Technical Data Report

Properties and Fate of Hydrocarbons Associated with Hypothetical Spills in the Open Water Area

ENBRIDGE NORTHERN GATEWAY PROJECT

SL Ross Environmental Research Ltd.
Ottawa, Ontario

Randy Belore, P.Eng.

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Abbreviations

CCAA .... Confined Channel Assessment Area
CRW .... CRW condensate
Hayco .... Hay and Company Consultants
MKH .... synthetic oil
Northern Gateway .... Northern Gateway Pipelines Limited Partnership
SLROSM .... SL Ross Oil Spill Model
SYN .... synthetic light oil
TDR .... technical data report
The Project .... the Enbridge Northern Gateway Project

1 Introduction

Northern Gateway Pipelines Limited Partnership (Northern Gateway) proposes to construct and operate the Enbridge Northern Gateway Project (the Project), which is an export oil pipeline and an import condensate pipeline between an inland terminal near Bruderheim, Alberta and a marine terminal near Kitimat, British Columbia. The Project will include:

- an export oil pipeline
- an import condensate pipeline
- a terminal facility (the marine terminal as part of Kitimat Terminal) to accommodate the loading and unloading of oil and condensate tankers

The purpose of this document is to investigate the possible behaviour of hydrocarbons (oil and condensate) in the open water area from inbound and outbound vessels associated with the Project. The spill examples considered for the open water near the Project include only large tanker spills (10,000 m^3). However, 10,000 m^3 and smaller (12 m^3 and 188 m^3) spills were modelled for the Confined Channel Assessment Area (CCAA) and marine terminal, respectively, in the Properties and Fate of Hydrocarbons Associated with Hypothetical Spills at the Marine Terminal and in the CCAA technical data report (TDR) (SL Ross 2010). The same physical oil and condensate properties were used in all assessments. Physical property test methods and results are presented in detail in the Properties and Fate of Hydrocarbons Associated with Hypothetical Spills at the Marine Terminal and in the CCAA TDR. Wind data specific to the open water spill areas were used in this modelling.

When oil is spilled in the marine environment, its physical and chemical properties change over time through evaporation and emulsification. These changes affect both the fate and behaviour of the spill and the effectiveness of countermeasures. For example, oil may be relatively fluid and non-viscous when initially spilled, but may become viscous within a short time. It is important to know whether this will happen and how long it will take. The detailed properties of the four hydrocarbon types of concern in the Project are reported in the Properties and Fate of Hydrocarbons Associated with Hypothetical Spills at the Marine Terminal and in the CCAA TDR. It was determined in the study that three of the hydrocarbons, Syncrude synthetic light oil (SYN), CRW condensate (CRW) and MacKay River Heavy bitumen diluted with synthetic oil (MKH) were adequate to represent the range of spill behaviours likely from the four hydrocarbon types of concern.

The objective of this study is to complete fate modelling for a representative range of hydrocarbon types in the spill examples developed for the open water area beyond the CCAA. The results of the fate modelling will be used for spill response planning purposes.

2 Fate Modelling for Marine Spills

2.1 Background

Two elements must be modelled in an oil spill example for use in spill response planning:

- the path that the hydrocarbon travels
- the properties or fate of the hydrocarbon as it travels

This section describes the properties or fate of oil and condensate with time after the spill under the prevailing environmental conditions for the spill example.

The following reasonable scenarios have been defined and modelled.

Two representative open water sites (see Figure 2-1) have been selected for the modelling of hypothetical hydrocarbon spills in each of the four seasons. The locations are Butterworth Rocks and Ness Rock respectively. It is assumed that:

- the total spill size is 10,000 m^3
- hydrocarbons will be present on the surface in the form of fifty individual parcels each with a volume of 200 m^3. This is a reasonable volume given the initial rapid spill of oil, the spreading characteristics, and water currents and winds in the area.

Hay and Company Consultants (Hayco) provided time series of representative wind speeds, and air and water temperatures for each spill location and season modelled. The winds used in the initial detailed oil fate modeling are representative of a moderate breeze (force 4). These data were used in the SL Ross Oil Spill Model (SLROSM) along with the specific oil property data collected from the oil analysis described in the Properties and Fate of Hydrocarbons Associated with Hypothetical Spills at the Marine Terminal and in the CCAA TDR to predict the fate of the oil for each spill scenario.

The general behaviour of the three hydrocarbons, based on the modelling results for the Butterworth Rocks October scenario, is provided in Section 2.2. This is followed by a series of graphs in Sections 2.3 and 2.4 that summarize the fate of the spill scenarios considering the range of hydrocarbons selected. Time histories of slick width, emulsion water content, emulsion viscosity, emulsion density, percentage of hydrocarbons evaporated and percentage of hydrocarbons dispersed are provided for each spill location and season. The open water spill example locations are much more exposed than the spill sites considered in the CCAA and, as a result, evaporation and dispersion rates are generally higher in the open water, and complete dissipation of the light CRW and SYN slicks occurs more quickly.

Section 2.5 provides additional modeling results for a calmer wind set (force 3), provided by Hayco, for the Butterworth Rocks spill site and a spill scenario involving 10,000 m^3 of synthetic oil. In this scenario 1,900 m^3 is released in the first hour followed by a 675 m^3 per hour discharge over 12 hours.

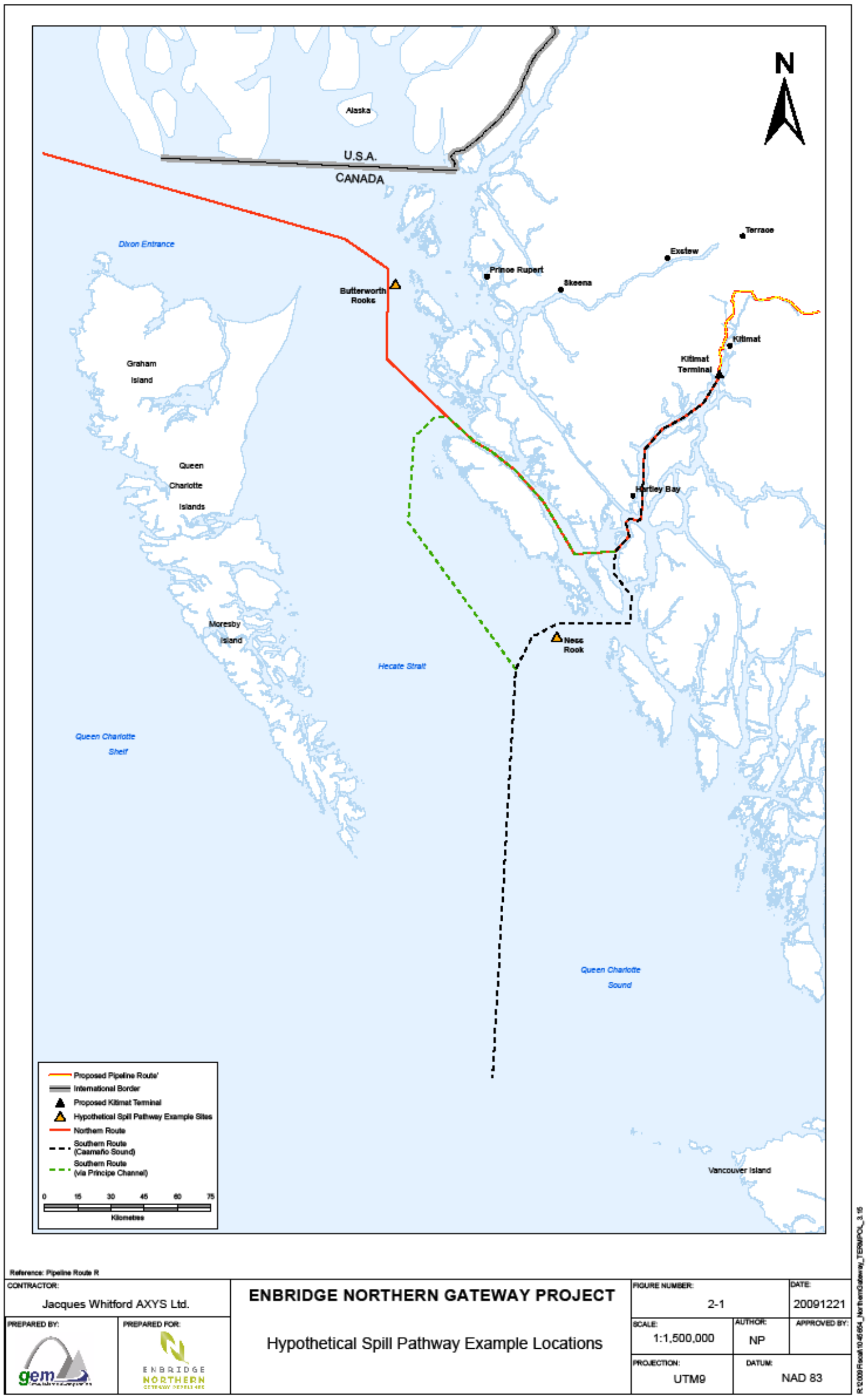

Figure 2-1 Oil Spill Example Locations in the Open Water Area

2.2 General Fate of the Three Oils

CRW is a condensate that will evaporate and disperse quickly once spilled. SYN is light oil, but will evaporate and disperse at a slower rate than the CRW condensate. MKH is a persistent oil that will form a water-in-oil emulsion that is slow to evaporate and disperse. Table 2-1 provides an example of the property changes with time that can be expected from 10,000 m^3 spills of these hydrocarbons. The data in Table 2-1 are predicted for the Butterworth Rocks fall (October) scenario. There are differences in the spill behaviour for the two spill sites and seasons. Figures in Sections 2.3 and 2.4 show detailed oil and condensate behaviour and properties for each spill site and season.

Table 2-1 Hydrocarbon Property Changes with Time: Hypothetical 10,000 m^3 Tanker Spill at Butterworth Rocks (October)

Time (h)	**Water Content**	**Viscosity** (cP)	**Density** (g/ml)	**Pour Point** (°C)	**% Evaporated**	**% Dispersed**
Oil Type						
12						
CRW @5 hrs	0	25	0.892	-22	57	43
SYN	0	34	0.909	-28	17	8
MKH	57	5760	0.994	-27	4	0.5
24						
CRW	-	-	-	-	-	-
SYN	0	48	0.915	-27	20	11
MKH	67	15,150	1.0	-26	5.5	0.9
48						
CRW	-	-	-	-	-	-
SYN @44 hrs	0	113	0.932	-22	24	76
MKH	75	52,100	1.01	-24	8.3	2
120						
CRW	-	-	-	-	-	-
SYN	-	-	-	-	-	-
MKH	75	97,700	1.01	-22	11.7	5.8

Of the three hydrocarbons analyzed, only MKH is likely to emulsify. If this oil emulsifies, it will attain high viscosities and densities. The oil is unlikely to sink in a marine environment, but will be easily over-washed by water. About 80% of the oil from a spill will be on the surface after 120 hours under October conditions at the Butterworth Rocks site. The CRW will completely evaporate and disperse after about a five-hour exposure. The SYN will survive on the surface for about 44 hours with 24% of the oil evaporating and 76% dispersing over this time. None of the oils will reach pour points where the oil will be a semi-solid at ambient temperatures.

2.3 Spill Fate: Hypothetical Tanker Spill at Butterworth Rocks

2.3.1 Hypothetical June Spill

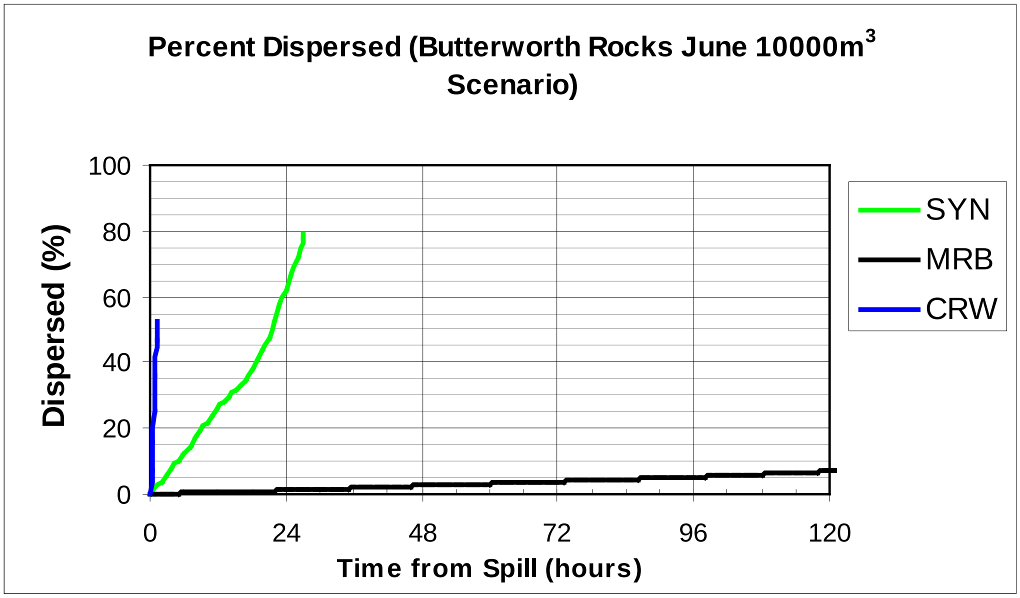

Figure 2-2 Percent Dispersed (Butterworth Rocks June 10,000 m^3 Scenario)

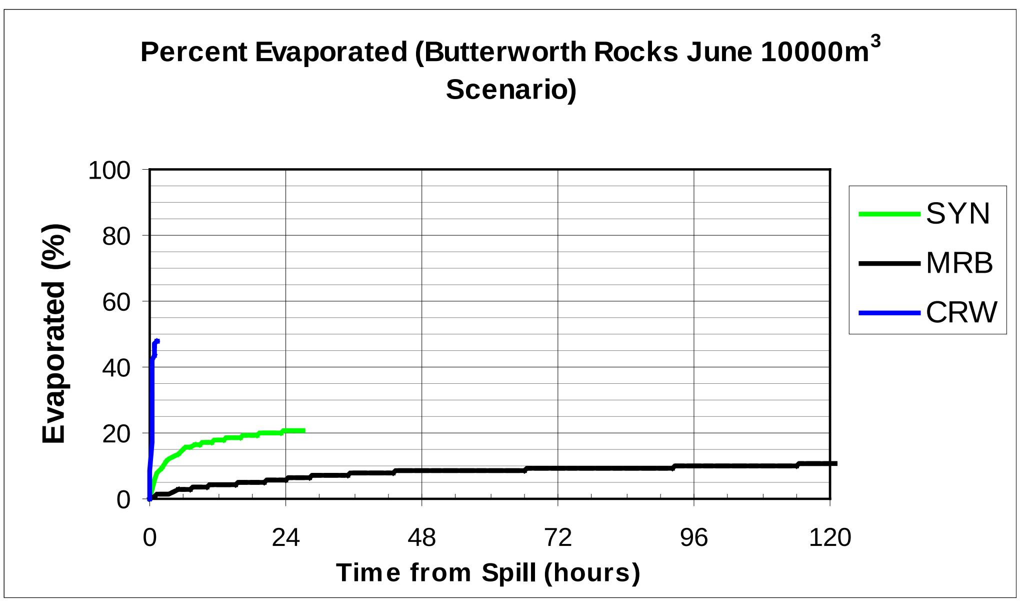

Figure 2-3 Percent Evaporated (Butterworth Rocks June 10,000 m^3 Scenario)

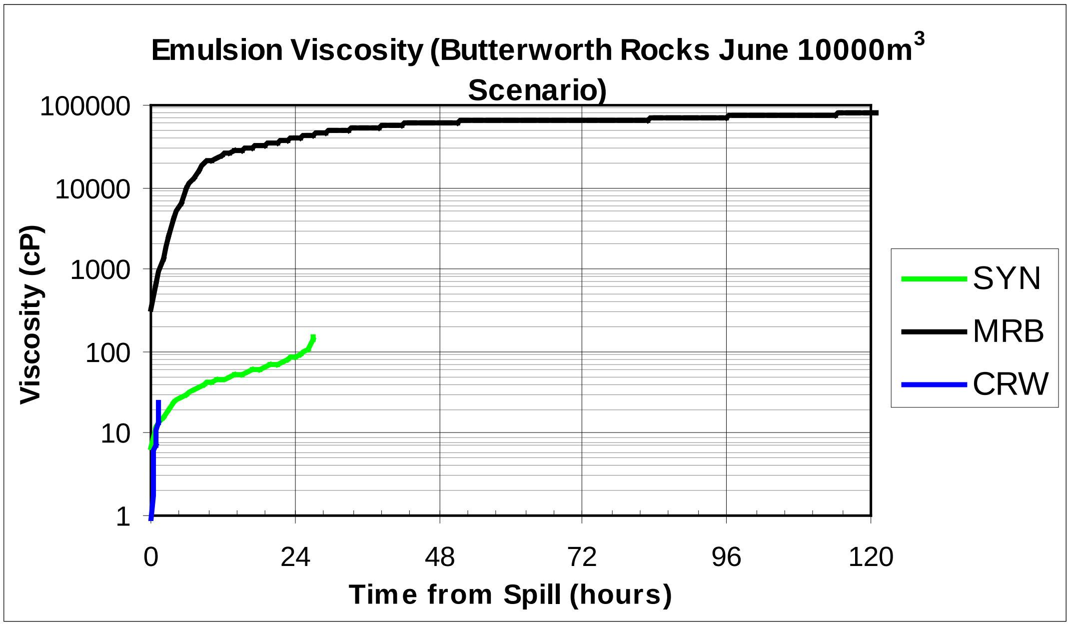

Figure 2-4 Emulsion Viscosity (Butterworth Rocks June 10,000 m^3 Scenario)

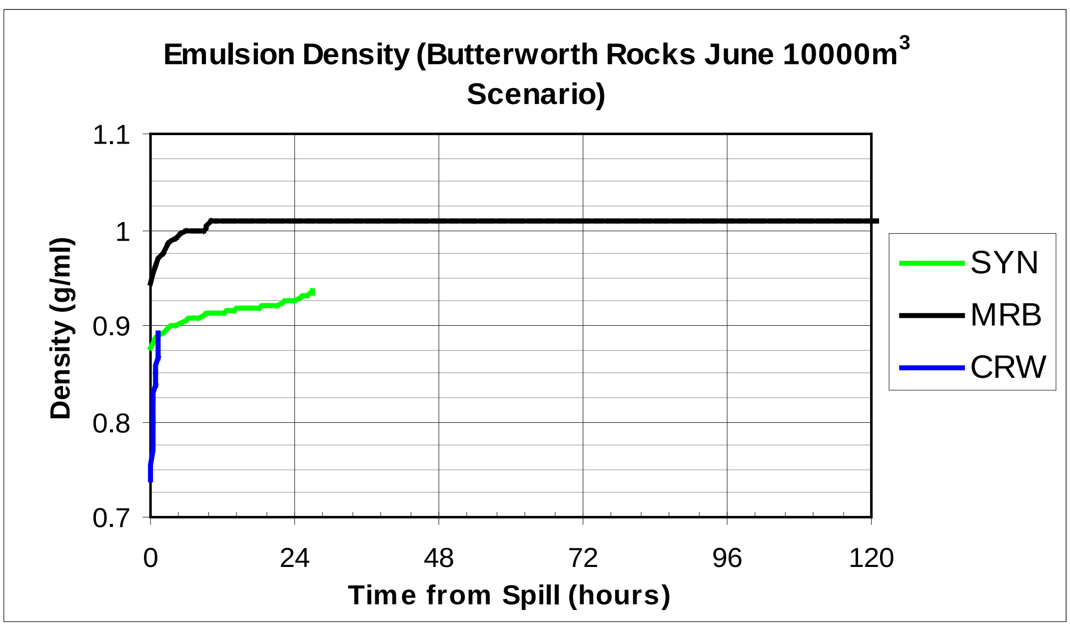

Figure 2-5 Emulsion Density (Butterworth Rocks June 10,000 m^3 Scenario)

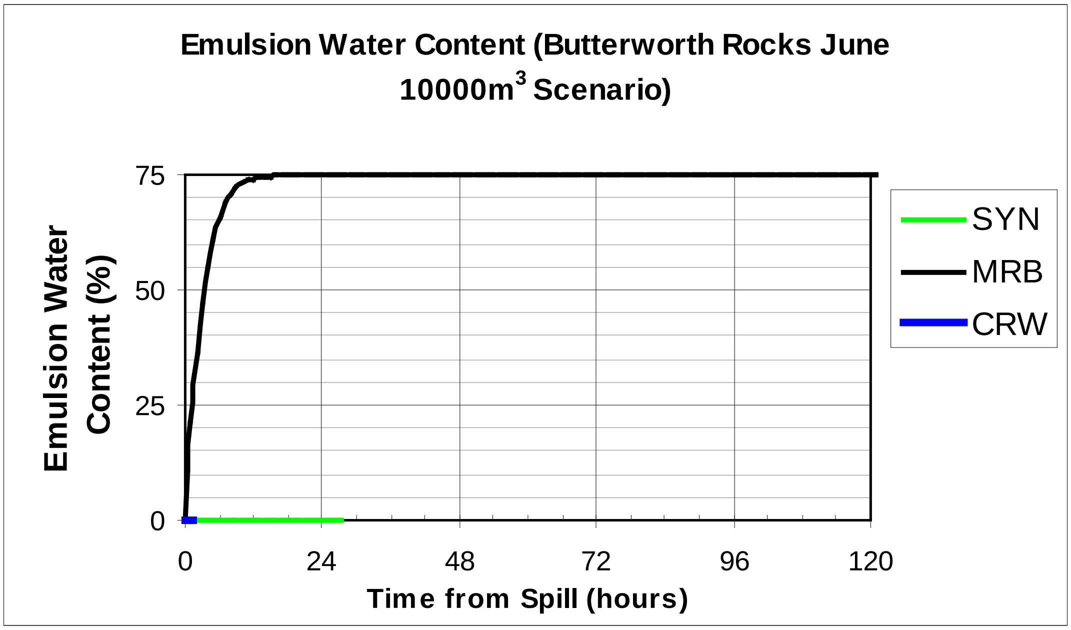

Figure 2-6 **Emulsion Water Content (Butterworth Rocks June 10,000 m^3 Scenario)**

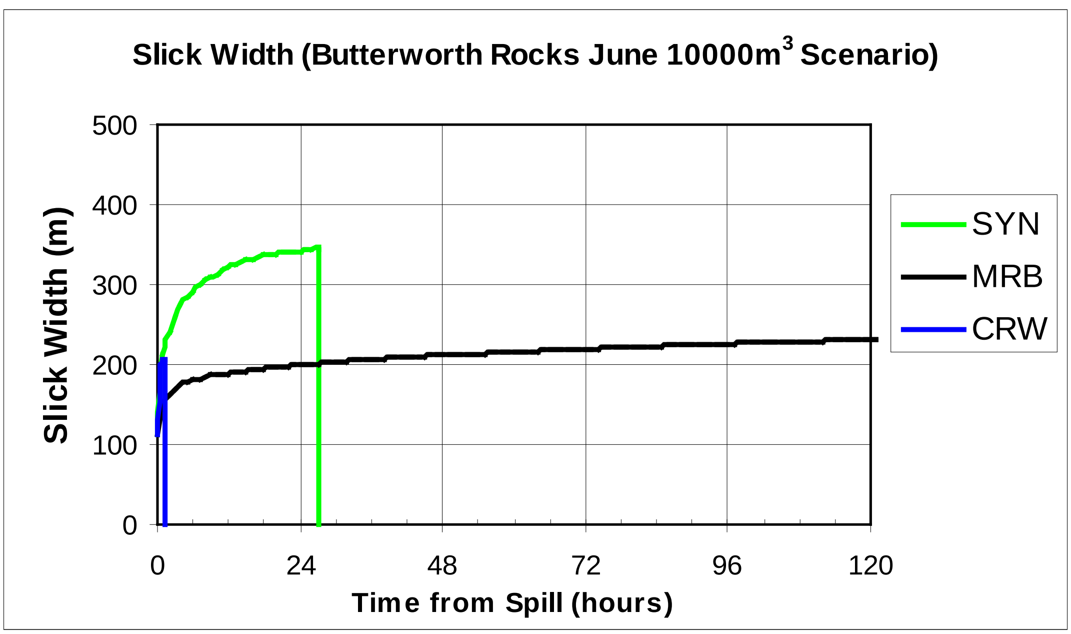

Figure 2-7 **Slick Width (Butterworth Rocks June 10,000 m^3 Scenario)**

2.3.2 Hypothetical October Spill

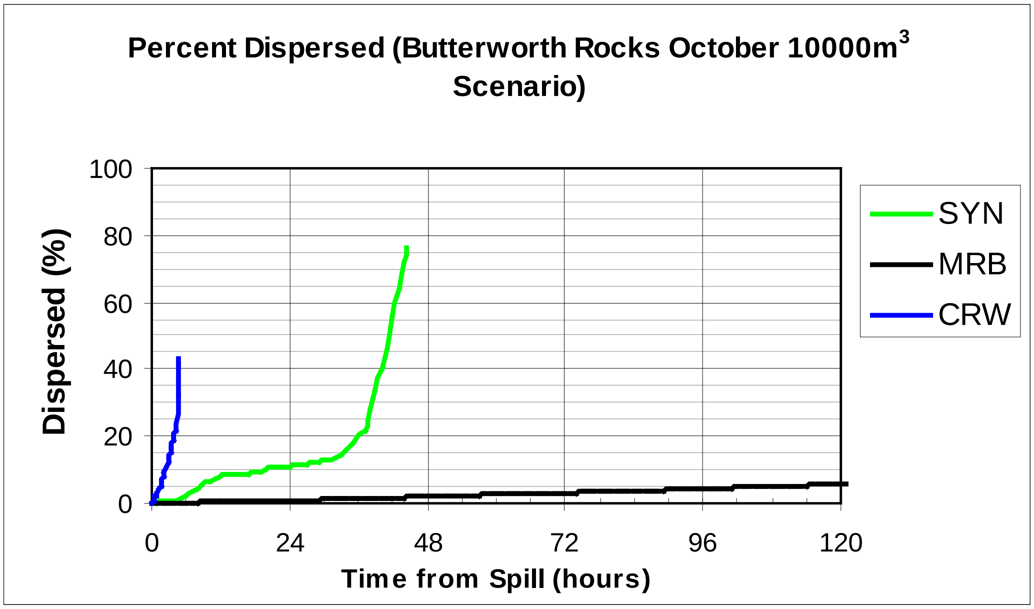

Figure 2-8 Percent Dispersed (Butterworth Rocks October 10,000 m^3 Scenario)

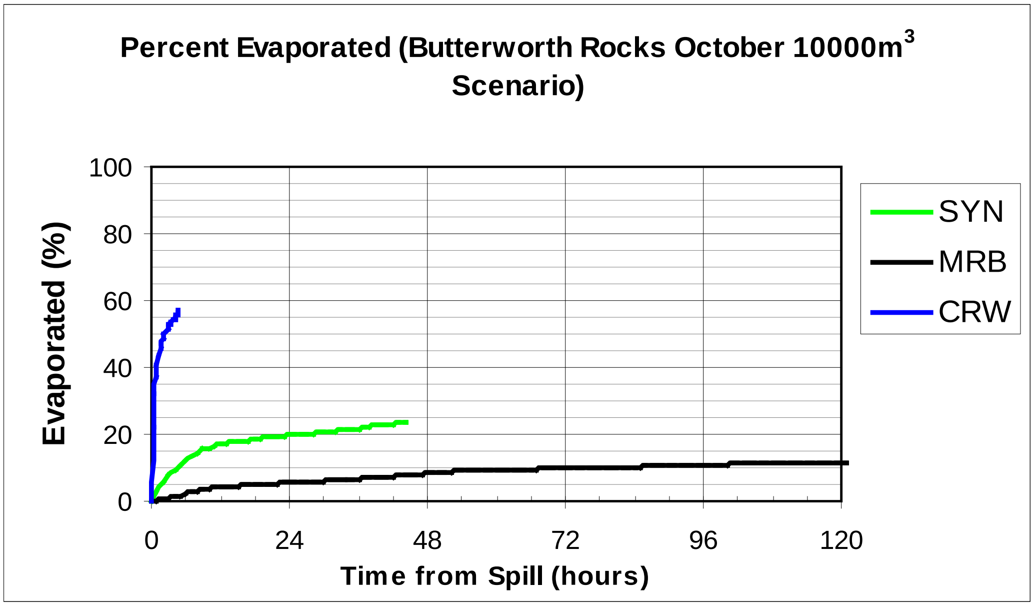

Figure 2-9 Percent Evaporated (Butterworth Rocks October 10,000 m^3 Scenario)

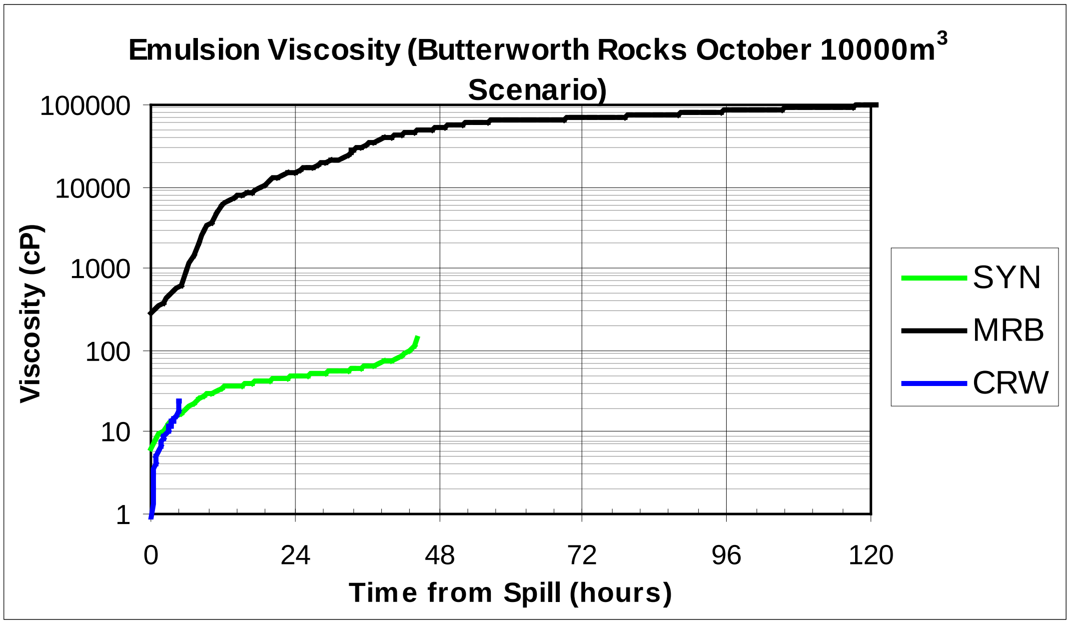

Figure 2-10 **Emulsion Viscosity (Butterworth Rocks October 10,000 m^3 Scenario)**

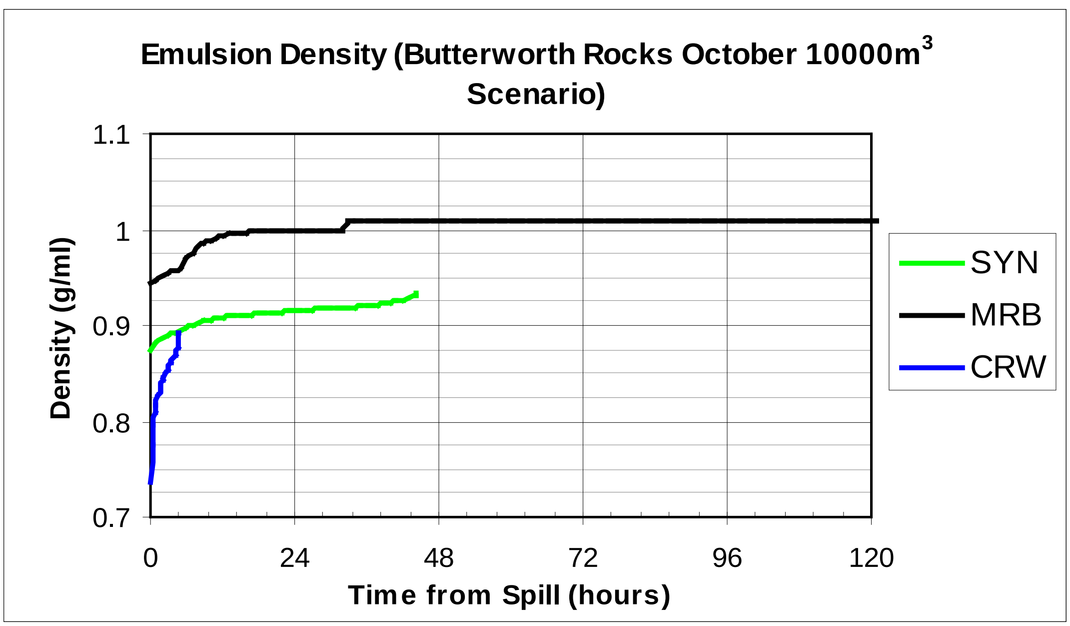

Figure 2-11 **Emulsion Density (Butterworth Rocks October 10,000 m^3 Scenario)**

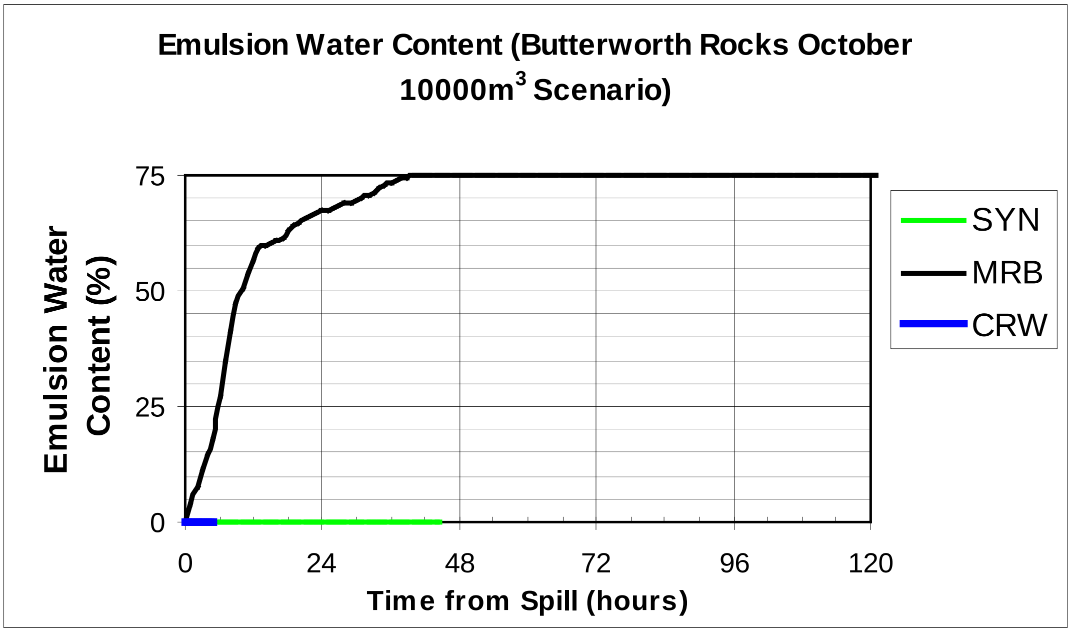

Figure 2-12 **Emulsion Water Content (Butterworth Rocks October 10,000 m^3 Scenario)**

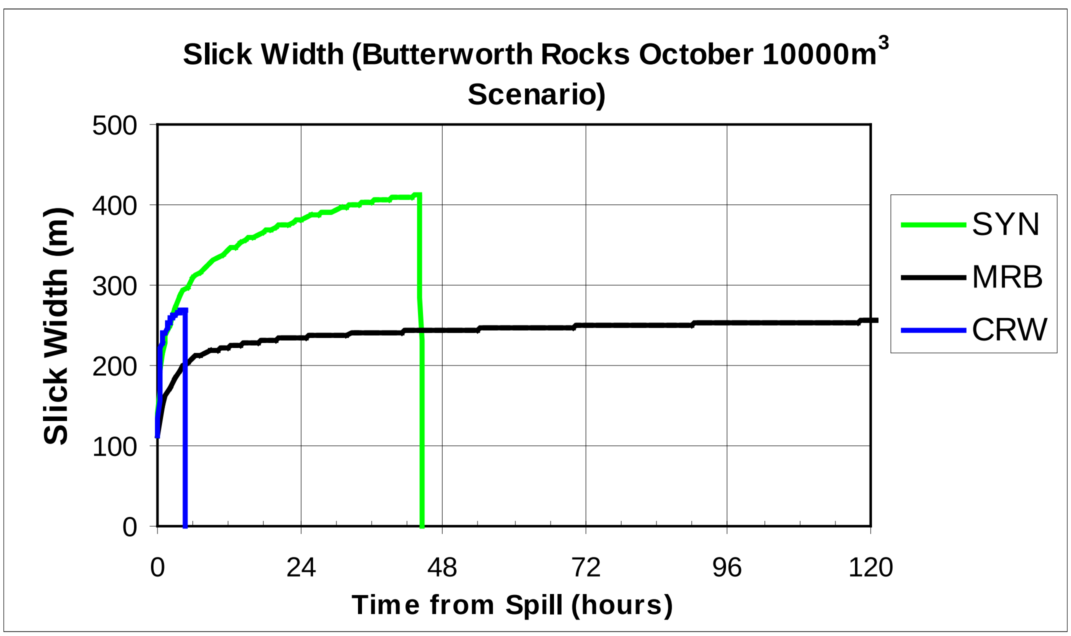

Figure 2-13 **Slick Width (Butterworth Rocks October 10,000 m^3 Scenario)**

2.3.3 Hypothetical January Spill

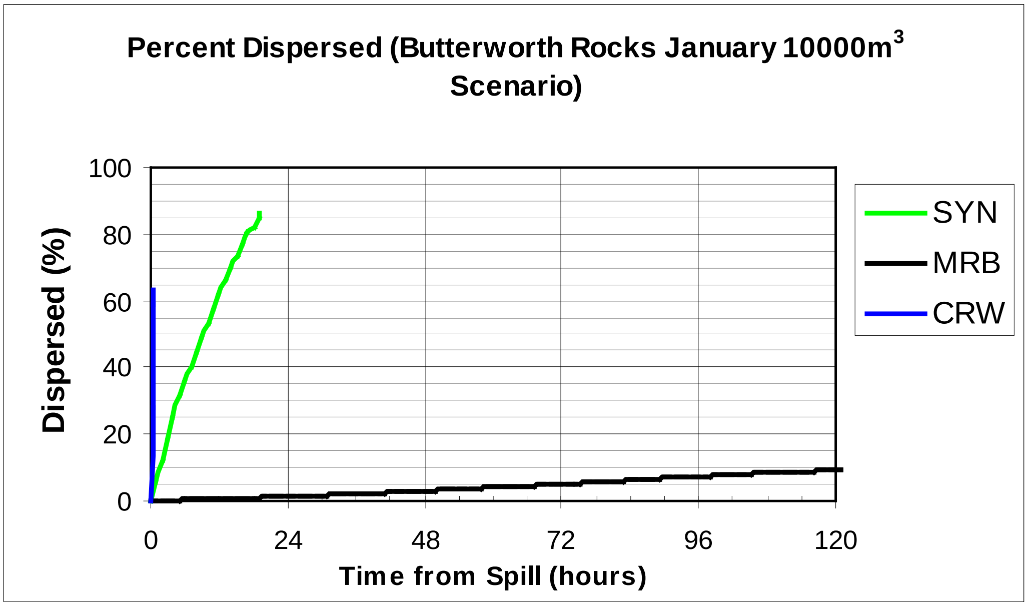

Figure 2-14 Percent Dispersed (Butterworth Rocks January 10,000 m^3 Scenario)

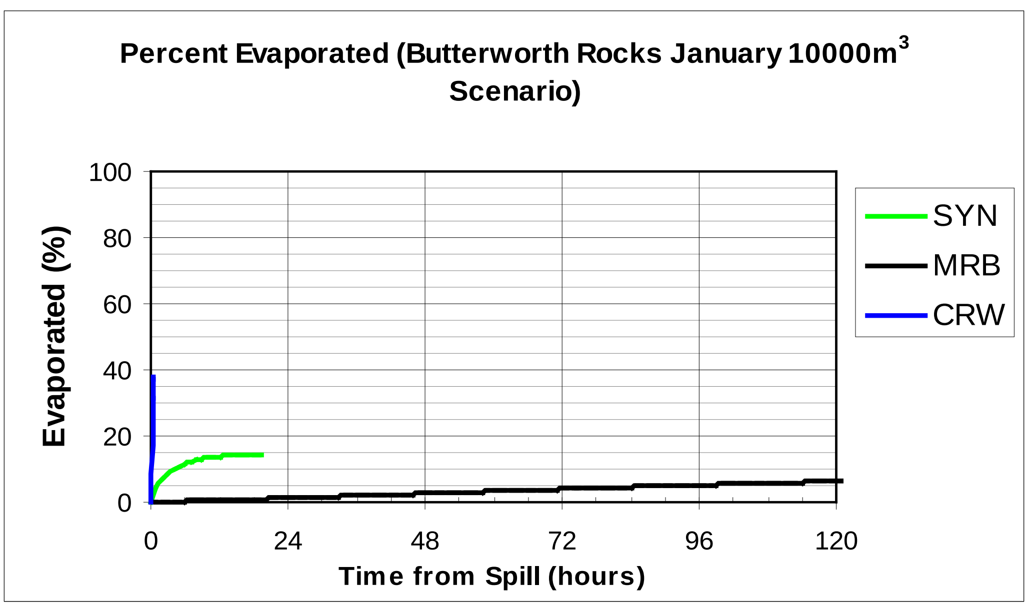

Figure 2-15 Percent Evaporated (Butterworth Rocks January 10,000 m^3 Scenario)

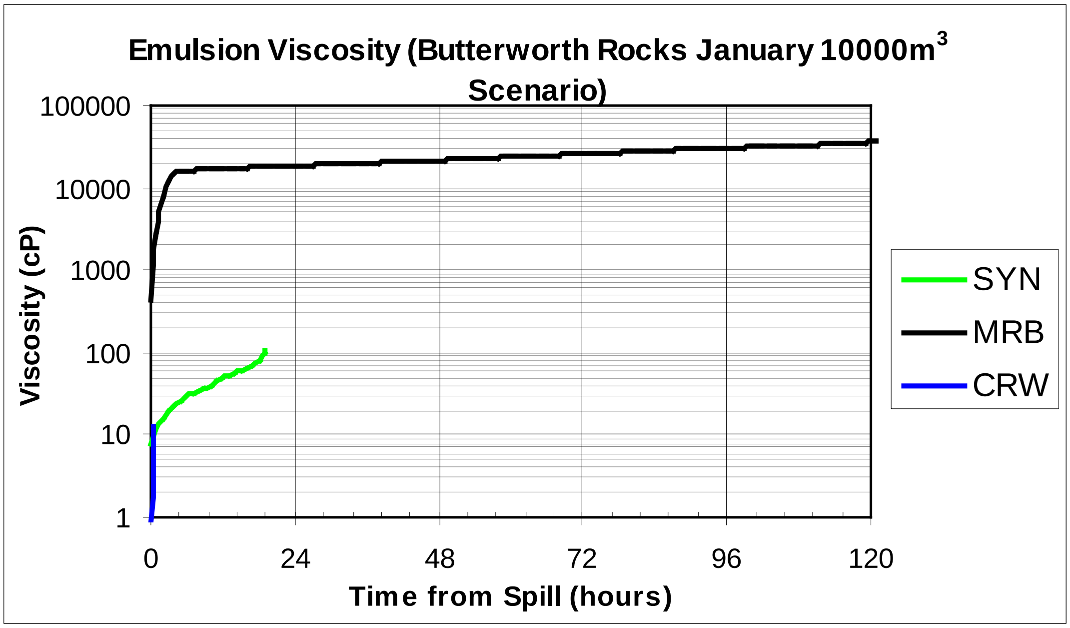

Figure 2-16 **Emulsion Viscosity (Butterworth Rocks January 10,000 m^3 Scenario)**

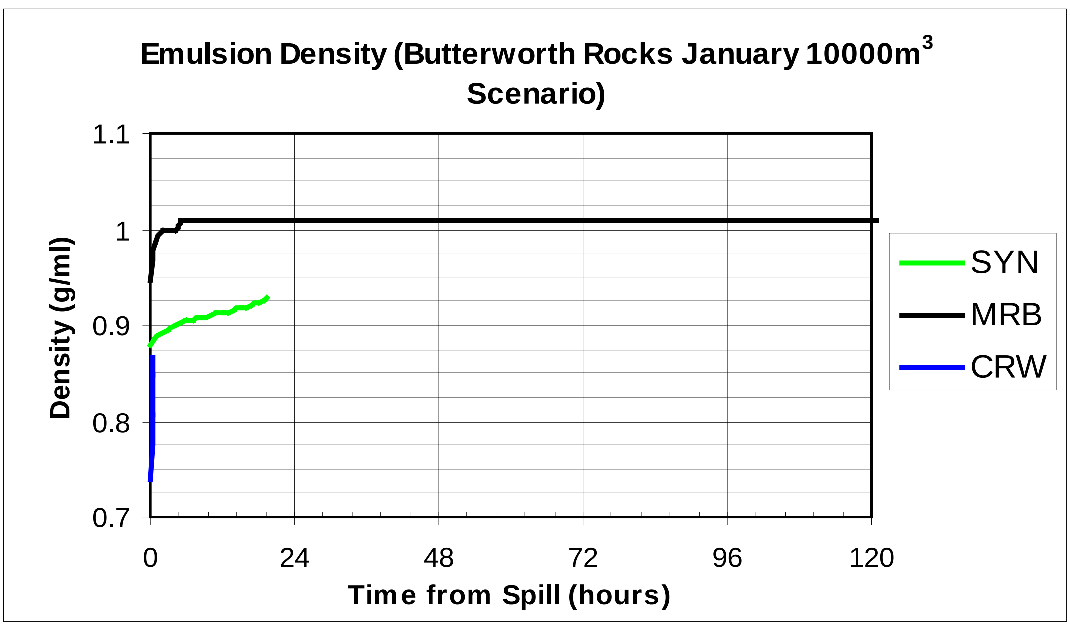

Figure 2-17 **Emulsion Density (Butterworth Rocks January 10,000 m^3 Scenario)**

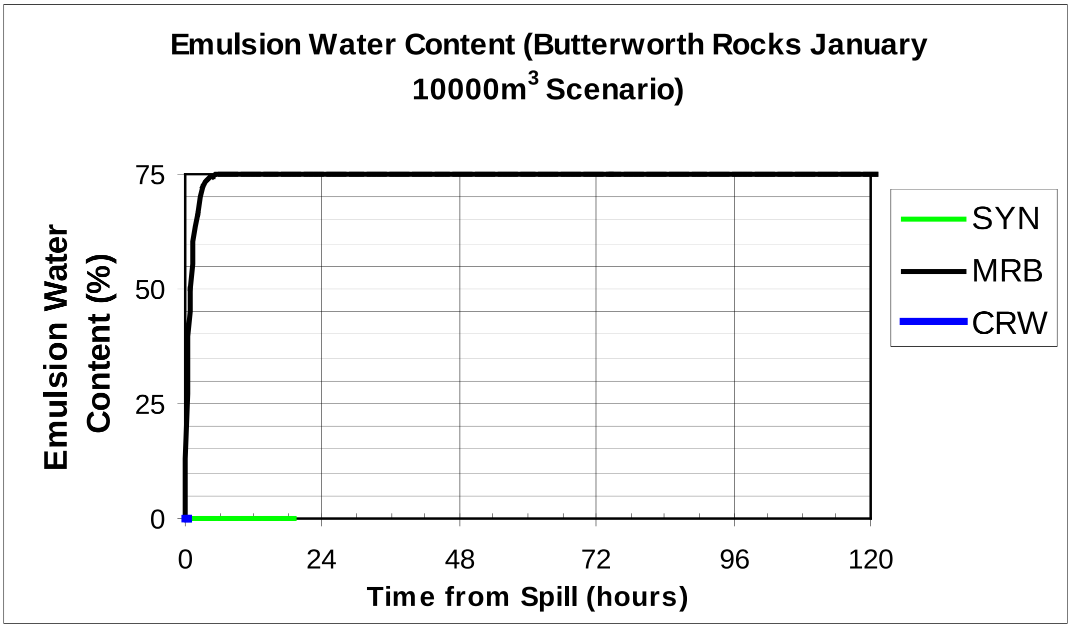

Figure 2-18 **Emulsion Water Content (Butterworth Rocks January 10,000 m^3 Scenario)**

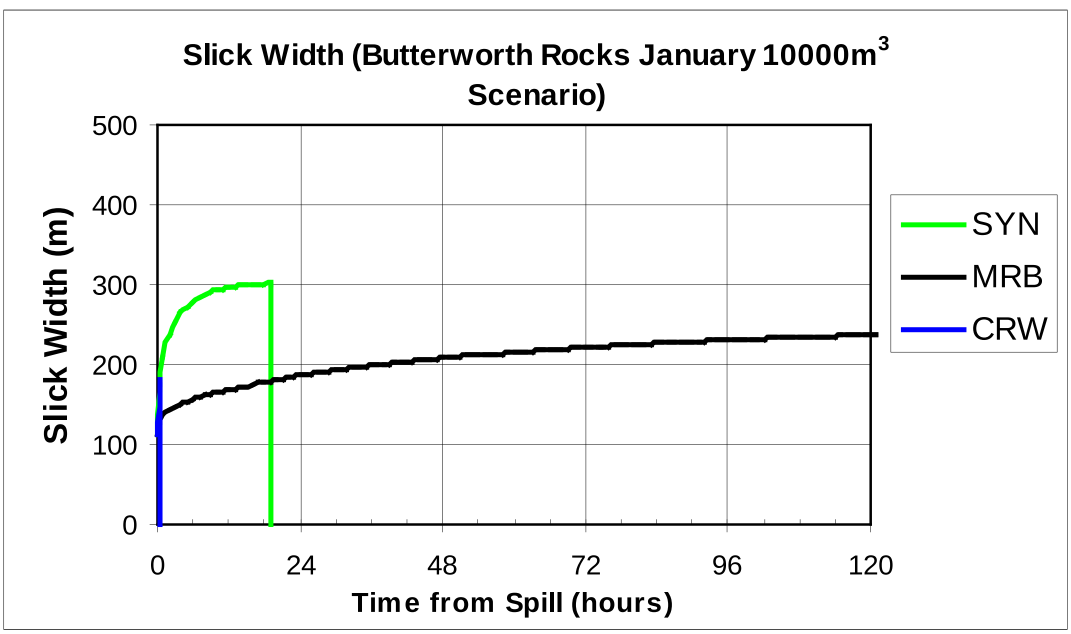

Figure 2-19 **Slick Width (Butterworth Rocks January 10,000 m^3 Scenario)**

2.3.4 Hypothetical April Spill

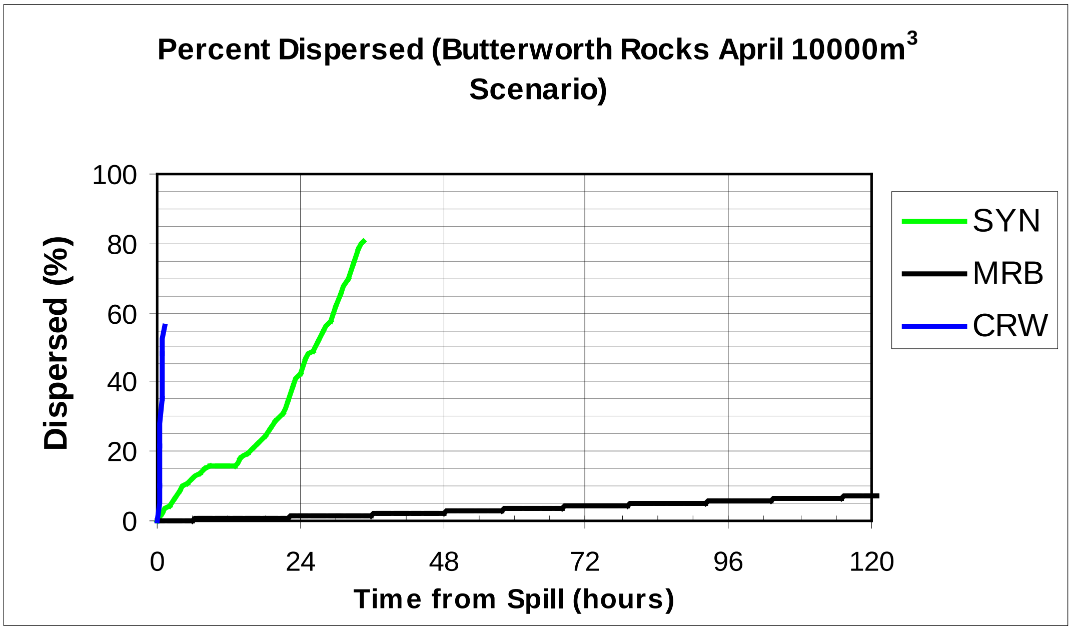

Figure 2-20 Percent Dispersed (Butterworth Rocks April 10,000 m^3 Scenario)

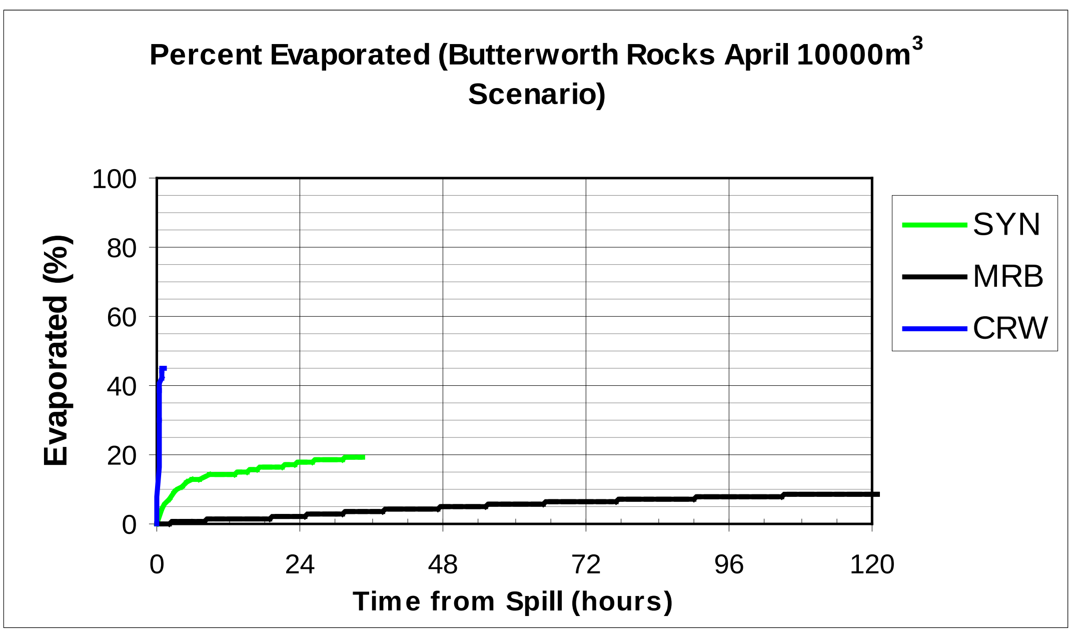

Figure 2-21 Percent Evaporated (Butterworth Rocks April 10,000 m^3 Scenario)

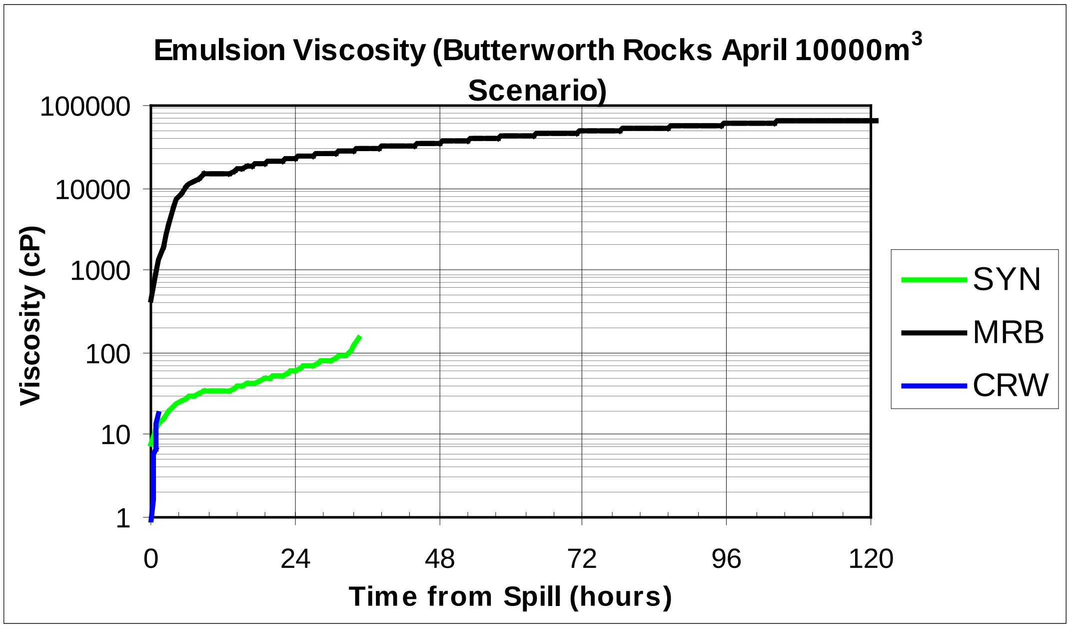

Figure 2-22 Emulsion Viscosity (Butterworth Rocks April 10,000 m^3 Scenario)

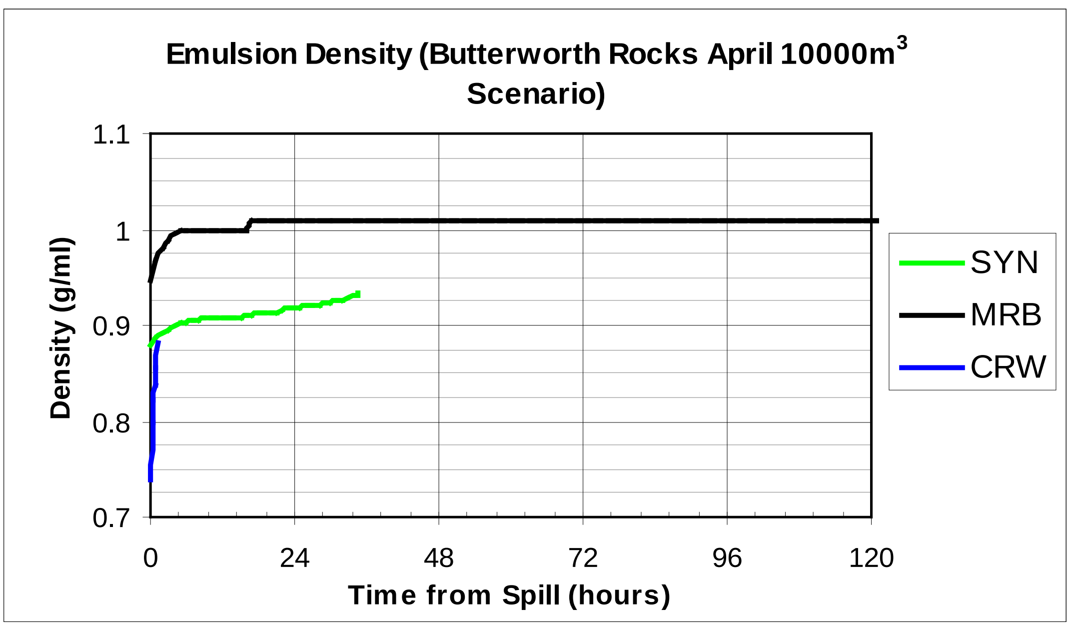

Figure 2-23 Emulsion Density (Butterworth Rocks April 10,000 m^3 Scenario)

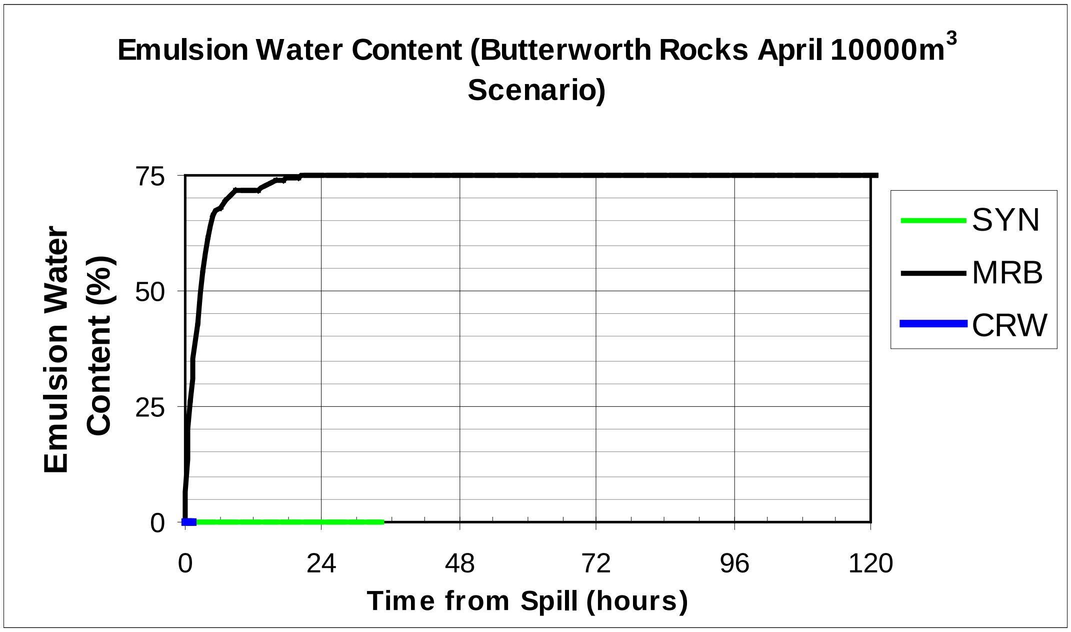

Figure 2-24 **Emulsion Water Content (Butterworth Rocks April 10,000 m^3 Scenario)**

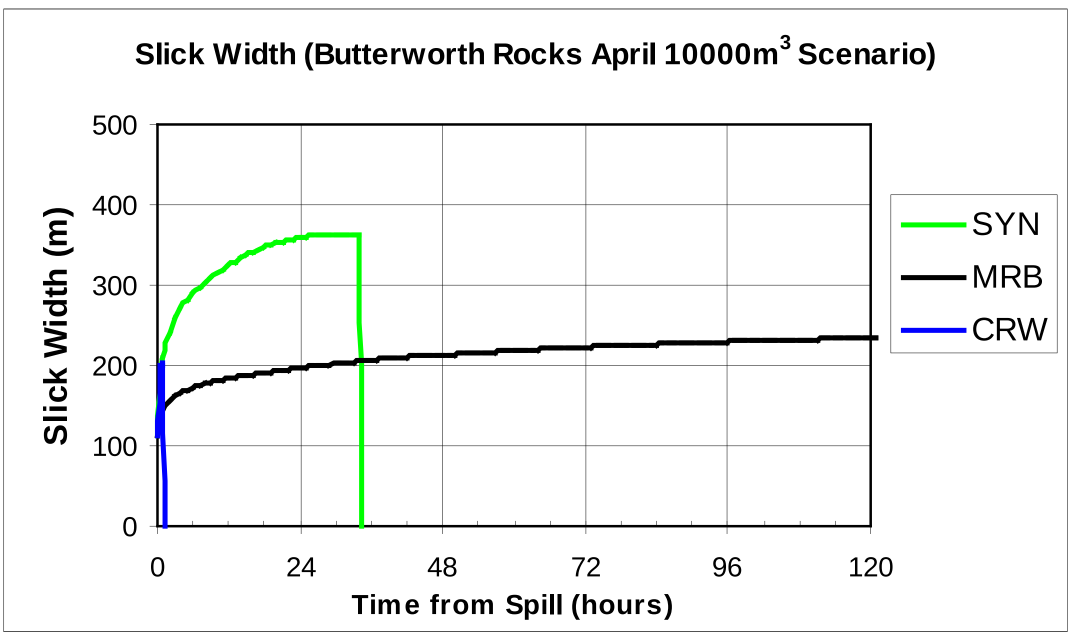

Figure 2-25 **Slick Width (Butterworth Rocks April 10,000 m^3 Scenario)**

2.4 Spill Fate: Hypothetical Tanker Spill at Ness Rock

2.4.1 Hypothetical June Spill

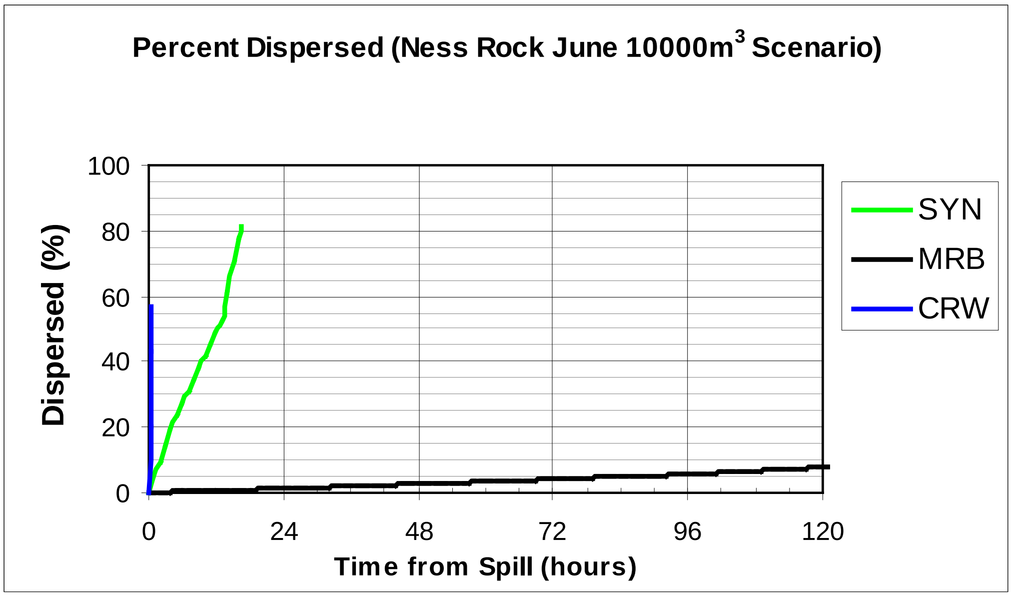

Figure 2-26 Percent Dispersed (Ness Rock June 10,000 m^3 Scenario)

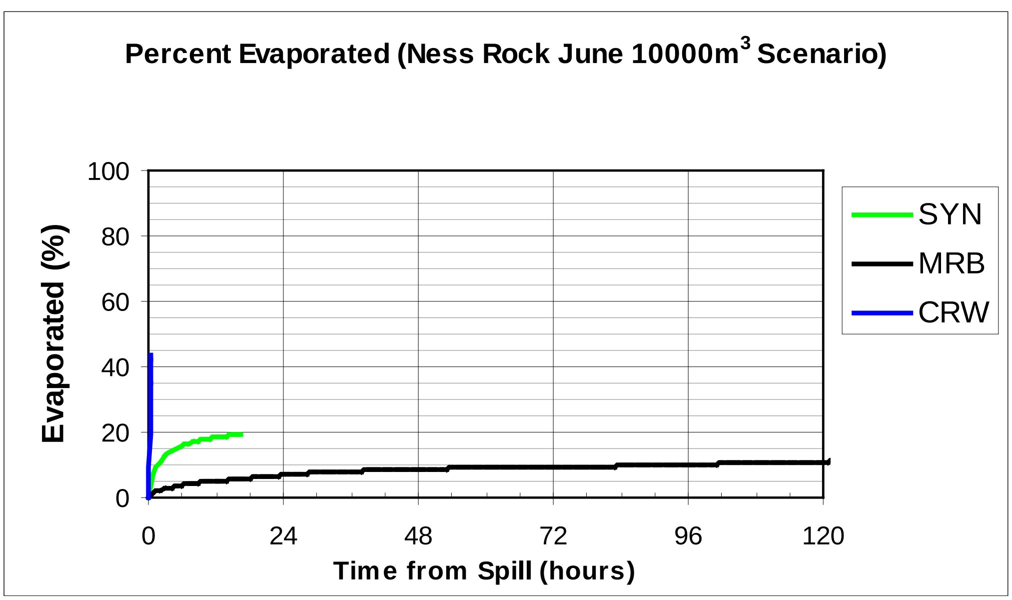

Figure 2-27 Percent Evaporated (Ness Rock June 10,000 m^3 Scenario)

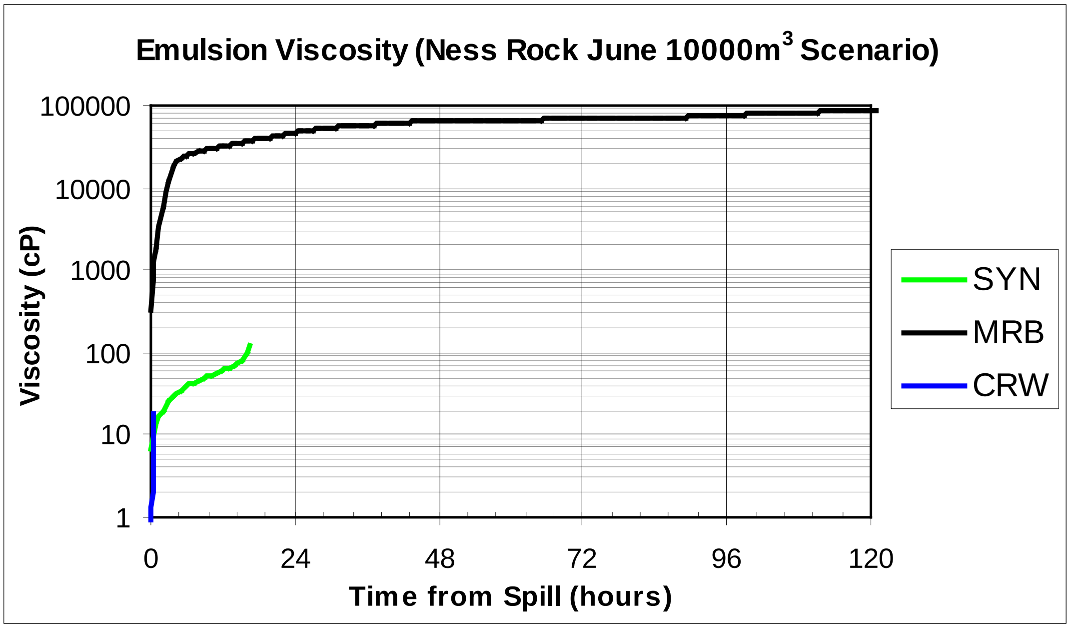

Figure 2-28 Emulsion Viscosity (Ness Rock June 10,000 m^3 Scenario)

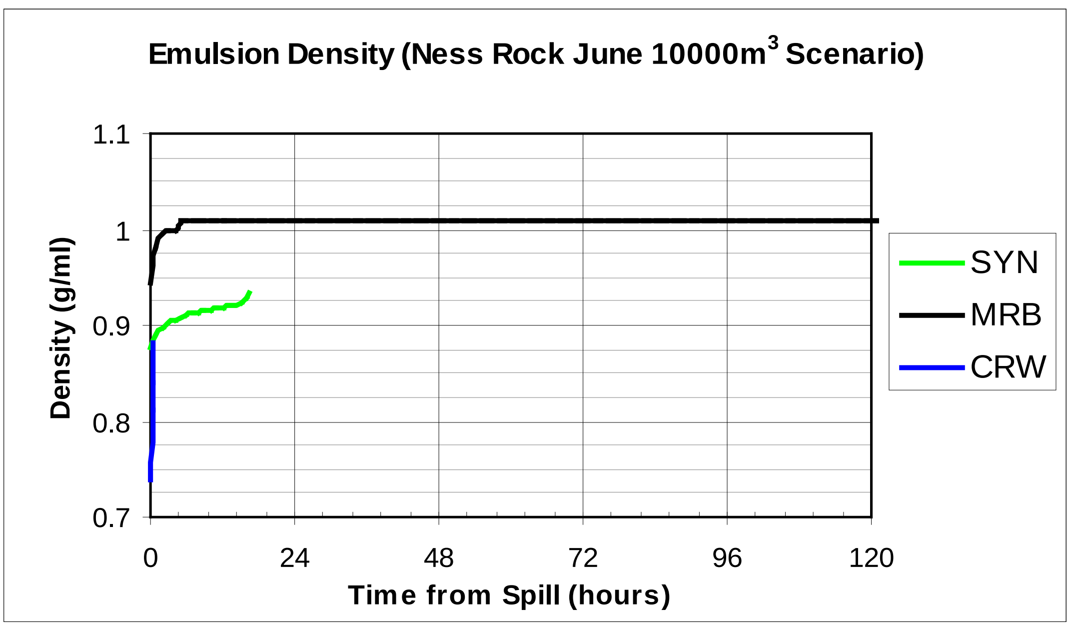

Figure 2-29 Emulsion Density (Ness Rock June 10,000 m^3 Scenario)

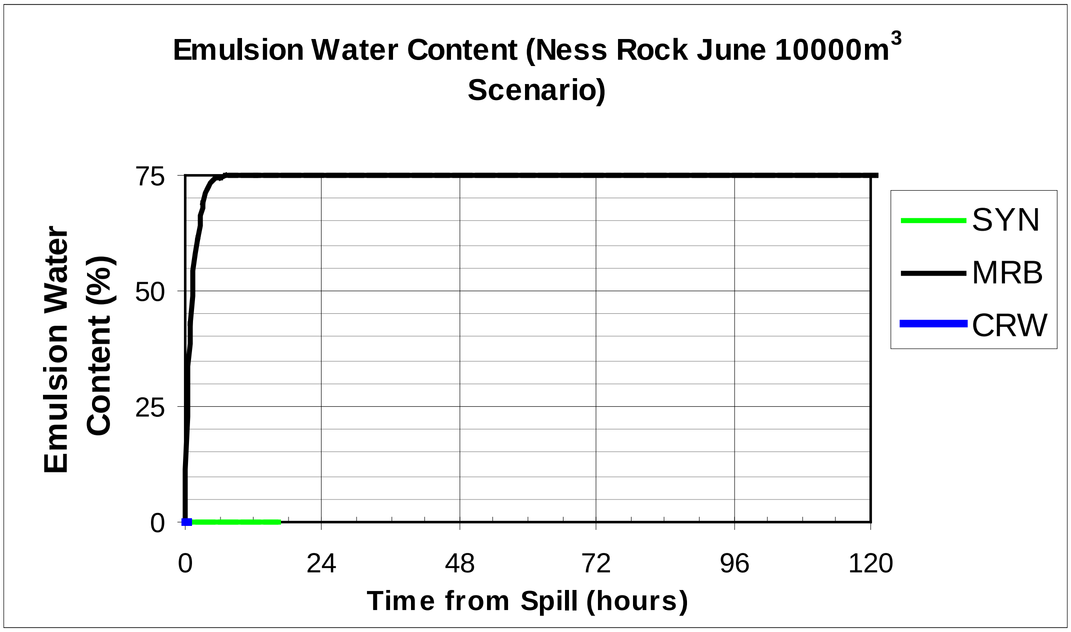

Figure 2-30 **Emulsion Water Content (Ness Rock June 10,000 m^3 Scenario)**

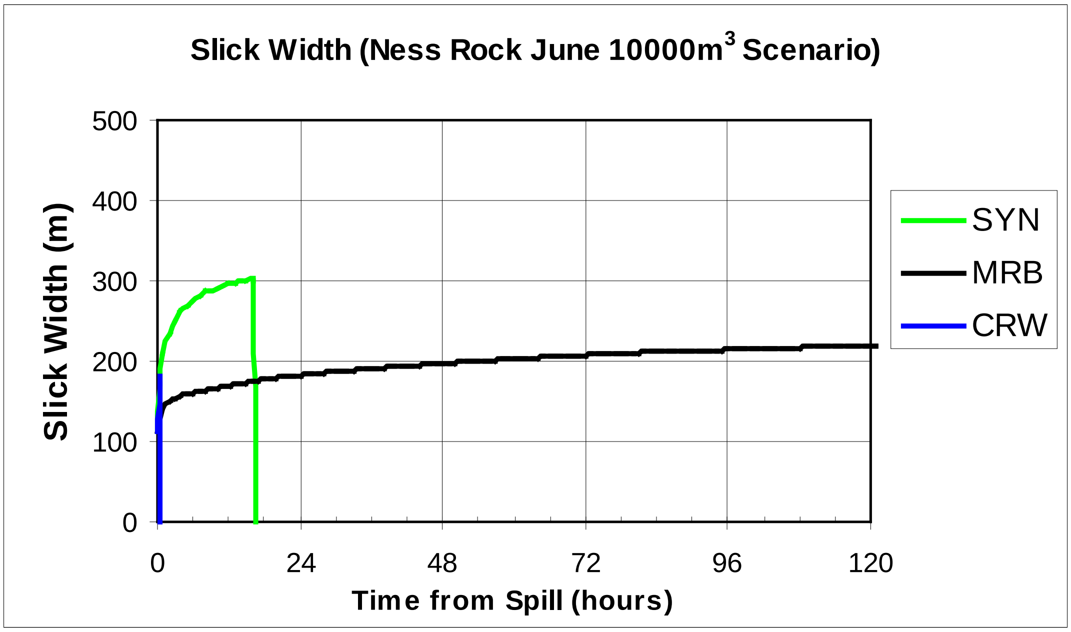

Figure 2-31 **Slick Width (Ness Rock June 10,000 m^3 Scenario)**

2.4.2 Hypothetical October Spill

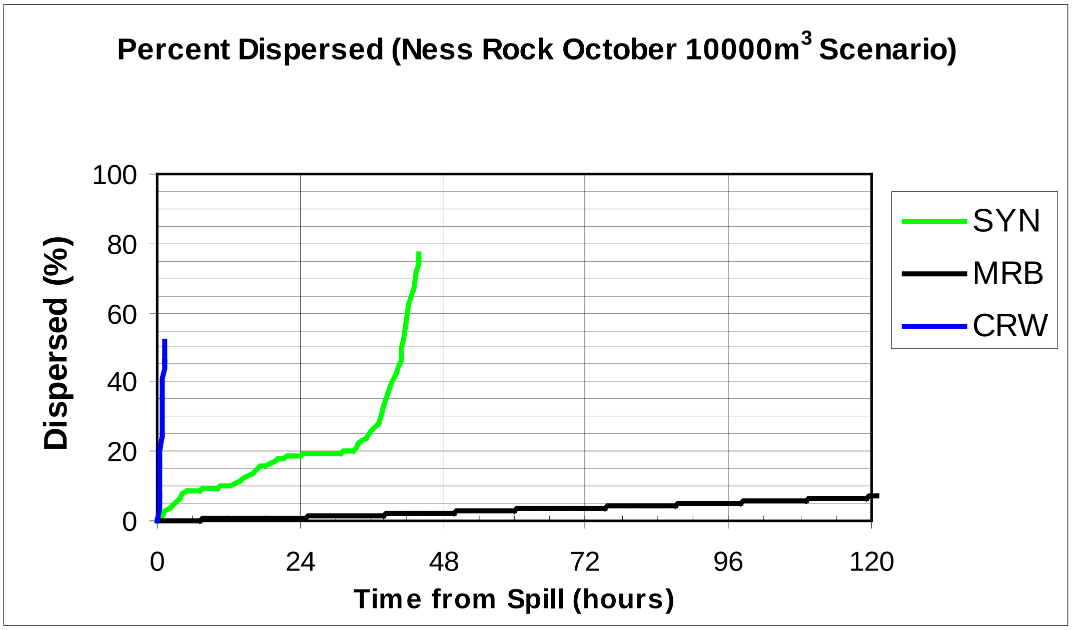

Figure 2-32 Percent Dispersed (Ness Rock October 10,000 m^3 Scenario)

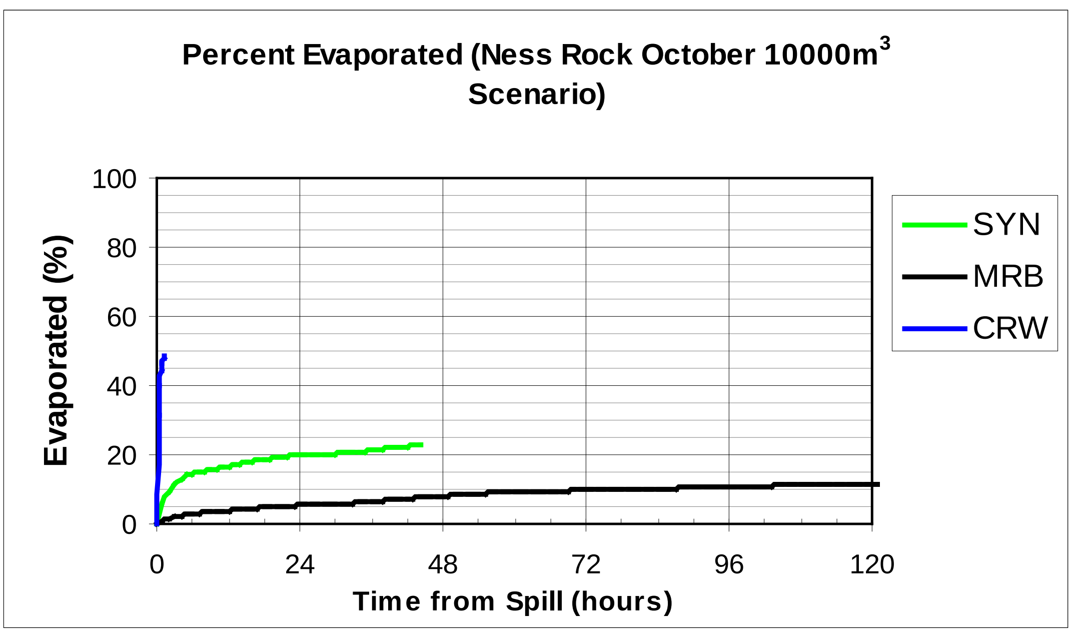

Figure 2-33 Percent Evaporated (Ness Rock October 10,000 m^3 Scenario)

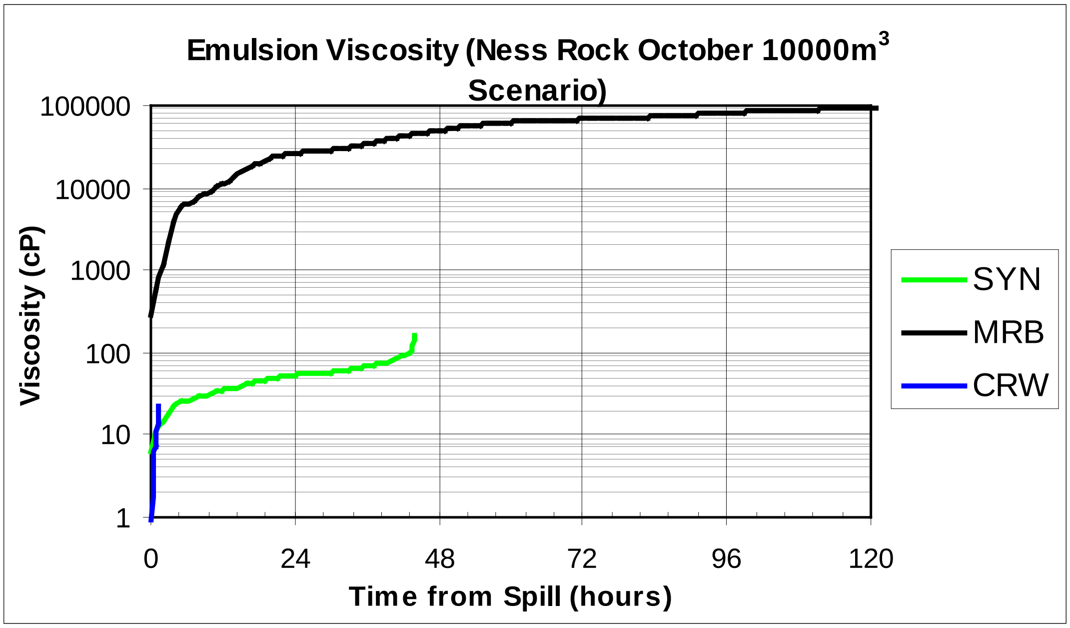

Figure 2-34 **Emulsion Viscosity (Ness Rock October 10,000 m^3 Scenario)**

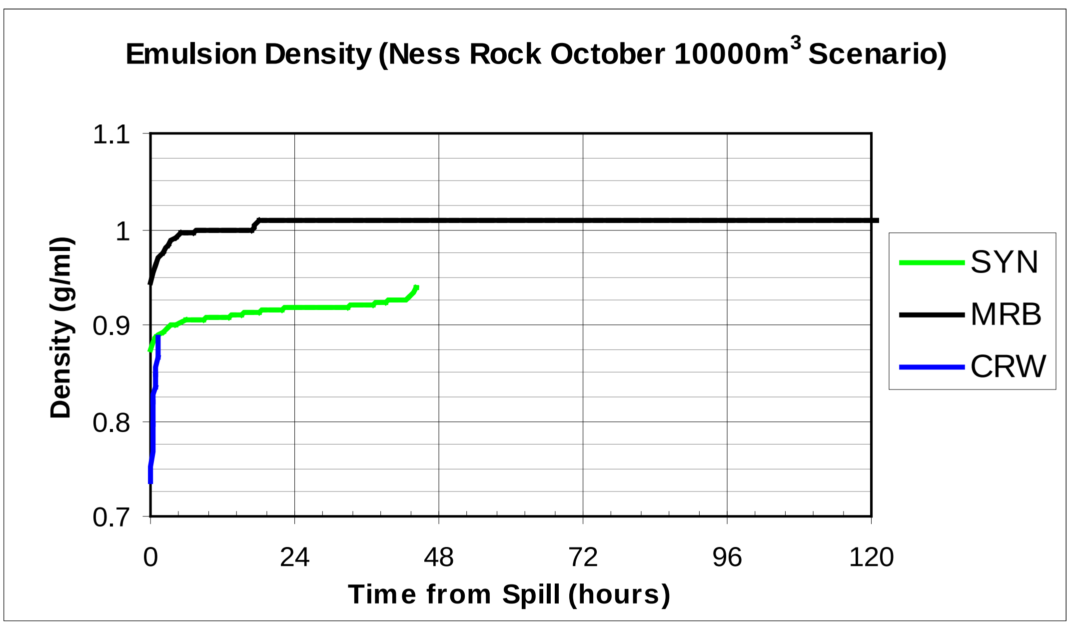

Figure 2-35 **Emulsion Density (Ness Rock October 10,000 m^3 Scenario)**

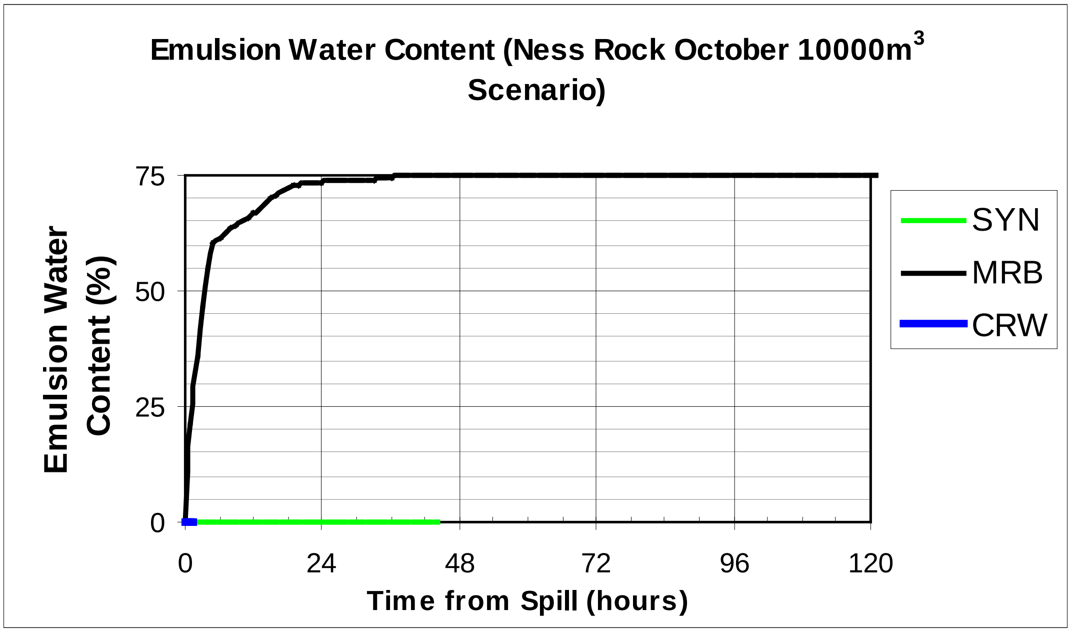

Figure 2-36 Emulsion Water Content (Ness Rock October 10,000 m^3 Scenario)

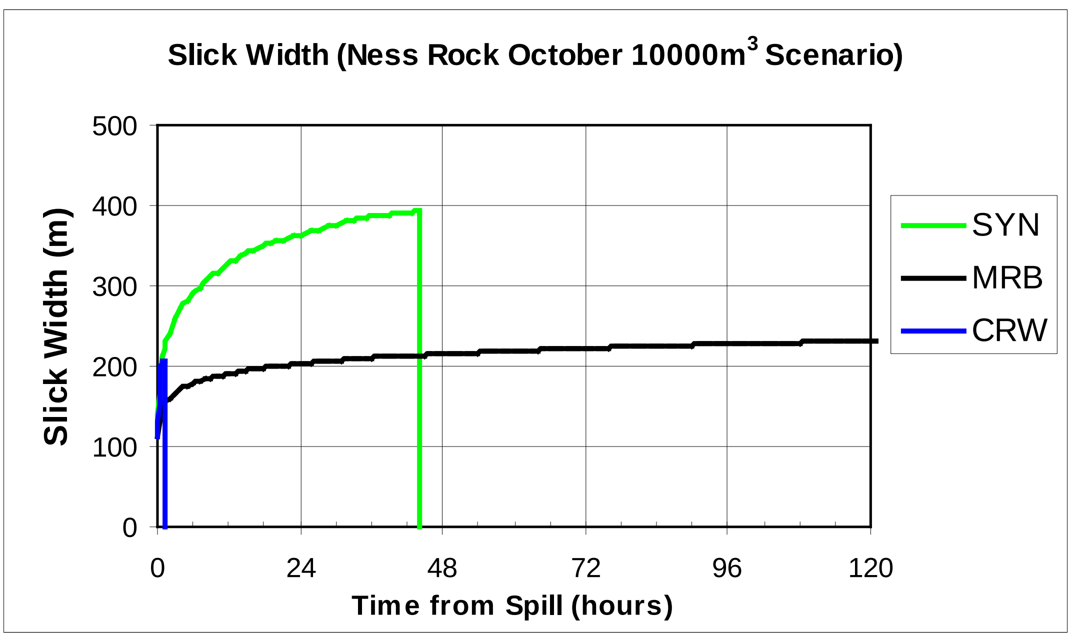

Figure 2-37 Slick Width (Ness Rock October 10,000 m^3 Scenario)

2.4.3 Hypothetical January Spill

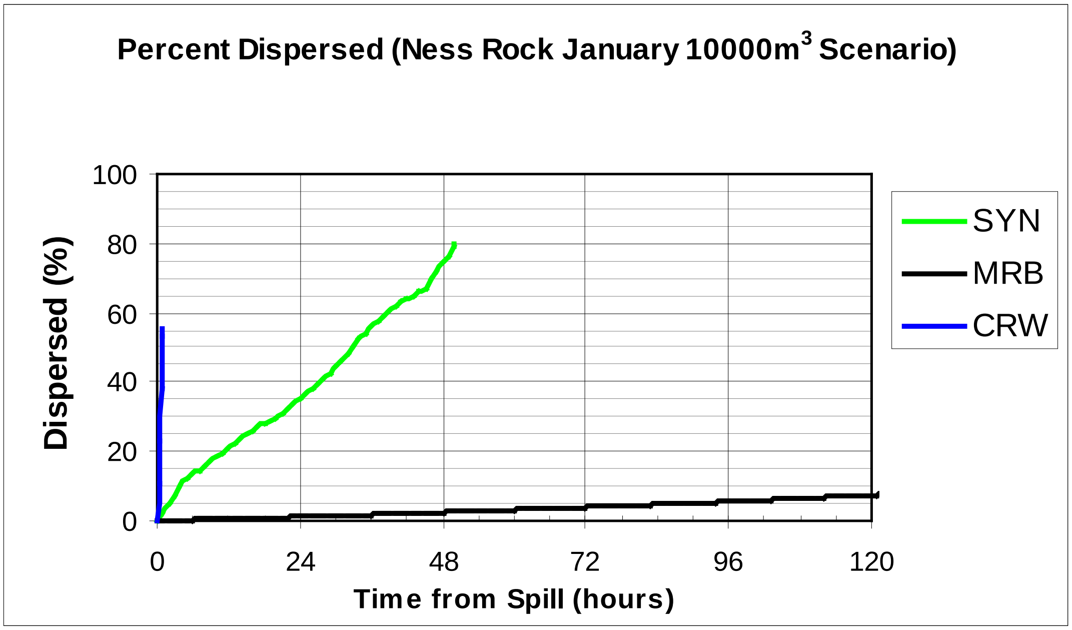

Figure 2-38 Percent Dispersed (Ness Rock January 10,000 m^3 Scenario)

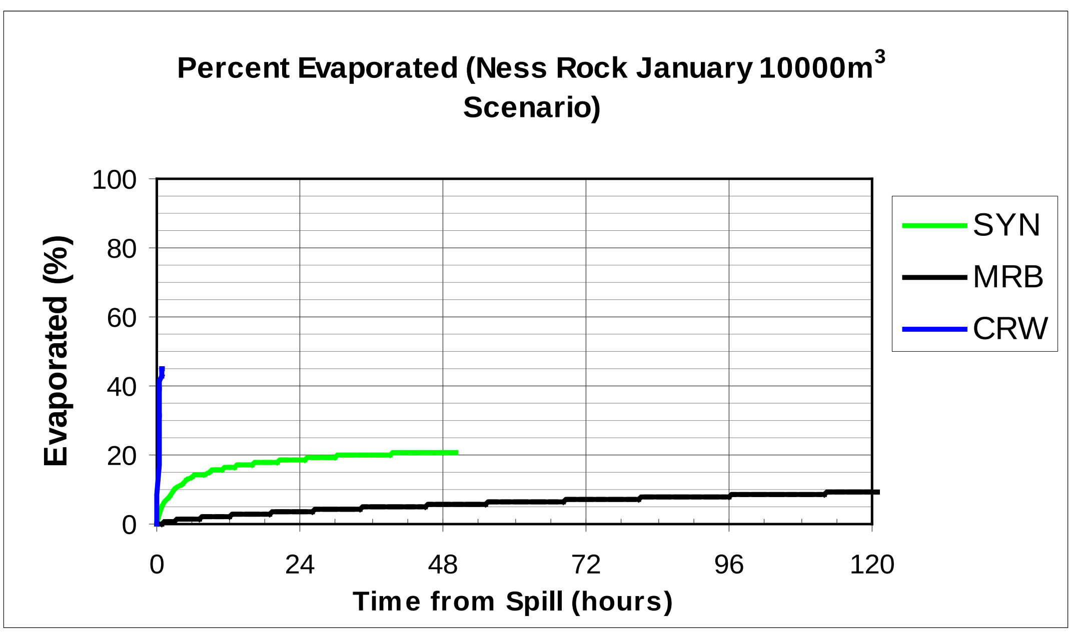

Figure 2-39 Percent Evaporated (Ness Rock January 10,000 m^3 Scenario)

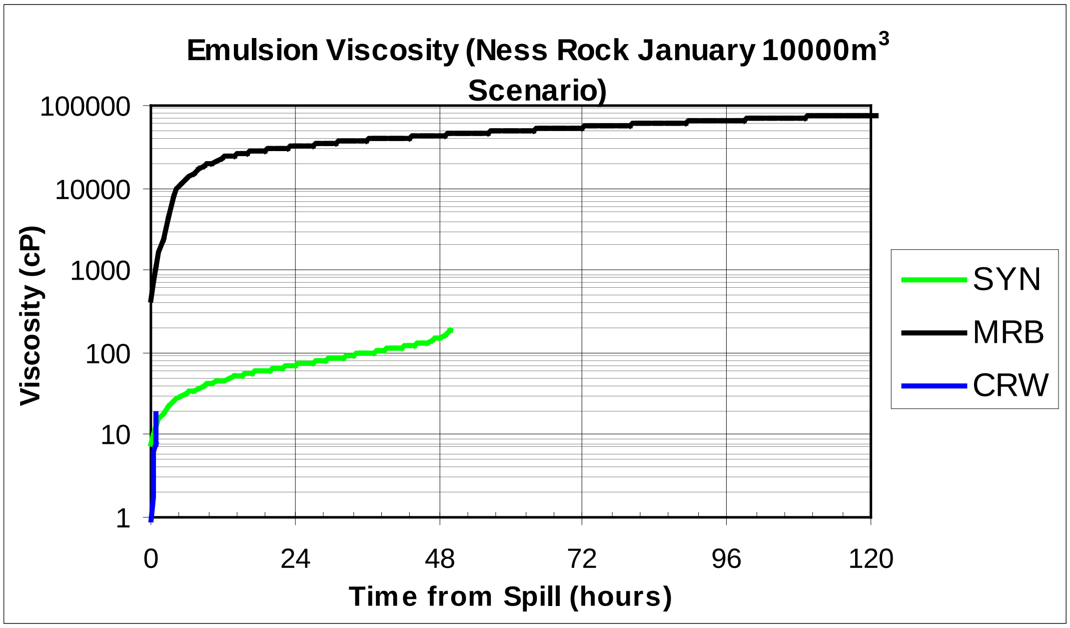

Figure 2-40 Emulsion Viscosity (Ness Rock January 10,000 m^3 Scenario)

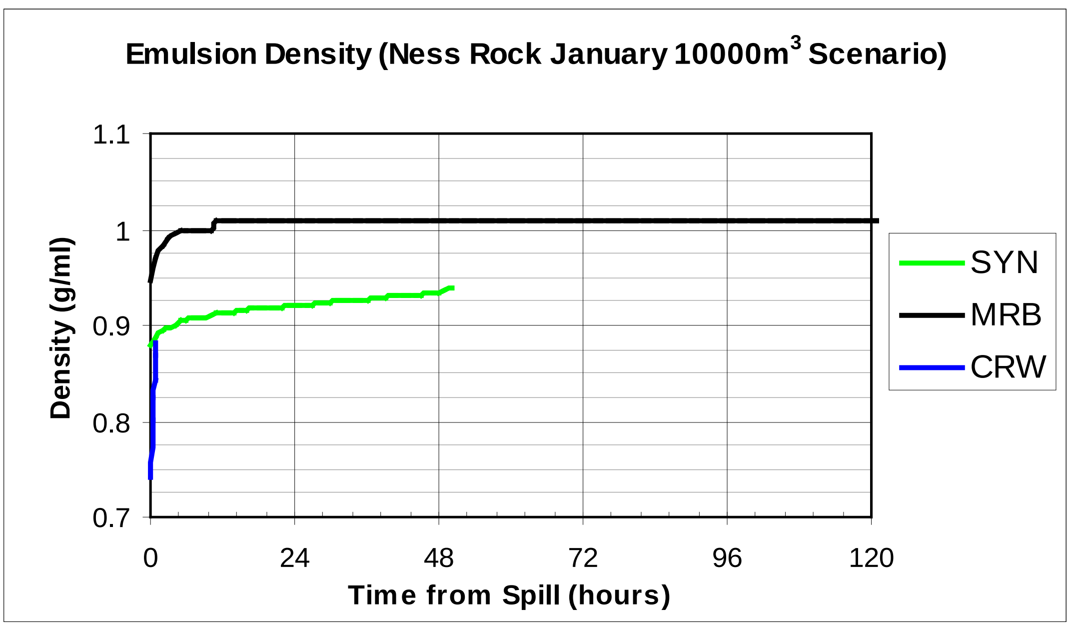

Figure 2-41 Emulsion Density (Ness Rock January 10,000 m^3 Scenario)

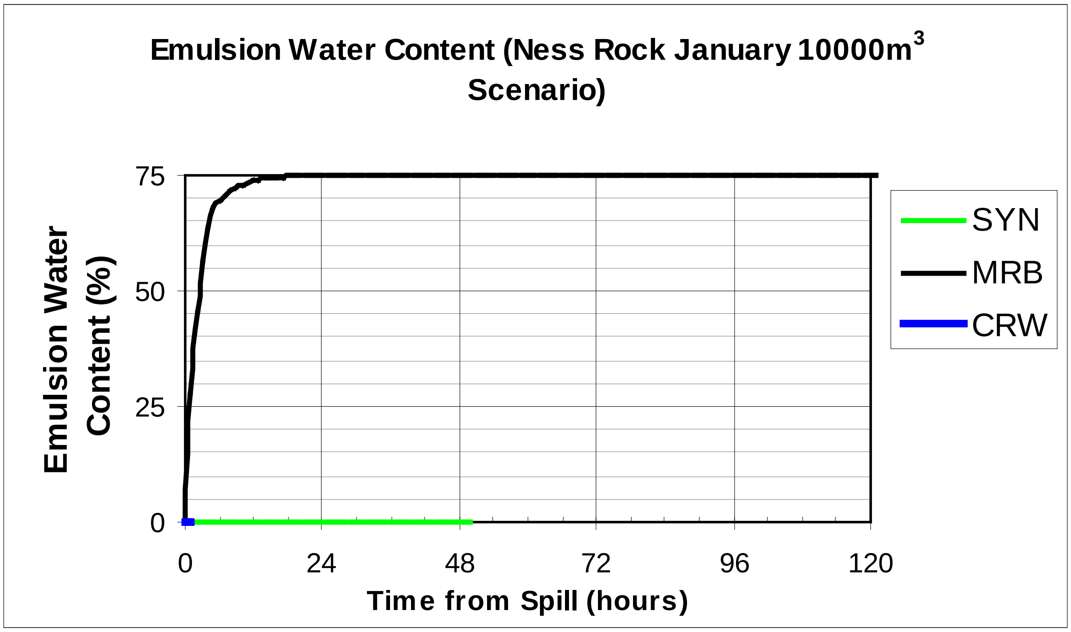

Figure 2-42 **Emulsion Water Content (Ness Rock January 10,000 m^3 Scenario)**

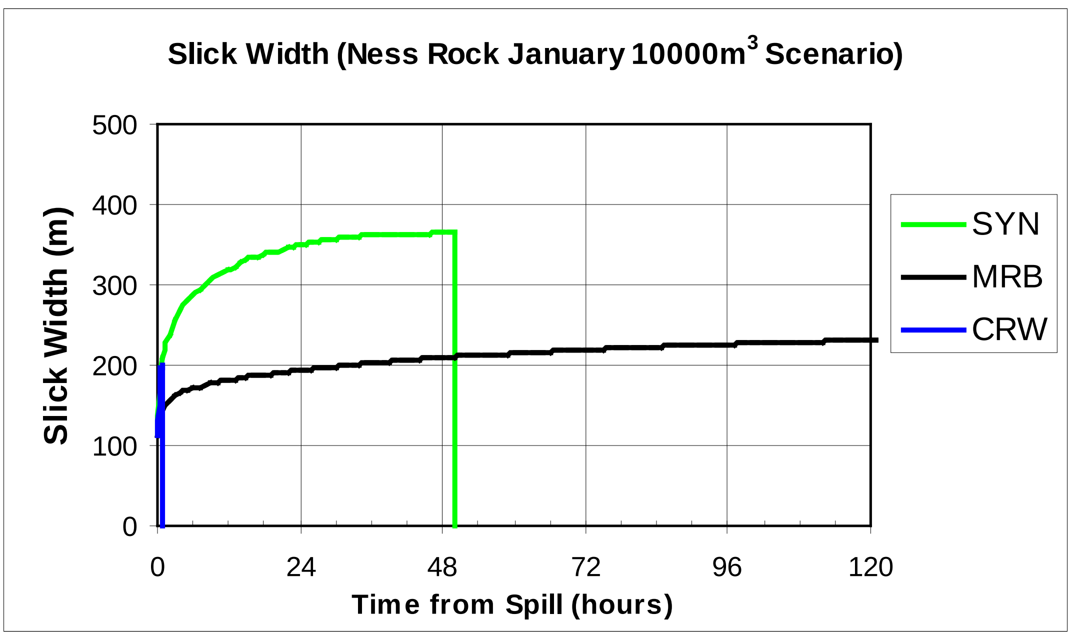

Figure 2-43 **Slick Width (Ness Rock January 10,000 m^3 Scenario)**

2.4.4 Hypothetical April Spill

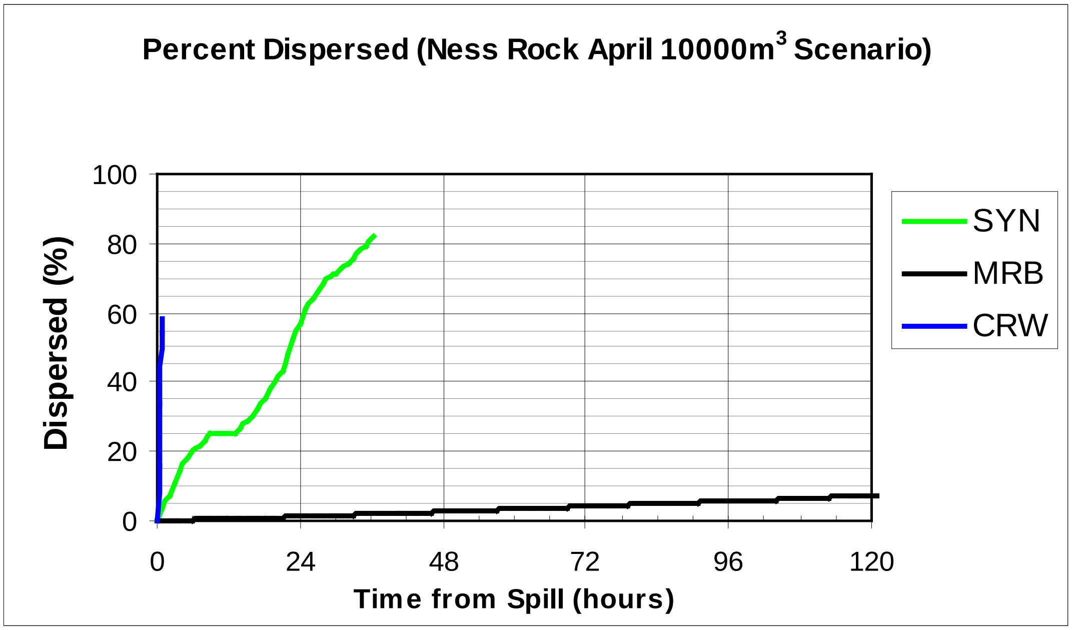

Figure 2-44 Percent Dispersed (Ness Rock April 10,000 m^3 Scenario)

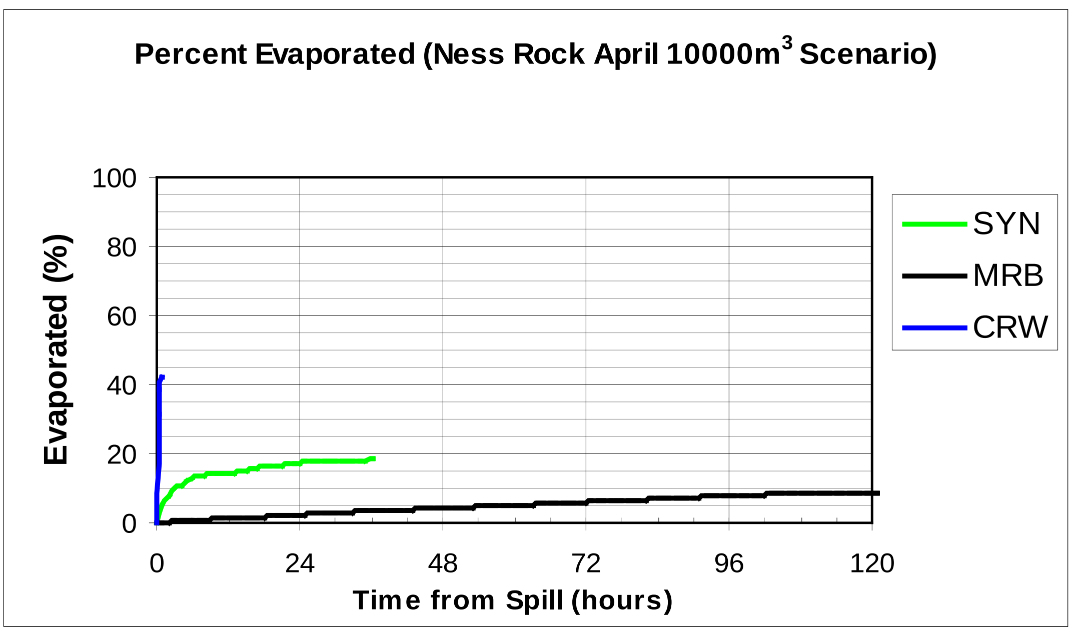

Figure 2-45 Percent Evaporated (Ness Rock April 10,000 m^3 Scenario)

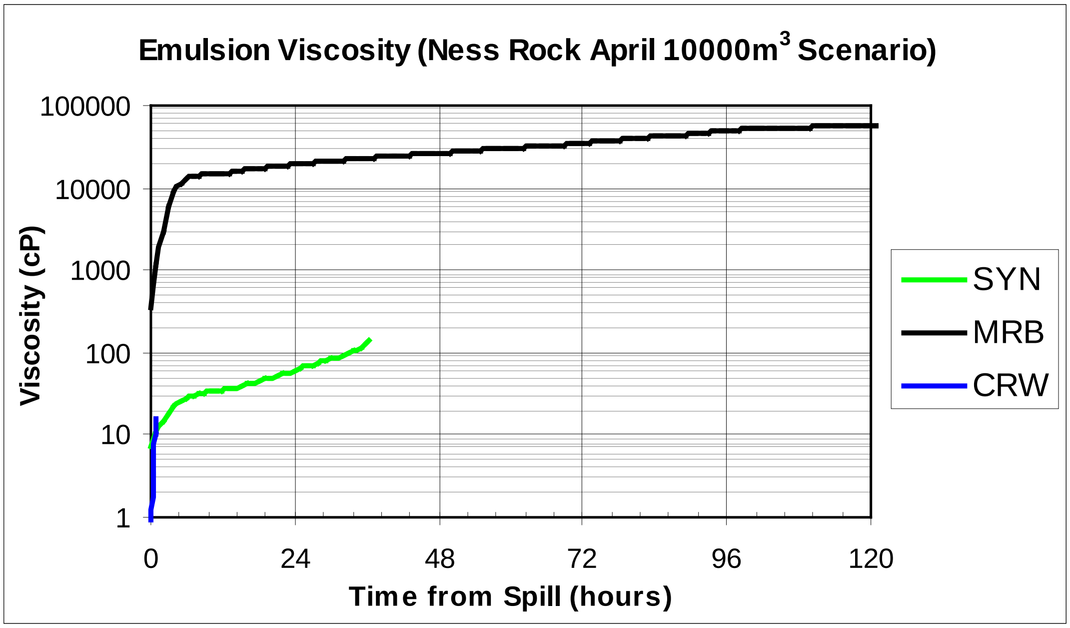

Figure 2-46 Emulsion Viscosity (Ness Rock April 10,000 m^3 Scenario)

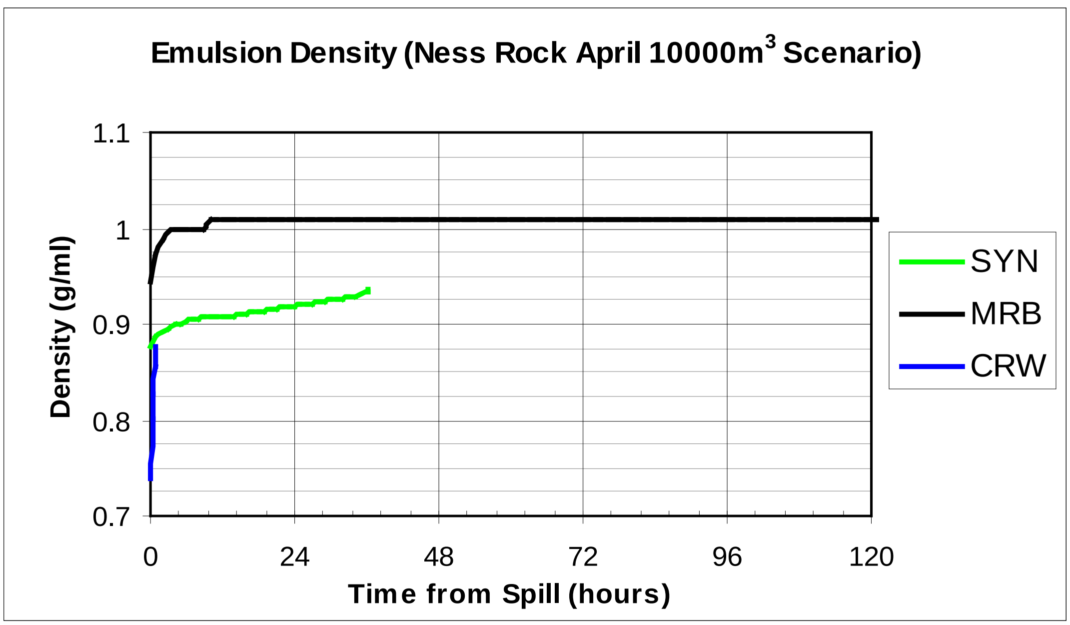

Figure 2-47 Emulsion Density (Ness Rock April 10,000 m^3 Scenario)

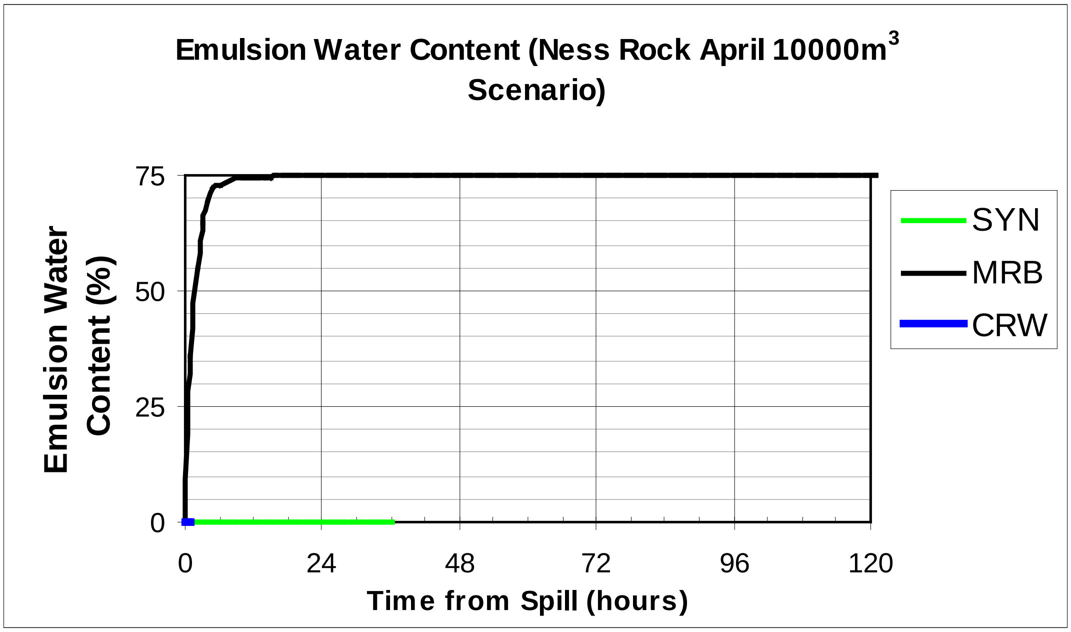

Figure 2-48 Emulsion Water Content (Ness Rock April 10,000 m^3 Scenario)

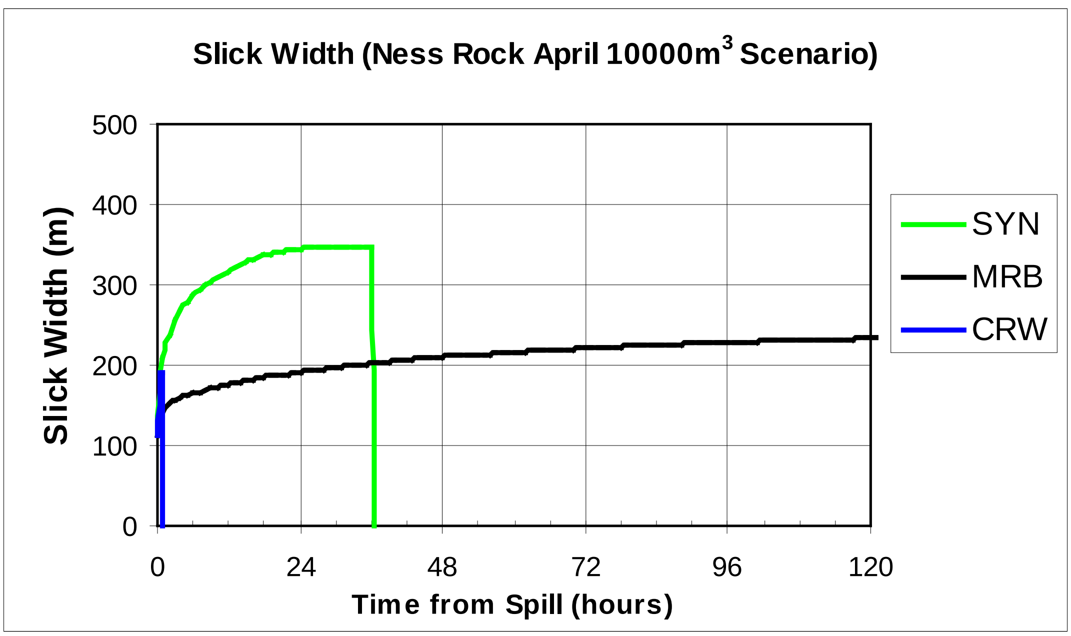

Figure 2-49 Slick Width (Ness Rock April 10,000 m^3 Scenario)

2.5 Butterworth Rocks Supplementary Modelling

Additional modeling completed using Syncrude synthetic light crude oil (SYN), a calmer wind history (force 3 breeze) for the Butterworth Rocks spill site and a longer term release is presented. In this scenario 1,900 m^3 is released in the first hour followed by a 675 m^3 per hour discharge over 12 hours (for a total release of 10,000 m^3). The fate of a 1,900 m^3 parcel of oil has been modelled using a wind history starting with the first hour of the wind data. The fate of twelve 675 m^3 parcels of oil have also been modelled individually with each parcel subjected to a starting wind time advanced by one hour so each hourly discharge is subjected to a slightly different wind history. Tables 2-2 and 2-3 show the percent evaporated and dispersed from each spillet over a five-day period.

Table 2-2 Percent of Spillet Evaporated versus Time

Time		Spillet Volume (m^3)												
		1900	625	625	625	625	625	625	625	625	625	625	625	625
days	hours	1st spillet	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th
		% Evaporated												
0.25	6	11.1	11.9	11.5	11.0	10.7	10.3	10.3	10.6	11.5	11.9	12.6	13.1	13.5
0.5	12	13.6	14.7	15.0	15.1	15.5	15.9	16.3	16.6	16.7	16.8	16.7	16.7	16.7
1	24	18.4	19.6	19.5	19.5	19.6	19.7	19.7	19.8	19.7	19.8	19.7	19.7	19.6
2	48	22.2	23.1	23.1	23.1	23.2	23.3	23.3	23.2	23.1	23.1	23.0	22.9	22.8
3	72	23.5	24.3	24.4	24.4	24.6	24.6	24.7	24.7	24.6	24.7	24.6	24.5	24.4
4	96	24.6	24.9	24.8	24.8	24.9	24.9	24.9	24.9	24.8	24.8	24.7	24.6	24.5
5	120	24.6	24.9	24.8	24.8	24.9	24.9	24.9	24.9	24.8	24.8	24.7	24.6	24.5

Table 2-3 Percent of Spillet Dispersed versus Time

Time		Spillet Volume (m^3)												
		1900	625	625	625	625	625	625	625	625	625	625	625	625
days	hours	1st spillet	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th
		% Dispersed												
0.25	6	2.7	2.8	2.6	2.3	1.5	1.0	0.9	0.9	1.5	1.5	1.9	2.6	3.3
0.5	12	3.3	3.6	3.8	3.8	3.3	3.7	4.3	4.8	5.3	5.3	5.4	5.7	6.4
1	24	8.6	11.0	11.0	11.1	10.6	11.0	11.6	12.1	12.5	12.6	12.6	12.6	12.8
2	48	24.3	31.3	31.5	31.9	31.5	31.4	31.4	31.2	31.0	30.5	30.2	29.8	29.6
3	72	31.4	42.8	46.2	49.4	52.3	56.7	61.1	63.4	66.9	69.5	70.7	71.1	73.3
4	96	73.8	75.2	75.8	75.7	75.6	75.4	75.4	75.2	75.4	75.4	75.3	75.8	76.4
5	120	75.4	75.2	75.8	75.7	75.6	75.4	75.4	75.2	75.4	75.4	75.3	75.8	76.4

The oil released on day one will persist on the surface for a maximum of 5 days while the oil released in subsequent days will survive for a maximum of 4 days. There are only minor differences in the amounts of oil dispersed and evaporated from the smaller spillets released over the last 12 hours of the spill. The thicker oil released during the first hour will evaporate and disperse somewhat slower than the oil released during the remainder of the spill.

Another set of simulations were run to further demonstrate the significance of slick volume on the fate of the Syncrude synthetic light crude oil and the Butterworth Rocks light wind data set (force 3 breeze). Instantaneous releases of 50 m^3, 200 m^3 and 10,000 m^3 were modelled. The percent of oil evaporated and dispersed and oil property and slick dimension changes as a function of time for these three initial slick volumes are compared in Figures 2-50 through 2-54. The simulation results show only minor differences in the fate of the 50 and 200 m^3 slicks. The 10,000 m^3 slick dispersed more slowly and remained on the surface for a longer time.

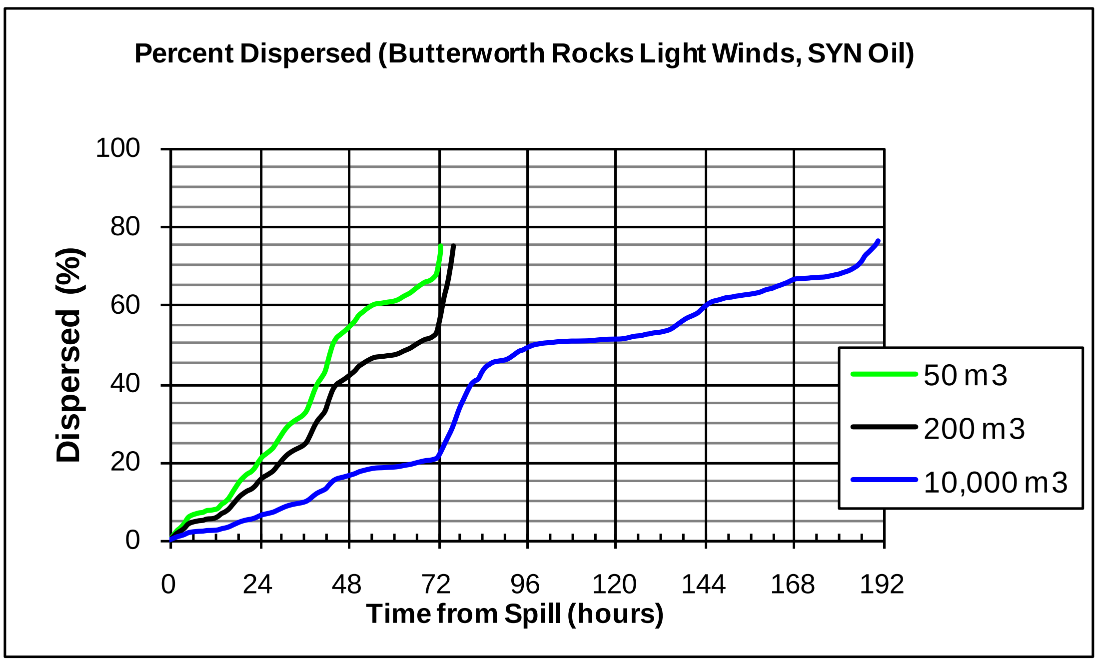

Figure 2-50 Percent Dispersed for Different Initial Slick Volumes (Butterworth Rocks Light Winds, SYN)

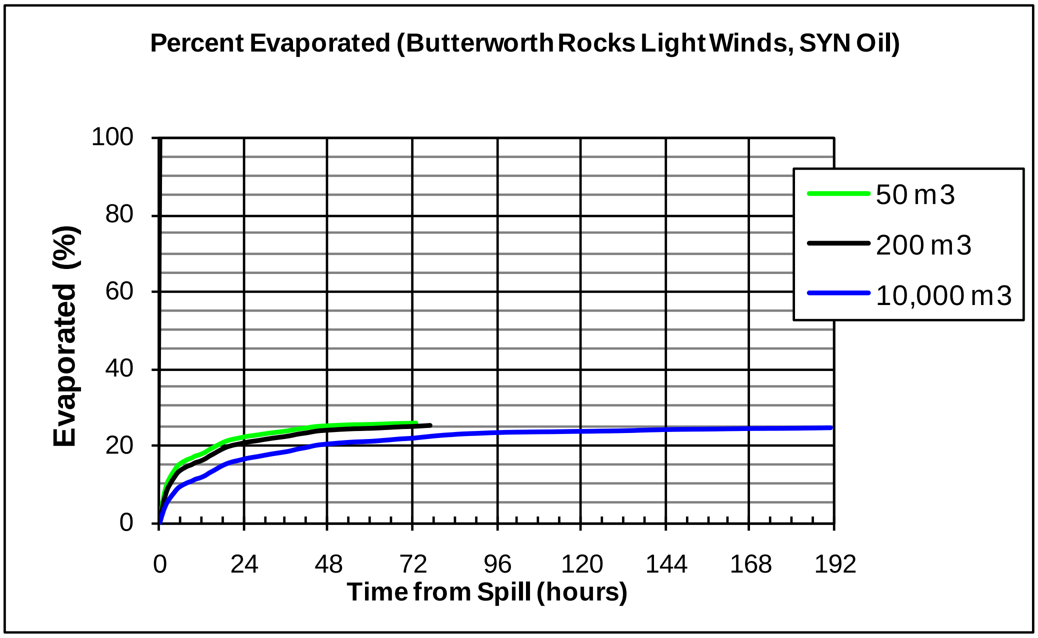

Figure 2-51 **Percent Evaporated for Different Initial Slick Volumes (Butterworth Rocks Light Winds, SYN)**

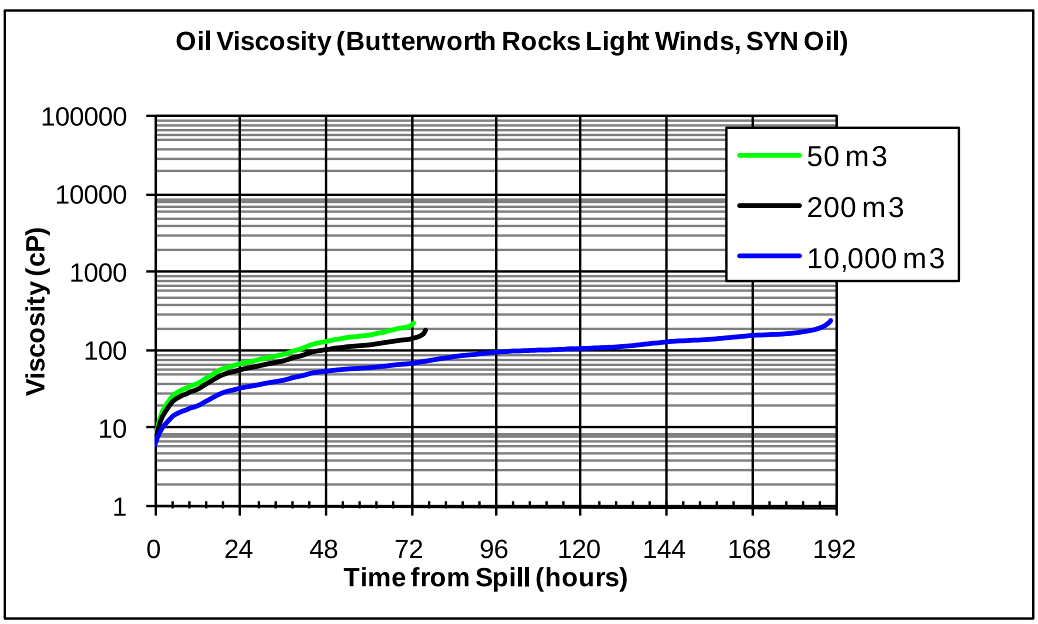

Figure 2-52 **Oil Viscosity for Different Initial Slick Volumes (Butterworth Rocks Light Winds, SYN)**

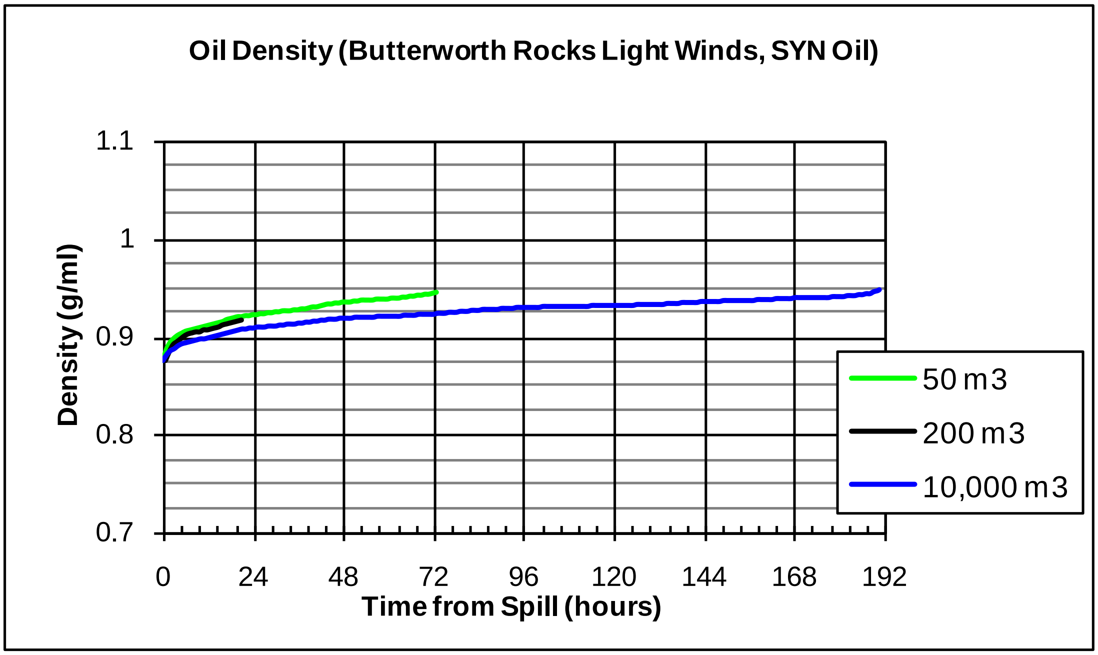

Figure 2-53 Oil Density for Different Initial Slick Volumes (Butterworth Rocks Light Winds, SYN)

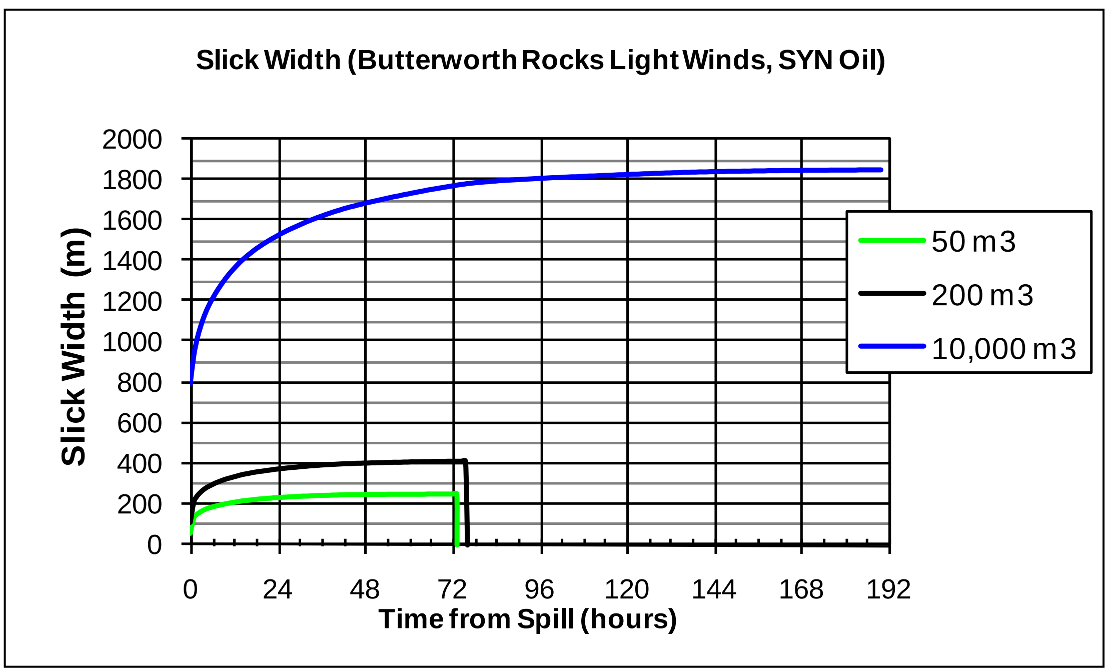

Figure 2-54 Slick Width for Different Initial Slick Volumes (Butterworth Rocks Light Winds, SYN)

3 References

SL Ross. 2010. Properties and Fate of Hydrocarbons Associated with Hypothetical Spills at the Marine Terminal and in the CCAA. Technical Data Report. Northern Gateway Pipelines Inc. Calgary, AB.