Response to the Sea Empress Incident, 1996
(Application of Dispersant and Bioremediation Technologies)

Dr Peter Wood
Principal Consultant
National Environmental Technology Centre
AEA Technology Environment

Introduction

The tanker Sea Empress ran aground near Milford Haven, South Wales, on the 15 February 1996. Over the next few days 72 000 tonnes of Forties Blend crude oil and 480 tonnes of heavy fuel oil were released into the sea. A rapid at sea response was undertaken but, nevertheless, oil came ashore along 200 km of coastline. Over the next few weeks a massive shoreline clean-up operation was undertaken.

This paper outlines some of the new approaches to oil spill response and monitoring that were undertaken during this incident. These are:

- monitoring of dispersant effectiveness at sea
- bioremediation
- Surf washing of oiled cobbles
- in-situ pit washing of oiled cobbles
- shingle washing operations.

Each is discussed in turn.

Monitoring Dispersant Effectiveness at Sea

The main approach to the clean up of oil at sea in the UK is to use approved chemicaldispersants. These are normally sprayed from aircraft onto relatively fresh oil. However, it is of critical importance to determine whether or not the dispersant is having an influence on the oil. (Not all oils are dispersible, especially once a degree ofweathering and emulsification has occurred.) Whereas dispersed oil can sometimes be seen in the sea from vessels or aircraft this is not always the case, especially with more viscous and weathered oils where the dispersant may act only slowly. Consequently, for the first time in a major oil spill, concentrations of dispersed oil were measured during dispersant application operations.

Monitoring of the dispersion process using flow-through-flourometry indicated that the dispersant operation enhanced the rate of natural dispersion. Scientists from the National Environmental Technology Centre monitored oil concentrations at different depths under and around the oil on the sea surface. They were able to show that, at 4 m depth, oil concentrations were around <1500 μg/l in areas treated with dispersant compared to around <500 μg/l in areas that had not been treated. This information confirmed that the dispersants were having an effect and was fed back to the response management centre. The centre was then able to continue dispersant spraying operations in the knowledge that the dispersants were being effective.

As expected the dispersants were found to be most effective on the fresh oil emerging from the grounded tanker. Therefore, the strategy for dispersant application was, in the first instance, to target any significant fresh releases of oil from the tanker. Once these had been successfuly treated then a secondary target was the large patches of more weathered oil.

When emulsions were being treated with dispersants it was found than an initial application tended to break the emulsion while subsequent additions increased the concentrations of dispersed oil.

Part of a successful dispersion operation is the judgement of when to stop treating a particular patch of oil. In the case of fresh oil emerging from the Sea Empress, while the oil tended to remain as a coherent slick, dispersant operations reduced it thickness until only sheens remained. In the case of weathered oil, as the successful dispersant operation progressed, the main problem became the low surface coverage of emulsion on the water surface. Once the coverage became around 30 % of the water surface it was not possible to achieve efficient application of the dispersant as so operations would terminate.

During the operations some 445 tonnes of dispersant were applied from aircraft. A notable feature of the spray response was the highly effective targeting achieved by the use of remote sensing aircraft positioned above the spray aircraft to direct the spray pattern. This operation is well established in the UK and allows the DC3 spray aircraft in particular to target effectively ribbons of oil as narrow as 10-20 m wide.

It is difficult to estimate accurately the split between the volume of oil that would have dispersed naturally and the volume that was dispersed chemically. In total it is estimated that some 47 % (33 800 tonnes) was dispersed of which some 7200 tonnes was naturally dispersed. This means that some 26 600 tonnes was chemically dispersed. Given that 445 tonnes of dispersant were used then this results in a ratio of 1 tonne of dispersant to 60 tonnes of oil chemically dispersed. Although this ratio is greater than that normally assumed (1 tonne of dispersant disperses 20 tonnes of oil), it is considered a reasonable estimate. High dispersion would be expected as the dispersant was applied to fresh crude oil and the monitoring did show that successful dispersion was readily occurring.

Bioremediation

Bioremediation was not used as a standard clean-up procedure for oiled beaches during the Sea Empress incident. However, the response management centre did take the opportunity to undertake some experimental studies.

AEA Technology scientists carried out a survey of a number of beaches to evaluate the potential for bioremediation. A preliminary survey suggested that six beaches should be considered once the manual clean-up had been completed on them. Factors considered in this selection process are the energy levels of the beach, the biodegradability of the oil, the natural nutrient levels of the shoreline and the type of substrate that is oiled.

The survey indicated that nutrient levels were adequate in the winter and early spring, but that reduced temperature was a limiting factor. However, a later survey indicated that, in the summer when temperatures had increased, nutrient deficiency became the limiting factor.
However, it would be possible to overcome this problem by the addition of artificial nutrients.

An experimental plot was established at Bullwell Bay. This is a low energy beach occurring within Milford Haven. The beach consists of pebble, gravel and stones overlying clay and is highly permeable to water and air. Both Forties Blend and heavy fuel oil were present and sediment samples indicated that an appropriate bacterial population existed. Following relevant regulatory approval, additions of nutrients such as nitrogen and phosphorus were undertaken to stimulate the growth of these naturally occurring hydrocarbon degrading bacteria. Nine plots were established on the beach; three receiving weekly additions of nutrients, three receiving monthly additions of a slow release nutrients, and three receiving no additional nutrients. The Environment Agency also undertook monitoring during the experiment to ensure that the nutrient additions had no impact to the near-shore environment.

The results indicated that both nutrient types increased the rate of biodegradation of the heavy fuel oil and the Forties Blend with equal effectiveness The treatment had no measurable effect on the nutrient content of the near-shore seawater and there were no detectable toxic effects. It was concluded that the slow release method may prove to be a cost effective technique for enhancing the natural recovery of low energy shorelines.

Surf Washing of Oiled Cobbles

A technique known as surf washing was used on two beaches during the Sea Empress incident. The technique is essentially a matter of using tracked excavators while the water is at low tide to relocate material from the oiled zone at the high water mark (the berm) towards the middle of the intertidal zone. As the tide rises the energy imparted in the surfzone is then sufficient to remove significant amounts of the Forties Blend emulsion from the oiled cobbles. The natural mineral fines found within the beach and/or in the waters of the surf zone interact with oil to form mineral-oil flocs and so prevents the dropletes from coalescing. The flocs then become dispersed in the water column.

Two locations, Amroth and Marros, had extensively oiled cobble beaches and were considered appropriate sites for surf washing operations.

At Amroth stranded emulsion on the cobble storm beach was found to be associated with fine minerals including mica, chlorite, kaolinite, quartz, calcite, feldspar. When this emulsion was introduced into the sea clay-oil flocs formed which again had the same suite of minerals but with less of the non-clay mineral (quartz, calcite and feldspar). The flocs that formed were generally 30 μm or more in size. This provided an opportunity for the responders to undertake a surf washing strategy to clean the cobble beach.

Successive surf washing episodes were subsequently undertaken at Amroth and were successful in reducing the concentrations of oil in the beach material During this surf washing operation chemical evidence indicates that oil found within the particulate matter of near-shore waters was biodegraded to a greater extent than the oil stranded on the shoreline.

At Marros stranded emulsion on the cobble storm beach was again found to be associated with fine minerals and again formed flocs when introduced into seawater. Observations at Marros indicated that high concentrations of emulsion on the surface cobbles persisted for about 14 days after oiling. However by 50 days after oiling the emulsion had become unstable and more mobile and had penetrated the beach to depths of up to 3 m and had reached a less permeable substrate of superficial glacial/solifluxion deposits. This resulted in some oil being subjected to tidal fluctuations in the cobble beach and a subsequent loss of some oil by sheening.

Examination of the oil composition in samples of stranded emulsion at Marros indicated that no significant biodegradation occurred on the beach between 14 and 51 days following the spill. Consequently during this time it is considered that the major process contributing to a reduction of the quantity of oil on the beach would be sheening. It is considered that this sheening process would have continued for many months had a surf washing operation not taken place.

A surf washing operation was undertaken at Marros over a seven day period commencing 47 days after oiling. Table 1 indicates the statistics of the operation. An estimated 8150 tonnes of oiled cobbles was moved a distance of between 12 and 18 m seaward along a length of 850 m. The tonnage of cobbles that it was necessary to relocate was a direct result of the depth of penetration of the emulsion within the beach. Had the beach been relocated earlier, before the emulsion became unstable, then the tonnage requiring relocation would have been less.
Analysis of samples collected after 2 tides following surf washing show that oil concentrations did not exceed 22 ppm both at the surface and at depth. This represents a considerable reduction compared to concentrations prior to relocation, up to > 700 ppm, which is considered to be the direct result of enhanced oil dispersion processes coupled with the surf washing operations. Further support for this hypothesis is

provided by detailed GC-MS analysis (alkanes:hopane ratio) which confirmed that the loss of stranded beach emulsion was not due to a stimulation in biodegradation activity.

Determination of oil concentrations off-shore during the surf washing process confirmed that dispersion of the oil into the water column was occurring. Oil concentrations at 1 m depth were up to 600 μg/l near the shore but dropped to 150 μg/l within a kilometre of the coast.

From the results obtained, it is concluded that, in those situations where clay-oil-flocculation can be demonstrated as occurring, surf washing should now be considered as an effective oil spill countermeasure for the treatment of polluted beaches. Furthermore, as biodegradation of the oil appears to be enhanced in the sea following interaction with fines, surf washing should be considered as a mechanism that effectively enhances the rate of oil removal from the ecosystem.

Taqble 1:Nominal Statistics of the Relocation Exercise at Marros Beach

Date	Beach relocated						Seaward distance relocated, m
	Length, m	Width, m	Maximum height, m	Mean height, m	Volume, m^3	Weight, t*	
15 April	150	2.0	0.5	0.5	150	275	12
16 April	115	2.5	1.0	1.0	290	525	12
17 April	125	3.0	1.5	1.0	375	675	12
18 April	175	2.5	1.5	1.0	440	800	12
19 April	150	6.0	2.0	1.5	1350	2450	12
20 April	25	7.0	3.0	2.0	350	625	18
**	(100)	-	-	-	(900)	(1650)	(6)
21 April	110	7.0	3.0	2.0	1540	2800	18
Total	850	-	-	-	4495	8150	-

* determined as volume x 2.6 (assumed cobble density) x 0.7 (assumed packing density)

** material originally relocated on 19 April but which was not reworked by the tides and therefore needed to be moved lower down the beach

In-situ Pit Washing of Oiled Cobbles

Pit washing was used for the first time during the Sea Empress incident to clean cobbles. Large pits were dug to hold between 50 and 100 tonnes of material and lined with a heavy duty plastic liner. Cobbles were added and washed under high pressure water and an approved degreaser (surface cleaner). Oil could then be skimmed off the surface of the pit and the cleaned cobbles returned to the beach. In some cases sunken skips were used as the pit. It should be noted that this method of cleaning cobbles removes only the bulk oil. The remaining stained cobbles were not returned to the surface of the cobble zone but were buried to prevent re-oiling.

Shingle Washing Operations

Washing stations were set up at several locations. These were established from readily available equipment such as cement mixes, skips, temporary tanks, conveyors and scaffolding. Oiled material is fed into a lorry-mounted cement mixer and seawater with an approved degreaser, and occasionally diesel, added. (However, later operations used neither degreaser or diesel as it was found that these were not necessary.) Operating the cement mixer agitates the material and loosens the oil. The mixture is then left to separate. The oily water is then run-off into watertight skips or tanks and the oil removed by surface skimmers. The cleaned shingle was then returned to the beach.

Treatment rates would depend on the degree of oiling, the capacity of the cement mixer and the number of cement mixers used. Cement mixers have a nominal capacity of 10 tonnes and, with a treatment cycle of 2 hours, some 50 tonnes per day can be treated. However, more recent work by AEA Technology suggests that treatment cycles of this length may not always be necessary.

Conclusion

The clean-up response to the Sea Empress incident can be considered to have been very successfiul. An opportunity was taken to undertake innovative approaches to oil spill response and monitoring for both at sea operations and shoreline clean-up. Real time monitoring has proved to be a very useful to enable decision making during a response and to enhance protection of the environment.

Monitoring of dispersed oil concentrations during dispersant spraying operations provide proof of dispersant effectiveness. Surf washing should now be considered as an effective oil spill response measure. In-situ pit washing and shingle washing operations in cement mixers have also proved to be successful for the cleaning of otherwise difficult material. Bioremediation with the use of additions of slow release nutrients may prove to be a cost effective technique for enhancing the natural recovery of low energy environments.