Web-GIS Based Waste Calculator for Oil Spill Preparedness and Response

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Developing response strategies for waste management is a critical element of oil spill preparedness and response. Application of waste management plans for practical and appropriate shoreline responses helps reduce potential for adverse impact to people and the environment and also to reduce response times, waste quantities and the cost of clean-up activities. Well defined plans estimate waste type and quantity which then allow the most appropriate shoreline removal technique to be identified. Suitable transport requirements, storage and treatment options may then be considered.

Consistent waste planning sets a common standard which can be developed to improve oil spill response readiness and highlight areas of risk. Common guidelines for producing waste management plans are nascent and a consistent approach is yet to be adopted by all oil and gas operators.

Geographical Information Systems (GIS) are transforming the visualisation of relationships in spatial data. Oil spill models that forecast shoreline oiling quantity and characteristics are well developed (Reed, M, 2012). A means of forecasting waste quantities from an oil spill generated at a shoreline when the shoreline type, oil type and viscosity is known has initially been investigated (PAS Inc., 2009). The quality of Shoreline Environmental Sensitivity Index (ESI) data is evolving.

BP is developing means of shoreline waste calculation using a webGIS interface application to integrate outputs of oil spill modelling and ESI data. This enables estimation of waste quantity for a selected area whilst also facilitating improved planning through early selection of storage locations and appropriate transportation.

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1. Introduction

As part of BP's oil spill preparedness and response efforts a series oil spill contingency plans are being developed and maintained. These plans define an oil spill response strategy based on a range of selected oil spill scenarios and a series of oil spill response techniques.

The management of oil spill waste is part of this contingency planning process. It includes an assessment of the potential volume of waste generated as the result of shoreline clean-up operation. It also estimates the type of waste expected and defines the waste treatment options.

The volume of waste generated during an oil spill response operation is not directly correlated to the initial quantity of spilled oil. A review of historical oil spill event (see Figure 1) shows that volume of oil initially lost and the amount of waste collected during response operation varies. Oil spills can produce greater volumes of waste than the oil originally spilled. (IPIECA, 2004)

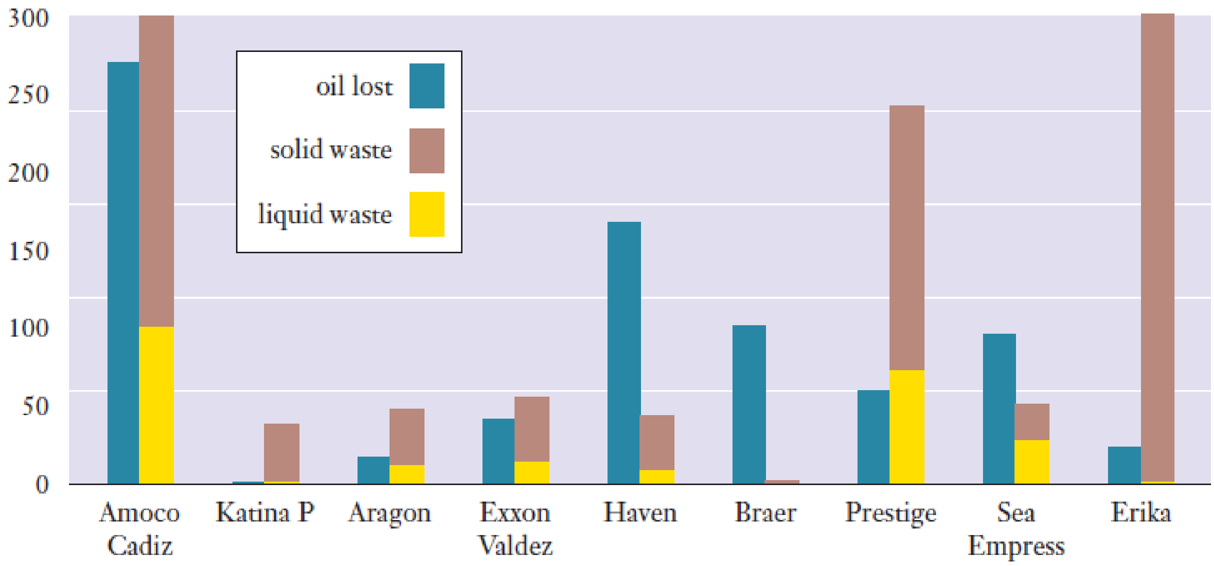

Figure 1 Waste generated during historical oil spill incidents (in thousand tonnes) (IPIECA, 2004)

As part of its Environmental Technology Programme BP developed an Oil Spill Waste Assessment Tool (OSWAT), this tool facilitates the consistent assessment of waste volume and helps integration with other oil spill preparedness tools.

Waste volume depends on a range of factors; the Oil Spill Waste Assessment Tool (OSWAT) is an integrated tool enabling consistent assessment of waste volumes for a specific oil spill scenario.

Using a web-based Geographical Information Systems (GIS) interface the OSWAT integrates three existing tools:

- the Arctic Council Waste Management Tool (PAS/TOSTC.2009),

- the SINTEF OSCAR oil spill trajectory modelling (Reed, M, 2012),
- the NOAA Environmental Sensitivity Index (ESI) (NOAA, 2002) GIS. .

Waste volume assumptions are based on the oil spill waste calculator developed for the Arctic Council by Polaris and the oil Spill Training Company (PAS/TOSTC.2009). The web-interface is using geo-processing tools to integrate the OSCAR shoreline oiling volumes and the ESI type of shoreline.

This paper describes the methodology and assumption included in OSWAT and presents the outcomes of a validation exercise conducted on the Amoco Cadiz oil spill which occurred in west France in 1978.

2. The Oil Spill Waste Assessment Tool (OSWAT)

Most of oil spill clean-up operations, particularly those on-shore, results in the collection of substantial quantity of waste and oily waste (ITOPF 2011). The primary purpose of the oil spill waste calculator is to specify and quantify potential waste streams generated from shoreline clean-up operations.

The tool is providing recommendations on the range of feasible shoreline clean-up techniques and volume of waste likely to be associated.

The approach of the OSWAT is to identify waste volume based on geo-spatial information. GIS software can integrate and compare geo-spatial data using geo-processing tools. OSWAT integrates the geospatial data of shoreline oiling from OSCAR (Reed, M, 2012) and geospatial data on shoreline substrate from the Environmental Sensitivity Index (ESI) mapping (NOAA, 2002).

3. OSWAT input parameters

OSWAT integrates following key factors into the calculation of the waste volumes generated from shoreline clean-up:

- Quantity of oil reaching the shoreline
- Type of oil and weathering status
- Types of shoreline substrate
- Shoreline clean-up techniques
- Clean-up treatment end points

The chapters below describe how these factors are integrated into OSWAT.

3.1 Quantity of oil reaching the shoreline

The quantity of oil reaching the shoreline can significantly vary depending on the weathering process of the oil at sea, the location of the event and prevailing conditions (winds, currents). The first step in assessing the waste volume is to understand the oil spill scenario and the potential volume of oil reaching the shoreline.

The OSWAT integrates the shoreline oiling volume and locations provided by OSCAR trajectory modelling. It classifies the shoreline oiling into 4 categories: Very, light oiling, light oiling, moderate oiling and heavy oiling (see Table 1 Shoreline oiling category definition (Polaris/OSCT 2009) . These categories are based on the Artic Council Waste Management Tool (Polaris/OSCT 2009).

The conversion factor from OSCAR shoreline oiling (kg/m^2) to OSWAT categories (m^3/m) is described in Annex 1.

Surface Oil Category	Oil Width Threshold (m)	Oil Distribution (0.1=10%)	Oil Thickness (m)	length of shoreline (m)	Threshold Oil Volume (m3/m of shoreline)
Very Light lower threshold	1	0.05	0.001	1	0.00005
Light lower threshold	1.5	0.1	0.001	1	0.00015
Moderate lower threshold	2.5	0.5	0.001	1	0.00125
Heavy lower threshold	4.5	1	0.001	1	0.0045

Table 1 Shoreline oiling category definition (Polaris/OSCT 2009)

3.2 Oil type

Heavy crude oil, light condensate or diesel products have different fate and behaviour process. For example heavy crude oil is likely to from a viscous stable emulsion, while condensate is likely to evaporate.

Shoreline clean-up technique has to be customised to the type of oil: light product might be left to natural recovery while heavy crude oil would require manual removal.

In consequence the type of waste generated during shoreline clean-up operation would vary.

The OSWAT integrates the oil viscosity information as indicator of the oil type. The viscosity is calculated within OSCAR and can be extracted from the Mass Balance.

The OSWAT classifies oil type into four depending on their viscosity (see Table 2). These categories are based on the Artic Council Waste Management Tool (Polaris/OSCT 2009).

Oil type	Viscosity	Example	Oil type category upper threshold based on OSCAR Viscosity (cP)
Volatile	Like water	Gasoline products	200
Light	Like water	Diesel and light crudes	2000
Medium	Intermediate products and medium crudes	Intermediate products and medium crudes	5000
Heavy	Like molasses	Residual products and heavy crudes	10000
Solid	Bitumen, Tar, asphalt, does not poor	Bitumen, tar, asphalt	100000

Table 2 Oil type category definition based on emulsion viscosity

3.3 Type of shoreline substrate

The nature of shoreline substrate influences both the behaviour of the oil and the type of clean-up technique and in consequence the amount of waste likely to be generated.

Shoreline type substrate can be classified using the Environmental Sensitivity Index (ESI) (NOAA, 2002). The ESI establishes a classification of the shoreline type based on its physical and biological character of the shoreline environment.

Depending on the steepness of the shoreline, exposure to wave energy and the nature of the substrate, the quantity of oil retained by the shoreline and weathering of the oil would vary. For example sheltered salt marshes are likely to retain higher volumes of oil than exposed rocky shore. As they are protected from wave energy biodegradation is expected to be slower.

The OSWAT integrates ESI Code GIS data and classify shoreline type in 5 categories (See table 3). These categories are based on the Artic Council Waste Management Tool (Polaris/OSCT 2009).

OSWAT shoreline substrate categories	ESI Rank	ESI Rank title
Bedrock or Solid	ESI 01	Rank of 01: Exposed, Impermeable Vertical Substrates
Bedrock or Solid	ESI 02	Rank of 02: Exposed, Impermeable Substrates, Non-Vertical
Sand and mixed sediment	ESI 03	Rank of 03: Semi-Permeable Substrate, Low Potential for Oil Penetration and Burial; infauna present but not usually abundant
Coarse Sediment Beach	ESI 04	Rank of 04: Medium Permeability, Moderate Potential for Oil Penetration and Burial; infauna present but not usually abundant
Coarse Sediment Beach	ESI 05	Rank of 05: Medium-to-High Permeability, High Potential for Oil Penetration and Burial; infauna present but not usually abundant
Cobbler/Boulder	ESI 06	Rank of 06: High Permeability, High Potential for Oil Penetration and Burial
Wetland - vegetation	ESI 07	Rank of 07: Exposed, Flat, Permeable Substrate; infauna usually abundant
Bedrock or Solid	ESI 08	Rank of 08: Sheltered Impermeable Substrate, Hard; epibiota usually abundant
Wetland - vegetation	ESI 09	Rank of 09: Sheltered, Flat, Semi-Permeable Substrate, Soft; infauna usually abundant
Wetland - vegetation	ESI 10	Rank of 10: Vegetated Emergent Wetlands

Table 3 ESI classification and integration in the Waste Calculator shoreline substrate

3.4 Shoreline clean-up techniques

For each unique combination of shoreline oiling, shoreline substrate, type of oil, OSWAT associate a fourth dimension: the type of shoreline clean-up techniques. 7 shoreline clean-up techniques are included in OSWAT:

- Natural recovery: this involves leaving the stranded oil to natural weathering. It can be used for example on shoreline exposed to high waves energy and on light oils.

- Flushing and recovery: the oil is remobilized by low pressure high volume water stream. It can be practical on most shoreline types but effectiveness decreases as the oil viscosity increases.

- Manual Removal: the technique involves manual labour and hand tools to remove oil. It can be used practically and effectively in any location and shoreline type. It is most applicable for small amount of viscous oil and remote location.

- Mechanical Removal: the oil or oil material are removed from the shore using mechanical equipment (bulldozers scrapers or excavators). Mechanical removal can be used on all shoreline but bedrock or solid man-made structure.

- Surf Washing: In situ sediment mixing and/or relocation

- In situ burning: the objective is to remove or reduce the shoreline oiling by combustion.

- Bioremediation (In-situ): this treatment technique can be applied on light oiling

Historical oil spills data show that each types of clean-up technique have a large impact on the quantity of waste associated with the oil recovery. For example, the use mechanical recovery to clean the shoreline is likely to generate large volume of waste. This technique is less selective and segregation of waste is less effective.

3.5 Treatment and point

This refers to the clean-up effort required before agreeing to close the response operations. Clean-up effort can be focussed on bulk oil removal or removal to a coat or stain. The later would generate higher volumes of waste.

4. OSWAT Assumptions for waste volumes calculation

OSWAT assumptions for the waste calculation are based on the Artic Council Waste Management Tool (Polaris/OSCT 2009) is based on a series of historical oil spill events and associated quantities of waste recorded.

Actual waste volumes were recorded for each combination of (1) Quantity of oil, (2) type of oil, (3) type of shoreline substrate, (4) response technique and (5) treatment end-point. Information on these volumes is link to the length of shoreline under this specific combination to obtain a volume of waste per meter of shoreline (m^3/m).

Waste volumes were recorded for each combination in a database. The table below is showing the validation summary.

RESPONSE * selected sites only	**Waste Volume Generated**	**Width of Oiled Zone (m)**	**Documented Waste Volume (m^3/m)**	**Waste Management Calculated Volume (m^3/m)**
T/V *Arrow* * mechanical removal	4,000 m^3/km	3	2.2 – 4.0	1.8 – 4.5
M/V *Selandang Ayu* * mechanical removal	2,500 m^3/km	1.5	3.5	1.8 – 4.5
T/B *Bouchard B-155* mechanical removal	1,860 m^3/km	3	1.9	1.8
M/V *Cosco Busan* washing + manual removal	42 m^3/km	2	0.02	0.05 – 0.2
M/S *Server* washing + manual	33 m^3/km	?	~0.03	0.05 – 0.2
T/V *Exxon Valdez* washing	19 m^3/km	>3	0.02	0.02 – 0.07

Table 4 Comparison of operation Data and Calculated volumes for Polaris 2009

5. Case study on Amoco Cadiz

A validation exercise was conducted to test OSWAT assumptions and calculations based on OSCAR oil spill trajectory and the ESI shoreline type for the Amoco Cadiz oil spill.

5.1 Amoco Cadiz oil spill

The tanker Amoco Cadiz ran aground off the coast of Brittany on 16th March 1978 following a steering gear failure. Over a period of two weeks the entire cargo of 223,000 tonnes of light Iranian and Arabian crude oil and 4,000 tonnes of bunker fuel was released into heavy seas. Much of the oil quickly formed a viscous water-in-oil emulsion, increasing the volume of pollutant by up to five times. By the end of April oil emulsion had impacted 320km of the Brittany coastline (ITOPF).

The beach clean-up operations unfolded into two stages: the first involved pumping the oil which was still liquid, and the second involved clearing solid the waste.

The report on the volume of waste varies depending on sources.

- Le CEDRE refers to more than 100,000 tonnes of oil emulsion and other wastes in total were collected and a large part of solid waste was neutralised with quicklime.
- Polaris (2009) refers to 8,500 tonnes of liquid waste and 165,000 tonnes of solid waste.
- REMPEC (2011) mentions 250,000 tonnes of waste were recovered in total.
- IPIECA (2004) chart reported in figure 1 relate 300,000 tonnes with roughly 80,000 tonnes of liquid waste and 220,000 tonnes of solid waste.

5.2 OSCAR shoreline oiling upload

As part of the Coastal oil spill JIP work, SINTEF conducted an OSCAR trajectory modelling of the Amoco Cadiz scenario (see figure 2). SINTEF collected hydrodynamic data (winds, currents, tides) for March 1978 and ran trajectory modelling. The simulation was made available by SINTEF for the purpose of the OSWAT validation.

The results suggest that approximately 50,000 tonnes of oil is reaching the shoreline, the rest of the oil evaporated, sedimented, biodegraded and dispersed. The oil reaching the shoreline formed an emulsion encapturing approximately 74% of water. The predicted volume of emulsified oil reaching the shoreline is 190,000 tonnes (see Figure 2 below).

The shoreline oiling geospatial data produced in OSCAR was imported into the OSWAT with the methodology described in chapter 3.1. The results of this shoreline oiling classification are shown Figure 3 below.

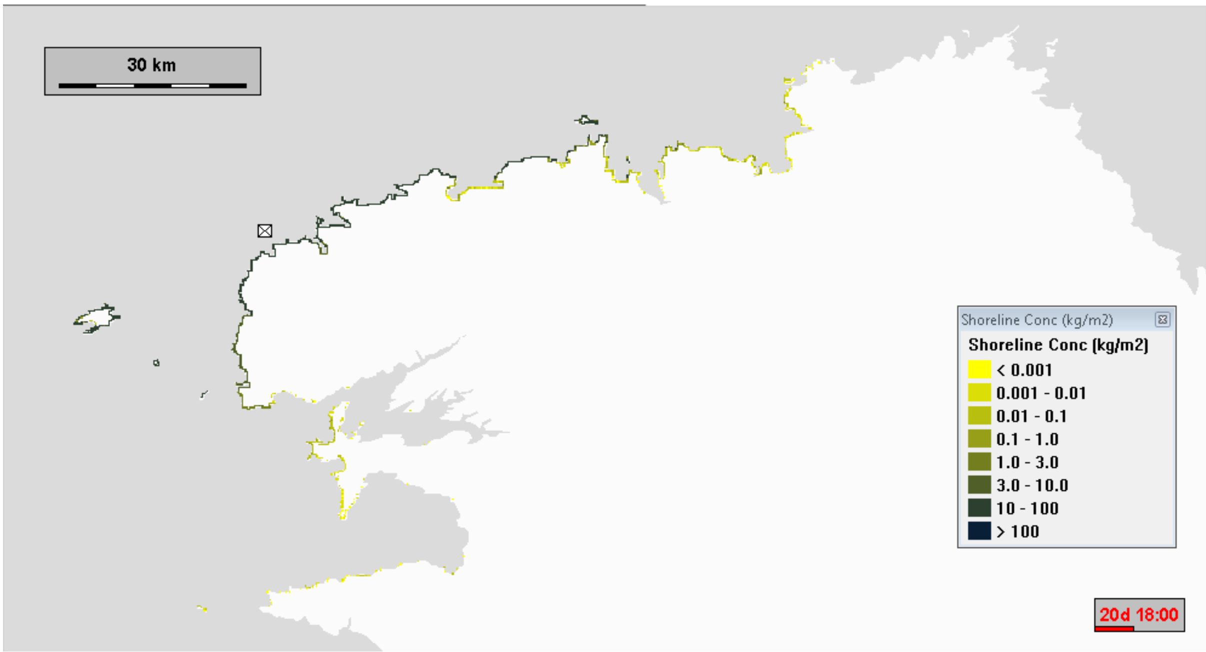

Figure 2 Amoco Cadiz shoreline oiling at its maximum extent (day 20,5 of the release

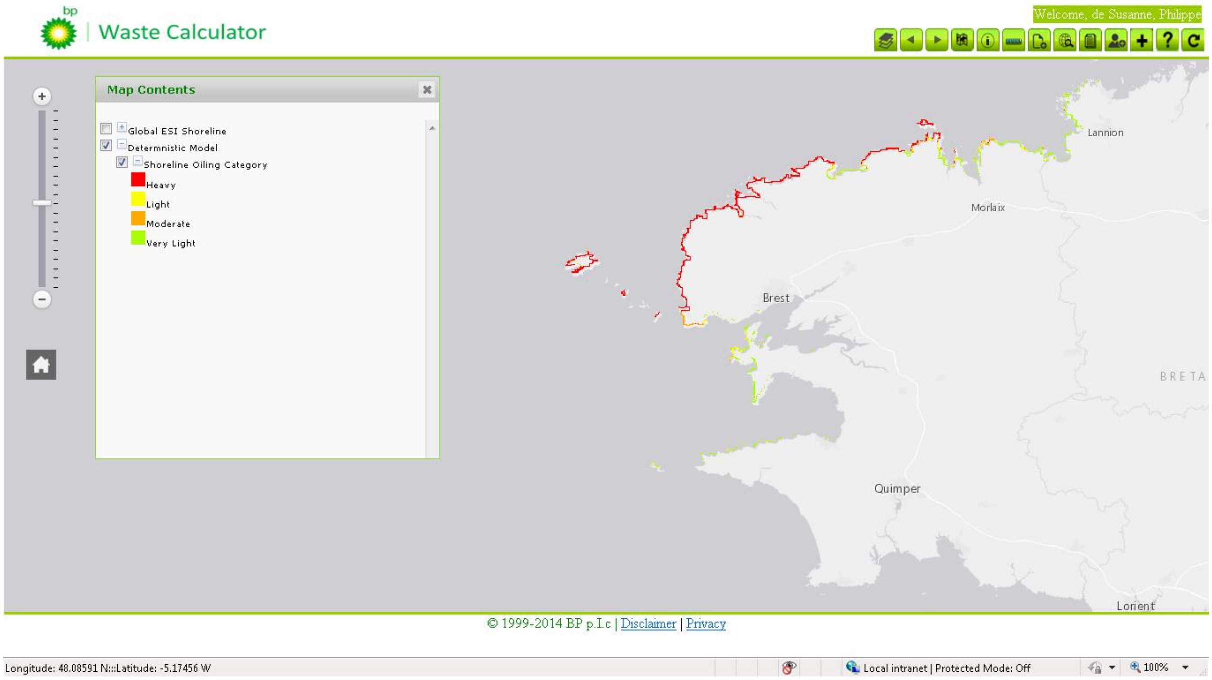

Figure 3 OSCAR Shoreline oiling import into the Waste Calculator Tool

5.3 Oil type

In the Amoco Cadiz scenario the weathered emulsified oil is classified as “Heavy”. The mean viscosity fall within the range of 10,000 to 100,000 Centipoises.

5.4 ESI Upload

Le CEDRE developed ESI shoreline GIS for the French POLMAR oil spill contingency plan. The map details the type of shoreline for the Finistère (French county where Amoco Cadiz ran aground). ESI data about shoreline substrates was imported into the OSWAT and the 10 ESI Index where converted into the 5 shoreline categories of OSWAT.

The geospatial intersection performed by OSWAT shows that three types of shoreline are impacted “Bedrock or Solid”, “Coarse Sediment Beach”, “Wetland - vegetation”.

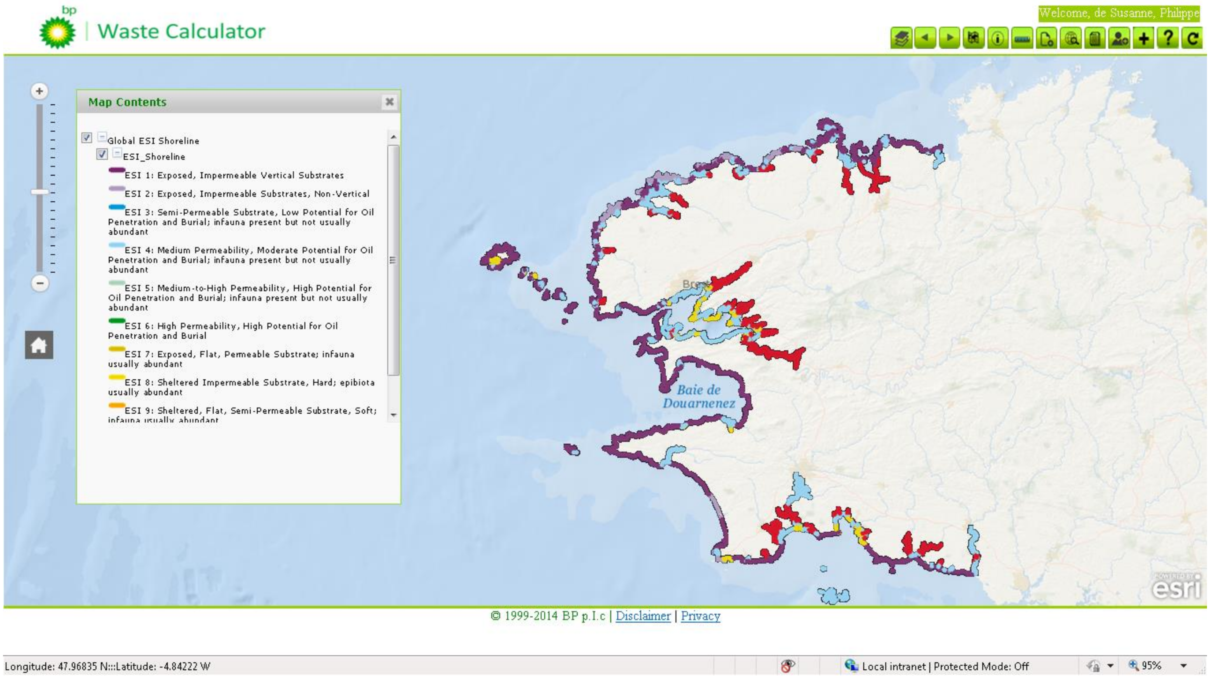

Figure 4 ESI shoreline imported in the waste calculator tool

5.5 Amcoco Cadiz shoreline clean-up technique

We assumed the main shoreline clean-up technique for heavy oil volume on rocky shore during the Amaoco Cadiz was flushing and Recovery. For “Coarse Sediment Beach” and “Wetland - vegetation” the response technique used during the Amoco Cadiz was mainly manual removal which involved manual labour and hand tools (example shovels, rakes and vacuum), (See Figure 5 below).

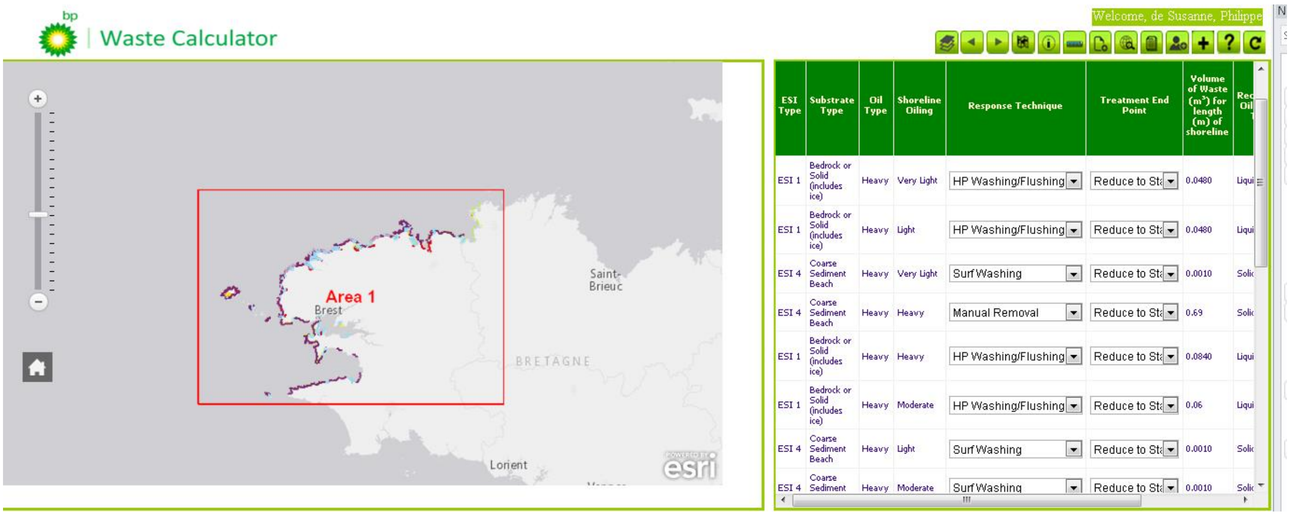

Figure 5 Illustration of the waste calculator interface for the selection of shoreline clean-up

5.6 Waste calculation results

Once the parameters for the clean-up techniques are selected OSWAT produce an estimation of waste volumes for each specific combination of the 3 type of shoreline, 4 types of oil quantity, 2 type of shoreline clean-up technique as show on the Table 5 below.

For each of these combinations, the geo-processing tool allocates a length of shoreline amounting to total of 2454 km.

Substrate Type	Oil Type	Shoreline Oiling	Response Technique	Volume of Waste per m of shoreline (m³/m)	Sum of Shoreline Length (km)	Volume of liquid waste (m³)	Volume of solid waste (m³)
Bedrock or Solid	Heavy	Very Light	Flushing & Recovery	0.048	331	15,936	
		Light	Flushing & Recovery	0.048	65	2,627	
		Moderate	Flushing & Recovery	0.06	65	3,955	
		Heavy	Flushing & Recovery	0.084	454	38,207	
Coarse Sediment Beach	Heavy	Very Light	Manual Removal	0.165	114		18,909
		Light	Manual Removal	0.24	33		8,142
		Moderate	Manual Removal	0.39	19		7,285
		Heavy	Manual Removal	0.69	175		121,178
Wetland - vegetation	Heavy	Very Light	Manual Removal	0.48	40		19,336
		Light	Manual Removal	0.68	10		7,229
		Moderate	Manual Removal	1.08	3		4,249
		Heavy	Manual Removal	1.88	20		39,172
Total						**60,725**	**225,500**

Table 5 Waste volume estimation for Amoco Cadiz showing selected response technique (total of 286,225 tonnes)

6. Results and discussions

OSWAT's assessment of the waste volumes for the Amoco Cadiz shows a total of 286,225 tonnes; out of which 60,725 tonnes are liquid and 225,500 tonnes are solid. Among the 286,225 tonnes of waste about 89,718 tonnes are classified as operational waste.

The results correlate with IPIECA (2004) which relates 300,000 tonnes with 80,000 tonnes of liquid waste and 220,000 tonnes of solid waste.

This exercise helped to validate the assumptions made for both the calculation methods and the geo-spatial approach.

However results of waste calculation should always be considered carefully when used for oil spill response planning. It is important to recognise there are a range of limitations in the application of this method.

OSWAT assumes the same level of training and expertise for the responders in the clean-up technique. However, volumes generated during a response are largely dependent on the qualification of shoreline clean-up team and other external factor related to the management of the response.

It is also important to recognise the limitations of the trajectory modelling software. As the accuracy of the shoreline oiling estimation is function of the quality of input parameter.

The waste quantity assessments taken from the Arctic Council Waste Management Tool (PAS/TOSTC.2009) are derived from broad estimates based on field observations and it intends to provide a range of potential waste volume as opposed to a specific number. The shoreline oiling and shoreline types are divided in large categories and waste volume assessments are to be taken as an indication of possible range of impact as opposed to specific values.

Another potential limitation identified is related to the resolution of the baseline map used in OSWAT. Too low resolution may lead to under estimation of the waste volumes as calculations are dependent on the length of shoreline, particularly for scattered rocky shoreline of West of France. For the Amoco Cadiz OSCAR modelling report indicates a length of impacted shoreline of 350 kilometres. Whereas the high resolution shoreline baseline used in OSWAT indicate a total length of 2500 km as opposed to 350km. (see figure 6 below). Further validation should be conducted on different historical oil spill scenario which occurred in a different shoreline environment like for example sandy shore.

Figure 6 Illustration of shoreline resolution and shoreline length

7. Conclusion

The OSWAT tool has been rolled-out within BP and found valuable to support of the waste management plans for oil spill preparedness. The tool helped to produce quantitative assessment of the potential volume of waste generated as the result of shoreline clean-up operation. The tool was also found valuable to assess the type of waste expected and to identify the waste treatment options.

The validation exercise of OSWAT on the Amoco Cadiz historical oil spill indicates that the waste volume estimations are consistent with historical events. This finding helped to validate both the assumption made by the Arctic Council Waste Management Tool (PAS/TOSTC.2009) and the OSWAT geo-spatial integration of OSCAR trajectory model and ESI GIS.

A next step in the development of this tool would be to conduct further validation testing in a different shoreline environment. This would help to refine waste volume estimation for specific combination of oil quantity, oil type, and substrate type and shoreline clean-up technique.

Annex 1 OSCAR Shoreline oiling integration

OSCAR trajectory modelling software is producing geospatial information of oil spill scenarios assessing a range of weathering mechanisms.

The waste calculator tool is integrating OSCAR shoreline oiling data in shapefile format. However the shoreline oiling concentration produced by OSCAR need to be converted into waste calculator shoreline oiling categories.

For OSCAR deterministic simulation shoreline oiling are provided in weight of oil per surface units of shoreline (Kg/m^2). In the waste calculator shoreline oiling is defined in volume of oil per meter of shoreline (m^3/m). It is also grouped into 5 categories (see Table 6 below).

Conversion from OSCAR (Kg/m^2) to Waste calculator categories (m^3/m) include the following operations:

- Converting weight (Kg) to volume (m^3) with the oil density (ρ)
- Converting surface of shoreline (m^2) to length of shoreline (m) with the width (d)

The conversion factor, depending on the density of the oil and the shoreline width and was calculated with the following formula:

$Y = X * d / (1000*\rho)$

Y= shoreline oiling in m3/m
X= shoreline oiling in kg/m2
d = shoreline width
ρ= emulsion density

Surface Oil Category	Waste calculator category upper threshold oil Volume (m^3/m))	Upper threshold converted in OSCAR units kg/m^2 (with shoreline width d= 2m)
Very Light	0.00015	0.075
Light	0.00125	0.625
Moderate	0.0045	2.25
Heavy	no upper	

Table 6 Shoreline oiling categories upper thresholds in m^3/m and conversion in kg/m^2

Annex 2 References

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