNAIRE FOR TRIANGLE TEST

Name:_____ Date/Time: _____

Product: American Plaice

1. Taste the samples in the order indicated and identify the odd sample. You must choose one of the samples.

Code	Check Odd Sample
214	_____
594	_____
733	_____

2. Comments:

_____

_____

_____

_____

_____

_____

_____

_____

Figure 6-3 Questionnaire for Taste Evaluation by Triangle Test

QUESTIONNAIRE FOR HEDONIC SCALING

Name: _____ Date/Time: _____

Product: American Plaice

1. Taste these samples and check how much you like or dislike each one.

	55		15
_____	like extremely	_____	like extremely
_____	like very much	_____	like very much
_____	like moderately	_____	like moderately
_____	like slightly	_____	like slightly
_____	neither like nor dislike	_____	neither like nor dislike
_____	dislike slightly	_____	dislike slightly
_____	dislike moderately	_____	dislike moderately
_____	dislike very much	_____	dislike very much
_____	dislike extremely	_____	dislike extremely

2. Comments: _____

Figure 6-4 Questionnaire for Taste Evaluation by Hedonic Scaling

The rest of the samples were used for hedonic scaling tests. In this test, one sample from the Study Area and one from the Reference Areas were presented to panelists. Panelists were instructed to rate how much they liked or disliked each sample on the form provided to them. A nine-point hedonic scale was used, with ratings ranging from “like extremely” (9) to “dislike extremely” (1) (see Figure 6-4 for full range of ratings).

6.1.2.4 Fish Health Indicators

MFO induction was assessed in liver samples of plaice as 7-ethoxyresorufin O-deethylase (EROD) activity according to the method of Pohl and Fouts (1980) as modified by Porter *et al.* (1989).

Fixed liver and gill samples were processed for histological analysis using standard histological methods (Lynch *et al.* 1969). Details on these methods are provided in Appendix C-3.

6.1.3 Data Analysis

6.1.3.1 Overview

The commercial fish component of the White Rose EEM program uses a multiple-reference design, usually with four Reference Areas and one Study Area. In 2016, three of the four Reference Areas were sampled (Reference Areas 1, 2, 3) because intense commercial fishing activity prevented sampling in Reference Area 4. Multi-reference designs are common in environmental monitoring programs when a single Study Area of interest (*i.e.*, one production area) exists (Underwood 1993). The goal of these "asymmetrical" designs is to assess for potential environmental effects at a Study Area relative to the average of several representative Reference Areas. Using multiple reference areas better estimates the natural variability in environmental conditions of the larger region, thus providing a more accurate benchmark against which to compare environmental conditions at the Study Area.

6.1.3.2 Biological Characteristics

Biological characteristics (*i.e.*, morphometric and life history characteristics) of plaice and crab were analyzed to determine if there were differences among composites that could affect results of body burden analyses. Additional analyses on plaice were performed in the context of the Fish Health Assessment (described below). Analyses were restricted to plaice and crab used for body burden analyses in 2016. Formal comparisons among years were not conducted.

Plaice

Composite mean gutted weights of plaice were compared among Areas using asymmetrical ANOVA to test for differences in size among Reference Areas and between Reference and Study Areas for chemistry composites. Differences in maturity stages between the Study and Reference Areas were assessed with Fisher's Exact Test. Biological characteristics and condition were compared among Areas via ANOVA (or ANCOVA equivalents for condition or liver and gonad indices). Total length, gutted weight and age were analyzed using ANOVA (*i.e.*, with no covariate or X variable). The regression analogues of three condition indices - Fulton Condition Factor (CF), Hepatosomatic Index (HSI) and Gonadosomatic Index (GSI) - were analyzed via ANCOVA, which compares regression intercepts or adjusted means among Areas. Differences among Reference Areas and between the Reference and Study Areas were tested.

Crab

Biological characteristics of crab included carapace width and claw height (*i.e.*, size), and frequency of recent moults based on the shell condition index. Recent moults included crab with shell condition index values of 1 or 2. Non-recent moults included crab with condition index values of 6 (probably one year since moult) and 3 or 4 (two or more years since moult)[21].

Asymmetrical ANOVA was used to test for significant differences in carapace width and claw height between the Reference and Study Areas.

6.1.3.3 Body Burden

Plaice

Spatial Variations in 2016

Body burden data from composite samples were available for both liver and fillet tissue. Variables associated with liver tissue that were statistically analyzed were those that were frequently detected[22] and included fat content, moisture content, concentrations of nine metals frequently detected (arsenic, cadmium, copper, iron, manganese, mercury, selenium, silver, and zinc) and concentrations of $>C_{10}$-C_{21}, $>C_{21}$-C_{32} hydrocarbons, and naphthalene. Values less than laboratory detection limits were set at ½ laboratory detection limits prior to statistical analysis.

Fewer variables were detected in plaice fillets tissue than in liver tissue. Variables analyzed in fillets were moisture content and concentrations of arsenic, mercury, and zinc.

Log_{10}-transformed values for liver and fillets were compared among Areas in an asymmetrical ANOVA.

Variations in Temporal Trends

Differences in temporal trends in plaice liver variables were tested using a two-way asymmetrical ANOVA of composite tissue concentrations from 2004, 2005, 2006, 2008, 2010, 2012, 2014 and 2016[23,24] (Table 6-5). In this ANOVA, linear orthogonal contrasts (Hoke *et al.* 1990) were used to test for differences in linear and quadratic time trends between Reference and Study Areas. Variations were judged relative to variations in average concentrations among Reference Areas (*i.e.*, the Among-Reference Term in Table 6-5).

[21] The shell condition index used for White Rose is the index used by Fisheries and Oceans Canada in Newfoundland offshore surveys.

[22] Variables with greater than 25% of test results below laboratory detection limits were not included in statistical analyses.

[23] Data from 2000 were not included in analyses because Reference Area data were collected in different locations during that year (see Husky Energy 2004 for details on baseline collections).

[24] Due to missing data from Reference Area 3 (2008) and Reference Area 4 (2008 and 2016), Reference Areas were pooled into two groups to prevent loss of denominator degrees of freedom in the orthogonal study design. Reference Areas 1 and 4 were pooled into one group (North Reference Area) while Reference Areas 2 and 3 were pooled into another (South Reference Area).

Table 6-5 ANOVA Used for Comparison of Body Burden Variables Among Years (2004, 2005, 2006, 2008, 2010, 2012, 2014, and 2016)

Source/Term	df	Description
Study *vs* Reference (SR)	1	Tests for differences in concentration between Study and Reference Areas that are consistent across years
Year (overall)	7	Tests for differences in concentration among years that are consistent in both Study and Reference Areas
Linear Trend	1	Tests for a linear trend that is similar across all areas
Quadratic Trend	1	Tests for a trend that involves an increase followed by a decrease (or vice versa), in a fashion that is similar across all areas
SR x Year	7	Tests for variations in concentration between Study and Reference Areas that change from year to year
SR x Linear Trend	1	Tests for differences in linear time trends between the Reference and Study Areas
SR x Quadratic Trend	1	Tests for differences in quadratic time trends between the Reference and Study Areas
Among References (= Error)	7	Natural variance in concentrations among Reference Areas within years

Note: - df = degrees of freedom.

Crab

Spatial Variations in 2016

Crab leg body burden variables analyzed were moisture content as well as concentrations of eight frequently detected[25] metals (arsenic, boron, copper, mercury, selenium, silver, strontium, and zinc). Values less than laboratory detection limits were set at ½ laboratory detection limits prior to statistical analysis.

Log_{10}-transformed values for the above variables were compared among Areas with an asymmetrical ANOVA.

Variations in Temporal Trends

Differences in temporal trends in crab tissue variables were tested using a two-way asymmetrical ANOVA of composite tissue concentrations from 2004, 2005, 2006, 2008, 2010, 2012, 2014 and 2016[26] (Table 6-5), as described above. Linear orthogonal contrasts (Hoke *et al.* 1990) were used to test for differences in linear and quadratic time trends between Reference and Study Areas. Variations were judged relative to variations in average concentrations among Reference Areas (*i.e.*, the Among-Reference Term in Table 6-5).

6.1.3.4 Taste Tests

The triangle and hedonic scaling test procedures (Botta 1994) were used to compared Study Area samples to pooled Reference Area samples.

[25] Variables with greater than 25% of test results below laboratory detection limits were not included in statistical analyses.

[26] As with plaice, data from baseline were not included in these analyses because Reference Area data were collected in different locations.

The triangle test datum is the number of correct sample identifications over the number of panelists. This value was calculated and compared to values in Appendix C-4 (after Larmond 1977) to determine statistical significance. For a panel size of 24, a statistically significant discrimination between Areas (at $\alpha = 0.05$) requires that 13 panelists correctly identify samples.

Hedonic scaling results were processed in ANOVA and presented graphically in frequency histograms.

Ancillary comments from panelists were tabulated and qualitatively assessed for both tests.

6.1.3.5 Fish Health Indicators

Mixed Function Oxygenase Activity

ANOVAs were used to compare MFO activity in pre-spawning and spent females. MFO values were log-transformed for analyses.

Histopathology

Both male and female fish from each Area were combined for histopathological analysis.

Liver Histopathology

The Fisher's Exact Test was used to compare macrophage aggregates, inflammatory response and parasite counts among Areas. Other liver abnormalities were rare or absent and were not statistically analyzed.

Gill Histopathology

The Fisher's Exact Test was used to compare frequencies of fish with at least one lamella affected by the different lesions among Areas. Statistical analysis was not conducted on telangiectasis because low incidence prevented comparisons.

6.2 Results

6.2.1 Biological Characteristics

6.2.1.1 Plaice

Summary statistics for composite mean gutted weights of plaice are provided in Table 6-6.

Table 6-6 Summary Statistics for Plaice Composite Mean Gutted Weight (g) (2016)

Area	*n*	Min	Max	Mean	SD
Reference Area 1	6	300	1610	732	270
Reference Area 2	3	370	1692	645	285
Reference Area 3	3	286	1360	659	278
Reference Average	12	319	1554	679	277
Study Area	10	218	1538	664	307

Notes: - *n* = number of composites per Area. Refer to Table 6-2 for number of fish per composite.
- SD = standard deviation.

Variations in mean fish weight within composites did not differ significantly among Reference Areas (p = 0.268) nor between the Study and Reference Areas (p = 0.436, Table 6-7). The average Reference Area fish was 679 g ± 277 g, while the average Study Area fish was 664 g ± 307 g. The box plot in Figure 6-5 illustrates the homogeneity of gutted weights among fish from the Reference Areas as well as Study Area fish.

Table 6-7 Results of ANOVA Comparing Plaice Composite Mean Gutted Weight (g) Among Areas (2016)

Source	SS	df	MS	F-Ratio	*p*
Reference *vs* Study	4376	1	4376	0.6337	0.436
Among Reference	19499	2	9749	1.53[a]	0.268
Error	124302.05	18.00	6906		

Note: - [a] F-ratio calculated using MS error from separate ANOVA testing for differences among Reference Areas 1 to 3 (MS = 6377; df = 9).

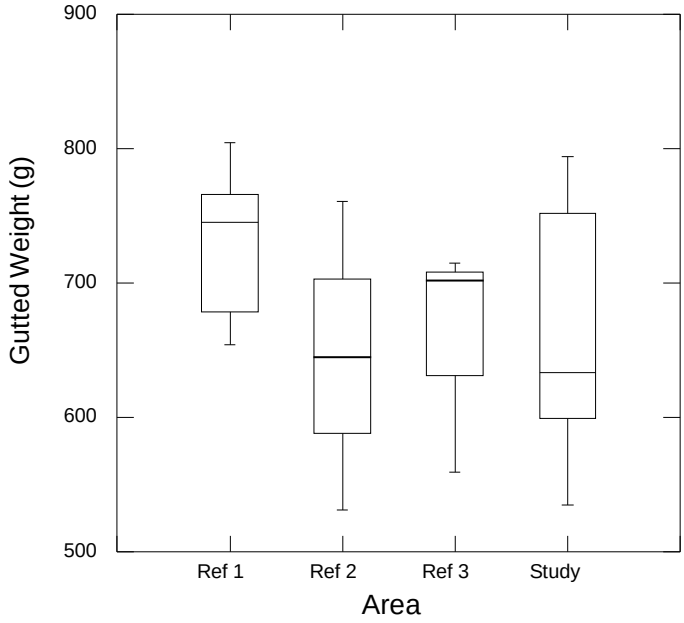

Figure 6-5 Box Plot of Plaice Gutted Weight (g)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks, were they present, would indicate values falling within the quartile ±3 x interquartile spread. Open circles would indicate values falling outside the quartile ±3 x interquartile spread.

Additional analyses on biological characteristics and condition of plaice by sex and maturity stage is undertaken within the context of fish health indicator assessment. More relevant information is provided below, with details in Appendix C-3.

Female plaice outnumbered males in all Areas (Table 6-8), accounting for 93% of the 180 fish processed. Sex ratios did not significantly differ (p = 0.108; Fisher's Exact Test) between the Reference (F:M≈23:1) and Study (F:M≈7.6:1) Areas.

Table 6-8 Numbers of Female and Male Plaice (2016)

Area	Females		Males		Total
	Number	%	Number	%	Number
Reference Area 1	56	93.3	4	6.7	60
Reference Area 2	29	96.7	1	3.3	30
Reference Area 3	30	100.0	0	0	30
All Reference Areas	115	95.8	5	4.2	120
Study Area	53	88.3	7	11.7	60
All Areas	168	93.3	12	6.7	180

Notes: - All References = Sum of the three Reference Areas.
- All Areas = sum of the Reference and Study Areas.

Most females (77%) examined were mature (*i.e.*, stages F-510 to F-570), and few (6%) of the mature females were spent (*i.e.*, stages F-550 to F-570) (Table 6-9). Frequencies of pre-spawning (*i.e.*, F-500, F-510 to F-540, F-580) and spent (*i.e.*, F-550 to F-570) mature females did not vary significantly between the combined Reference Areas and the Study Area (Fisher's Exact test, p = 1.00).

Table 6-9 Frequency of Maturity Stages of Female Plaice (2016)

Area	Immature F-500 [a]		Maturing to spawn this year F-510 to F-540 [a]		Partly spent F-550 [a]		Spent this year F-560 + F-570 [a]		Maturing to spawn next year F-580 [a]		Total No.
	No.	%	No.	%	No.	%	No.	%	No.	%	
Reference Area 1	4	7	46	82	0	0	6	11	0	0	56
Reference Area 2	13	45	16	55	0	0	0	0	0	0	29
Reference Area 3	9	30	20	67	1	3	0	0	0	0	30
All Reference Areas	26	23	82	71	1	1	6	5	0	0	115
Study Area	12	23	36	69	0	0	3	6	1	2	52
All Areas	38	23	118	71	1	1	9	5	1	1	167

Notes: - [a] Maturity stages were defined per procedures used by DFO (Appendix C-3, Annex A).
- All References = Sum of the three Reference Areas.
- All Areas = sum of the Reference and Study Areas.
- One female fish excluded from analysis due to uncertain maturity stage.

Since female fish undergo physical and physiological changes during their reproductive period, it can be informative to carry out comparisons of biological characteristics and condition between like maturity stages, when numbers permit. In 2016, sufficient numbers of immature (stage F-500) and pre-spawning females (stages F-510 to F-540) were caught to allow comparison.

Biological characteristics and condition of immature females (expressed as means ± standard deviations (SDs)) from the Reference and Study Areas are summarized in Table 6-10. Across all sampling locations, immature females varied in length from 33 to 53 cm, in gutted weight from 256 to 1,404 g, and in age from 7 to 16 years. No significant differences were found between Study and Reference Areas for any of the variables examined (p > 0.05; Table 6-11). However, gonad weight (as a function of gutted weight) was significantly different among Reference Areas (p = 0.012; Table 6-11), with values at Reference Area 2 being 20% greater than those at Reference Area 3.

Table 6-10 Mean Biological Characteristics and Condition of Immature Female Plaice (2016)

Statistics	Area				Total
	Reference 1	Reference 2	Reference 3	Study	
Number of Fish	4	13	9	12	38
Length (cm)	37.5 ± 0.6	41.1 ± 2.5	39.7 ± 6.1	39.1 ± 6.1	39.7 ± 4.7
Weight (g)	473 ± 48	571 ± 130	591 ± 318	596 ± 430	573 ± 290
Gutted Weight (g)	381 ± 26	492 ± 116	503 ± 253	493 ± 327	483 ± 226
Liver Weight (g)	5.5 ± 1.9	8.3 ± 3.4	7.3 ± 4.2	9.2 ± 6.1	8.1 ± 4.5
Gonad Weight (g)	12.3 ± 8.4	16 ± 6.9	13.2 ± 12	15.8 ± 12.8	14.9 ± 10.2
Age (years)	8.8 ± 1	10.6 ± 1.2	10.3 ± 1.3	9.8 ± 2.2	10.1 ± 1.6
Condition Factor[a]	0.7 ± 0	0.7 ± 0.1	0.8 ± 0	0.7 ± 0.1	0.7 ± 0.1
HSI[b]	1.4 ± 0.5	1.7 ± 0.8	1.4 ± 0.3	2 ± 1	1.7 ± 0.8
GSI[c]	3.1 ± 2	3.2 ± 0.9	2.2 ± 1.2	3 ± 1.2	2.9 ± 1.2

Notes: - [a] Condition Factor = 100 × gutted weight/length³.
- [b] HSI = hepatosomatic index = 100 × liver weight/gutted weight.
- [c] GSI = gonadosomatic index = 100 × gonad weight/gutted weight.
- Values are means ± 1 SD.

Table 6-11 Results of ANCOVA Comparing Biological Characteristics and Condition of Immature Female Plaice (2016)

Variable (Y)	Covariable (X)	*p*-value	
		Among Reference (AR)	Study versus References (SR)
Length		0.299	0.324
Gutted Weight		0.570	0.646
Age		0.134	0.393
Gutted Weight	Length	0.063	0.093
Liver Weight	Gutted Weight	0.682	0.296
Gonad Weight	Gutted Weight	0.012*[a]	0.164

Notes: - [a] This Area was excluded from this test due to violation of assumption of parallel slopes among Reference Areas because of the small sample size in Reference Area 1 (n = 4).
- Results were based on log-transformed values of Y and X variables.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

Biological characteristics and condition of pre-spawning females (expressed as means ± SD) from the Reference and Study Areas are summarized in Table 6-12.

Table 6-12 Biological Characteristics and Condition of Pre-spawning Female Plaice (2016)

Statistics	Area				Total
	Reference 1	Reference 2	Reference 3	Study	
Number of Fish	46	16	20	36	118
Length (cm)	46.5 ± 3.3	47.3 ± 6.3	45.4 ± 4.2	46.1 ± 3.6	46.3 ± 4
Weight (g)	904 ± 236	936 ± 358	858 ± 318	921 ± 271	906 ± 277
Gutted Weight (g)	741 ± 193	788 ± 315	717 ± 270	748 ± 229	745 ± 234
Liver Weight (g)	11.5 ± 4.5	9.4 ± 4.1	10.1 ± 4.4	12.6 ± 7.4	11.3 ± 5.6
Gonad Weight (g)	30 ± 10.7	32.1 ± 15	30.8 ± 14.5	34.2 ± 11.6	31.7 ± 12.2
Age (years)	12 ± 1.5	11.9 ± 1.4	11.7 ± 2	11.9 ± 1.7	11.9 ± 1.6
Condition Factor[a]	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.8 ± 0.2	0.7 ± 0.1
HSI[b]	1.6 ± 0.5	1.2 ± 0.4	1.4 ± 0.5	1.7 ± 0.9	1.5 ± 0.7
GSI[c]	4 ± 0.9	4.6 ± 3.3	4.2 ± 0.7	4.8 ± 2.2	4.4 ± 1.8

Notes: - [a] Condition factor = 100 × gutted weight/length³.
- [b] HSI = hepatosomatic index = 100 × liver weight/gutted weight.
- [c] GSI = gonadosomatic index = 100 × gonad weight /gutted weight.
- DFO maturity stages F-510, F-520, F-530 and F-540 were combined for these analyses.
- Values are means ± 1 SD.

Across all sampling locations, pre-spawning females varied in length from 38 to 67 cm, in gutted weight from 282 to 1,692 g, and in age from 8 to 15 years. No significant differences were found among Reference Areas for any of the variables examined for pre-spawning females ($p > 0.05$; Table 6-13). However, gonad weight (as a function of gutted weight) was significantly different between Study and Reference Areas ($p = 0.02$; Table 6-13), with Study Area values 3% greater than pooled Reference Area values.

Table 6-13 Results of ANCOVA Comparing Biological Characteristics and Condition of Pre-spawning Females Plaice (2016)

Variable (Y)	Covariable (X)	*p*-value	
		Among Reference (AR)	Study versus References (SR)
Length		0.228	1.000
Gutted Weight		0.663	1.000
Age		0.775	0.903
Gutted Weight	Length	0.741	0.528
Liver Weight	Gutted Weight	0.082	0.140
Gonad Weight[a]	Gutted Weight	0.244[a]	0.020*[b,c]

Notes:
- [a] Reference Area 2 was removed from analysis for this specific test due to violation of assumption of parallel slopes among Reference Areas (see Appendix C-3, Annex B, for details).
- [b] Data were pooled across all Reference Areas for this specific test due to violation of assumption of parallel slopes among Reference Areas.
- [c] Four fish were excluded from statistical analyses because they were outliers and violated test assumptions outliers (1, 15, 29, and 108). Retention of all data resulted in a *p*-value of 0.033.
- ANCOVA were based on log-transformed values of *Y* and *X* variables.
- DFO maturity stages F-510, F-520, F-530 and F-540 were combined for these analyses.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

6.2.1.2 Crab

Shell condition index values for the crab collected in 2016 and used for body burden analyses are provided in Table 6-14. The majority of the crab collected had moulted in 2016 (Table 6-14).

Table 6-14 Number (and %) of Crab and Associated Shell Index Values (2016)

Index Value	Year of Molt	Area				
		Ref 1	Ref 2	Ref 3	All Ref	Study
1,2	2016	63%	36%	57%	52%	68%
6	2015	8%	36%	3%	16%	16%
3,4	2014 or earlier	28%	28%	40%	32%	17%
Total Crabs (*n*)		71	36	30	137	120

Summary statistics for composite means for carapace width and claw height are provided in Table 6-15. Neither crab carapace width nor claw height differed significantly between the Reference and Study Areas ($p > 0.05$; Table 6-16). In contrast, mean carapace width and claw height varied significantly among the Reference Areas ($p \leq 0.05$; Table 6-16) with Reference Area 1 having the greatest values of all sites examined for both variables (Table 6-15).

Table 6-15 Summary Statistics for Biological Characteristics of Crab Based on Composite Mean Carapace Width and Claw Height (2016)

Variable	Area	*n*	Min	Max	Mean	SD
Carapace width (mm)	Reference Area 1	6	74.0	131.0	109.8	11.86
	Reference Area 2	3	60.0	126.0	93.6	17.82
	Reference Area 3	3	33.0	142.0	96.0	23.23
	All Reference Areas	12	55.7	133.0	99.8	17.6
	Study Area	10	60.0	178.0	103.5	20.41
Claw height (mm)	Reference Area 1	6	11.0	37.0	25.9	4.38
	Reference Area 2	3	8.0	28.0	18.9	6.47
	Reference Area 3	3	10.0	35.0	21.0	6.76
	All Reference Areas	12	9.7	33.3	21.9	5.9
	Study Area	10	7.0	37.0	23.0	6.54

Note: - SD = standard deviation.

Table 6-16 Results of ANOVA Comparing Crab Biological Characteristics Among Areas (2016)

Variable	Source	Type III SS	df	Mean Squares	F-Ratio	*p*-value
Carapace Width	Study *vs* Reference	21	1	21	0.168	0.687
	Among Reference	743	2	371	4.57[a]	0.043*
	Error	2209	18	123		
Claw Height	Study *vs* Reference	0.143	1	0.143	0.011	0.918
	Among Reference	117	2	58.6	8.55[b]	0.008**
	Error	235	18	13.1		

Note: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- [a] F-ratio calculated using MS error from separate ANOVA testing for differences among Reference Areas 1 to 3 (MS = 81.3; df = 9).
- [b] F-ratio calculated using MS error from separate ANOVA testing for differences among Reference Areas 1 to 3 (MS = 6.85; df = 9).

6.2.2 Body Burden

6.2.2.1 Plaice

Liver

Summary statistics for detected substances in plaice liver in 2004, 2005, 2006, 2008, 2010, 2012, 2014, and 2016, and raw data for 2016 are provided in Appendix C-2. Arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected frequently in all years. Silver has been detected frequently since 2014. These nine metals, fat and moisture content, and concentrations of $>C_{10}$-C_{21}, $>C_{21}$-C_{32} hydrocarbons and naphthalene are analyzed quantitatively.

Hydrocarbons in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} range have been detected in all years and have shown no resemblance to drill fluid or petroleum hydrocarbons (J. Kiceniuk, pers. comm.; Maxxam Analytics, pers. comm.; petroforma inc., pers. comm.), and similar compounds also have been consistently observed in liver tissue at the nearby Terra Nova site (Suncor Energy 2013). As in previous years, additional Gas Chromatography/ Mass Spectrometer analysis of two liver samples in 2016 (see Appendix C-2) indicated that there was no indication of drill fluid or petroleum hydrocarbons in those samples.

Unlike previous years, naphthalene was detected in all liver samples (Table 6-17). To further verify results, additional laboratory analyses were performed on bile of 12 fish (two from each of the Reference Area and six from the Study Area) to assess for the

presence of naphthalene metabolites. Results showed that naphthalene metabolites were present in bile at background levels, indicating that compounds in liver had insufficient time to be metabolized into the bile and, therefore, suggesting that exposure to naphthalene was very recent. In general, naphthalene in liver should be metabolized and appear in bile in a matter of hours (see Appendix C-2 for a full discussion).

Table 6-17 Summary Statistics for Naphthalene Concentration (mg/kg, wet) in Plaice Liver ((2016)

Area	*n*	Min	Max	Mean	SD
Reference Area 1	6	0.10	0.12	0.11	0.01
Reference Area 2	3	0.13	0.14	0.14	0.01
Reference Area 3	3	0.14	0.17	0.16	0.02
All Reference Areas	12	0.10	0.17	0.13	0.02
Study Area	10	0.07	0.14	0.10	0.02

Notes: - SD = standard deviation.
- Although differences between Areas were not large, Study Area concentrations were significantly lower than Reference Area concentrations (see Table 6-18 in the next section).

Potential explanations for the presence of naphthalene in plaice liver in 2016 include exposure immediately before capture, onboard contamination of liver tissues and contamination of liver tissues at the testing laboratory. Contamination of tissues at the testing laboratory has been excluded (Maxxam Analytics, pers. comm.). Neither exposure immediately before capture or on-board contamination can be excluded at this time. However, given the similar levels among testing Areas, and given the distance between these Areas, it is highly unlikely that all fish would have been exposed to similar levels of naphthalene before capture. Given that all fish were held and processed together onboard vessel, the most reasonable explanation for naphthalene in liver in 2016 is on-board contamination. The source of this potential on-board contamination has been investigated and has not been identified. Additional precautions will be taken for future surveys to reduce the potential for on-board contamination.

Although likely due to on-board contamination, the analyses below treat naphthalene like any other variable.

Spatial Variations in 2016

The results of ANOVA are presented in Table 6-18, and the spatial variations in variable concentrations are illustrated in the box plots in Figure 6-6. Manganese, naphthalene, zinc and $>C_{10}$-C_{21} hydrocarbons concentrations varied significantly among Reference Areas ($p \leq 0.05$, Table 6-18; Figure 6-6). Cadmium, manganese, naphthalene and $>C_{10}$-C_{21} hydrocarbons concentrations all varied significantly between the Reference Areas and Study Area ($p \leq 0.05$, Table 6-18; Figure 6-6). Cadmium was higher in the Study Area while manganese, naphthalene, and $>C_{10}$-C_{21} hydrocarbons concentrations were generally lower in the Study Area (Figure 6-6).

Table 6-18 Results of ANOVA Comparing Plaice Liver Body Burden Variables among Areas (2016)

Variable	*p*-values	
	Among Reference	**Reference *vs* Study**
Fat	0.401	0.103
Moisture	0.568	0.205
Arsenic	0.127	1.000
Cadmium	0.279	0.039*
Copper	0.364	0.600
Iron	0.059	0.355
Manganese	0.016*	0.003**
Mercury	0.781	0.254
Selenium	0.225	0.755
Silver	0.064	0.289
Naphthalene[1]	**< 0.001*** **	**< 0.001*** **
Zinc	0.012**	1.000
$>C_{10}$-C_{21}	0.033*	0.007**
$>C_{21}$-C_{32}	0.112	1.000

Notes:
- Values are probabilities of no difference among areas, or no difference among or between the Areas.
- Variables were $\log_{10}$-transformed prior to analysis.
- [1]Evidence suggests that naphthalene in plaice liver in 2016 resulted from exposure during on-board processing (see previous section)
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

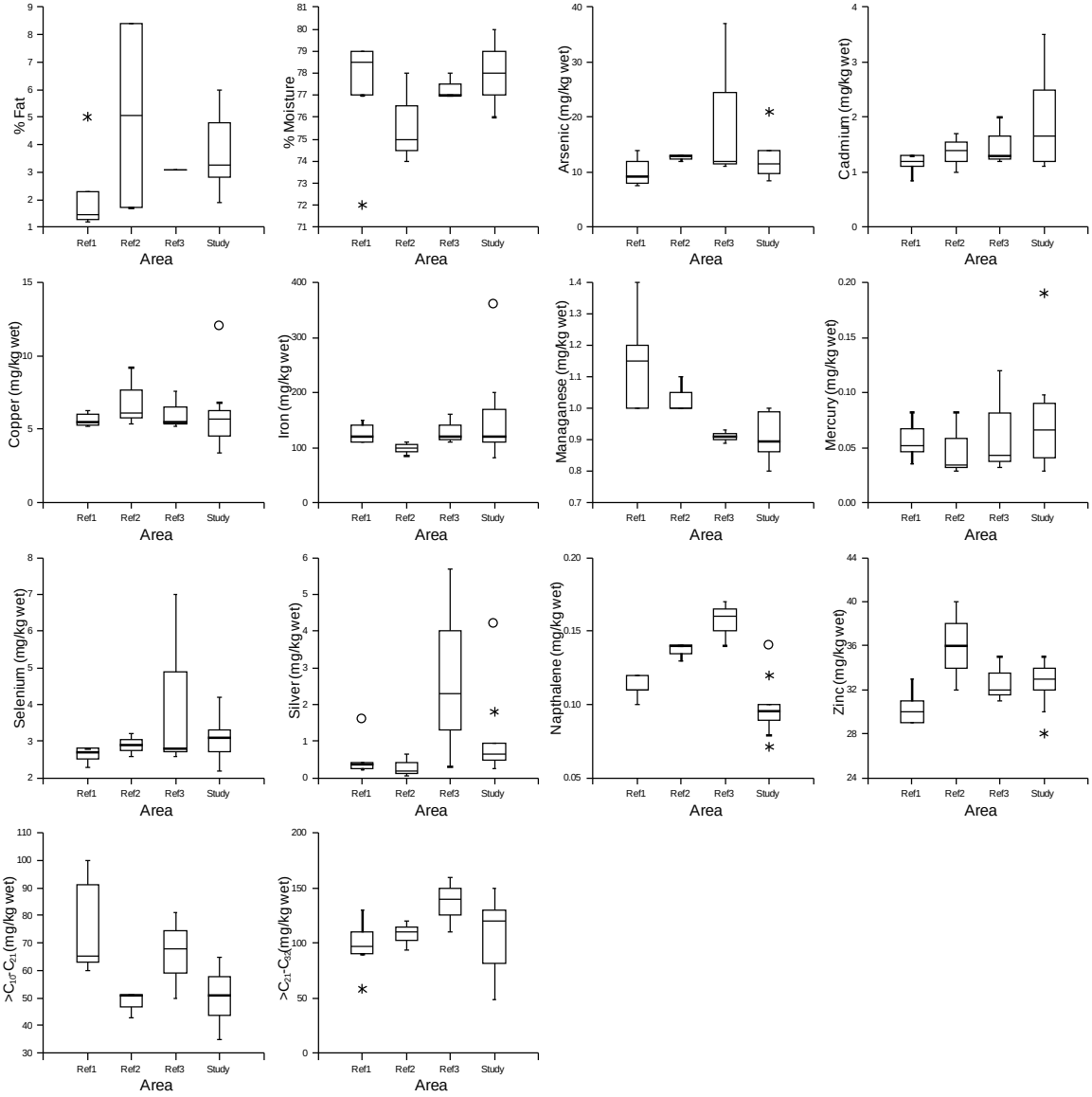

Figure 6-6 Box Plots of Variable Concentrations in Plaice Livers in Reference and Study Areas (2016)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles indicate values falling outside the quartile ±3 x interquartile spread.

Variations in Temporal Trends

Variations in mean concentrations of frequently detected variables in plaice livers between 2004 and 2016 are illustrated in Figure 6-7. Significant area-wide trends ($p \leq 0.05$) were noted for all variables, except for manganese (Table 6-19). Percent fat and $>C_{10}$-C_{21} hydrocarbon concentrations decreased over time, in all Areas (Figure 6-7). All remaining variables increased over time, in all Areas (Figure 6-7). Only $>C_{21}$-C_{32} hydrocarbon concentrations differed significantly between the Reference and Study Areas ($p \leq 0.05$, Table 6-19), with this difference influenced by the higher values in the Study Area in 2006 and 2010 (Figure 6-7). All variables except selenium and $>C_{10}$-C_{21} hydrocarbon concentrations produced significant quadratic effects across all Areas ($p \leq 0.05$, Table 6-19), though no analyte significantly differed between Reference and Study Areas in a quadratic fashion (Table 6-19; also see Figure 6-7).

Table 6-19 Results of ANOVA Testing for Differences in Average Plaice Liver Body Burden Variables and Temporal Trends Between the Reference and Study Areas (2004 to 2016)

Variable	Linear		Quadratic	
	Area-Wide Trend	Difference Between Reference and Study	Area-Wide Trend	Difference Between Reference and Study
Fat	**<0.001*** **	0.781	**<0.001*** **	0.598
Moisture[1]	**<0.001*** **	0.129	**<0.001*** **	0.136
Arsenic	**<0.001*** **	0.826	**<0.001*** **	0.680
Cadmium	**<0.001*** **	0.223	0.003**	0.351
Copper	**<0.001*** **	0.141	**<0.001*** **	0.227
Iron	**<0.001*** **	0.734	0.005**	1.000
Manganese	1.00	0.138	0.031*	0.080
Mercury	**<0.001*** **	0.883	**<0.001*** **	0.471
Selenium[2]	**<0.001*** **	0.086	0.441	0.286
Zinc	**<0.001*** **	1.000	**<0.001*** **	0.502
$>C_{10}$-C_{21}	**<0.001*** **	0.162	0.141	0.138
$>C_{21}$-C_{32}[3]	**<0.001*** **	0.048*	**<0.001*** **	0.169

Notes:
- Values are probabilities of no temporal trend or no difference in temporal trends.
- Variables were $\log_{10}$-transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

[1] Missing moisture values required the exclusion of 2008 data from analyses, resulting in denominator degrees of freedom decreasing from 7 to 6.

[2] A statistical outlier was noted for selenium (a low value of 7 mg/kg in one fish from Reference Area 3). Removal of this outlier changed the significance of the Area-Wide Trend Quadratic contrast from significant ($p = 0.044$) to non-significant (Area Term $p = 0.441$). Results presented are those with the statistical outlier excluded.

[3] Statistical outliers were noted for $>C_{21}$-C_{32}. (low values of 42.9 and 36.6 mg/kg in two Reference Area fish in 2014 and a high value of 660 mg/kg in one Study Area fish in 2006). Removal of these outliers changed the significance of the Reference and Study contrast from not significant (Area Term $p = 0.488$) to significant (Area Term $p = 0.048$). Results presented are those with the statistical outliers excluded. Removal of these outliers should not bias data interpretation as they were consistent with the statistical trend confirming higher $>C_{21}$-C_{32} hydrocarbon concentrations at Study Areas relative to Reference Areas (Table 6-19; Figure 6-7).

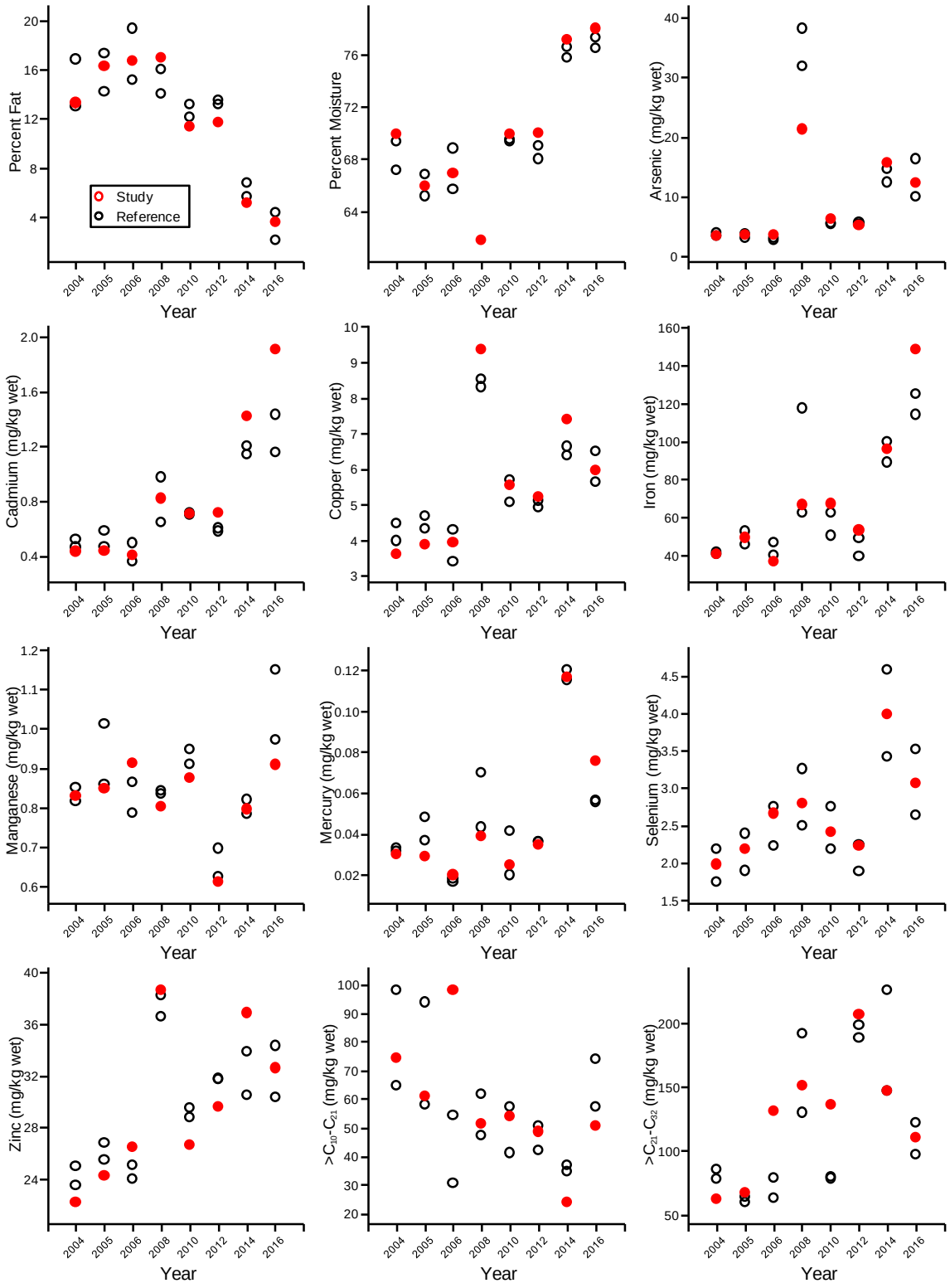

Figure 6-7 Variations in Area Means of Detectable Metals and Hydrocarbons in Plaice Liver Composites from 2004 and 2016

Note: Values shown are annual averages within Areas. Red circles are Study Area averages; open circles are averages for each Reference Area.

Fillets

Summary statistics for concentrations of detected substances in 2004, 2005, 2006, 2008, 2010, 2012, 2014, and 2016, and raw data for 2016 are provided in Appendix C-2. Arsenic, mercury, and zinc were detected frequently in plaice fillet tissue in all years. These metals and moisture content were analyzed quantitatively.

Boron, copper, iron, lead, nickel, selenium, and strontium were detected in fillets in some years (Appendix C-2). One fillet sample from Reference Area 4 had detectable compounds in the $>C_{10}$-C_{21} hydrocarbon range in 2005, two samples from the same Area had detectable compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon ranges in 2006, and one sample from Reference Area 3 had detected levels of compounds in the $>C_{10}$-C_{32} hydrocarbon range in 2014. However, chromatograms for these samples did not indicate the presence of drill muds or petrogenic compounds (J. Kiceniuk, pers. comm.; petroforma inc., pers. comm.).

Spatial Variations in 2016

ANOVA was used to test for differences between the Reference Areas and the Study Area, and data are plotted in Figure 6-8. A significant difference in zinc concentrations among Reference Areas was noted (p = 0.026, Table 6-20), with the lowest values found in Reference Area 3 (Figure 6-8). Significantly lower zinc concentrations were also noted at the Study Area relative to the Reference Areas (p = 0.004, Table 6-20; also see Figure 6-8).

Table 6-20 Results of ANOVA Comparing Plaice Fillet Body Burden Variables among Areas (2016)

Variable	*p*-values	
	Among Reference	**Study *vs* Reference**
Moisture	0.504	0.175
Arsenic	0.734	0.710
Mercury	0.085	0.069
Zinc	0.026*	0.004**

Notes: - Values are probabilities of no difference among Areas, or between Reference and Study Areas.
- Variables were $\log_{10}$-transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

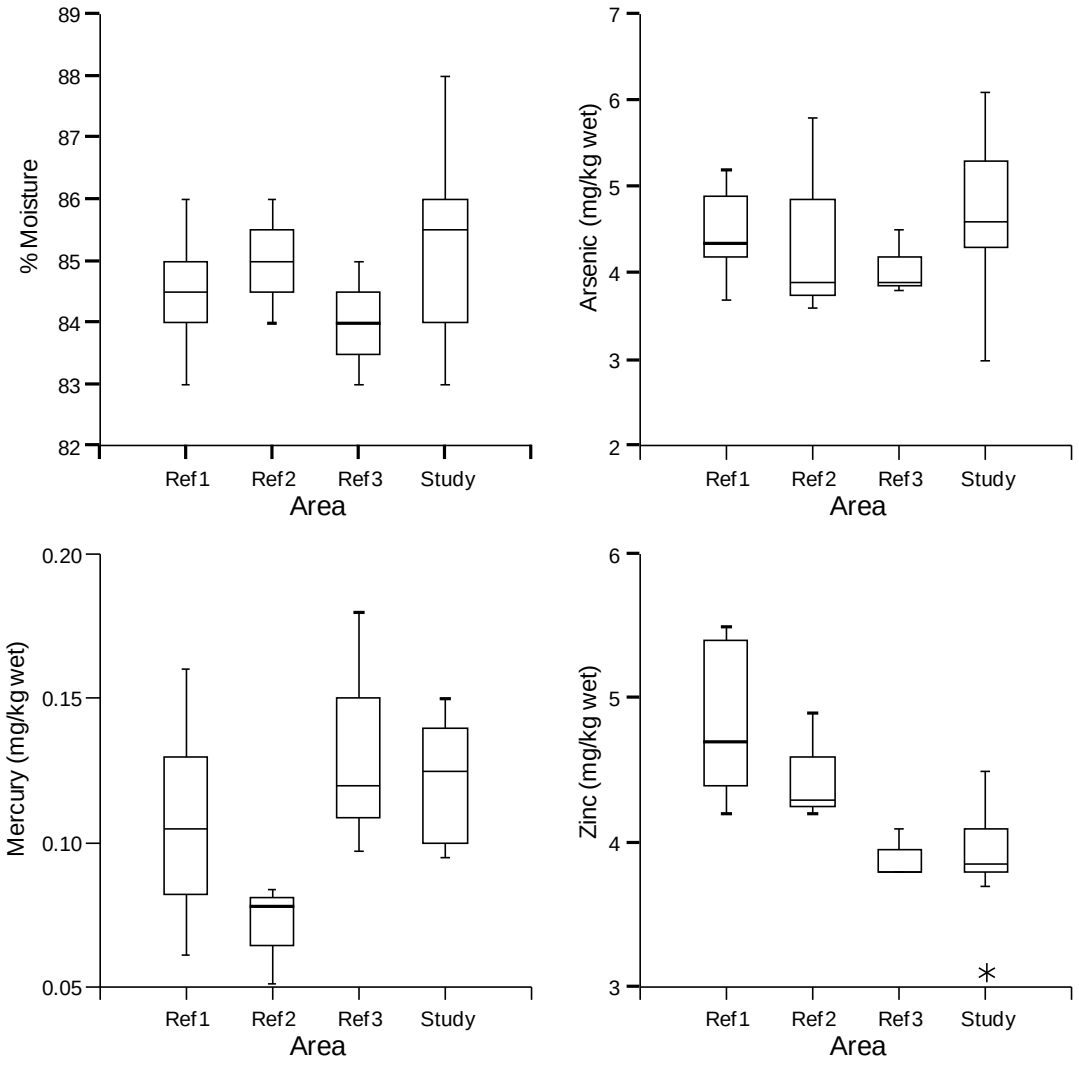

Figure 6-8 Box Plots of Variable Concentrations in Plaice Fillets in Reference and Study Areas (2016)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles, if present, would indicate values falling outside the quartile ±3 x interquartile spread.

Variations in Temporal Trends

Significant linear area-wide trends were seen for fillet moisture content, arsenic, and mercury concentrations ($p \leq 0.05$, Table 6-21), with a general increase over time in both the Study and Reference Areas (Figure 6-9). Significant area-wide quadratic trends (in this case, a decrease followed by an increase) were seen for all variables ($p \leq 0.05$, Table 6-21; Figure 6-9), with no difference between the Reference and Study Areas ($p > 0.05$).

Table 6-21 Results of ANOVA Testing for Differences in Average Fillet Body Burden Variables and Temporal Trends Between the Reference Areas and the Study Areas (2004 to 2016)

Variable	Linear		Quadratic	
	Area-Wide Trend	Difference Between Reference and Study	Area-Wide Trend	Difference Between Reference and Study
Moisture	**<0.001*** **	0.719	**<0.001*** **	0.401
Arsenic	**<0.001*** **	0.945	**<0.001*** **	0.553
Mercury	0.003**	0.119	0.002**	0.130
Zinc	0.123	0.714	**<0.001*** **	0.613

Notes: - Values are probabilities of no temporal trend or no difference in temporal trends.
- Variables were $\log_{10}$-transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

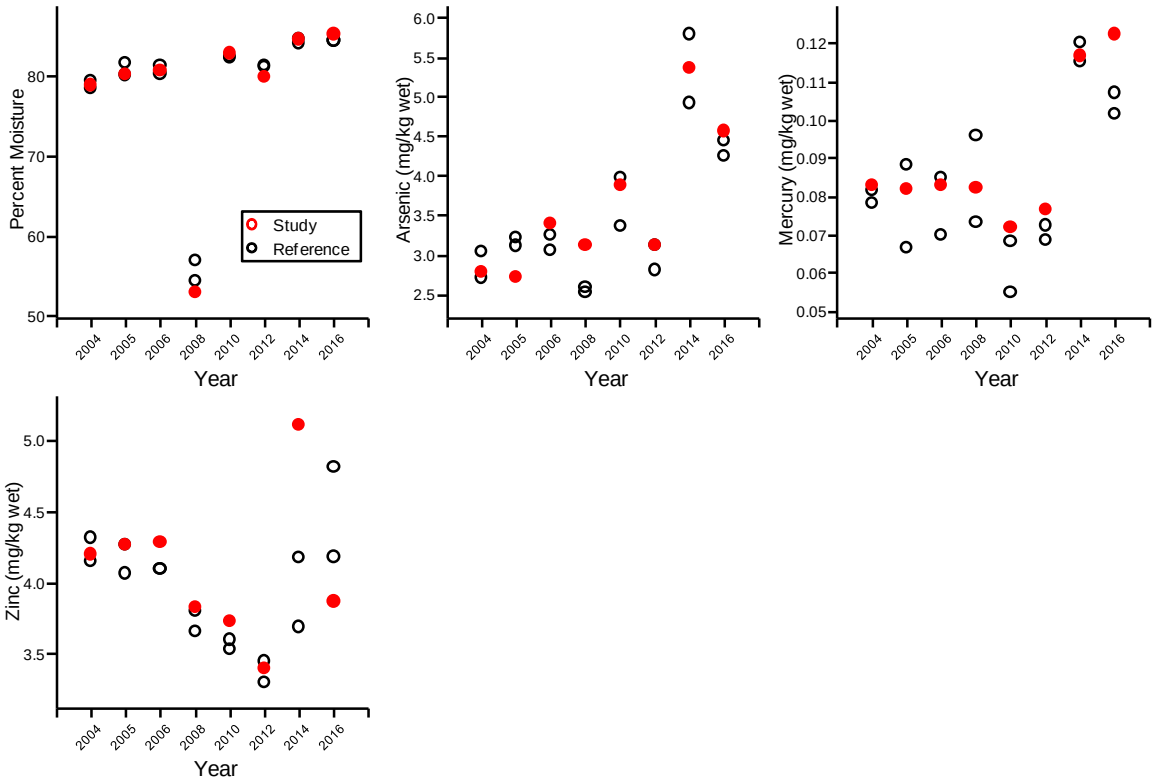

Figure 6-9 Variations in Moisture, Mercury, Arsenic and Zinc Concentrations in Plaice Fillets from 2004 to 2016

Note: Values shown are annual averages within Areas. Red circles are Study Area averages; open circles are averages for each Reference Area.

6.2.2.2 Crab

Summary statistics for concentrations of detected substances in crab claw composites in 2004, 2005, 2006, 2008, 2010, 2012, 2014, and 2016 are provided in Appendix C-2, as are raw data for 2016. Arsenic, boron, copper, mercury, selenium, silver, strontium, and zinc were detected frequently in crab claw tissue across all years. These metals and moisture content are analyzed quantitatively. Iron was detected in all tissues in 2014, when it was measured at a lower detection limit (Table 6-4). Aluminum, cadmium, cobalt, and lead were detected sporadically across all years (Appendix C-2).

Spatial Variations in 2016

Percent moisture as well as concentrations of arsenic, silver, and strontium varied significantly among Reference Areas in 2016 ($p \leq 0.05$, Table 6-22; Figure 6-10). Boron concentrations in crab tissues were significantly different between the Study Area and the Reference Areas ($p = 0.031$, Table 6-22), and were 13% higher at the Study Area relative to the Reference Areas mean boron concentration (also see Figure 6-10).

Table 6-22 Results of ANOVA Comparing Crab Body Burden Variables among Areas (2016)

Variable	*p*-value	
	Among Reference	**Study *vs* Reference**
Moisture	0.001**	0.637
Arsenic	**<0.001*** **	0.489
Boron	0.989	0.031*
Copper	0.322	0.383
Mercury	0.052	0.120
Selenium	0.153	0.489
Silver	**<0.001*** **	0.805
Strontium	**<0.001*** **	0.489
Zinc	0.443	0.078

Note: - Values are probabilities of no difference among or between the Areas.
- Variables were $\log_{10}$-transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

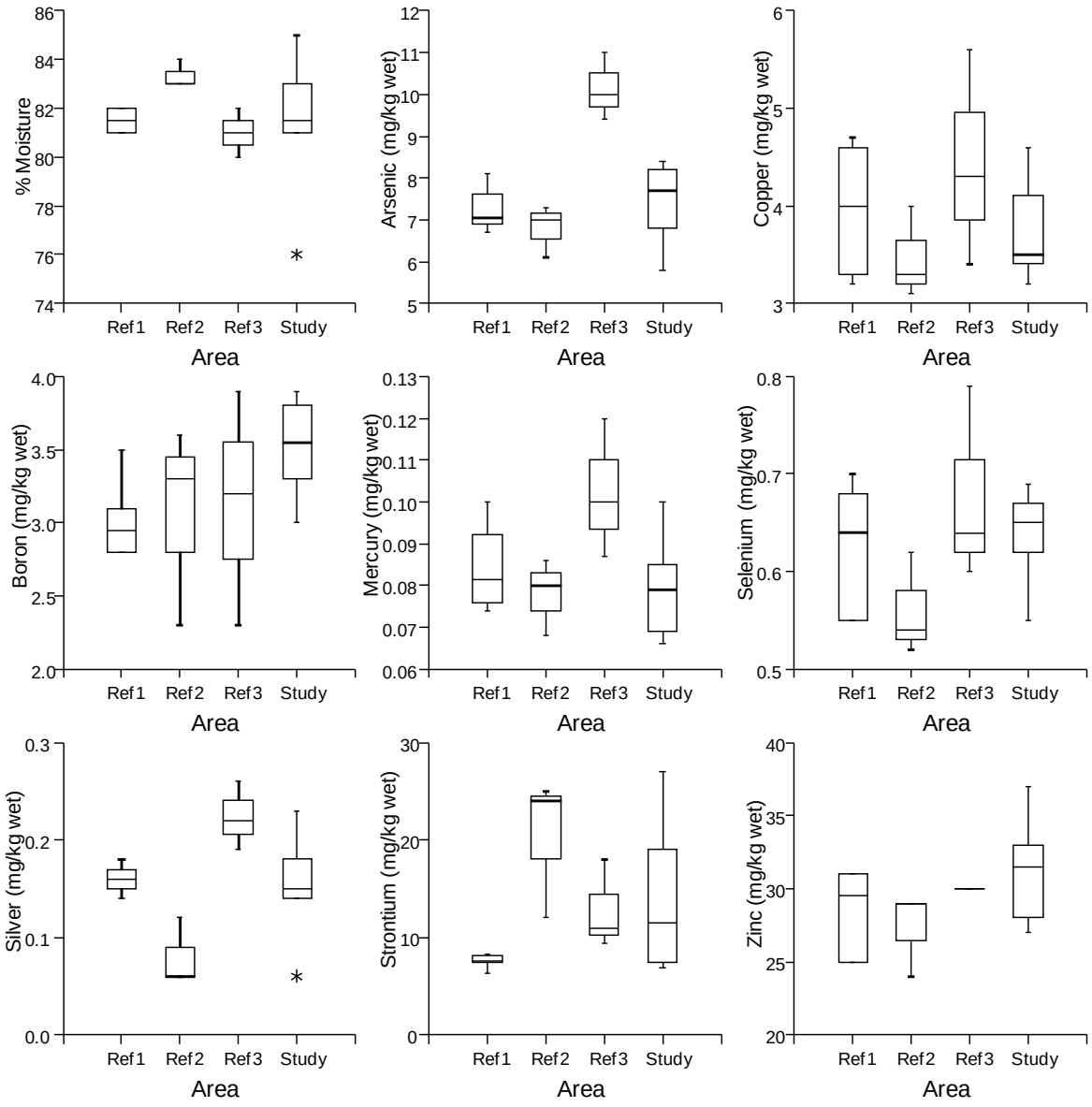

Figure 6-10 Box Plots of Variable Concentrations in Crab Claw in Reference and Study Areas (2016)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles, if present, would indicate values falling outside the quartile ±3 x interquartile spread.

Variations in Temporal trends

Significant differences in linear trends across all Areas were noted for boron and silver concentrations ($p \leq 0.05$, Table 6-23). Boron and silver concentrations generally decreased over time (Figure 6-11). No significant differences in linear trends were noted between the Study and Reference Areas for most analytes. Significant differences in quadratic trends across all Areas were noted for moisture, arsenic, boron, copper, selenium, and silver concentrations ($p \leq 0.05$, Table 6-23; also see Figure 6-11). Significant differences in linear and quadratic trends between the Study and Reference Areas were noted for arsenic ($p \leq 0.05$, Table 6-23). Overall values declined after initial sampling followed by relative increases in 2014 and 2016 in all Areas, but the decline was more pronounced in the Study Area (Figure 6-11).

Table 6-23 Results of ANOVA Testing for Differences in Average Crab Body Burden Variables and Temporal Trends Between the Reference Areas and the Study Areas (2004 to 2016)

Variable	Linear		Quadratic	
	Area-Wide Trend	Difference Between Reference and Study	Area-Wide Trend	Difference Between Reference and Study
Moisture	0.127	1.00	**<0.001*** **	1.00
Arsenic	0.158	0.015*	**<0.001*** **	0.041*
Boron	0.014*	0.510	0.018*	0.384
Copper	0.107	0.265	**<0.001*** **	0.351
Mercury	0.152	0.766	0.096	0.894
Selenium	0.146	0.582	0.030*	0.582
Silver	**<0.001*** **	0.200	**<0.001*** **	0.246
Strontium	0.245	0.635	0.070	0.788
Zinc	0.200	0.441	0.695	1.00

Notes:
- Values are probabilities of no trend, or no difference in temporal trends.
- Variable concentrations were $\log_{10}$-transformed prior to the analyses.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

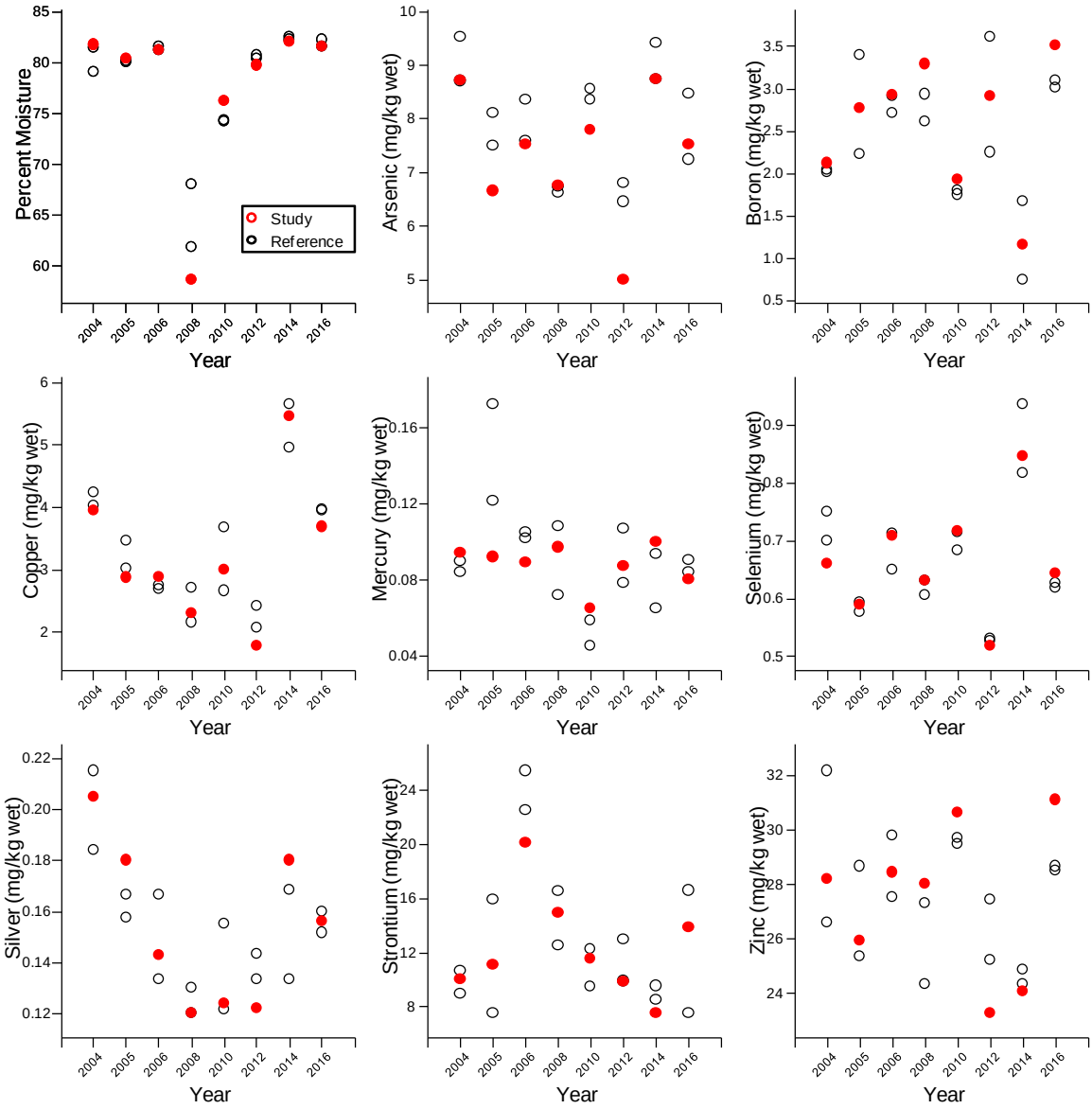

Figure 6-11 Variation in Area Means of Detectable Variable Concentrations in Crab Claw Composites from 2004 to 2016

Note: Values shown are annual averages within Areas. Red circles are Study Area averages; open circles are averages for each Reference Area.

6.2.3 Taste Tests

6.2.3.1 Plaice

No significant difference in taste was noted between plaice from the Study and Reference Areas in 2016 in both the triangle and hedonic scaling tests. Panelists for the triangle test were successful in discriminating 10 out of 24 samples. These results are not significant (p > 0.05, Appendix C-4). ANOVA statistics for hedonic scaling are provided in Table 6-24. The results were not significant (p = 0.10) and, from the frequency histogram (Figure 6-12), samples from both the Study and Reference Areas

were assessed similarly for preference. From ancillary comments (Tables 6-25 and 6-26, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 6-24 ANOVA for Taste Preference Evaluation of Plaice by Hedonic Scaling (2016)

Source of Variation	SS	df	MS	F	*p*-value
Between Groups	6.02	1	6.02	2.9	0.10
Within Groups	98.96	46	2.15		
Total	104.98	47			

Note - $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in **bold**).

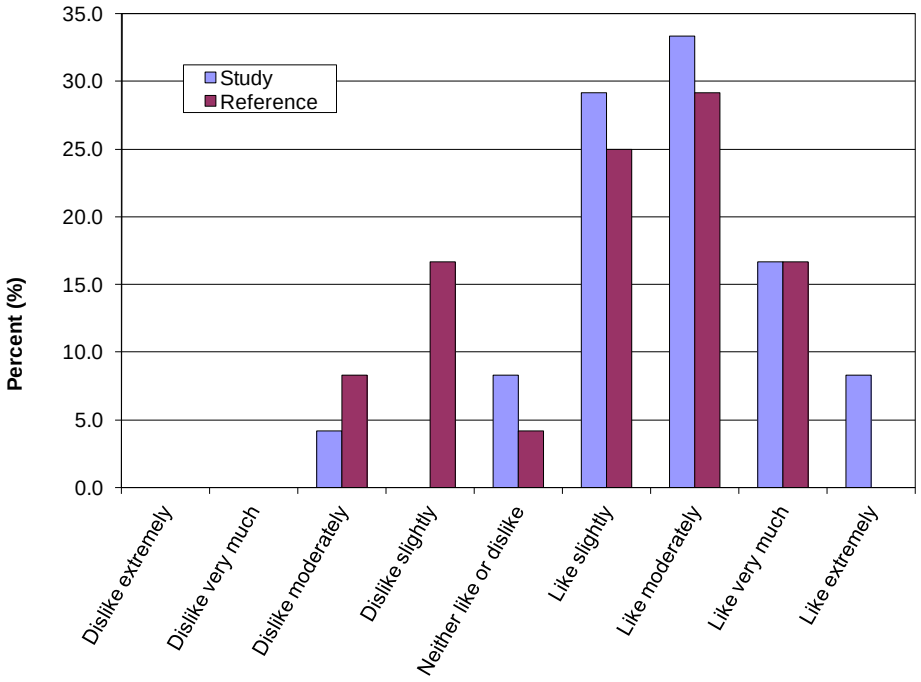

Figure 6-12 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2016)

Table 6-25 Summary of Comments from the Triangle Taste Test for Plaice (2016)

Reference Area	Study Area
Correctly identified as odd sample	**Correctly identified as odd sample**
I think #804 (Reference) is the odd one because it's odour is not as strong as the other two (#186 (Study) and #435 (Study))	82 (Reference)/932 (Reference) had a slightly sweeter flavour
Looked different from other samples, more minced	503 (Study) blander than others
Very, very slight	
210 (Reference) chosen but I can detect very little difference in the samples overall	
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
394 (Reference) stronger fish flavour	Very similar
Not confident I had chosen the correct sample as all three tasted very similar	More flavour in 753 (Study); others slightly bland
Strong taste	Sweeter taste and odour

Note: - Comments are transcribed except that the text for “reference” and “study” was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.

Table 6-26 Summary of Comments from the Hedonic Scaling Taste Test for Plaice (2016)

Preferred Reference Area	Preferred Study Area
Taste about the same	Taste about the same
Very good	194 (Reference) more "fishy" taste
Found both a little bland	194 (Reference) doesn't taste much like fish at all
#463 (Reference) is milder, I think	Very similar, just a slightly better flavour in 133 (Study)
Not a significant difference between the two samples	Very little difference
Both have pleasant, slight sweet odour and flavour. No presence of objectionable odours or flavours. OK	194 (Reference) tasted watery to me, seemed a little mushy, seemed like a lighter smell
15 (Reference) tastes sweeter and overall has more taste	Very good
55 (Study) slightly stronger odour. 15 (Reference) milder odour. Both tasted very light	Found both a little bland
	725 (Reference) had a sweeter flavour but was less desirable
	If the extra flavouring is due to chemical additives, I would rather a less flavourful product and prepare it myself*.
	Both have pleasant, slight sweet odour and flavour. No presence of objectionable odours or flavours. OK
	55 (Study) a tad bit sweeter
	Both samples acceptable
	55 (Study) slightly stronger odour. 15 (Reference) milder odour. Both tasted very light

Note: - Comments are transcribed except that the text for "reference" and "study" was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.
* No additives were used in the preparation of samples.

6.2.3.2 Crab

No significant difference in taste was noted between crab from the Study and Reference Areas in both the triangle and hedonic scaling tests. Panelists for the triangle test were successful in discriminating 9 out of 24 samples. These results were not significant ($p > 0.05$, Appendix C-4). ANOVA statistics for hedonic scaling are provided in +Table 6-27. The results were not significant ($p = 0.60$) and, from the frequency histogram (Figure 6-13), samples from both the Study and Reference Areas were assessed similarly for preference. From ancillary comments (Tables 6-28 and 6-29, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 6-27 ANOVA for Taste Preference Evaluation of Crab by Hedonic Scaling (2016)

Source of Variation	SS	df	MS	F	*p*-value
Between Groups	0.75	1	0.75	0.28	0.60
Within Groups	125.17	46	2.72		
Total	125.92	47			

Note - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

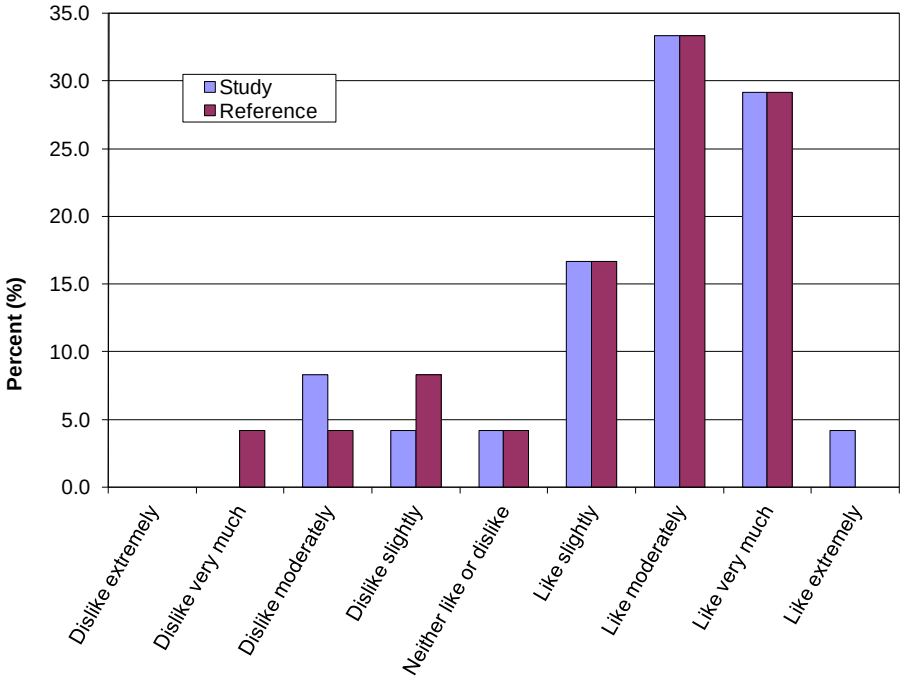

Figure 6-13 Crab Frequency Histogram for Hedonic Scaling Taste Evaluation (2016)

Table 6-28 Summary of Comments from the Triangle Taste Test for Crab (2016)

Reference Area	Study Area
Correctly identified as odd sample	**Correctly identified as odd sample**
660 (Reference) blander sample	All very similar; 872 (Study) slightly stronger in flavour
I think #660 (Reference) is the odd one because it has milder odour	I did not taste a difference
All tasted very similar	361 (Study) was slightly off in flavour and saltier
	Not much difference in any of the samples
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
No discernible difference in smell. 288 (Reference) may be blander than the other two, but no real discernible difference in taste	201 (Study) tasted a little sweeter
Sweeter	Couldn't taste any difference. Had to pick one
All very similar	Did not like much about this product
Very little difference. I will 'guess' that 288 (Reference) is sweeter	Very little difference between samples, difficult to choose
826 (Reference) was not as sweet	926 (Study) smells different
A guess - I could not notice a discernible difference	It seems sample 926 (Study) is the off and more preferred one

Note: - Comments are transcribed except that the text for “reference” and “study” was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.

Table 6-29 Summary of Comments from Hedonic Scaling Taste Tests for Crab (2016)

Preferred Reference Area	Preferred Study Area
Very similar	Very similar
Both samples were very acceptable	355 (Study) - marginally sweeter than 660 (Reference)
No difference between them	Both samples were very acceptable
No detectable difference	660 (Reference) smells more ???
Very slight difference in flavour of the two samples	No difference between them
I like crab meats especially when it's served chilled	No detectable difference
Chalky	839 (Reference) was much sweeter but had a slightly off flavour
Very similar	A little lighter in flavour
No detectable difference	No detectable off flavours on either sample
Has slight, sweet, pleasant flavour, not indicative of top quality/freshness, but close. Very good flavour	Very similar
	No detectable difference
	Has slight, sweet, pleasant flavour, not indicative of top quality/freshness, but close. Very good flavour
	901 (Study) more flavourful. 69 (Reference) yucky texture and a piece of shell! Not a lot of flavour

Note: - Comments are transcribed except that the text for “reference” and “study” was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.

6.2.4 Fish Health

6.2.4.1 Gross Pathology

No visible abnormalities were observed upon necropsy on the skin or fins of plaice or on the external surface of the gonad, digestive tract, liver, body cavity, or spleen (Appendix C-3, Annex C).

6.2.4.2 Mixed Function Oxygenase Activity

MFO enzyme activities, measured as EROD, in the liver of plaice males (all maturity stages combined), and immature, pre-spawning and spent females are provided in Appendix C-3, Annex D. Results of immature and pre-spawning females are summarized in Figure 6-14. EROD activity was comparable among the various female maturity groups, with immature fish having a mean value of 18.1 ± 8.53 pmol/min/mg protein (n = 38), pre-spawning fish averaging 14.2 ± 9.01 pmol/min/mg protein (n = 118), and spent fish having a mean value of 11.3 ± 6.55 pmol/min/mg protein (n = 10).

No significant differences were found in EROD activity among Reference Areas or between the Study Area and the Reference Areas for immature or pre-spawning females (Table 6-30). Too few males, partially spent females, or spent females were captured to permit statistical comparisons.

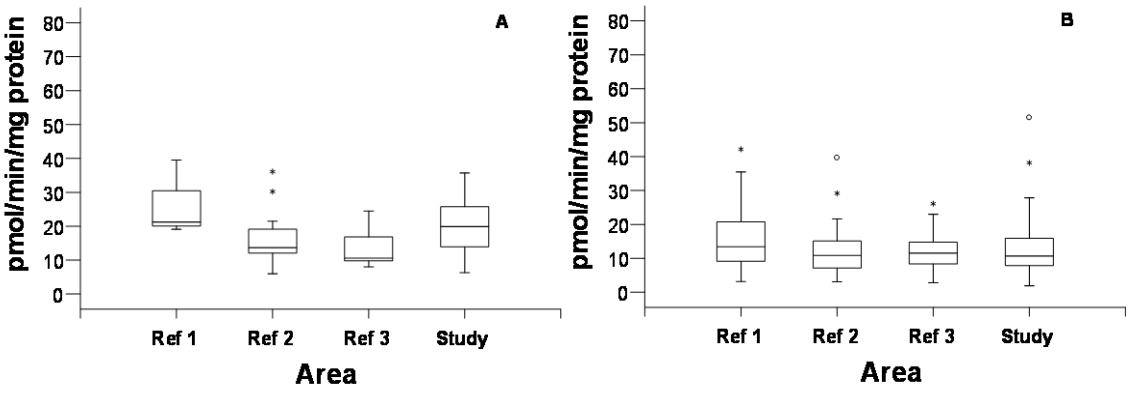

Figure 6-14 Box Plots of EROD Activity in the Liver of: A) Immature (F-500) and B) Pre-spawning (F-510 to F540) Female Plaice (2016)

Notes: Horizontal line in middle of box = median; Box = 25th to 75th percentile (or interquartile range, IQR); Vertical lines = whiskers; include all values within 1.5 x IQR (75th minus 25th percentiles); the box + whiskers will often include all the points, especially when *n* is small; open circles are far outside values, >3 x IQR; asterisks are outside values, >1.5 x IQR.
See Appendix C-3, Annex A for DFO maturity stage classifications.

Table 6-30 Results of ANOVA Comparing EROD Activities in Female Plaice (2016)

Variable (Y)	*p*-value	
	Among References (AR)	**Study versus References (SR)**
Immature Females	0.091	0.323
Pre-Spawn Females	0.266	0.681

Notes:
- EROD activities were log-transformed.
- **p* ≤ 0.05; ***p* ≤ 0.01; ****p* ≤ 0.001 (in **bold**).
- * See Appendix C-3, Annex A for maturity stage classifications.

6.2.4.3 Histopathology

Liver Histopathology

A total of 180 plaice livers were examined, 60 from the Study Area and Reference Area 1 and 30 from Reference Areas 2 and 3. Results were expressed as percentage of fish affected by each type of lesion/observation (or prevalence of lesion) in each Area (Table 6-31). The complete data set is provided in Appendix C-3, Annex E. Representative photographs of normal liver as well as several histological changes are included in Appendix C-3, Annex G.

Table 6-31 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2016)

Hepatic Lesions	Measure	Area					
		Reference 1	Reference 2	Reference 3	All References	Study	Total
Number of Fish	Number	60	30	30	120	60	180
Nuclear Pleomorphism	Number	2	0	0	2	1	3
	%	3.3	0	0	1.7	1.7	
Megalocytic Hepatosis	Number	0	0	0	0	0	0
	%	0	0	0	0	0	
Focus of Cellular Alteration	Number	0	1	0	1	1	2
	%	0	3.3	0	0.8	1.7	
Proliferation of Macrophage Aggregates [a]	Number	2	1	5	8	6	14
	%	3.3	3.3	16.7	6.7	10	
Fibrillar Inclusions	Number	0	0	0	0	0	0
	%	0	0	0	0	0	
Inflammatory Response [b]	Number	18	10	10	38	4	42
	%	30	33.3	33.3	31.7	6.7	
Hepatocellular Vacuolation	Number	1	4	0	5	2	7
	%	1.7	13.3	0	4.2	3.3	
Parasites	Number	37	16	15	68	33	101
	%	61.7	53.3	50	56.7	55	
Golden Rings	Number	0	0	0	0	0	0
	%	0	0	0	0	0	

Notes: - [a] Defined as scores greater than 3 on a 0-7 relative scale.
- [b] Inflammation response including mild, moderate, and severe scores.

Two cases of nuclear pleomorphism were detected in Reference Area 1 and one case was detected in the Study Area. No cases of megalocytic hepatosis or fibrillar inclusions were observed. One case of focus of cellular alteration was detected in Reference Area 2 and one was detected in the Study Area. Proliferation of macrophage aggregates was detected in 14 fish; in six from the Study Area and in two, one and five fish from Reference Areas 1, 2 and 3, respectively. Inflammatory response was detected in 42 fish; in four fish from the Study Area and in eighteen, ten and ten fish from Reference Areas 1, 2 and 3, respectively. Seven cases of hepatocellular vacuolation were detected, in two fish from the Study Area and in one and four fish from Reference Areas 1 and 2, respectively. Although such liver conditions are of interest, they are generally not a result of the presence of chemical pollutants (see Appendix C-3 for further discussion).

Statistical analyses were conducted only on macrophage aggregates, inflammatory response, and parasites since the low incidence of all the other hepatic lesions prevented comparisons. There were no significant differences in either macrophage aggregates (Fisher exact test, $p = 0.557$) or in the presence of parasites (Fisher exact test, $p = 0.874$) between fish from the Study and Reference Areas. Inflammatory response was significantly greater (Fisher exact test, $p \leq 0.001$) for Reference Areas (31.7%) versus the Study Area (6.7%; Table 6-31).

Gill Histopathology

Gill sections were examined for the presence of various gill lesions associated with chemical toxicity. These included epithelial lifting, basal, distal and tip hyperplasia, fusion, and telangiectasis. For each fish, lamellar counts were performed on four filaments and are presented as the percentage of secondary lamellae affected by each type of lesion in relation to the total number of secondary lamellae counted (between 268 and 716 lamellae per fish) in Appendix C-3, Annex F.

Accurate counts were not possible for three fish from the Reference Area 1, seven fish from Reference Area 2, five fish from Reference Area 3 and six fish from the Study Area. Therefore, these fish were excluded from analysis. Detailed histopathological studies were thus carried out on gill tissues of 105 fish from the Reference Areas and 54 fish from the Study Area. In all cases, the percentages of lamellae in individual fish affected by the lesions were low; all were less than 3.3% (see Annex F, Appendix C-3). Representative photographs of gill slides used during the analysis can be found in Appendix C-3, Annex G. Means ± SD of percentages of lamellae presenting each type of lesion per site are provided in Table 6-32.

Table 6-32 Mean Percent Occurrence of Lesions in the Gill Tissues of Plaice (2016)

Statistics	Area				
	Reference 1	Reference 2	Reference 3	Study	Total
Number of Fish	57	23	25	54	159
Distal Hyperplasia[a]	0.0165 ± 0.0798	0.0894 ± 0.3958	0.1521 ± 0.515	0.0554 ± 0.2442	0.0615 ± 0.2942
Tip Hyperplasia[a]	0.0623 ± 0.2351	0.0629 ± 0.1513	0.029 ± 0.0881	0.0979 ± 0.2046	0.0692 ± 0.1964
Basal Hyperplasia 1[ab]	0.0836 ± 0.2253	0.0191 ± 0.0657	0.0215 ± 0.0783	0.1104 ± 0.2736	0.0736 ± 0.2144
Basal Hyperplasia 2[ac]	0.0569 ± 0.1877	0.0317 ± 0.106	0.0172 ± 0.0862	0.0156 ± 0.0674	0.033 ± 0.1306
Fusion[a]	0.0226 ± 0.1269	0.0676 ± 0.1987	0.1606 ± 0.6601	0.0713 ± 0.3174	0.0674 ± 0.3366
Telangiectasis[a]	0.0121 ± 0.0913	0	0	0	0.0043 ± 0.0547

Notes:
- Values are means ± 1 SD.
- [a] Mean percentage of lamellae presenting the lesion.
- [b] Basal hyperplasia 1: increase in thickness of the epithelium reaching 1/3 to 2/3 of total lamellar length.
- [c] Basal hyperplasia 2: increase in thickness of the epithelium reaching more than 2/3 of total lamellar length.

Statistical comparisons were carried out on the number of fish exhibiting lesions between the Study Area versus the combined Reference Areas (Table 6-33) using Fisher's Exact Test. Lesions were considered "present" if they occurred on any of the lamellae examined for each fish. Statistical analysis was not conducted on telangiectasis as the low incidence prevented statistical comparisons.

With the exception of tip hyperplasia, none of the gill lesions occurred either more or less frequently in Study Area fish compared to Reference Area fish (Fisher Exact test, $p > 0.05$ in all cases). The occurrence of tip hyperplasia was significantly greater (Fisher exact test, $p = 0.031$) in the Study Area (28%) compared to Reference Areas (14%; Table 6-33).

Table 6-33 Number of Plaice with Specific Types of Gill Lesions and Percentages of Fish Exhibiting the Lesions (2016)

Gill Lesions	Measure	Area				
		Reference 1	Reference 2	Reference 3	Mean Reference	Study
Number of Fish	Number	57	23	25	35	54
Distal Hyperplasia	Number	3	2	5	3	6
	%	5	9	20	11	11
Tip Hyperplasia	Number	7	4	3	5	15
	%	12	17	12	14	28
Basal Hyperplasia 1[a]	Number	9	2	2	4	12
	%	16	9	8	11	22
Basal Hyperplasia 2[b]	Number	6	2	1	3	3
	%	11	9	4	8	6
Fusion	Number	2	3	2	2	4
	%	4	13	8	8	7
Telangiectasis	Number	1	0	0	0.3	0
	%	2	0	0	1	0

Notes: - Hyperplasia and fusion were considered "present" if those conditions occurred on any of the lamellae examined for each fish.
- [a] Basal hyperplasia 1: increase in thickness of the epithelium reaching 1/3 to 2/3 of total lamellar length.
- [b] Basal hyperplasia 2: increase in thickness of the epithelium reaching more than 2/3 of total lamellar length.

6.3 Summary of Results

6.3.1 Biological Characteristics

There were no significant differences in plaice mean gutted weight and measures of crab size (carapace width and claw height) between Reference Area composites and Study Area composites for plaice and crab used in body burden analyses.

Difference among Areas for additional plaice biological characteristics were examined within the context of fish health analyses. Few (12) males were captured, and almost all of the females examined were mature (129 of 168 females, or 77%). The frequency of pre-spawning and spent mature females did not differ significantly between the Reference and Study Areas.

Sufficient numbers of fish allowed comparison of plaice length, age, gutted weight (corrected for length) and liver and gonad weight (corrected for gutted weight) between the Reference and Study Areas for immature and pre-spawning females. No significant differences were noted between the Reference Areas and the Study Area for biological characteristics of immature females. This was also true for most biological characteristics of pre-spawning females. However, gonad weight relative to gutted weight for pre-spawning females in the Study Area was generally higher (by 3%) than in the Reference Areas.

6.3.2 Body Burden

Compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon range were again detected in all plaice liver samples in 2016. As in previous years, additional Gas Chromatography/Mass Spectrometer analysis did not indicate the presence of drill fluid or petroleum hydrocarbons in those samples. In 2016, naphthalene was also detected at low levels in

all liver samples and additional analyses indicated that this compound likely resulted from on-board contamination of liver tissues during handling. Naphthalene was the only PAH detected.

In 2016, most frequently detected compounds in plaice liver (% fat, % moisture, arsenic, copper, iron, mercury, selenium, silver, zinc, and $>C_{21}$-C_{32} hydrocarbons) did not vary significantly in concentration between the Study and Reference Areas. However, cadmium concentration was higher in the liver of plaice from the Study Area (1.65 mg/kg in the Study Area versus a mean of 1.30 mg/kg in Reference Areas); manganese, naphthalene, and $>C_{10}$-C_{21} hydrocarbon concentrations were generally higher in the liver of plaice from the Reference Areas.

There were no significant differences between the Study Area and the Reference Areas in linear or quadratic trends over time (2004 to 2016) for most frequently detected compounds in plaice liver. However, a difference between the Study and Reference Areas in linear trends over time was noted for $>C_{21}$-C_{32} hydrocarbons, likely driven by higher values in the Study Area in 2006 and 2010.

For plaice fillets in 2016, there were no significant differences in % moisture, arsenic, and mercury concentrations between the Study Area and the Reference Areas. Zinc concentrations were lower in fillets from the Study Area compared to the Reference Areas. Across years, no significant differences between the Study and Reference Areas were noted in linear and/or quadratic trends.

For crab tissue in 2016, there were no significant differences between the Study Area and the Reference Areas for most frequently detected compounds (% moisture, arsenic, copper, mercury, selenium, silver, strontium, and zinc). However, boron concentration in crab tissue was higher in the Study Area compared to the Reference Areas (3.55 mg/kg in the Study Area versus a mean of 3.15 mg/kg in the Reference Areas). Across years, no significant differences between the Study and Reference Areas were noted in linear and/or quadratic trends for most variables. However, significant differences in linear and quadratic trends between the Study and Reference Areas were noted for arsenic, with overall values declining in earlier years followed by relative increases in 2014 and 2016; and the earlier decline more pronounced in the Study Area.

6.3.3 Taste Tests

There were no significant differences in taste test results between Study and Reference Areas plaice or crab. From ancillary comments, there were no consistent comments identifying abnormal or foreign odour or taste.

6.3.4 Fish Health Indicators

There were no visible lesions on the skins, fins, or internal organs of any plaice.

There were no significant differences in EROD activity between the Reference Areas and the Study Area for both immature and pre-spawning females. Low numbers prevented comparison between Areas for males and other female maturity groupings.

In general, liver lesions more commonly associated with chemical toxicity were absent in the Study and Reference Areas. Sufficient incidences of lesions allowed comparison among Areas for macrophage aggregates, inflammatory response, and parasite counts. The prevalence of macrophage aggregates and parasites did not differ between the Study and Reference Areas. However, the prevalence of inflammatory response was greater in the Reference Areas.

For gill histopathology, with the exception of tip hyperplasia, no significant differences were found for any of the studied conditions between fish from the Study Area and the Reference Areas. The overall number of lamellae affected by tip hyperplasia was low (the highest percentage of lamellae affected was 1.5%). However, more fish from the Study Area exhibited tip hyperplasia than fish from the Reference Areas (28% in the Study Area compared to 14% in the Reference Areas).

7.0 Water Quality Component

7.1 Background

In 2004, Husky designed the Sediment and Commercial Fish components of its EEM program and made a commitment to design a Water Quality component to coincide with the discharge of produced water from the *SeaRose FPSO* (Husky Energy 2004). In 2008, Husky collected preliminary seawater samples around White Rose to aid in the design of the Water Quality program. In March 2010, Husky submitted a Water Quality monitoring program design document to the C-NLOPB (Husky Energy 2010a) and that design document was integrated into the overall EEM program design document in November 2010 (Husky Energy 2010b).

The Water Quality monitoring program at White Rose currently involves collection of seawater and sediment samples around White Rose and in two Reference Areas located approximately 28 km to the northeast and northwest of the *SeaRose FPSO*. The program has also involved modelling of constituents of produced water to identify constituents that would be most likely to be detected in seawater samples or sediment samples. The ultimate goals of the modelling exercises were to find a potential tracer for produced water and/or fine-tune the Water Quality sampling program at White Rose to increase the likelihood of produced water detection (details are provided in Husky Energy 2010a, 2010b; also see Section 1).

Because the Water Quality monitoring program at White Rose has been modified based on modelling, the model results for produced water discharge are summarized before seawater and sediment field results in the sections that follow.

7.2 Seawater

7.2.1 Modelling Study

Full model results predicting the concentration of selected produced water constituents in seawater were provided as part of the 2010 EEM report (Husky Energy 2011).

Conclusions and recommendations from the seawater modelling exercise were as follows:

- Naphthalene is likely a good indicator of the presence of produced water from White Rose.
- To be most effective, Near-field sampling should be adaptive, with stations positioned in relation to water current direction (*i.e.*, down-current) at the time of sampling (*i.e.*, station should not be fixed).
- Sampling at Mid-field stations (approximately 1 to 5 km from source) should be effective for those constituents with a high probability of detection. Mid-field stations should be at fixed locations in the direction of the prevailing seasonal current.

- Aside from biological/chemical reactivity and physical properties, the probability of detection of a constituent is dictated by its release concentration and its laboratory detection limit. Therefore, the lowest reliable detection limit should be used for the analysis of field samples.

Recommendations were first implemented for the 2012 field program and continue to be implemented.

7.2.2 Field Sampling

7.2.2.1 Water Sample Collection

Water collection for the 2016 EEM Program was conducted from September 6 to September 7, 2016, using the offshore supply vessel *Atlantic Kingfisher*. Collection stations for the 2016 program are shown in Figure 7-1. In accordance with recommendations in Section 7.2.1, samples in the Near-field were collected down-current from the *SeaRose FPSO*. In 2016, those stations were located to the southwest of the *SeaRose FPSO*. Station coordinates and distance to the *SeaRose FPSO* are provided in Appendix D-1.

Water samples were collected at 10 m below surface (“surface”), 40 m below surface (“mid-depth”), and 10 m above bottom (“bottom”) using a string of three Teflon-lined, 10 L Niskin-X bottle water samplers (Figure 7-2). All stations were sampled for physical and chemical characteristics. Compounds analyzed included BTEX (benzene, toluene, ethylbenzene, and xylenes), $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, PAHs (polycyclic aromatic hydrocarbons) and alkyl PAHs, phenols and alkyl phenols, volatile organic acids, metals, total inorganic and organic carbon (TIC and TOC, respectively), total suspended solids (TSS) and ammonia. Samples were stored as detailed in Table 7-1.

A conductivity, temperature, depth (CTD) recorder cast was performed at all Water Quality stations to assess the depth of the thermocline relative to Niskin bottle sample location.

The following Quality Assurance/Quality Control (QA/QC) protocols were implemented for collection of samples. Field duplicates were collected for water chemistry at four stations. Sampling personnel were supplied with new latex gloves for each station. Samples were decanted from the Niskin samplers into the labelled jars. Processed samples were transferred to cold storage within one hour of collection. Once ashore, samples to be analyzed by RPC were transferred to cold storage at Stantec and then shipped to RPC; samples to be analyzed by Maxxam were dropped off at the Maxxam Laboratory in St. John’s for shipment to the Maxxam laboratory in Halifax. Samples were delivered to laboratories within prescribed sample holding time.

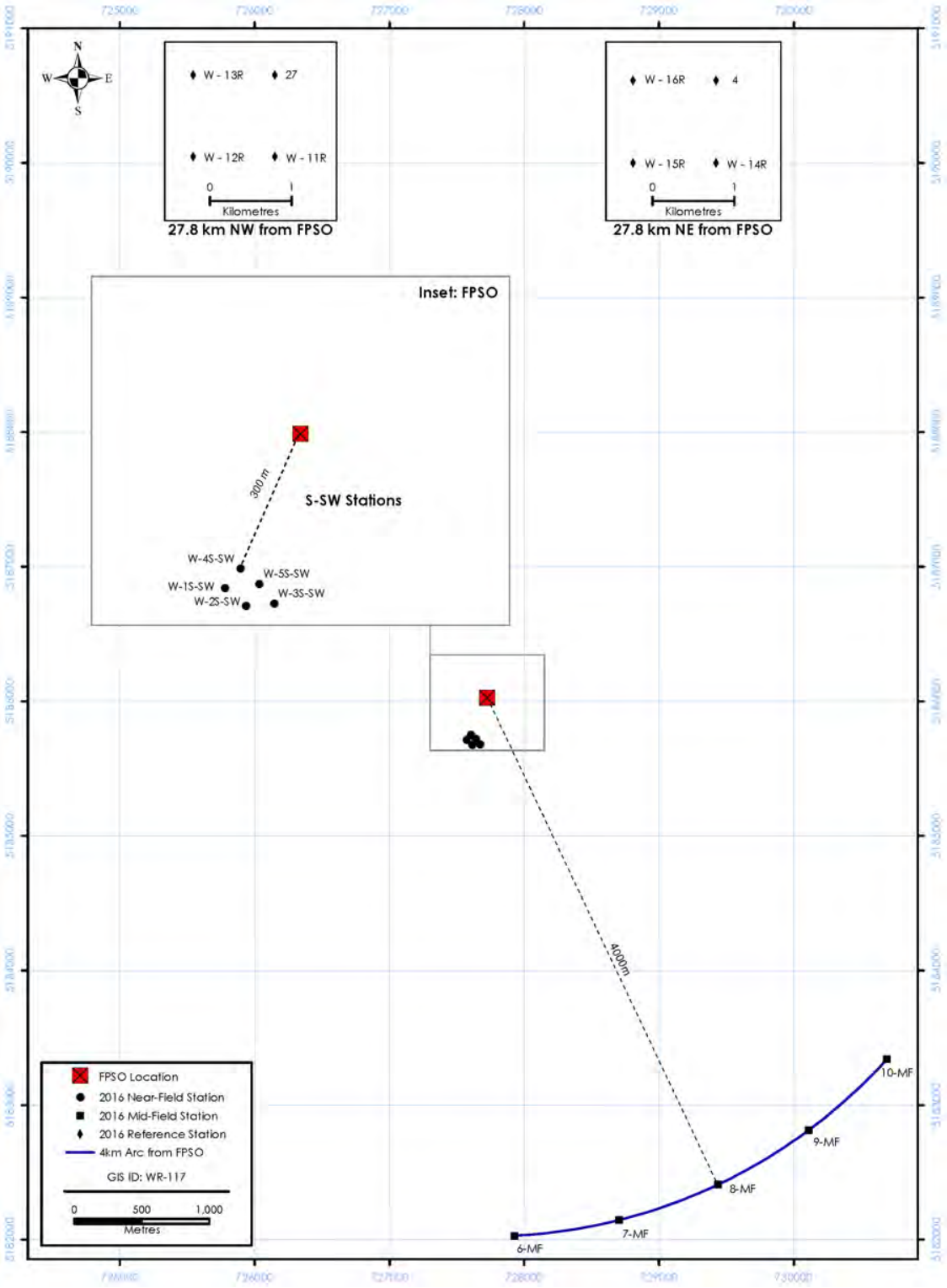

Figure 7-1 Water Quality Stations 2016

Notes: The inset represents an expanded view of the centre of the development. The blue line shows that mid-field stations are distributed on an arc, with each station 4000 m from the centre of the development.

Figure 7-2 Niskin Bottle Water Samples

Table 7-1 Water Sample Storage

Analysis	Storage Container	Preservative Description and Comments	Storage Temperature	Holding Time
Atlantic MUST [a]	2 – 250 mL clear glass bottles 2 – 40 mL vials	Sodium bisulphate Sodium bisulphate	4ºC	7 days
PAHs & Alkyl PAHs	1 – 1 L amber glass bottle	None	4ºC	7 days
Phenols & Alkyl Phenols & Volatile Organic Acids	1 – 1 L amber glass bottle	None	4ºC	7 days
Trace Metals	1 – 120 mL (or 200 mL) plastic bottle	None	4ºC	6 months
Mercury	1 - 100 mL amber glass	Potassium dichromate ($K_2Cr_2O_7$ in nitric acid)	4ºC	28 days
Ammonia	1 – 100 mL amber glass bottle	Sulphuric acid	4ºC	28 days
TOC	1 – 100 mL amber glass bottle	Sulphuric acid	4ºC	28 days
TSS	1 L plastic bottle	None	4°C	7 days
TIC	1 – 200 mL plastic bottle	No preservative required. Fill to top	4°C	28 Days

Note: - [a] BTEX, >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons.

7.2.2.2 Laboratory Processing

Water samples were processed for constituents listed in Table 7-2. In the 2010 EEM program, most constituents were processed at RPC, Fredericton, NB. From 2012 to 2016, inorganic constituents (trace metals, mercury) were processed at Maxxam Analytics (Halifax, NS) because detection limits for most inorganic constituents of interest were lower at that analytical laboratory, as per recommendations in Section 7.2.1. TIC/TOC/TSS and ammonia were also processed at Maxxam Analytics from 2012

to 2016. The remaining constituents were processed at RPC. Details on analytical methods for RPC and Maxxam Analytics are provided in Appendix D-2.

Table 7-2 Water Chemistry Constituents (2010, 2012, 2014 and 2016)

Constituent	Unit	Detection Limit			
		2010	2012	2014	2016
Hydrocarbons					
Benzene	mg/L	0.001	0.001	0.001	0.001
Toluene	mg/L	0.001	0.001	0.001	0.001
Ethylbenzene	mg/L	0.001	0.001	0.001	0.001
Xylenes	mg/L	0.001	0.001	0.001	0.001
C_6-C_{10} (less BTEX)	mg/L	0.01	0.01	0.01	0.01
>C_{10}-C_{21}	mg/L	0.05	0.05	0.05	0.05
>C_{21}-C_{32}	mg/L	0.1	0.1	0.1	0.1
Phenols and Alkyl Phenols					
Phenol	µg/L	10	10	10	10
o-cresol	µg/L	10	10	10	10
m,p-cresol	µg/L	10	10	10	10
Total C2 Phenols	µg/L	20	20	20	20
Total C3 Phenols	µg/L	20	20	20	20
Total C4 Phenols	µg/L	20	20	20	20
Total C5 Phenols	µg/L	20	20	20	20
4-n-hexylphenol	µg/L	10	10	10	10
2,5-diisopropylphenol	µg/L	10	10	10	10
2,6-diisopropylphenol	µg/L	10	10	10	10
2-tert-butyl-4-ethylphenol	µg/L	10	10	10	10
6-tert-butyl-2,4-dimethyphenol	µg/L	10	10	10	10
4-n-heptylphenol	µg/L	10	10	10	10
2,6-dimethyl-4-(1,1-dimethypropyl)phenol	µg/L	10	10	10	10
4-(1-ethyl-1-methylpropyl)-2-methylphenol	µg/L	10	10	10	10
4-n-octylphenol	µg/L	10	10	10	10
4-tert-octylphenol	µg/L	10	10	10	10
2,4-di-sec-butylphenol	µg/L	10	10	10	10
2,6-di-tert-butylphenol	µg/L	10	10	10	10
4-n-nonylphenol	µg/L	20	20	20	20
2-methyl-4-tert-octylphenol	µg/L	10	10	10	10
2,6-di-tert-butyl-4-methylphenol	µg/L	10	10	10	10
4,6-di-tert-butyl-2-methylphenol	µg/L	10	10	10	10
PAHs and Alkyl PAHs					
Naphthalene	µg/L	0.01	0.05	0.05	0.05
1-Methylnapthalene	µg/L	NA	NA	0.05	0.05
2-Methylnapthalene	µg/L	NA	NA	0.05	0.05
Acenaphthylene	µg/L	0.01	0.01	0.01	0.01
Acenaphthene	µg/L	0.01	0.01	0.01	0.01
Fluorene	µg/L	0.01	0.01	0.01	0.01
Phenanthrene	µg/L	0.01	0.01	0.01	0.01
Anthracene	µg/L	0.01	0.01	0.01	0.01
Fluoranthene	µg/L	0.01	0.01	0.01	0.01
Pyrene	µg/L	0.01	0.01	0.01	0.01
Benzo(*a*)anthracene	µg/L	0.01	0.01	0.01	0.01
Chrysene/Triphenylene	µg/L	0.01	0.01	0.01	0.01
Benzo(*b*)fluoranthene	µg/L	0.01	0.01	0.01	0.01
Benzo(*k*)fluoranthene	µg/L	0.01	0.01	0.01	0.01
Benzo(*e*)pyrene	µg/L	0.01	0.01	0.01	0.01
Benzo(*a*)pyrene	µg/L	0.01	0.01	0.01	0.01
Indenopyrene	µg/L	0.01	0.01	0.01	0.01
Benzo(*g,h,i*)perylene	µg/L	0.01	0.01	0.01	0.01
Dibenzo(*a,h*)anthracene	µg/L	0.01	0.01	0.01	0.01
C1-Naphthalenes [a]	µg/L	0.05	0.10	0.10	0.10
C2-Naphthalenes [a]	µg/L	0.05	0.10	0.10	0.10
C3-Naphthalenes	µg/L	0.05	0.10	0.10	0.10
C1-Phenanthrenes	µg/L	0.05	0.10	0.10	0.10
C2-Phenanthrenes	µg/L	0.05	0.10	0.10	0.10
C3-Phenanthrenes	µg/L	0.05	0.10	0.10	0.10
Dibenzothiophene	µg/L	0.05	0.10	0.10	0.10

Constituent	Unit	Detection Limit			
		2010	2012	2014	2016
C1-Dibenzothiophenes	µg/L	0.05	0.10	0.10	0.10
C2-Dibenzothiophenes	µg/L	0.05	0.10	0.10	0.10
C3-Dibenzothiophenes	µg/L	0.05	0.10	0.10	0.10
Perylene	µg/L	0.01	0.01	0.01	0.01
Biphenyl	µg/L	0.01	0.05	0.05	0.05
Organic Acids					
Acetic Acid	mg/L	2	2	2	2
Propionic Acid	mg/L	2	2	2	2
Iso-butyric Acid	mg/L	2	2	2	2
Butyric Acid	mg/L	2	2	2	2
Iso-valeric Acid	mg/L	2	2	2	2
n-valeric Acid	mg/L	2	2	2	2
Radionuclides [b]					
Radium-228	Bq/L	1	NA	NA	NA
Radium-226	Bq/L	0.3	NA	NA	NA
Lead-210	Bq/L	1	NA	NA	NA
Metals					
Aluminum	µg/L	5	10	10	10
Antimony	µg/L	1	0.5	0.5	0.5
Arsenic	µg/L	10	0.5	0.5	0.5
Barium	µg/L	0.1	1	1	1
Beryllium	µg/L	0.05	1	1	1
Boron	µg/L	10	50	50	50
Cadmium	µg/L	0.05	0.05	0.05	0.05
Calcium	mg/L	0.05	1	1	1
Chromium	µg/L	2	0.5	0.5	0.5
Cobalt	µg/L	0.5	0.10	0.10	0.10
Copper	µg/L	5	0.5	0.5	0.5
Iron	µg/L	10	5	5	10
Lanthanum	µg/L	0.2	NA	NA	NA
Lead	µg/L	0.05	0.1	0.1	0.1
Lithium	µg/L	5	20	20	20
Magnesium	mg/L	10	1	1	1
Manganese	µg/L	0.01	0.50	0.50	0.50
Mercury	µg/L	0.025	0.013	0.013	0.013
Molybdenum	µg/L	0.1	1.0	1.0	1.0
Nickel	µg/L	5	0.20	0.20	0.20
Potassium	mg/L	20	1	1	1
Phosphorus	µg/L	NA	50	50	50
Selenium	µg/L	10	0.5	0.5	0.5
Silicon	µg/L	NA	100	100	1000
Silver	µg/L	0.02	0.05	0.05	0.05
Sodium	mg/L	0.05	1	1	1
Strontium	µg/L	10	10	10	10
Sulfur	mg/L	0.05	20	20	20
Tellurium	µg/L	0.5	NA	NA	NA
Thallium	µg/L	2	0.10	0.10	0.10
Tin	µg/L	NA	1.0	1.0	1.0
Titanium	µg/L	NA	10	10	10
Uranium	µg/L	0.1	0.05	0.05	0.05
Vanadium	µg/L	1	10	10	10
Zinc	µg/L	1	1	1	1
Other					
Unionized Ammonia	mg/L	NA	0.0001	0.0001	0.0001
TIC	mg/L	0.5	0.5	0.5	0.5
TOC	mg/L	0.5	5	5	5
TSS	mg/L	5	0.5	0.5	1
XCide450	mg/L	0.5	0.5	NA	NA
SCW4453	mg/L	1	0.03	NA	NA

Note:
- [a] Includes 1- and 2-Chloronaphthalene.
- [b] Radionuclide sampling was discontinued in 2012 based on model results that showed that probability of detection in water samples was zero (Husky Energy 2011).
- Measurement of the process chemicals XCide450 and SCW4453 was discontinued in 2014 in accordance with recommendations in the 2012 EEM report (Husky Energy 2013).

7.2.2.3 Data Analysis

General Water Quality

Data analyses focused on 2016 data, with qualitative comparisons to results from 2010 to 2014. Data collected during baseline (2000) are not comparable to EEM data because the Water Quality monitoring program at White Rose measures a greater number of constituents, many at lower laboratory detection limits, than in 2000. Similarly, preliminary data collected in 2008 are not discussed here because not all constituents were measured at all depths. Data from 2000 and 2008 are reported in Husky Energy (2001) and Husky Energy (2010a).

Frequently Detected variables

In 2016, the Water Quality component of the White Rose EEM program used a multiple-Reference and multiple Study Area design, with two Reference Areas and one Near-field and one Mid-field Study Area. Boxplots of variables that occurred above laboratory detection limit in all or most cases[27] were generated for each Area.

Overall Area differences were tested on frequently detected variables using ANOVA with Depth and Area as factors. Variables were $\log_{10}$ transformed. When no significant Area x Depth interaction was detected, the ANOVA was repeated excluding the Area x Depth interaction term from the model, with levels of significance for the factors Area and Depth reported as such. If overall Area differences were significant, then Study versus Reference (SR), Between Study (BS) Between Reference (BR), Near-field versus Reference (NF *vs* R) and Mid-field versus Reference (MF *vs* R) contrasts were examined. Statistical outliers (studentized residual > |4|) were retained in ANOVA if their removal did not change results from significant to not-significant, or vice versa. Otherwise, discussion is provided on results with and without outliers. One surface sample with substantially lower metals concentrations (*i.e.*, lower salinity) was likely influenced by the presence of freshwater[28] and was removed from analysis.

Values below detection limit were set to ½ detection limit for plotting and ANOVA.

Infrequently Detected Variables

Percent occurrence of infrequently detected variables in the Study Areas (Near-field and Mid-field combined) and the Reference Areas (NE and NW Reference Areas combined) was plotted and qualitatively compared. When occurrence was more frequent in Study Area samples, the Study Area (Near-field or Mid-field) with higher occurrence was identified.

[27] Variables that occurred above detection limit in more than 75% of overall cases.

[28] The surface sample at station W-3S-SW was potentially influenced by rain water. The field crew reported that it was raining during this collection. It is not believed that the sample was affected by produced water, because White Rose produced water has a higher, not lower, salinity than seawater.

Produced Water Constituents

Concentrations of produced water constituents were compared to concentrations at Reference Area stations to generate an estimate of expected enrichment resulting from release of produced water. Individual stations were then examined for produced water constituents with expected concentrations on release more than 10 times seawater concentrations. The concentration of produced water constituents was obtained from a produced water chemical characterization from January 30, 2017.

Analyses were performed using Systat (version 13) and Excel 2007.

7.2.2.4 Results

General Water Quality

Raw data and summary statistics for variables measured in seawater samples (Table 7-2) are provided in Appendix D-2. Conductivity, temperature, depth profiles are provided in Appendix D-3. The beginning of the thermocline was between 10 and 15 m at Near-field and Mid-field stations; the end of the thermocline was between 50 and 65 m. The beginning of the thermocline was between 15 and 25 m at NW and NE Reference Area stations; the end was between 45 and 50 at NW Reference Area stations, but it was between 40 and 50 m at NE Reference Area stations. Therefore, most mid-depth samples (40 m depth) were collected within the thermocline, but some samples collected in the NE Reference Area may have been collected below the thermocline.

Frequently Detected Variables

In 2016, arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, potassium, sodium, strontium, sulphur, uranium and TIC were detected in all samples; aluminum and lead were above detection limit in 80% of samples. With the exception of TIC, which varied over the narrow range of 27 and 29 mg/L, all these variables were included in quantitative analyses for 2016.

Boxplots by area and depth for variables with most values above the laboratory detection limit are provided in Figure 7-3. Values indicated in red in Figure 7-3 identify data that were excluded from ANOVA (see below for further information). Boxplots are not provided for TIC because values varied over a very narrow range.

Results of ANOVA comparing the concentration of frequently detected variables among Areas are provided in Table 7-3.

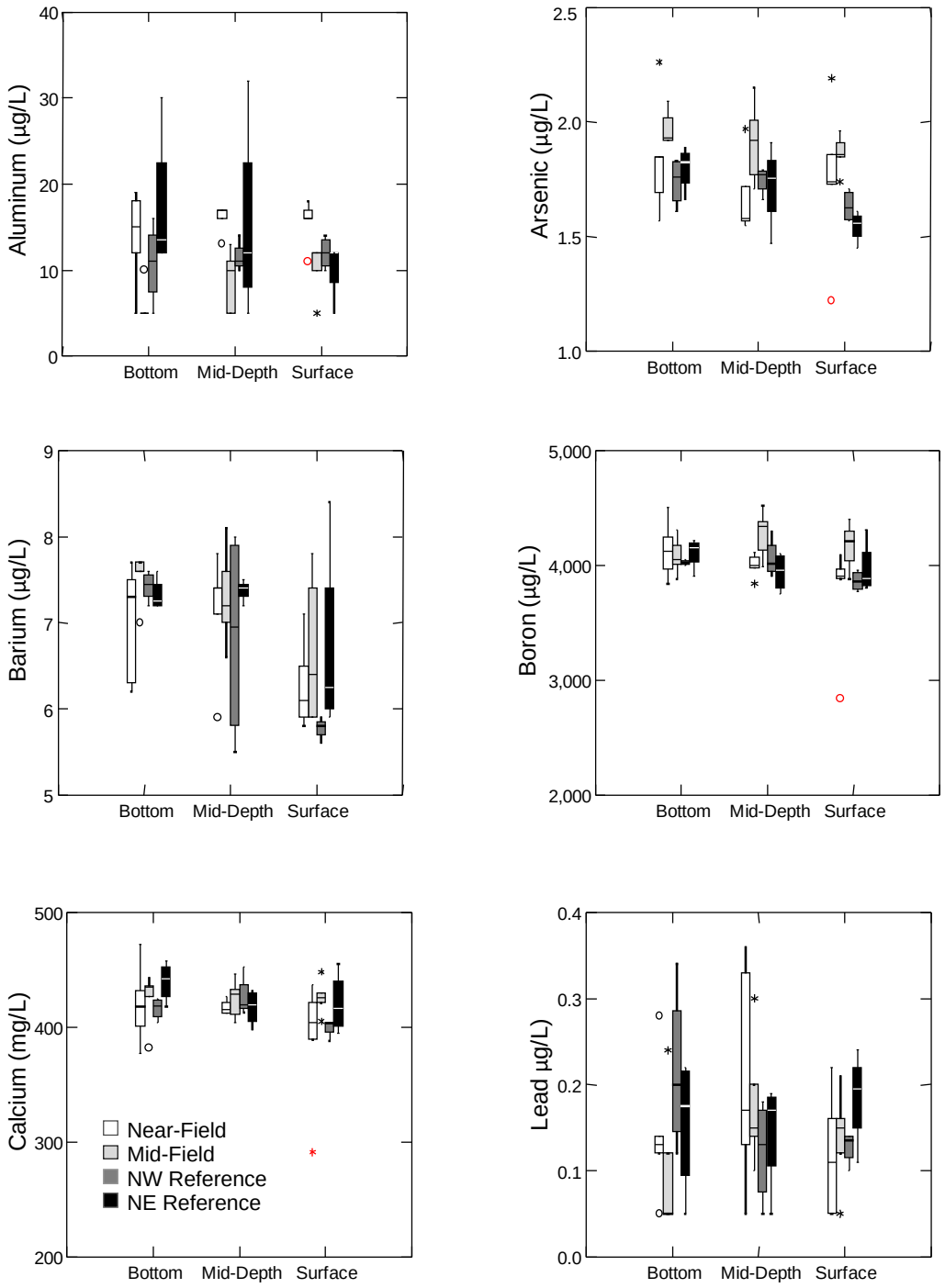

Figure 7-3 Boxplots of Water Chemistry by Area and Depth for 2016

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles indicate values falling outside the quartile ±3 x interquartile spread. Values indicated in red identify those data that were excluded from ANOVA (see Section 7.2.2.3).

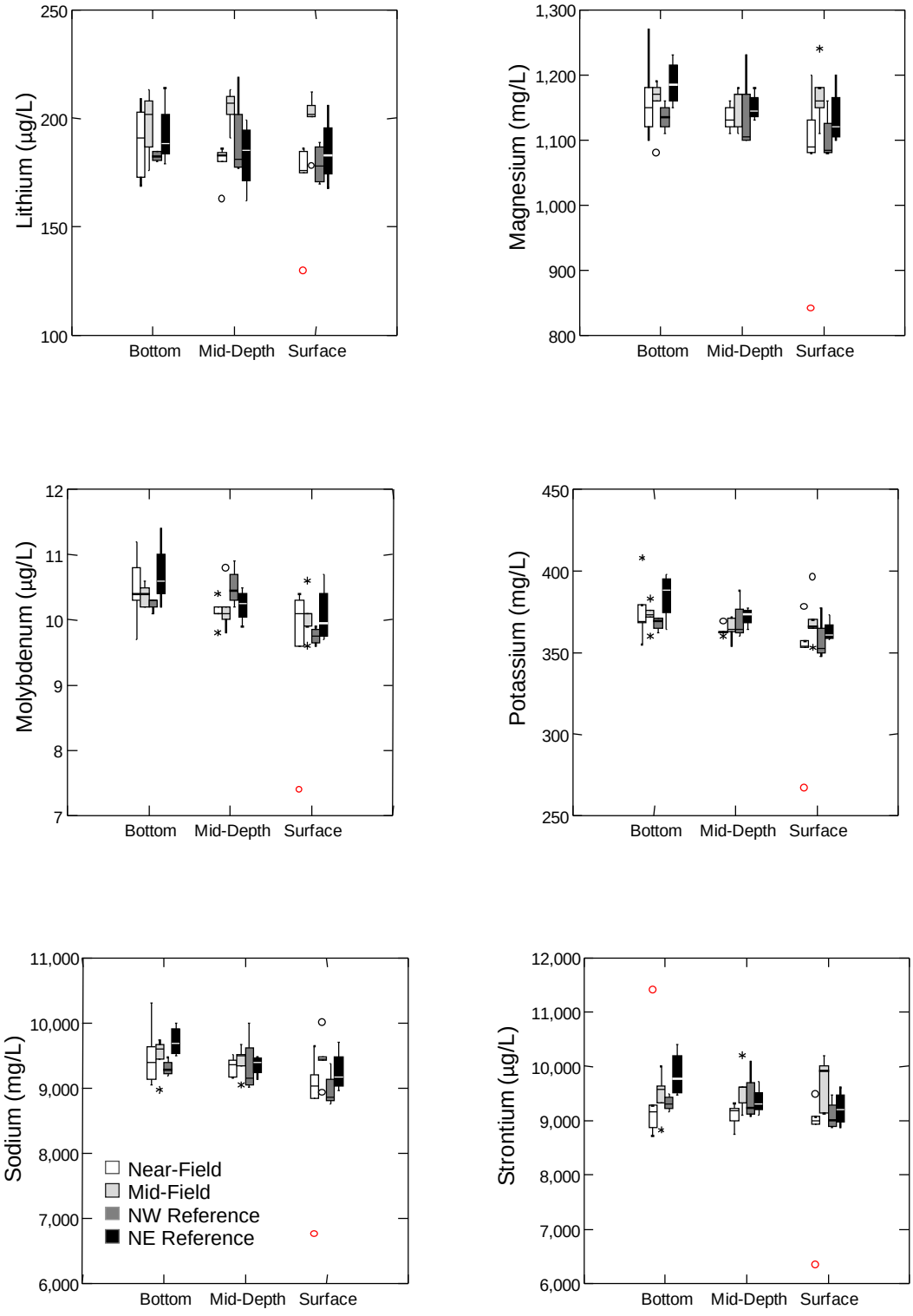

Figure 7-3 Boxplots of Water Chemistry by Area and Depth for 2016 (cont.)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles indicate values falling outside the quartile ±3 x interquartile spread. Values indicated in red identify those data that were excluded from ANOVA (see Section 7.2.2.3).

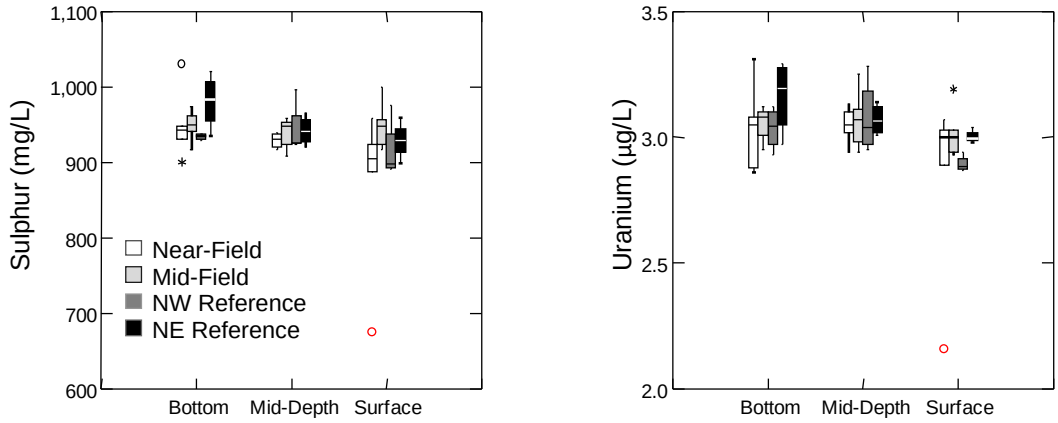

Figure 7-3 Boxplots of Water Chemistry by Area and Depth for 2016 (cont.)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles indicate values falling outside the quartile ±3 x interquartile spread. Values indicated in red identify those data that were excluded from ANOVA (see Section 7.2.2.3)..

Table 7-3 Results of ANOVA (*p*-values) Testing Differences Between Areas and Depth

	***p*-values**							
Variable	**Area**	**Depth**	**AxD**	**SR**	**BS**	**BR**	**NF vs R**	**MF vs R**
Aluminum	**<0.001*** **	0.549	0.311	0.368	**0.001*** **	0.502	0.135	0.003**
Arsenic	**0.001*** **	0.091	0.153	**0.001*** **	0.034*	0.714	0.086	**<0.001*** **
Barium	0.151	**<0.001*** **	0.703					
Boron	0.026*	0.250	0.261	0.026*	0.044*	0.758	0.456	0.003**
Calcium	0.331	0.359	0.559					
Lead	0.821	0.789	0.313					
Lithium	0.002**	0.635	0.697	0.072	**0.001*** **	0.549	0.625	**0.001*** **
Magnesium	0.147	0.180	0.721					
Molybdenum	0.701	0.002**	0.279					
Potassium	0.301	0.009**	0.519					
Sodium	0.148	0.036*	0.668					
Strontium[1]	0.004**	0.642	0.552	0.588	**0.001*** **	0.174	0.018*	0.106
Sulphur	0.266	0.056	0.503					
Uranium	0.314	0.023*	0.616					

Notes:
- 'Area' tests for differences among the four areas, overall. Additional tests were performed when significant Area differences were noted.
- 'Depth' tests for depth differences, overall.
- 'AxD' tests for differences in depth gradients among Areas.
- 'SR' tests for differences between the Study Areas and the Reference Areas.
- 'BS' tests for differences between the Near-field and the Mid-field Study Areas
- 'BR' tests for differences between the two Reference Areas.
- 'NF vs R' tests for differences between the Near-field Study Area and the Reference Areas.
- 'MF vs R' tests for differences between the Mid-field Study Area and the Reference Areas.
- Reported *p*-values for Area and Depth were from models with the interaction term removed when the interaction term was not significant.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- [1] A statistical outlier was noted for strontium (a bottom sample at Station W-5S-SW; also see Figure 7-3). Removal of this outlier changed the significance of the Area term from not-significant (Area Term $p = 0.162$) to significant (Area Term $p = 0.004$). Results presented are those with the statistical outlier excluded. Discussion on the potential relevance of this outlier is provided in the section dealing with potential produced water constituents.

As in previous years, concentrations for a number of variables were influenced by depth (significant Depth term in Table 7-3). Significant differences among Areas were noted for aluminum, arsenic, boron, lithium, and strontium. In general, results point to more frequent differences between the Mid-field Study Area and the remaining sampling Areas. Mid-field values for arsenic, boron and lithium were significantly higher than values in either the Near-field Study Area or the Reference Areas (MF vs R and significant BS contrasts, Table 7-3; Figure 7-4). Strontium values were also higher in the Mid-field compared to the Near-field Study Area (BS contrast, Table 7-3). Mid-field values for aluminum were significantly lower than in other areas (significant MF vs R and significant BS contrasts, Table 7-3, Figure 7-4).

No significant differences were noted between the Near-field Study Area and the Reference Areas for aluminum, arsenic, boron and lithium. In general, strontium levels (excluding one high outlier at station W-5S-SW) were significantly lower in the Near-field relative to the Reference Areas (Table 7-3, Figure 7-4). The outlier at station W-5S-SW is discussed in greater detail below. There was no significant difference between the two Reference Areas (BR contrast).

Although Area differences have been noted in the past, no consistent differences have been observed from 2010 to 2016. In 2010, molybdenum and sulphur concentrations differed significantly between the Study Area and the Reference Areas, with concentrations lower in the Study Area in that year (Husky Energy 2011). In 2012, barium differed significantly between the Study and Reference Areas, with concentrations higher in bottom samples in the Near- and Mid-field, and lower in mid-depth and surface samples in those two Areas compared to the Reference Areas (Husky Energy 2013). In 2014, barium concentrations were higher at mid-depth in Reference Area samples, and concentrations were higher in Near-field surface samples, relative to other samples at similar depths.

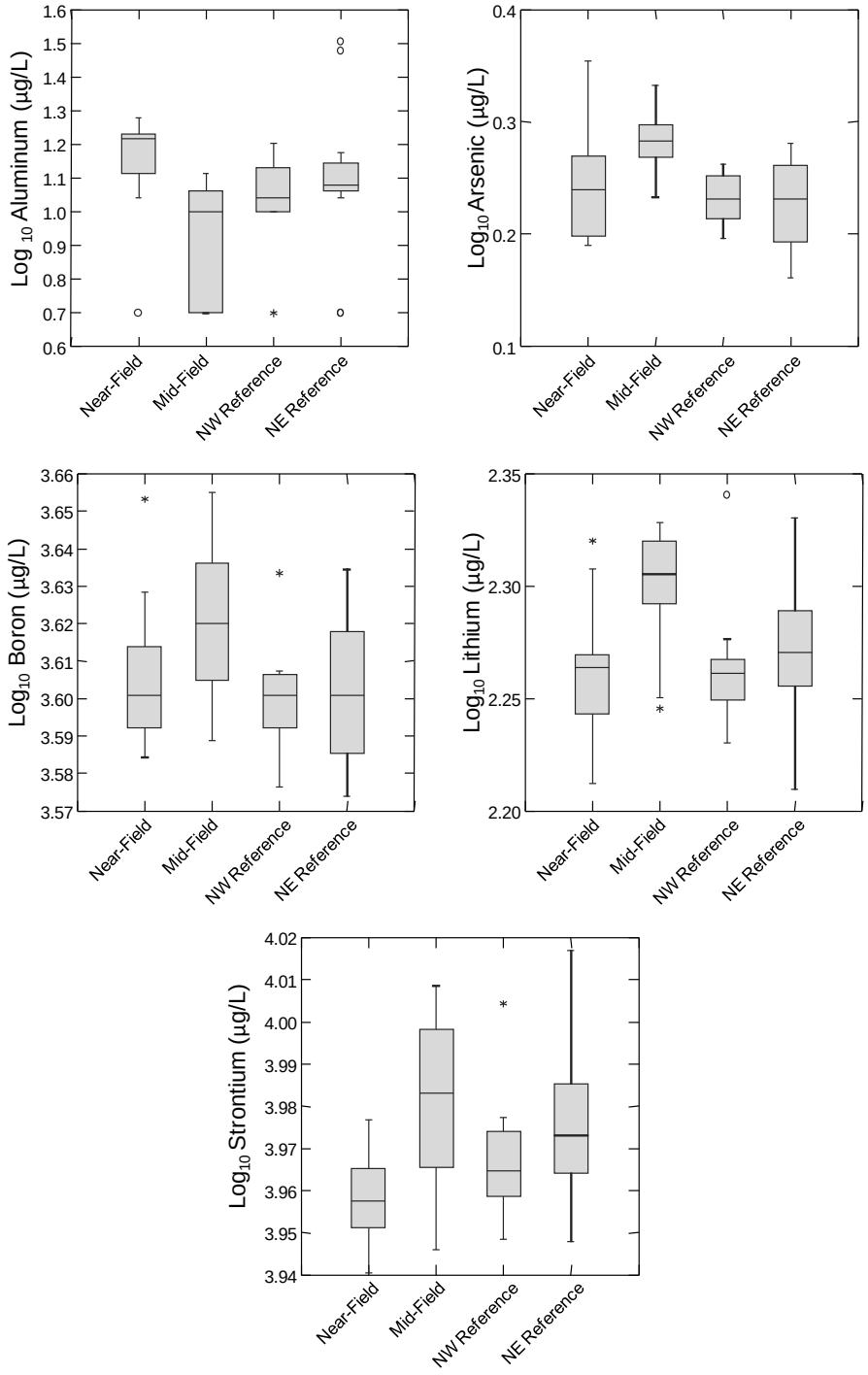

Figure 7-4 Boxplot by Area for Variables with Significant Area Differences

Notes: Plots include only the values used in ANOVA (*i.e.*, they exclude the surface sample at station W-3S-SW and the bottom sample at station W-5S-SW).
The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles indicate values falling outside the quartile ±3 x interquartile spread.

Infrequently Detected Variables

The following variables (in order of decreasing occurrence) were not included in quantitative analyses because they were detected in 1 to <75% of the samples: TSS, mercury, zinc, phosphorous, selenium, unionized ammonia, nickel, thallium, toluene, benzene, manganese, naphthalene, >C_{10}-C_{21} hydrocarbons [29], 1-Methylnaphthalene, 2-Methylnaphthalene, >C_{10}-C_{32} hydrocarbons, cadmium, chromium, copper and iron. Phenols and alkyl phenols and organic acids were not detected in any water samples.

TSS, mercury, zinc, phosphorous and selenium occurred in more than 30% of samples. Of these, selenium occurred more frequently in Study Area samples (in 80% of Mid-field Study Area Samples and 20% of Near-field Study Area samples). Mercury occurred more frequently in Reference Area samples (Figure 7-5).

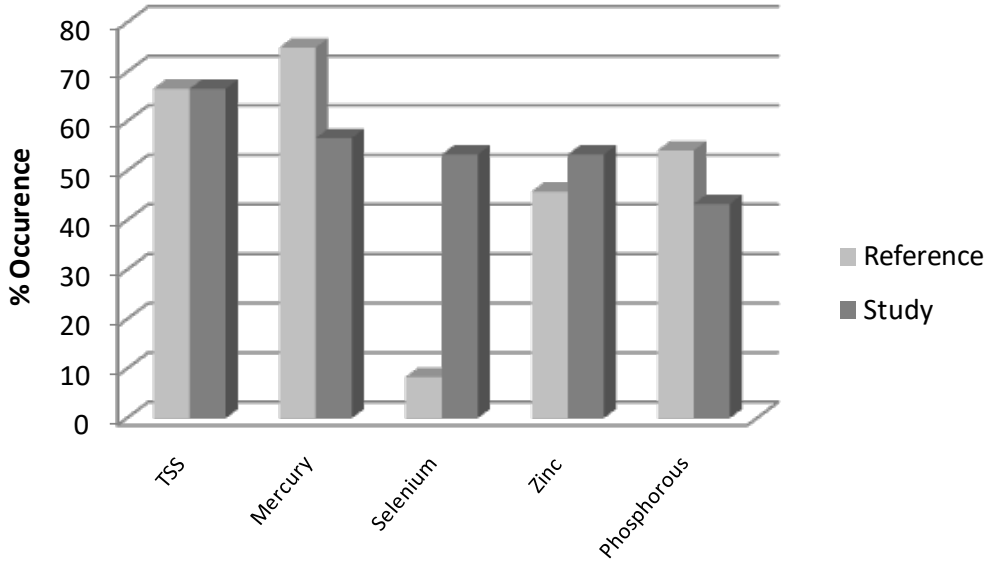

Figure 7-5 % Occurrence by Area of Variables that Occurred above Laboratory Detection Limit in 30 to <75% of Samples

Remaining variables were detected in less than 30% of samples (*i.e.*, 1 to 8, or very few, samples). Of these, benzene, toluene, naphthalene, 1- and 2-Methylnaphthalene, copper and iron were detected more frequently in the Study Area (with all occurrences in the Near-field Study Area); unionized ammonia, manganese, thallium, >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons, cadmium and chromium were detected more frequently in Reference Area samples (Figure 7-6).

[29] Appendix D-2 reports the hydrocarbon ranges >C_{10}-C_{16} and >C_{16}-C_{21}. Results for >C_{10}-C_{21} hydrocarbons are the sum of these two ranges.

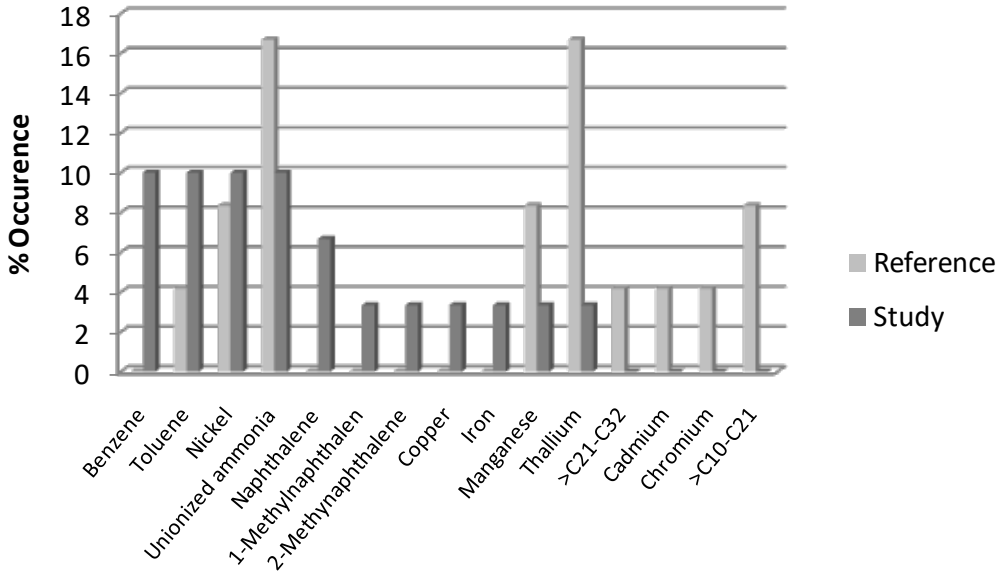

Figure 7-6 % Occurrence by Area of Variables that Occurred above Laboratory Detection Limit in 1 to <30% of Samples

Produced Water Constituents

This section examines data specifically in relation to produced water constituents and provides information at the level of stations. Previous sections examined Area differences in general.

Examination of seawater and produced water chemistry indicates that the following variables could be enriched in seawater as a result of produced water discharge: benzene, toluene, naphthalene, 1- and 2-methylnaphthalene, iron, ammonia[30], barium, manganese, nickel, thallium, zinc, lithium and strontium. This is based on observed concentrations in produced water that were more than 10 times those noted in reference area seawater; and excludes those variables that were not detected in either the Near- or Mid-field Study Areas.

The naphthalene, 1- and 2-methylnaphthalene, benzene and toluene were detected in the surface sample at Station W-5S-SW. Naphthalene, benzene and toluene were also detected in the surface sample at Station W-4S-SW, and benzene and toluene were detected in the surface sample at Station W-3S-SW[31]. As these stations were down-current of the *SeaRose FPSO*, it is possible that these constituents originated from produced water. However, toluene was also detected in the Reference Area, at station 4, at mid-depth. All concentrations were low, but the highest concentrations were generally noted in the surface sample at Station W-5S-SW (Appendix D-2).

[30] Total ammonia rather than unionized ammonia is examined in the section because estimates of unionized ammonia would be irrelevant for produced water, since pH and temperature would affect the relative concentration of unionized ammonia immediately on release to seawater. Unionized ammonia is examined in remaining sections, as it is more toxic to aquatic organisms (EPA 1998).

[31] The surface sample from Station W-3S-SW was removed from statistical analysis in previous sections because of the potential influence of rain water.

Of the remaining variables expected to be enriched by the addition of produced water, one notably high level of zinc (16.7 µg/L versus all other values less than 7 µg/L) was detected in the surface sample of station W-5S-SW; iron was detected in a mid-depth sample at station W-4S-SW and not elsewhere; and the highest strontium concentration was noted in the bottom sample at Station W-5S-SW (this value was also identified as a statistical outlier in ANOVA). These three findings support the idea that produced water constituents were detected at Near-field stations.

There was no clear pattern to the concentrations of remaining constituents that could be enriched by the addition of produced water (Appendix D-2). Ammonia was only detected at seven stations (four in the NW Reference Area and three in the Study Areas), with the highest concentrations in the NW Reference Area. Barium was detected in all samples and varied in concentration over a narrow range (5.5 to 8.4 µg/L), with no obvious pattern of higher concentration in the Study Areas. Lithium ranged in concentration from 130 µg/L to 219 µg/L, with higher concentrations (over 200 µg/L) occurring more frequently in the Mid-field Study Area (11 out of 16 samples were from the Mid-field Study Area). Manganese was only detected in three samples at levels near detection limit (0.50 µg/L); at two Reference Area stations and one Near-field station. Low levels of nickel were only detected in five samples; at two Reference Area stations and three Study Area stations. Low levels of thallium were detected in five samples; in four Reference Area samples and on Study Area sample.

7.3 Sediment

7.3.1 Modelling Study

Full model results predicting the concentration of selected produced water constituents in sediments were provided as part of the 2012 EEM report (Husky Energy 2013).

7.3.1.1 Constituent Selection

Concentrations of produced water constituents from the *SeaRose FPSO* were compared to concentrations in marine sediments around White Rose to identify those constituents that could settle to sediments at sufficiently high concentrations to act as tracers. Based on this, accumulation of Ra-228 was modelled, with results applicable to other potential tracers in produced water (see Husky Energy 2013 for details).

7.3.1.2 Conclusions and Recommendations

The following conclusions were drawn from the modelling study:

- Radium radionuclides are not expected to be effective tracers of produced water constituents in sediments[32].
- Close attention should be paid to any increase in iron concentrations in sediments, particularly to the south, since modelling showed that deposition of constituents likely would be greater to the south of the *SeaRose FPSO*.

[32] Based on this, the collection and examination of sediment radionuclide data as a potential tracer for produced water was discontinued.

7.3.2 Field Sampling

7.3.2.1 Sediment Sample Collection and Laboratory Processing

Sediment collection and laboratory processing are described in Section 5. In addition to the sediment stations sampled as part of the Sediment Quality component of the EEM program (*i.e.*, Sediment Quality Triad stations), one sediment core was also collected for chemistry analysis at those stations sampled for water (Figure 7-1).

7.3.2.2 Data Analysis

Quantitative analysis of sediment data for the Water Quality portion of the White Rose EEM program focuses on iron concentration in sediments, as per recommendations in Section 7.3.1.2. Quantitative analyses on other sediment quality variables at Sediment Quality Triad stations are provided in Section 5.

The following procedures were used to determine if iron concentrations in sediments were associated with releases from the *SeaRose FPSO*. The analysis was carried out in four main steps. First, correlations between iron concentrations in sediments and distance to the *SeaRose FPSO* were computed for each year. Plots of the Spearman rank correlations over time were produced to make it easier to visualize changes in the strength of the distance relationship. The second step involved the production of scatterplots of iron concentrations in relation to distance from the *SeaRose FPSO*, for each year of the program. The third step involved maps of iron concentration in 2016 relative to baseline concentration to better visualize the full spatial distribution of iron. The fourth step involved the use of repeated-measures regression to test for changes in mean iron concentrations across the sampling area from before (2000, 2004, 2005, 2006) to after (2008, 2010, 2012, 2014, and 2016) discharge from the *SeaRose FPSO*. As was the case in Section 5, repeated-measures regression involved only those stations sampled repeatedly over all years (n = 36).

Iron tends to covary with other metals in the sampling area. There was some concern that the background variations in metals concentrations might mask variations in iron that were due to discharge from the *SeaRose FPSO*. A two-step procedure was conducted to create a measure of iron concentrations that was independent of the concentrations of other metals. Principal components analysis (PCA) was carried out in the first step using logged concentrations of aluminum, barium, chromium, lead, manganese, strontium, uranium and vanadium. The PCA axis scores were used as summary measures of overall metals concentrations in the sediments, similar to what has been done in the assessment of metals concentrations in relation to active drill centres (Section 5). Residuals from regression of iron concentrations ($\log_{10}$) on PCA axis scores can be considered to be representative of variations in iron that are independent of concentrations of other metals. The second step was regression of iron on PCA axis scores. Residuals of iron were then examined using Spearman rank correlations, scatterplots, maps and repeated-measures regression, similar to what was done with concentrations of iron.

7.3.2.3 Results

Summary statistics for sediment physical and chemical characteristics at Water Quality stations are provided in Appendix D-2. Raw data for sediment physical and chemical characteristics at all sediment stations (Sediment Quality Triad and Water Quality stations) are provided in Appendix B. Sediment chemistry results at Water Quality stations were qualitatively similar to results at Sediment Quality Triad stations, with aluminum, barium, iron, lead, manganese, strontium, uranium and vanadium detected at every station[33]. In 2014, a low-level of one PAH (dibenzo(*a,h*)anthracene; 0.06 mg/kg) was detected in sediments at station W-15R (a reference station), located approximately 28 km from the *SeaRose FPSO*. In 2012, low levels of 15 PAHs were detected at station W-2SE, located 0.32 km from the *SeaRose FPSO*. In 2010, low levels of four PAHs were detected at Station 16[34], located 0.74 km from the *SeaRose FPSO*. Otherwise, PAHs have not been detected in White Rose sediments in other EEM years.

Principal Components Analysis

All metals were strongly associated (*i.e.*, $r_P > |0.6|$) with scores on the first PCA axis (Table 7-4). Therefore, the first PCA axis was a good summary of overall concentrations of metals. Barium concentrations correlated strongly with both the first and second PCA axes; therefore, the second axis was a summary of variations in barium that were independent of variations in overall metals concentrations. Barium is examined in detail in Section 5. Residuals of iron concentrations (log_{10}) were obtained from regression against scores on the first PCA axis.

Table 7-4 Principal Component Analysis Component Loadings (Correlations) of Metals Concentrations (All Years)

Parameter	Principal Component	
	1	2
Aluminum	**0.790**	0.134
Barium	**0.636**	**-0.655**
Chromium	**0.631**	0.357
Lead	**0.709**	-0.560
Manganese	**0.726**	0.492
Strontium	**0.870**	-0.406
Uranium	**0.658**	0.225
Vanadium	**0.775**	0.427
Variance Explained	53.1	19.1

Note: - **Bold** indicates component loading (correlation) greater than 0.6 or -0.6.

Spearman Rank Correlations

Spearman rank correlations for iron in relation to distance to the *SeaRose FPSO*, and for iron residuals, for all years, are illustrated in Figures 7-7 and 7-8. Spearman rank correlations were not significant for iron in 2016 (ρ_S = -0.108, $p > 0.05$, All stations; ρ_S = -0.261, $p > 0.05$, repeated-measures stations). Rank correlations were not significant for iron in any year (Figure 7-7).

[33] Two stations, 4 and 27, were common to both the Sediment Quality and the Water Quality programs from 2012 to 2016. Four stations, 4, 8, 16 and 27, were common to both the Sediment Quality and the Water Quality programs in 2010. Therefore, summary statistics for these sets of stations are not fully independent.
[34] In 2010, station 16 acted as both an Sediment Quality Triad and a Water Quality station. Therefore, those PAHs are in summary statistics for both Sediment Quality Triad and Water Quality stations.

Similarly, rank correlations were not significant for iron residuals when all stations or repeated-measures stations were considered in 2016 (ρ_s = 0.006, p > 0.05, All stations; ρ_s = 0.06, p > 0.05, repeated-measures stations; Figure 7-8).

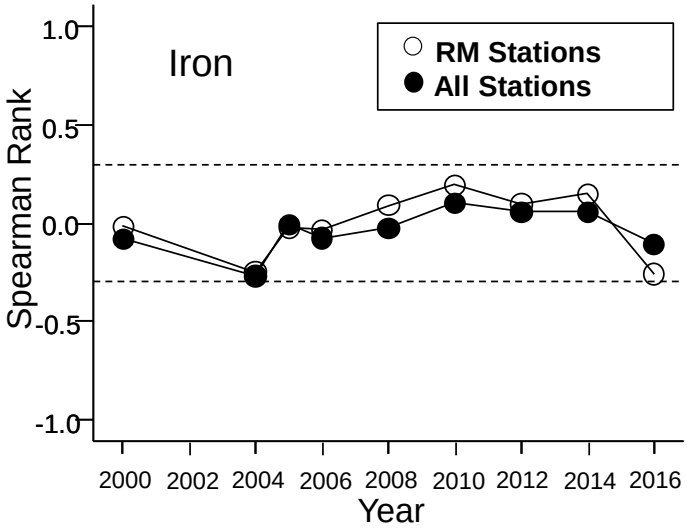

Figure 7-7 Spearman Rank Correlations with Distance from *SeaRose FPSO* for Iron Concentrations in Sediments

Notes: Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year (n = 36 for repeated-measures (RM) stations, and varies from 44 to 69 depending on EEM year for all stations).

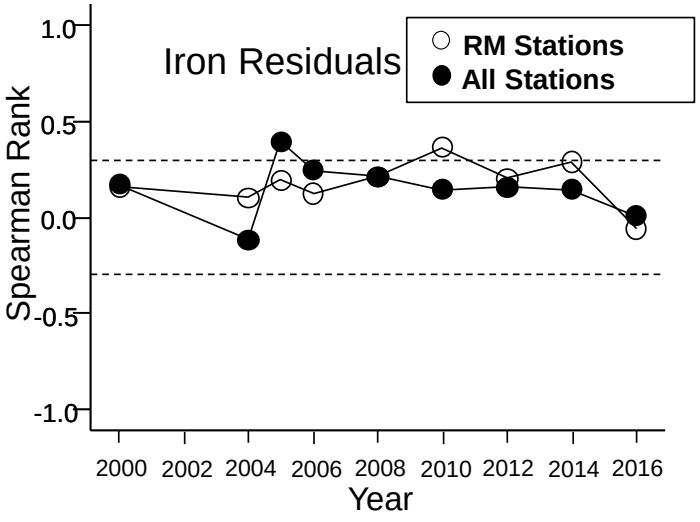

Figure 7-8 Spearman Rank Correlations with Distance from the *SeaRose FPSO* for Iron Residuals

Notes: Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year (n = 36 for repeated-measures (RM) stations, and varies from 44 to 69 depending on EEM year for all stations).

Scatterplots

The relationships between iron concentrations and iron residuals and distance to the *SeaRose FPSO* are illustrated in the Figures 7-9 and 7-10. The plots indicate no increase in iron concentrations in sediments near the *SeaRose FPSO*.

Maps

Maps of stations with iron and iron residuals within and above the baseline background range are provided in Figures 7-11 and 7-12. Iron concentrations in Figure 7-11 are not corrected for the natural association between iron and other metals, and metals concentrations are elevated at the Northeast Reference Area. Those four stations are deeper than remaining stations and this could reflect a natural tendency for metals to increase with depth. The map of iron residuals (Figure 7-12), which would correct for the natural association among metals, does not show high iron at those four stations, relative to concentrations of other metals.

In 2012, there was a tendency for higher iron residuals between 5 and 10 km from the *SeaRose FPSO*, with more frequent enrichment to the south of the *SeaRose FPSO* (Husky Energy 2013). This increase in iron residuals between 5 and 10 km from the *SeaRose FPSO* was less apparent in 2014, but higher iron residual values did tend to occur more frequently to the northwest of the *SeaRose FPSO* (Husky Energy 2017). In 2016, this trend continued within 2 and 10 km of the *SeaRose FPSO*, predominantly to the east and southeast (Figure 7-12).

Repeated-Measures Regression

Results of repeated-measures regression are provided in Table 7-5. For repeated-measures stations, there were no significant differences in slopes of the relations between iron or iron residuals and distance to the *SeaRose FPSO* from before to after produced water discharge began at the *SeaRose FPSO* (in March 2007). There has been a significant increase in sediment iron concentrations in the sampling area from before to after produced water discharge began at the *SeaRose FPSO* (p = 0.011). Figure 7-13 indicates higher levels predominantly in 2008 and 2010. There was no change in mean iron residuals from before to after discharge began (p = 0.131), although Figure 7-14 does indicate higher levels in 2010.

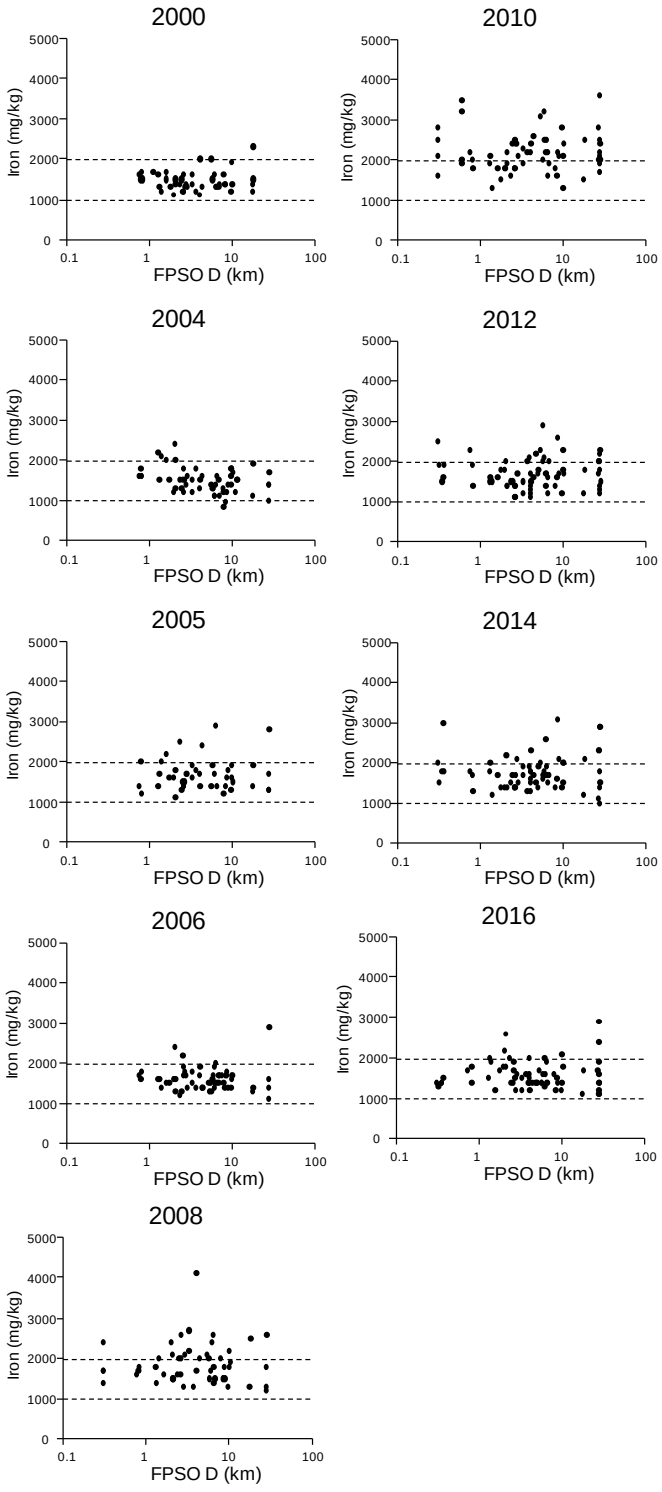

Figure 7-9 Variation in Iron Concentrations in Sediments (mg/kg) with Distance from the *SeaRose FP*SO (all Years)

Notes: *SeaRose FPSO* D = distance (km) to the *SeaRose FPSO*. Background iron concentrations are indicated by horizontal lines (992 mg/kg and 1,970 mg/kg, respectively), based on the mean values ± 2 SDs from 2000 (baseline).

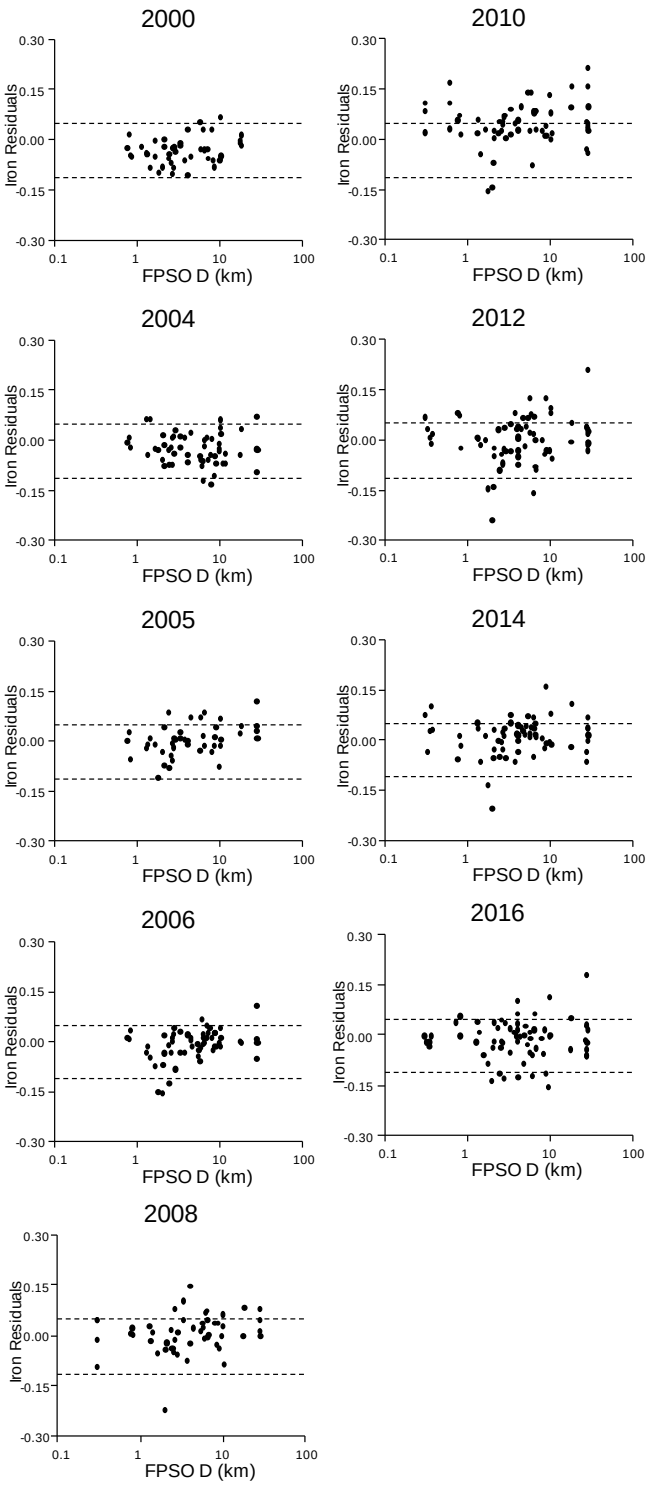

Figure 7-10 Variation in Iron Residuals with Distance from the *SeaRose FPSO* (all Years)

Notes: *SeaRose FPSO* D = distance (km) to the *SeaRose FPSO*. Background iron residuals are indicated by horizontal lines (-0.113 and 0.047, respectively), based on the mean values ± 2 SDs from 2000 (baseline).

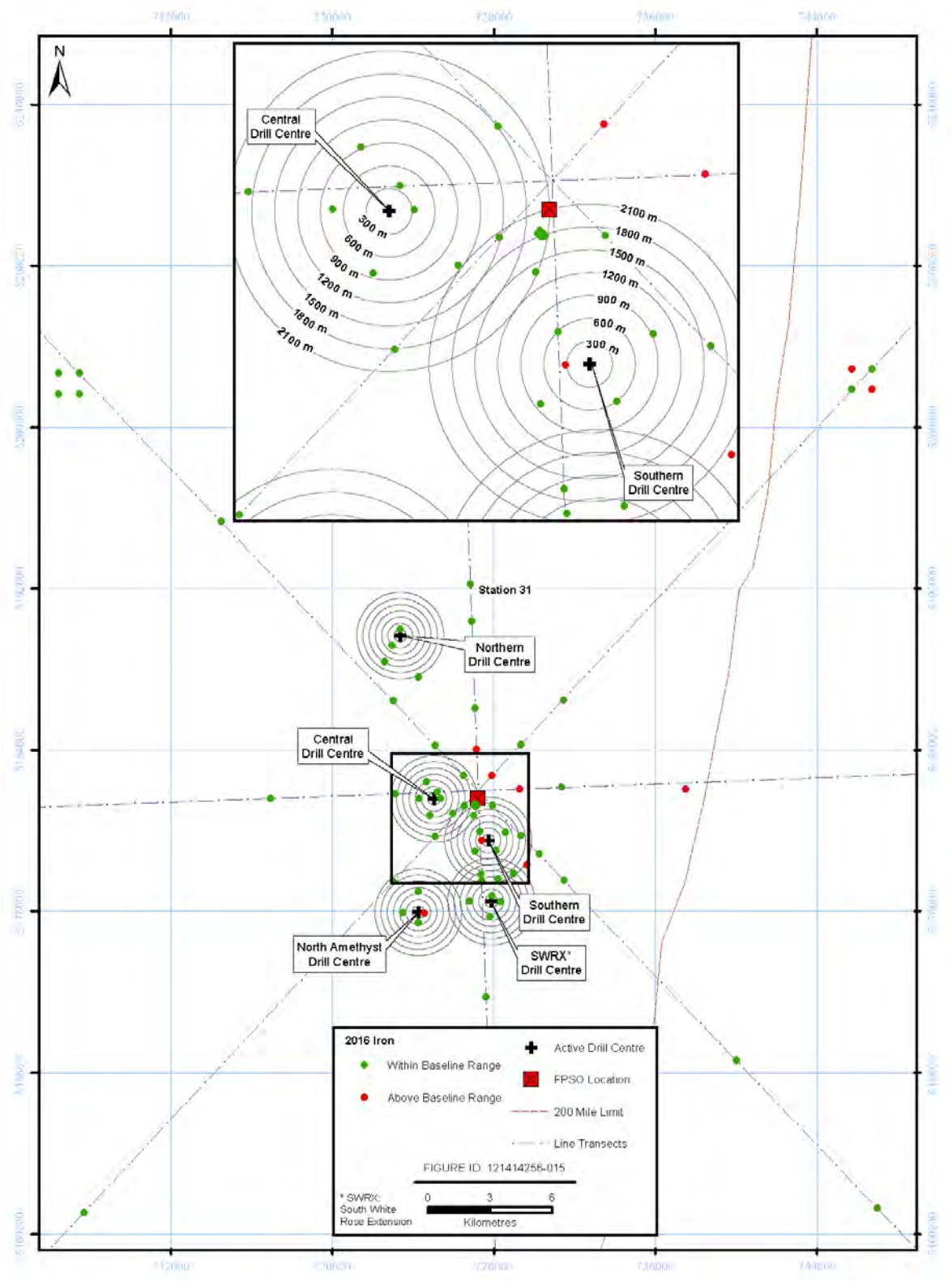

Figure 7-11 Location of Stations with Iron Concentrations Within and Above the Baseline Range (2016)

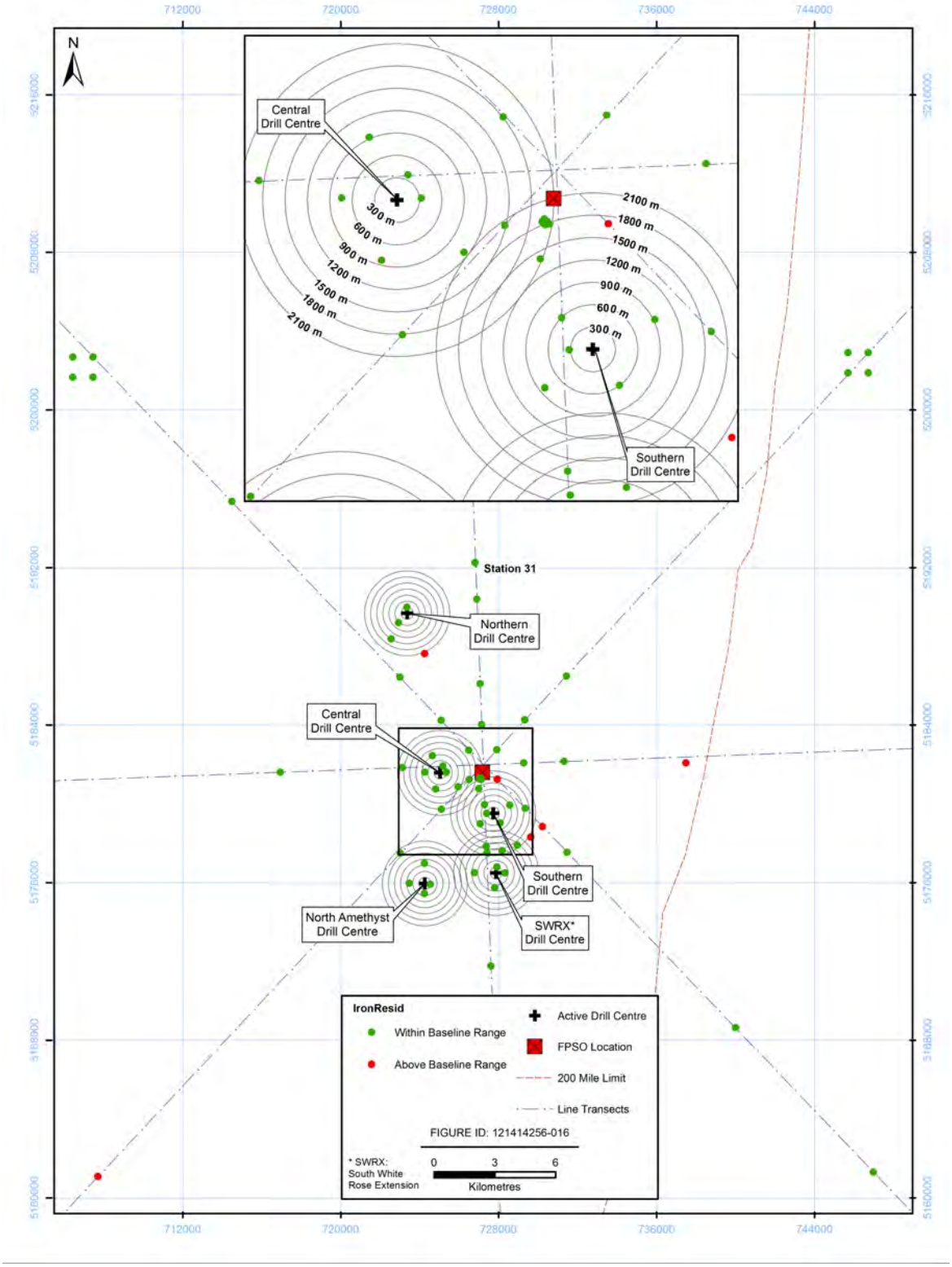

Figure 7-12 Location of Stations with Iron Residuals Within and Above the Baseline Range (2016)

Table 7-5 Repeated-measures Regression Testing for Changes in Iron Concentrations, and Iron Residuals over Time

Variable	Change in Slope from Before to After	Change in Mean from Before to After
Iron	0.276	0.011
Iron Residuals	0.396	0.131

Notes: - Values are probabilities.
- n = 36

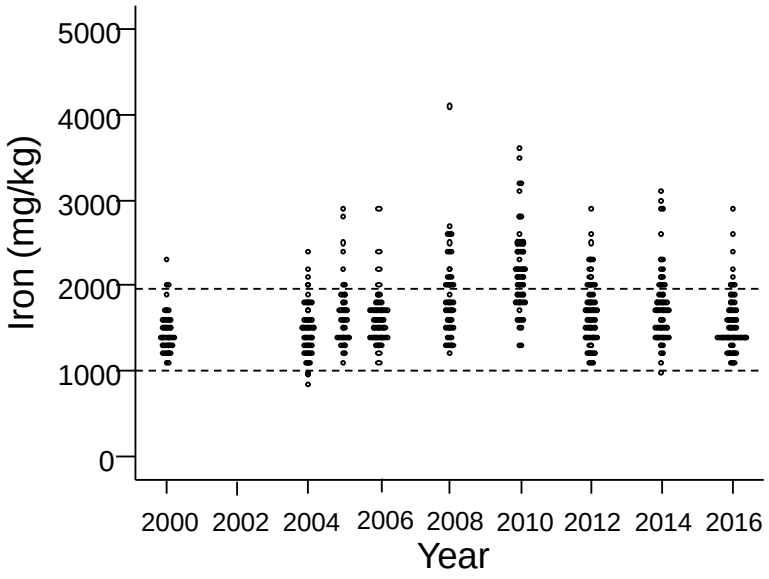

Figure 7-13 Dot Density Plot of Iron Concentrations in Sediments (mg/kg) by Year

Note: Background iron concentrations are indicated by horizontal lines (992 mg/kg and 1,970 mg/kg, respectively), based on the mean values ± 2 SDs using data from 2000.

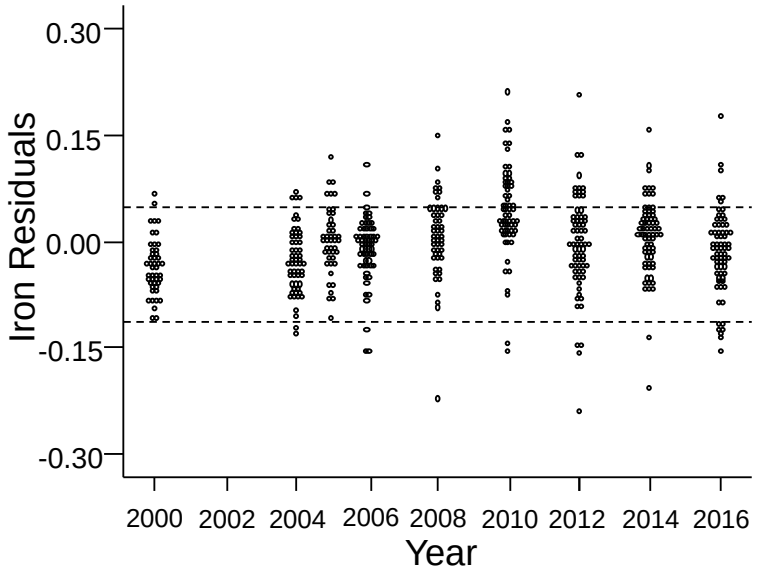

Figure 7-14 Dot Density Plot of Iron Residuals by Year

Note: Background iron residuals are indicated by horizontal lines (-0.113 and 0.047, respectively), based on the mean values ± 2 SDs using data from 2000.

From Figures 7-13 and 7-14 and analyses above, evidence of enrichment of iron in sediments is weak and, change, if any, since the release of produced water has been subtle.

7.4 Summary of Results

7.4.1 Water

The following variables were detected in all seawater samples: arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, potassium, sodium, strontium, sulphur, uranium and TIC. Aluminum and lead were above detection limit in 80% of samples. With the exception of TIC, which varied over the narrow range of 27 and 29 mg/L, all these variables were included in quantitative analyses for 2016. The remaining variables were detected in 1% to 75% of the samples and were therefore not included in the quantitative analyses. Phenols and alkyl phenols and organic acids were not detected in any water samples.

Significant differences among sampling Areas (Near-field, Mid-field and NE and NW Reference Areas) were noted for aluminum, arsenic, boron, lithium and strontium. In general, results pointed to more frequent differences between the Mid-field Study Area and the remaining sampling Areas. Mid-field values for arsenic, boron and lithium were significantly higher than values in either the Near-field Study Area or the Reference Areas. Strontium values were also generally higher in the Mid-field, but the difference was only significant between the two Study Areas. Mid-field values for aluminum were significantly lower than in other areas. Although not analyzed quantitatively because of low occurrence, selenium occurred relatively frequently (in more than 30% of samples) and it occurred more frequently in Mid-field Study Area samples than in remaining Areas.

Other than these differences in the Mid-field, strontium was generally lower (excluding one outlier) in the Near-field relative to the Reference Areas. Mercury, also not analyzed quantitatively because of intermediate (30 to 75%) occurrence, occurred more frequently in Reference Area samples.

Differences among Areas were generally small. Values in the Mid-field Study Area were generally within the range of values in remaining Areas (Table 7-6). Excluding one high outlier for strontium in the Study Area (11,400 μg/L), concentrations ranged from 8,720 to 9480 μg/L (median = 9,070 /L) in the Study Areas and from 8,870 to 10,400 μg/L (median = 9,310 μg/L) in the Reference Areas. Mercury levels ranged from <0.013 to 0.032 (median = 0.013) in the Study Areas and from <0.013 to 0.035 (median = 0.027) in the Reference Areas.

Table 7-6 Summary Statistics for Selected Variables in the Mid-field Versus Remaining Areas

Variable	Mid-field Study Area (µg/L)			Remaining Areas (µg/L)		
	Minimum	Maximum	Median	Minimum	Maximum	Median
Aluminum	<10	13	10	<10	32	12.5
Arsenic	1.7	2.2	1.9	1.5	2.3	1.7
Boron	3,880	4,520	4,170	3750	4,500	3,990
Lithium	176	213	202	162	219	184
Selenium	<0.5	1.3	0.8	<0.5	0.9	<0.5
Strontium	8,830	10,200	9,620	8,830	10,400	9,230

Note: - 'Outliers that were noted and removed in ANOVA were removed from calculations of summary statistics in this table. This was done because this table is provided to further explain ANOVA results.

Produced water constituents (specifically: naphthalene, 1- and 2-methylnaphthalene, benzene, toluene, zinc, iron and strontium) may have been detected at some Near-field stations (stations W-3S-SW, W-4S-SW and W-5S-SW) located 300 m down-current from the *SeaRose FPSO*. If correct, results are consistent with modelling that predicted that naphthalene would likely be a good indicator of the presence of produced water in seawater.

7.4.2 Sediment

Modelling results indicated that iron concentrations could potentially be enriched in sediments (Husky Energy 2013). In 2016, there was a tendency for iron enrichment to the east and southeast of the *SeaRose FPSO.* As in previous years, there was also some indication of an increase in iron since produced water discharge began at the *SeaRose FPSO*. At present, the link between iron enrichment in sediments and produced water release from the *SeaRose FPSO* remains weak.

8.0 Discussion

8.1 Sediment Quality Component

Examination of sediment quality is standard in many EEM programs (*e.g.*, Hurley and Ellis (2004); Bjørgesaeter and Gray (2008); Netto *et al.* (2009); Pozebon *et al.* (2009); Santos *et al.* (2009)). The White Rose EEM program examines potential project effects on sediment chemistry, sediment toxicity and benthic community structure. These three sets of measurements are collectively known as the Sediment Quality Triad (Chapman 1992). The assessment of effects at White Rose is based on the change in relationships between Sediment Quality Triad variables and distance from the development. Distance to the nearest drill centre is used to assess drilling effects at the whole-field level. Occurrence above or below the range of values observed during baseline sampling (2000) is used to assess effects from individual drill centres.

8.1.1 Physical and Chemical Characteristics

Hydrocarbons in the $>C_{10}$-C_{21} range and barium in sediments were influenced by drilling operations in 2016, with concentrations elevated up to estimated threshold distances[35] of 2.7 and 1.2 km from the nearest active drill centre, respectively. Significant threshold distances have been detected for $>C_{10}$-C_{21} hydrocarbons and barium in all years since drilling began. The threshold distance for $>C_{10}$-C_{21} hydrocarbons has varied from 5.9 to 10.4 km from 2004 to 2008, and from 2.7 to 5.8 km from 2010 to 2016. Generally, 95% confidence intervals for $>C_{10}$-C_{21} hydrocarbon threshold estimates overlapped. However, confidence intervals for the 2016 estimate did not overlap with those of estimates from 2004 to 2008, indicating a significant reduction in threshold distance in 2016 compared to those earlier years. The threshold distances for barium also tended to be greater in earlier EEM years; 2 to 3.6 km from 2004 to 2010 versus approximately 1 km since 2012; although in this case, the 95% confidence interval for the 2016 estimate overlapped with those from all previous years except 2005.

The maximum $>C_{10}$-C_{21} hydrocarbon concentration in 2016 was 150 mg/kg (at station 20, located 0.37 km from the Central Drill Centre) and the maximum barium concentration was 2,400 mg/kg (at station NA1, located 0.29 km from the North Amethyst Drill Centre). The maximum $>C_{10}$-C_{21} hydrocarbon concentration in 2016 was similar to that noted in 2014 (120 mg/kg). The maximum for barium was higher than in 2014 (1,400 mg/kg), but similar to or lower than levels noted in most other EEM years. Elevated concentrations of hydrocarbons and barium are expected near drill centres at offshore oil developments; examples of concentrations at White Rose and at other developments are provided in Table 8-1. Levels of hydrocarbons and barium at White Rose were within the ranges noted from other projects and are among the lowest values of any of the listed project examples (Table 8-1).

[35] *i.e.*, the distance at which values return to background values.

Table 8-1 Total Petroleum Hydrocarbons and Barium with Distance from Source at White Rose and at Other Developments

Location	Year of Study	Distance from Source (m)	TPH (mg/kg)	Barium (mg/kg)
White Rose	2016	300 to 750	1.2 to 153	150 to 2400
		750 to 2,500	1.03 to 23.3	150 to 590
		2,500 to 5,000	0.73 to 2.0	140 to 180
	2014	300 to 750	<0.3 to 120	140 to 1,400
		750 to 2,500	0.45 to 21	150 to 560
		2,500 to 5,000	<0.3 to 17	160 to 790
	2012	300 to 750	<0.3 to 527	110 to 4,000
		750 to 2,500	0.86 to 21.10	140 to 450
		2,500 to 5,000	<0.3 to 3.18	140 to 210
	2010	300 to 750	9.9 to 819	250 to 2,700
		750 to 2,500	0.5 to 11.40	160 to 480
		2,500 to 5,000	0.4 to 1.40	160 to 200
	2008	300 to 750	2.2 to 1,615	170 to 3,400
		750 to 2,500	1.3 to 55.7	160 to 600
		2,500 to 5,000	<0.3 to 4.2	160 to 210
	2006	300 to 750	1.5 to 576	200 to 3,100
		750 to 2,500	0.7 to 53.4	150 to 770
		2,500 to 5,000	<3	140 to 250
	2005	300 to 750	<3 to 261.7	210 to 810
		750 to 2,500	<3 to 54.6	140 to 380
		2,500 to 5,000	<3	150 to 220
	2004	300 to 750	8.99 to 275.9	190 to 1,400
		750 to 2,500	<3 to 22.2	120 to 470
		2,500 to 5,000	<3 to 6.9	140 to 230
	2000	300 to 750	<3	140 to 180
		750 to 2,500	<3	140 to 210
		2,500 to 5,000	<3	150 to 210
Grand Banks, Terra Nova (Suncor Energy 1998, 2001, 2002, 2003, 2005, 2007, 2009, 2011, 2013)	2012	140 to 750	<3 to 310	140 to 4,900
		750 to 2,500	<3 to 7.5	72 to 330
		2,500 to 5,000	<3	82 to 200
	2010	140 to 750	<3 to 767	130 to 4,200
		750 to 2,500	<3 to 339	87 to 420
		2,500 to 5,000	<3	69 to 160
	2008	140 to 750	<3 to 343	130 to 7,200
		750 to 2,500	<3 to 11	89 to 280
		2,500 to 5,000	<3	78 to 210
	2006	140 to 750	8 to 986	240 to 16,000
		750 to 2,500	<3 to 30	110 to 340
		2,500 to 5,000	<3	89 to 230
	2004	140 to 750	8 to 6,580	140 to 2,100
		750 to 2,500	3 to 72	100 to 340
		2,500 to 5,000	<3 to 4	63 to 190
	2002	140 to 750	<3 to 931	110 to 2,200
		750 to 2,500	<3 to 49	84 to 330
		2,500 to 5,000	<3 to 5	83 to 200
	2001	750 to 2,500	<3 to 30	100 to 190
		2,500 to 5,000	<3 to 8	87 to 180
	2000	750 to 2,500	<3 to 14	92 to 210
		2,500 to 5,000	<3 to 6	80 to 230
	1997	750 to 2,500	<3	87 to 190
		2,500 to 5,000	<3	79 to 280

Location	Year of Study	Distance from Source (m)	TPH (mg/kg)	Barium (mg/kg)
Gulf of Mexico (NPO-895) (Candler *et al.* 1995)	1993	50 200 2,000	134,428 80 to 11,460 24	47,437 542 to 5,641
Gulf of Mexico (MAI-686) (Kennicutt *et al.* 1996)	1993	200 500 3,000	40 43 49	1,625 1,134 1,072
Gulf of Mexico (MU-A85) (Kennicutt *et al.* 1996)	1993	200 500 3,000	42.3 31.7 27.1	3,706 1,817 1,094
Gulf of Mexico (HI-A389) (Kennicutt *et al.* 1996)	1993	200 500 3,000	65 33 32	13,756 3,993 1,293
North Sea (Beatrice) (Addy *et al.* 1984)	1982	250 750 3,000	8 to 759 5 to 105 3 to 73	-
Dutch Continental Shelf (K14-13) (Daan and Mulder 1996)		200	54 to 161	-
North Sea (Daan *et al.* 1994)	1994	200	2 to 4,700	
Norway (Valhall) (Hartley 1996)	1985	250 500 3,000	-	19,000 to 96,000 3,700 to 9,300 280 to 430
North Sea (Brent) (Massie *et al.* 1985)	1981	800 3,200	41 to 61 33 to 43	-
North Sea (Forties) (Massie *et al.* 1985)	1980	800 3,200	9 to 78 16 to 55	-
Gulf of Mexico (Matagorda 622) (Chapman *et al.* 1991; Brooks *et al.* 1990)	1987	25 150 750 3,000	757 ±1,818	6,233 12,333 980
Santa Maria Basin (Hidalgo) (Phillips *et al.* 1998)	1991	125 500 1,000	-	1,250 975 1,050
Norway (Ekofisk) (Ellis and Schneider 1997)	1996	750 2,000 5,000	-	3,650 2,214 667
Norway (Gyda 2/1-9) (Bakke *et al.* 1995)	1994	100 to 200	236	-
Norway (Tordis) (Gjøs *et al.* 1991)	1990	500	8,920	-
Norway (U/a 2/7-29) (Vik *et al.* 1996)		200	1,000 to 2,368	-
North Sea (UK) (UKOOA 2001)	1975 to 1995	0 to 500 >500 to 2,000 >2,000 to 5,000	124 to 11,983 3 to 164 3 to 76	84 to 2,040 7 to 1595 8 to 729

Note:
- TPH (total petroleum hydrocarbon) includes C_6-C_{32} hydrocarbons. This range is reported for comparison to other offshore operations.
- Absolute barium levels should not be compared across projects because of potential differences in measurement techniques (Hartley 1996) and differences in background levels.
- Distance for White Rose in 2016 is distance to nearest of the Northern, Central, Southern, North Amethyst and South White Rose Extension Drill Centres. Distance for White Rose in 2010 and 2012 is distance to nearest of the Northern, Central, Southern and North Amethyst Drill Centres. Distance in 2000, 2005, 2006 and 2008 is distance to nearest of the Northern, Central and Southern Drill Centres. Distance in 2004 is distance to the nearest of the Northern and Southern Drill Centres.
- Station 31 at White Rose, near an exploration well drilled in 2007, was excluded from 2008, 2010, 2012, 2014 and 2016 statistics.

In 2016, project-related effects on sediment lead concentrations were noted, with levels elevated to 1.4 km from drill centres. Project-effects on lead have been noted since 2006; confidence intervals about the 2016 estimate overlapped with those of previous years, and threshold distances have consistently been approximately 1 km. In 2016, the maximum lead concentration near drill centres (8 mg/kg) was noted at station 20, located 0.37 km from the Central Drill Centre [36]. Over all years, sediment lead concentrations have ranged from 1.6 mg/kg to 26 mg/kg, and all concentrations have been below the ISQG of 32 mg/kg. Based on ISQG, lead concentrations noted at White Rose would not be expected to induce biological effects.

Remaining sediment chemical and physical characteristics showed either no or subtle project-related effects. Strontium and sulphide levels were elevated to approximately 1 km from drill centres in 2016. Threshold relationships have been significant for these two variables in 2006, 2008 and, for strontium, in 2012, but they were not significant in 2016. In 2016, the maximum for strontium (92 mg/kg) occurred at station NA1, located 0.29 km from the North Amethyst Drill Centre. The maximum for sulphides (3.57 mg/kg) occurred at station S1 located 0.6 km from the Southern Drill Centre. Over all years, sediment strontium and sulphide concentrations respectively have ranged from 25 to 170 mg/kg and from 0 to 86.9 mg/kg.

There was an indication that sediment sulphur and fines content were elevated in the immediate vicinity of (0.5 km from) drill centres, as in some previous EEM years. In 2016, the maximum sulphur concentration (0.11 mg/kg) occurred at station 20, located 0.37 km from the Central Drill Centre. The maximum fines concentration (3.2%) occurred at station NA1, located 0.29 km from the North Amethyst Drill Centre. Over all years, sediment sulphur and fines concentrations have ranged up to 0.290 mg/kg and 3.7%, respectively.

There was no evidence of project-related effects for sediment gravel and redox potential, ammonia, TOC and metals other than barium, lead and strontium.

8.1.2 Laboratory Toxicity Tests

Sediments were generally non-toxic in 2016. Two (of 53) samples, from stations 20 and 31 were toxic to Microtox. Sediment concentrations of $>C_{10}$-C_{21} hydrocarbons, barium, sulphur and strontium were elevated above baseline or background levels at the two stations that were toxic to Microtox. Lead was also elevated at station 20. As noted previously, station 20 is located 0.37 km from the Central Drill Centre. Station 31 is located near the site of exploration drilling that occurred in 2007 – White Rose K-03. Together, these findings point to effects on Microtox at two stations; although only one station (station 20) was affected by the White Rose development. Station 31 was predominantly affected by discharges from delineation drilling that occurred there in 2007[37].

[36] A high lead value (11 mg/kg) was also noted at station 6 located more than 4 km from a drill centre.

[37] Delineation drilling effects and effects from the White Rose development at Station 31 cannot be fully decoupled. However, since the station is 0.4 km from the site of delineation drilling and more than 4 km away from White Rose drill centres, it is reasonable to conclude that it is predominantly influenced by delineation drilling.

No samples, including samples from stations 20 and 31, were toxic to laboratory amphipods in 2016. Amphipod survival was higher in samples collected near drill centres; a response that would not suggest project-effects. Survival did decrease with increasing sediment ammonia concentration. However, since there was no evidence that ammonia was affected by project activity, this association more likely is natural.

Over all eight EEM years, 6 (of 299 samples) have been toxic to Microtox and 14 (of 299) samples have been toxic to laboratory amphipods, indicating that sediments at White Rose are generally non-toxic.

8.1.3 Benthic Invertebrate Community Structure

As in previous years, there was evidence of project effects on total benthic abundance and biomass, and no evidence of effects on richness.

The relationship between total benthic abundance and distance to active drill centres was relatively weak, with no significant threshold distance for effects, as in prior years. In 2016, total abundance was reduced in the immediate vicinity (within less than 1 km) of drill centres. Multivariate analysis indicated that the taxa most affected were the polychaetes Paraonidae, Cirratulidae, Orbiniidae, Spionidae and Pholoidae, and the crustacean Tanaidacea. Abundances of Paraonidae, Tanaidacea, Orbiniidae and Spionidae were lower near drill centres; abundances of Cirratulidae and Pholoidae were higher near drill centres. Abundances of some taxa decreased, and abundances of others increased, thus explaining the minor overall effect on total abundance.

The overall relationship between total biomass and distance from active drill centres in 2016 was somewhat comparable to those observed in 2012 and 2014; however, threshold distances for effects on biomass were significant in 2012 and 2014, and were not significant in 2016. As was the case for total abundance, biomass was only reduced in the immediate vicinity of drill centres in 2016. Reduced abundances of larger echinoderms have previously been shown to be related to reduced biomass near drill centres (Husky Energy 2012 and 2014).

As in prior years, univariate analysis of abundances of individual taxa provided evidence of project effects on Paraonidae; and multivariate analyses of 2016 data confirmed that Paraonidae was the taxon most affected by project activity. Paraonidae abundance has been strongly related to distance from active drill centres, with threshold distances significant in every EEM year. The threshold distance for Paraonidae in 2016 was estimated at 1.2 km. As was the case for $>C_{10}$-C_{21} hydrocarbons and barium, there was an indication that threshold distances were larger in early EEM years (approximately 3 to 4 km from 2004 to 2008) and approximately 1 to 2.5 km from 2010 to 2016; although confidence intervals for these threshold estimates overlapped).

Total benthic abundance, biomass and abundances of Paraonidae were negatively correlated to concentrations of $>C_{10}$-C_{21} hydrocarbons. Total abundance and biomass and abundances of Paraonidae were lower in sediments with high concentrations of $>C_{10}$-C_{21} hydrocarbons. Higher concentrations of barium, sulphur, and strontium also co-occurred with lower biomass and lower abundances of Paraonidae. Abundances of Paraonidae were negatively correlated with sediment redox potential. This relationship indicates a decrease in abundance with increasing redox potential. Remaining correlations between sediment physical or chemical variables and benthos were weaker.

Sediment lead concentration was negatively correlations with biomass and Paraonidae abundance. Tellinidae and Amphipoda abundances were correlated with sediment percent fines.

Multivariate analysis confirmed correlations between sediment $>C_{10}$-C_{21} hydrocarbons and barium concentrations with benthic community structure and, to a lesser extent, also identified changes in community structure with varying sediment uranium and iron concentrations, sediment redox potential, and fines content. Since no project effects were noted for sediment redox potential and metals other than barium, lead, and strontium, these associations, as well as some of the correlations noted above for univariate measures, could be natural. In general, the association between $>C_{10}$-C_{21} hydrocarbon and barium concentrations, the two main indices of drill cuttings in sediment, and benthic responses confirms that responses were project-related.

In addition to an examination of change in benthic indices or abundances of individual taxa with distance from active drill centres as a group (as done above), the White Rose EEM program also relies on an examination of changes near individual drill centres. The first approach can be regarded as a whole-field approach, whereas the second approach targets the effect of individual drill centres. This combined approach allows for the efficient assessment of effects of individual drill centres as well as potential cumulative effects from multiple drill centres.

In 2016, total abundance was reduced below the baseline range at one station within 0.3 km of the North Amethyst and the SWRX Drill Centres; and at one station within 0.6 km of the Northern Drill Centre. Total benthic biomass was below the baseline range at one to four stations around each of the Central, North Amethyst, SWRX, Southern and Northern Drill Centres. Stations with reduced biomass extended to approximately 0.9 km around the Central, SWRX and Southern Drill Centres; and to approximately 0.3 km around the North Amethyst and Northern Drill Centres.

Paraonidae abundances were reduced to below the baseline range at a number of stations around Drill Centres. Abundances were reduced to approximately 1.8 km around the Central Drill Centre; approximately 0.9 km around the North Amethyst, SWRX and Southern Drill Centres; and approximately 0.6 km around the Northern Drill Centre. In 2016, the estimated threshold distance of 1.2 km for Paraonidae generated for the whole field generally agreed with the estimate of the zone of effects estimated through examination of abundances around each drill centre. This could indicate that cumulative effects from multiple drill centres have decreased relative to some prior years (if the zone of effects of drill centres overlap, the threshold model estimate will be larger than the estimate of the zone of effects from examination of abundances around each drill centre).

Overall, 2016 data suggest that the majority of effects on benthos were limited to 1 to 2 km of drill centres. This is also consistent with the 2016 multivariate assessment on benthos, which showed that stations within 2 km of drill centres differed from stations beyond 2 km.

After monitoring the effects of drilling on sediment quality eight times over a period of 12 years, distance relationships for sediment physical and chemical variables and benthos have varied in strength, and threshold distances have also varied somewhat from year to year. To date, there is no indication that effects are getting greater in

magnitude or in spatial extent. The reduction in threshold distances for sediment >C_{10}-C_{21} hydrocarbons and barium concentrations and Paraonidae abundances; and the weaker relationship between sediment strontium and sulphide concentrations and distance to drill centres from earlier to later EEM years suggests that effects may be getting more localized. In 2014, there was an indication that effects on benthic biomass may be getting stronger. This trend was partially diminished in 2016; while the 2016 correlation between biomass and distance from drill centres was comparable to that noted in 2012 and 2014, threshold distances were not statistically discernable.

8.2 Commercial Fish Component

8.2.1 Body Burden

On the East Coast of Canada, in the Gulf of Mexico, in the North Sea and elsewhere, fish and shellfish tissue have been examined for chemistry (body burden) to assess potential effects of offshore oil development on commercial fisheries resources (*e.g.*, Rushing *et al.* 1991; Neff *et al.* 2000; Husky Energy 2004 and references therein; Armsworthy *et al.* 2005; DeBlois *et al.* 2005). At White Rose, American plaice liver and fillet and snow crab claw tissues from the Study Area and the four distant Reference Areas, (located 28 km from the centre of the White Rose development), are usually examined for body burden. In 2016, sampling in Reference Area 4 was not possible because of intense commercial fishing activity in that area for crab. Therefore, additional transects were performed in Reference Area 1 to provide the necessary number and weight of plaice and crab for use in this EEM program.

Compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbon range were again detected in all liver samples in 2016. As in previous years, additional GC/MS analysis indicated that there was no indication of drill fluid or petroleum hydrocarbons in those samples. It has previously been speculated that these compounds are natural and perhaps diet related.

In 2016, naphthalene was detected at low levels in all liver samples. Additional analyses indicated that exposure to naphthalene was very recent and evidence pointed to contamination on board vessel as the most likely explanation for results observed'.

Since we have not been able to identify the source of the naphthalene, we cannot comment on contamination with additional compounds. However, of the chemistry variables tested, unusual results were only evident for naphthalene.

Most frequently detected analytes in plaice liver (% fat, % moisture, arsenic, copper, iron, mercury, selenium, silver, zinc and >C_{21}-C_{32} hydrocarbons) did not vary significantly in concentration between the Study and Reference Areas in 2016. However, cadmium concentration was generally higher in the liver of plaice from the Study Area (1.65 mg/kg in the Study Area versus a mean of 1.30 mg/kg in Reference Areas); manganese, >C_{10}-C_{21} hydrocarbon and naphthalene concentrations were generally higher in the liver of plaice from the Reference Areas. There were no significant differences between the Study Area and the Reference Areas in linear or quadratic[38] trends over time (2004 to 2016) for most of the frequently detected compounds in liver. However, a difference between the Study and Reference Areas in linear trends over time was noted for >C_{21}-C_{32} hydrocarbons, likely driven by higher values in the Study Area in 2006 and

[38] A quadratic trend over time would be an increase followed by a decrease, or vice versa.

2010. As noted above, the presence of these compounds in liver may be diet related; compounds are not petrogenic. Although cadmium concentrations were higher in Study Area liver in 2016, this difference has not been consistent over time.

There were no significant differences in % moisture, arsenic, and mercury concentrations in plaice fillet between the Study Area and the Reference Areas in 2016. Zinc concentrations were lower in fillets from the Study Area compared to the Reference Areas in 2016. There were no significant differences between the Study Area and the Reference Areas in trends over time (2004 to 2016).

For crab tissue in 2016, there were no significant differences between the Study Area and the Reference Areas for most of the frequently detected compounds (% moisture, arsenic, copper, mercury, selenium, silver, strontium, and zinc). However, boron concentration in crab tissue was higher in the Study Area compared to the Reference Areas (3.55 mg/kg in the Study Area versus a mean of 3.15 mg/kg in the Reference Areas).

Across years, no significant differences between the Study and Reference Areas were noted in linear and/or quadratic trends for most variables. However, significant differences in linear and quadratic trends between the Study and Reference Areas were noted for arsenic. Overall arsenic values declined after initial sampling followed by relative increases in 2014 and 2016 in all Areas, but the decline was more pronounced in the Study Area. As noted above, arsenic concentrations in crab tissue were similar between the Study and Reference Areas in 2016. Boron concentrations, higher in Study Area crab tissue in 2016, have not been consistently higher in tissue from the Study Area over time.

Concentrations of metals in plaice and crab tissues at White Rose have been generally similar between the Study and Reference Areas or, when they occurred, differences have been slight and have not persisted over time. To date, there is little evidence of metals contamination in tissues of plaice and crab originating from White Rose project activity. Hydrocarbons have rarely been detected in edible tissue (crab claws and plaice fillets) at White Rose.

8.2.2 Taste Tests

In 2016, there was no significant difference in taste between the Study and Reference Areas for both plaice and crab and there were no consistent comments from the taste panels identifying abnormal or foreign odour or taste. As in previous years, results do not indicate the presence of taint in either resource.

8.2.3 Fish Health Indicators

Cellular and sub-cellular bioindicator responses along with observations on visible lesions on skin and internal organs are valuable monitoring tools for identifying adverse health conditions in animals in advance of population level responses. As such, they can provide early warning of potential health effects and aid in identifying their nature, scope and cause (see reviews by Payne *et al.* 1987; Peakall 1992; Society of Environmental Toxicology and Chemistry Special Publication Series 1992; Adams 2002; Tillitt and Papoulias 2003; Schlenk *et al.* 2008).

8.2.3.1 Biological Characteristics and Condition of Fish

Information on fish biological characteristics and condition is valuable for interpreting results of bioindicator studies (Levine *et al.* 1995; Barton *et al.* 2002). Therefore, fish biological characteristics were examined within the context of these studies.

A total of 168 female and 12 male plaice were collected. No statistical analyses were performed on males given their low numbers. Most of the females collected (77%) were mature and, of those, 6% were spent. The frequency of pre-spawning and spent females did not vary significantly between the combined Reference Areas and the Study Area.

Sufficient numbers of fish allowed examination of biological characteristics (length, body weight, liver and gonad weight, and age) for immature and pre-spawning females. No significant differences were noted between the Reference Areas and the Study Area for biological characteristics of immature females. This was also true for most biological characteristics of pre-spawning females. However, gonad weight relative to gutted weight for pre-spawning females in the Study Area was generally higher (by 3%) than in the Reference Areas.

Overall, the difference observed in gonad weight of pre-spawning females between Areas could be attributed to normal inter-site variability linked to non-pollutant factors such as the reproductive status of the fish (*e.g.*, Mayer *et al.* 1989; Barton *et al.* 2002; Maddock and Burton 1999).

8.2.3.2 Gross Pathology

Gross pathology was assessed visually in all fish during the necropsies for any external or internal abnormalities. There were no visible lesions on the skin or fins or on internal organs of any fish.

8.2.3.3 Mixed Function Oxygenase Activity

Since basal levels of MFO enzymes can vary seasonally between males and females of the same species (*e.g.*, Walton *et al.* 1983; Mathieu *et al.* 1991), results were examined separately for each sex. Within the females, results were examined separately within general maturity groupings (immature, pre-spawning and spent), since maturity stage may result in some loss of sensitivity for resolving contaminant mediated differences (*e.g.*, Whyte *et al.* 2000). EROD activity was comparable among the various female maturity groups with immature fish having a mean value of 18.1 ± 8.53 pmol/min/mg protein, pre-spawning fish averaging 14.2 ± 9.01 pmol/min/mg protein and spent fish having a mean value of 11.3 ± 6.55 pmol/min/mg protein.

Numbers permitted statistical comparison of EROD activity among Areas for immature and pre-spawning females; there were no significant differences in EROD activity between the Reference Areas and the Study Area for both immature and pre-spawning females.

8.2.3.4 Histopathology

Detailed histopathological studies were carried out on liver tissues with observations on various lesions that have been commonly associated with chemical toxicity (*e.g.*, Myers

and Fournie 2002; Feist *et al.* 2004). In general, liver lesions more commonly associated with chemical toxicity were absent in both Areas. Of the lesions noted, statistical analyses were conducted on macrophage aggregates, inflammatory response and parasite counts, since the low incidence of all the other hepatic lesions prevented statistical comparisons. Overall, there were no significant differences in either macrophage aggregates, or in the presence of parasites between fish from the Study and Reference Areas.

Inflammatory response was significantly greater at the Reference Areas (31.67%) compared to the Study Area (6.67%). An inflammatory response typically involves a defensive reaction by vertebrate tissue to infection or injury caused by chemical or physical agents. The inflammation process is characterized by local vasodilation and extravasation of plasma into intercellular spaces as well as infiltration of white blood cells and macrophages into tissues. Inflammatory responses are known to appear following viral, bacterial or parasitic infections as well as tissue damage (*e.g.*, Feist *et al.* 2004). However, a level of inflammation can also be associated with normal tissue repair and maintenance processes. Although these liver conditions are of interest in relation to providing general information on their presence in the survey area, they are generally of lesser importance and not the result of the presence of chemical pollutants.

For gill histopathology, and except for tip hyperplasia, no significant differences were found for any of the studied conditions between fish from the Study Area and the Reference Areas. The overall number of lamellae affected by tip hyperplasia was low (the highest percentage of lamellae affected was 1.5%). However, more fish from the Study Area exhibited tip hyperplasia than fish from the Reference Areas (28% in the Study Area compared to 14% in the Reference Areas). The epithelium of the gills is a major site for the uptake of soluble chemical substances (Stentiford *et al.* 2003). As such, considerable attention has been given to their response to hydrocarbons (Solangi and Overstreet 1982; Mallat 1985; Khan 1995; Stentiford *et al.* 2003). The predominant effects of hydrocarbons on gill tissues seem to be tissue hypertrophy and/or hyperplasia (Haensly *et al.* 1982). However, hyperplasia of the gills seems to be a generalized response to wide variety of stressors such as other xenobiotics including ammonia and ammonium hydroxide (Smith and Piper 1975), pesticides (Jauch 1979), metals (Bilinski and Jonas 1973), pulp and paper mill effluents (Khan *et al.* 1994), water pH (Daye and Garside 1976), parasites (Eller 1975), amoebic disease (Munday *et al.* 2001), bacterial infections (reviewed in Mallat 1985), and other stressors. Hyperplasia and other alterations of the gill induced by irritants have been considered as part of a generalized systemic response to stressors (Mallat 1985). The lack of statistical significance in other markers of exposure (*e.g.*, EROD activity) during this study add weight to the possibility that the hyperplasia seen in the gills of the fish might be due to stressors other than hydrocarbons. Hyperplasia lesions have been found to be temporary and gills may recover their normal histological status once the stressor is removed (Solangi and Overstreet 1982).

8.2.3.5 Overall Fish Health

As in previous years, the results of the 2016 fish health survey indicated that the overall health of plaice is similar between the Reference Areas and the White Rose Study Area. The statistical difference that was noted in the biological characteristics of the fish (gonad weight as function of gutted weight) can reasonably be attributed to natural variability. The significantly higher inflammatory response in the liver of fish from the

Reference Area could be attributed to viral, bacterial or parasitic infections as well as tissue damage or could be associated with normal tissue repair and maintenance processes. With respect to the more frequent occurrence of tip hyperplasia in fish from the Study Area, it is difficult to attribute such damage to hydrocarbon exposure since hyperplasia could be caused by a wide variety of stressors. Moreover, the lack of significant differences in other markers described in the present study, including EROD activity, between the Study and Reference Areas seem to point to the possibility that gill hyperplasia may be due to factors other than hydrocarbon exposure.

8.3 Water Quality Component

The Water Quality monitoring program at White Rose currently involves collection of sediment and seawater samples in two Study Areas and in two Reference Areas, located approximately 28 km to the northeast and northwest of the *SeaRose FPSO*.

Based on results of modelling conducted in 2012 (see Husky 2013):

- Near-field Study Area stations, located at approximately 300 m from the *SeaRose FPSO*, are positioned at the time of sampling so that they are down-current from the *SeaRose FPSO*.

- Mid-field Study Area stations are located at 4 km from the *SeaRose FPSO* in the direction of the prevailing seasonal current (to the southeast of the *SeaRose FPSO*).

Samples are assessed for water and sediment chemistry.

8.3.1 Seawater Chemistry

The following variables were detected in all seawater samples: arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, potassium, sodium, strontium, sulphur, uranium, and TIC. Aluminum and lead were above detection limit in 80% of samples. With the exception of TIC, which varied over the narrow range of 27 and 29 mg/L, all these variables were included in quantitative analyses for 2016.

Significant differences among sampling Areas (Near-field, Mid-field and NE and NW Reference Areas) were noted for aluminum, arsenic, boron, lithium and strontium. In general, results pointed to more frequent differences between the Mid-field Study Area and the remaining sampling Areas. Mid-field values for arsenic, boron and lithium were significantly higher than values in either the Near-field Study Area or the Reference Areas. Strontium values were also generally higher in the Mid-field, but the difference was only significant between the two Study Areas. Mid-field values for aluminum were significantly lower than in other areas. Although not analyzed quantitatively because of low occurrence, selenium occurred relatively frequently (in more than 30% of samples) and it occurred more frequently in Mid-field Study Area samples than in remaining Areas. Although significant, difference among areas with small and mid-field Study Area concentrations were generally within the range of values noted in the remaining Areas.

Overall, these results point to subtle differences in water mass characteristics between the Mid-field Study Area and remaining Areas. Modeling results did indicate that produced water constituents could be more likely to be detected in the mid-field (Husky Energy 2013). However, the link between differences noted in the mid-field and

produced water discharge is not clear from these data. Boron, lithium and strontium are enriched in White Rose produced water, with concentrations nine times (for boron) or more that of seawater[39]. However, concentrations of aluminum, arsenic and selenium in seawater and produced water are approximately equivalent. Therefore, only half of the constituents showing differences between the mid-field and remaining areas could be influenced by the presence of produced water. Beyond this, there was no obvious difference in CTD profiles that would explain the noted differences.

Other than these differences in the Mid-field, strontium was generally lower (excluding one outlier) in the Near-field relative to the Reference Areas. Mercury, not analyzed quantitatively because of intermediate (30% to 75%) occurrence, occurred more frequently in Reference Area samples. Significant area differences have been noted in previous EEM years. However, to date, no consistent differences have been observed.

In addition to an examination of general trends, as done above, the White Rose EEM program also examines individual occurrences of potential produced water constituents in seawater samples. This examination indicated that the produced water constituents naphthalene, 1- and 2-methylnaphthalene, benzene, toluene, zinc, iron, and strontium may have been detected at some stations within 300 m of the *SeaRose FPSO*. Evidence of produced water constituents in seawater samples has been weak or absent in previous EEM years.

In 2016, Naphthalene, 1- and 2-methylnaphthalene, benzene and toluene, and a relatively high concentration of zinc were detected in the surface sample at Station W-5S-SW. The highest concentration of strontium was also noted in the bottom sample at that station. Naphthalene, benzene, and toluene were detected in the surface sample at Station W-4S-SW, and iron was detected in a mid-depth sample at that station (iron was not detected in any other seawater sample). Benzene and toluene were detected in the surface sample at Station W-3S-SW. As these stations were down-current of the *SeaRose FPSO*, it is possible that these constituents originated from produced water. All concentrations were low, but the highest concentrations were generally noted in the surface sample at Station W-5S-SW.

Phenol, alkyl phenols and organic acids were not detected in any seawater sample. BTEX and PAHs were not detected except for sporadic occurrences at stations W-5S-SW, W-4S-SW, and W-3S-SW, as noted above.

8.3.2 Sediment Iron Concentration

Modelling results indicated that iron concentrations could potentially be enriched in sediments (Husky Energy 2013). In 2016, there was a tendency for iron enrichment to the east and southeast of the *SeaRose FPSO.* As in previous years, there was also some indication of an increase in iron since produced water discharge began at the *SeaRose FPSO*. At present, the link between iron enrichment in sediments and produced water release from the *SeaRose FPSO* remains weak.

[39] These estimates are based on a January 2017 characterization of White Rose produced water and concentrations of metals noted in the Reference Areas in the 2016 survey.

8.4 Summary of Effects and Monitoring Hypotheses

As discussed in Section 1.7, monitoring hypotheses were developed in Husky Energy (2004) as part of EEM program design to test effects predictions and estimate physical and chemical zones of influence.

These hypotheses (reiterated in Table 8-2) were set up to guide interpretation of results. As noted in Section 1.7, the "null" hypothesis (H_0) always state that no pattern will be observed.

Given results observed in the 2016 EEM program, the null hypothesis is rejected for the Sediment Component of the program, but null hypotheses are not rejected for the Commercial Fish and Water Components. Rejection of the null hypothesis for the Sediment Component was expected, since drill cuttings modelling and EIS predictions indicate that there would be change in Sediment Quality Triad variables with distance from discharge sources. The following summarizes project effects and relates them to EIS predictions and/or literature-based information, as applicable.

Table 8-2 Monitoring Hypotheses

Sediment Component
H_0: There will be no change in Sediment Quality Triad variables with distance or direction from project discharge sources over time.
Commercial Fish Component
H_0(1): Project discharges will not result in taint of snow crab and American plaice resources sampled within the White Rose Study Area, as measured using taste panels.
H_0(2): Project discharges will not result in adverse effects to fish health within the White Rose Study Area, as measured using histopathology, haematology and MFO induction.
Water Component
H_0: The distribution of produced water from point of discharge, as assessed using moorings data and/or vessel-based data collection, will not differ from the predicted distribution of produced water.

Note: - No hypothesis was developed for plaice and snow crab body burden, as these tests are considered to be supporting tests, providing information to aid in the interpretation of results of other monitoring variables (taste tests and health).

As predicted, concentrations of $>C_{10}$-C_{21} hydrocarbons and barium were elevated by drilling activity near drill centres. To a lesser extent, sediment lead, sulphides, sulphur strontium, and fines content were also affected by drilling. Elevated concentrations of $>C_{10}$-C_{21} hydrocarbons and barium at White Rose in 2016 remain comparable to levels observed at other developments.

The spatial extent of contamination in 2016 was consistent with original predictions on the spatial extent of the zone of influence of drill cuttings (9 km from source; Hodgins and Hodgins 2000; Section 1.5). The $>C_{10}$-C_{21} hydrocarbon contamination extended to 2.7 km from source. Barium contamination extended to 1.2 km from source. Lead contamination extended to 1.4 km from source. No threshold could be estimated for sulphides, sulphur, strontium and fines, but levels were elevated to within 0.5 to 1 km from source[40].

[40] When thresholds cannot be fit to the data, estimates are qualitative rather than quantitative.

In 2016, samples from two stations were toxic to Microtox. Sediment concentrations of >C_{10}-C_{21} hydrocarbons, barium, sulphur and strontium were elevated above baseline or background levels at the two stations, lead was elevated at one of the stations, and both stations were within 0.5 km of a drilling discharge source. These findings point to effects on Microtox at two (of 53) stations. Conversely, no stations were toxic to laboratory amphipods, and laboratory amphipod survival was unrelated to physico-chemical variables shown to be affected by project-activity. Taken together, the Microtox and amphipod toxicity tests continue to indicate that sediments at White Rose are predominantly non-toxic.

In 2016, as in previous years, there was evidence of project effects on total benthic abundance and biomass, and no evidence of effects on richness. Effects on total abundance remain weak. In 2016, total abundance was reduced in the immediate vicinity (within less than 1 km) of drill centres, similar to what has been noted before. Effects on biomass in 2016 were less spatially extensive than in 2012 and 2014. In those two years, threshold distances could be estimated for biomass and effects were noted to 1.5 and 5.5 km, respectively. In 2016, a threshold could not be estimated and biomass was reduced within less than 1 km of drill centres[41].

Of the individual taxa, the polychaete family Paraonidae remains the most affected, with lesser effects noted on the polychaetes Cirratulidae, Orbiniidae, Spionidae and Pholoidae, and the crustacean Tanaidacea. The threshold distance for effects on Paraonidae in 2016 was estimated at 1.2 km.

Examination of data for drill centre stations (*i.e.*, the four to five stations immediately surrounding each drill centre) indicated effects on total abundance to a maximum distance of 0.6 km, at the Northern Drill Centre; effects on biomass to a maximum distance of 0.9 km, at the Central, SWRX and Southern Drill Centres; and effects on Paraonidae to a maximum distance of 1.8 km, at the Central Drill Centre.

Overall, 2016 data suggest that effects on total abundance and biomass are limited to within 1 km; and effects on Paraonidae are limited to 1 to 2 km. The latter is supported by multivariate analysis than indicated effects on community structure to 2 km.

As noted in previous EEM reports, the spatial extent of effects on benthic invertebrates at White Rose is generally consistent with the literature on effects of contamination from offshore oil developments. Davies *et al.* (1984) first described general zones of effects on benthic invertebrates around offshore platforms. The first zone was characterized by a highly disrupted benthic community within approximately 0.5 km of discharge source. The second zone was described as a transition zone in benthic community structure from affected to unaffected. This scheme has been generally used elsewhere. For instance, Gerrard *et al.* (1999) also describe a zone of approximately 0.5 km from source with a highly disrupted benthic community. Based on their review, the spatial extent of the transition zone from affected to unaffected could extend from 0.2 to 2 km.

Ratings of effects size are provided by Davies *et al.* (1984) and Kilgour *et al.* (2005). Davies *et al.* (1984) describes a highly disrupted community as impoverished and highly modified with abundances at or near zero. In agreement, Kilgour *et al.* (2005) state that benthic community effects are large when they co-occur with effects on fish and that this

[41] When threshold models cannot be fit to the data, estimates are qualitative rather than quantitative.

normally occurs when the benthic community is reduced to one or two types of organisms, and with either very high (10x more than normal) or very low (10x less than normal) abundances. This is not the condition at White Rose. In 2016, total abundance was reduced to less than 75% of the lower limit of the baseline range of variation at two stations near active drill centres [42], and the lowest abundance at these stations (900 individuals per m^2) was 63% of that lower limit. Biomass was reduced to less than 75% of the lower limit of the baseline range at five stations near active drill centres (less than the 11 stations noted in 2014) and the lowest biomass at these stations (113 g/m^2) was 41% of that lower limit. Richness levels did not fall to less than 75% of the baseline range at any station in 2016, as in previous years. Overall, richness has remained within the range of values noted in the baseline year (2000).

As noted in Husky's response to regulator comments on the 2014 EEM program, potential effects on benthic communities were assessed within the valued ecosystem component of Fish and Fish Habitat. In general, both the White Rose (Husky Oil Operations Limited 2000) and North Amethyst (LGL 2006) environmental assessments predictions are consistent with observations of both Davies *et al.* (1984) and Gerrard *et al.* (1999); highly disrupted communities can be expected near source. According to effect size criteria noted above, none of the stations at White Rose had highly disrupted benthic communities, although total abundance and/or biomass were reduced to less than 75% of the baseline range at six drill centre stations, located at distances ranging from 0.3 to 0.9 km a drill centre. More subtle changes in community structure were noted to 2 km.

Sediment contamination and effects on benthos noted in 2016 and in previous years have not translated into effects on the fisheries resources, as indicated by fish health assessment and taint tests. No project-related tissue contamination was noted for crab and plaice, neither resource was tainted, and plaice health was similar between White Rose and more distant Reference Areas.

There was no evidence of project effects on water quality overall, and concentrations of frequently detected compounds were generally similar among sampling areas. A difference was noted between the Mid-field Study Area and remaining areas (Near-field Study Area, NE and NW Reference Areas). However, these differences could not be attributed to produced water discharge. Conversely, six compounds known to be in high concentration in produced water (naphthalene, 1- and 2- methylnaphthalene, benzene, zinc, and strontium) were detected sporadically and at low concentrations at three Near-field stations. Since these stations were located 300 m down current of the *SeaRose FPSO*, produced water constituents may have been detected in 2016.

The White Rose environmental assessment (Husky Oil Operations Limited 2000) predicted that changes to physical and chemical characteristics of seawater as a result of liquid discharge would be localized near discharge source. The sporadic occurrence of low levels of potential produced water constituents at Near-field stations is consistent with these predictions. Since overall water quality in the Near-field was not affected (as per the more general comparison among areas described above), there are no effects on water quality per se. However, the findings confirm that the revised White Rose

[42] See Section 5 for a list of drill centre stations where values were reduced to below 75% of the baseline range.

Water Quality Monitoring design (Husky Energy 2010b), with adaptive sampling in the near-field, is effective.

Although there is evidence of project effects on fish habitat (physical and chemical parameters measured in sediments) and effects on benthic communities, those effects have been within predictions made in the EIS, and there is no evidence that additional mitigation measures are required at this time.

8.5 Recommendations for the 2018 EEM program

Based upon the results of the 2016 WR EEM program, the following recommendations are proposed:

8.5.1 Sediment Quality

The sediment quality portion of the report benefited from the addition of multivariate analysis of benthic community structure. These analyses confirmed that Paraonidae was the taxon most affected by project-activity and provided greater insight into which taxa were contributing to observed changes in total benthic abundance. The analysis was restricted to 2016 data. Going forward, the analysis should include an examination of change across years.

As was done in this 2016 report, multivariate analyses of community structure should be used to provide greater insight into effects on univariate measures of benthic communities. More subtle changes in community structure are of interest, but they are not necessarily useful to assess the magnitude of project effects (see discussion above on effect size; also see Assessment Criteria developed for the White Rose program in response to regulator comments (Husky Energy 2010b, Appendix A). That said, in time, multivariate analyses may indicate that some of the individual taxa examined in detail in the EEM program (Spionidae, Tellinidae and Amphipoda) would be better replaced by other taxa.

As there have never been any project effects on sediment gravel content, that variable should be dropped from univariate analysis. Gravel was initially included as a variable that might affect benthic community structure. The multivariate analysis that is now included in the program can better assess correlations between this and other variables and changes in the benthic community.

8.5.2 Commercial Fish

Although the source of naphthalene contamination in plaice liver tissue has not been identified, every precaution should continue to be made to avoid contamination after collection of samples.

Since 2014, trawl retrieval speed was adjusted to reduce mortality on by-catch. This practice should continue.

8.5.3 Water Quality

Any continued differences between the Mid-field Study Area and remaining sampling areas for some water quality variables should be examined further. It is possible that the observations in 2016 were unusual. No such differences were noted in prior years.

There continues to be a weak indication that iron could act as a tracer of produced water constituents in sediments. Therefore, the analysis of iron in sediments using chemistry data from both Sediment Quality Triad and water quality stations should continue. A trend over time term since release of produced water should be tested in subsequent years, in addition to change from before to after release, to assess changes since produced water release began.

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