CURRENT STATUS OF THE BAOAC (BONN AGREEMENT OIL APPEARANCE CODE)

A report to
the Netherlands
North Sea Agency
Directie Noordzee
by
Alun Lewis
Oil Spill Consultant

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1. Background of the current BAOAC

The Bonn Agreement Oil Appearance Code (BAOAC) is a series of five categories or 'Codes' that describe the relationship between the appearances of oil on the sea surface to the thickness of the oil layer (Table 1).

Code	Description Appearance	Layer Thickness Interval (µm)	Litres per km^2
1	Sheen (silvery/grey)	0.04 to 0.30	40 – 300
2	Rainbow	0.30 to 5.0	300 – 5000
3	Metallic	5.0 to 50	5000 – 50,000
4	Discontinuous True Oil Colour	50 to 200	50,000 – 200,000
5	Continuous True Oil Colour	200 to More than 200	200,000 - More than 200,000

Table 1. The Bonn Agreement Oil Appearance Code

The BAOAC was developed to replace the previously-used Bonn Agreement Colour Code.

The Colour Code was found to be difficult to use in several respects; some of the Colour Codes were difficult to distinguish from each other (particularly the upper two Colour Codes of "Brown / black" and "Dark brown / black") and "blue" colour was in two other categories ("Blue" and "Blue / brown"). Since oils of different types that may be spilled at sea can lead to many colours, from transparent through orange to brown and black, but are never blue, the use of this classification was difficult to justify. The BA Colour Code had also been adjusted on several occasions to try and rationalise the single thickness values associated with the colours.

The Contracting Parties of the Bonn Agreement decided to thoroughly review the basis for the Colour Code. This was done in a series of scientific studies:

- SINTEF Report STF66 F97075: The use of observed colour as a guide to oil film thickness - A literature review.

  This study found that while there was a theoretical justification for the lower Colour Codes (thinner oil film 'colours'), there was no theoretical justification for the higher Colour Codes (thicker oil layer 'colours').

- SINTEF Report STF66 The use of colour as a guide to oil film thickness - Laboratory experiments

  Laboratory experiments were conducted in this study. Oil films of known thicknesses were placed on water in trays and then photographed.

1.1 Main features of the BAOAC

The five Codes of the BAOAC are based on experimental evidence that has linked visual appearance to known oil thicknesses. Each of the Codes, apart from Code 5 (Continuous True Oil Colour), has a minimum and a maximum oil layer thickness.

- **Code 1 - Sheen (silvery/grey) - 0.04 to 0.30 microns**

  Under most viewing conditions, oil layers below 0.04 microns in thickness cannot be easily detected by the human eye and appear silvery / grey up to a thickness of 0.30 microns.

- **Code 2 – Rainbow - 0.30 to 5.0 microns**

  Oil layers in the range of 0.30 to 5.0 microns in thickness appear to be rainbow coloured (bands of individual colours of the rainbow; red, orange, yellow, green, blue, indigo and violet) because of the constructive and destructive interference of the wavelengths of white light caused by the presence of the oil film. Light is reflected from both the surface of the water underlying the oil and from the surface of the oil.

  The rainbow colours are strongest when the oil layer is of the same order as the wavelengths of these different colours (0.4 microns (400 nm) for violet and 0.65 microns (650 nm) for red), but the effect persists weakly for multiples of these oil thicknesses until the oil layer is opaque and prevents light from being reflected from the underlying water surface. Very opaque oils, such as black fuel oils, block the light at lower oil thickness than transparent oils such as Marine Diesel Oil (MDO).

- **Code 3 – Metallic - 5.0 to 50 microns**

  Oil layers in the range of 5.0 to 50 microns in thickness act as an imperfect mirror. The apparent colour varies depending on viewing conditions, but is sometimes the colour of the sky (blue or shades of grey). Whatever the apparent colour, the common visual effect is of a flat, almost uniform, surface without obvious features. After some debate, this effect is described as “metallic” in the BAOAC.

  Trials at sea have confirmed that aerial surveillance observers recognise the effect and reliable and consistently report oil layers of these thicknesses as appearing “metallic”.

- **Code 4 – Discontinuous True Oil Colour - 50 to 200 microns**

  Oil layers in the range of 50 to 200 microns in thickness are described as Code 4 - Discontinuous True Oil Colour. Code 4 is intermediate between Code 3 and Code 5, and consists of small areas, or patches, of Code 5, Continuous True Oil Colour in a background of Code 3, Metallic. This is an accurate description of the behaviour of the oil layer – it does not spread as an even thickness layer, but consists of thicker patches in a thinner layer.

Low viscosity oils, such as Marine Diesel Oil (MDO), tend to quickly spread out to form a thin layer of oil of rapidly diminishing thickness when spilled at sea. Slicks of low viscosity oils will be dominated by Codes 1 to 3 of the BAOAC, in varying proportion.

Higher viscosity oils, such as crude oils and residual fuel oils, form layers of oil with a high degree of local variation in thickness. There are localised areas of thicker oil set in a background of thinner oil. This occurs at practically all scales of measurement; on close examination of a small area of oil spread out on water there may be areas of thicker oil less than a millimetre across set in a background of much thinner oil (Figure 1). The initial spreading of a thin film of oil inhibits further spreading of oil from the thicker patches.

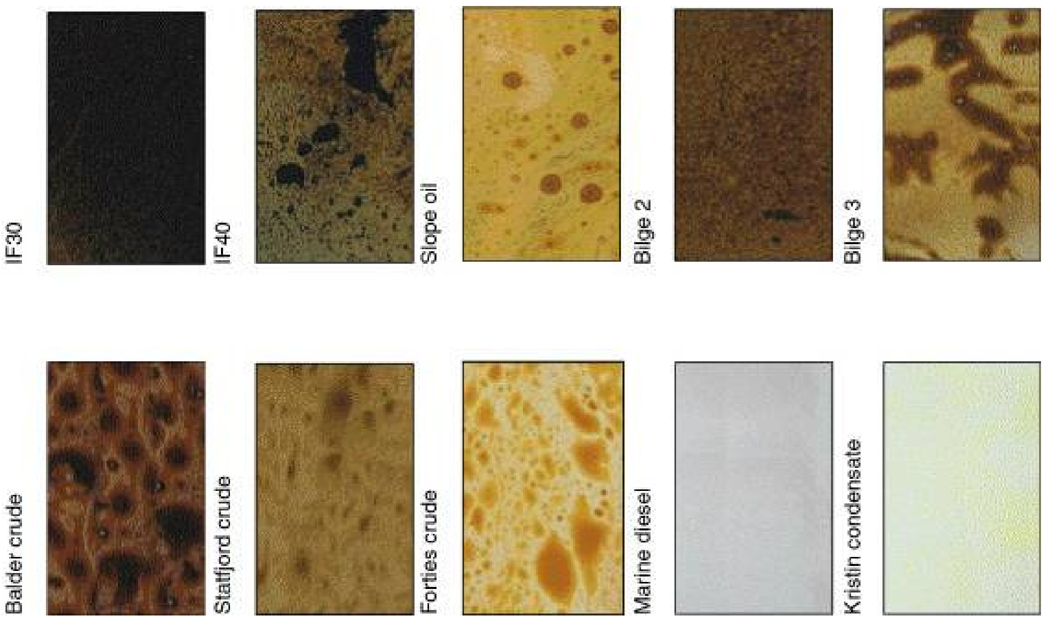

Figure 1. 50 micron thick layers of different oils

Experiments with oil layers in the range of 50 to 200 microns were the basis for naming this range of oil layer thickness as “Code 4 - Discontinuous True Oil Colour”; the true colour of the oil varied from black to very pale brown or orange, but it is seen against a background of much more transparent oil.

It is quite common to see patches of thicker oil against a background of thinner oil on a much larger scale (Figure 2). Experiments were conducted in a harbour owned by Fina Norge A/S on a fjord at Muruvik, about 20 km east of Trondheim. Six different types of oil were used in experiments where oil was released into hexagonal booms. The oil was photographed and sampled to determine the oil layer thickness in various areas of the oil slicks.

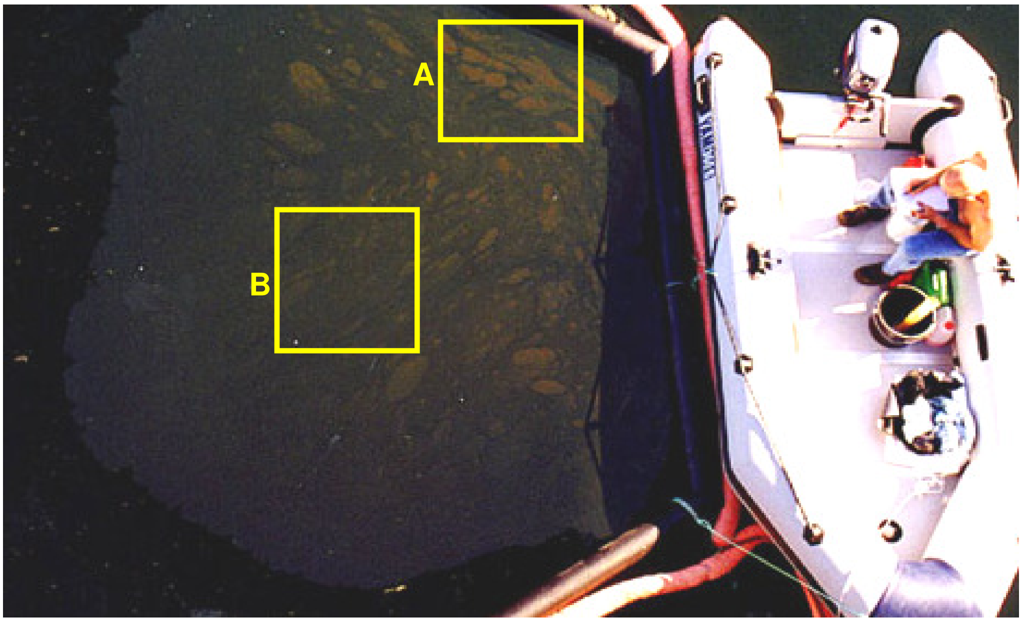

Figure 2. Areas of thicker oil set against a background of thinner oil

If the patches of thicker oil are large enough - several centimetres or more across - to be distinguished as discrete separate entities (such as in area A in Figure 2) it would be reasonable to describe these areas of Code 5 - Continuous True Oil Colour.

However, if the patches are not large enough to be easily distinguished as separate areas (such as in area B in Figure 2), they could be described as Code 4 - Discontinuous True Oil Colour.

Distinguishing between Code 4 and Code 5 is discussed further in Section 3.1 of this report.

- **Code 5 – Continuous True Oil Colour – More than 200 microns**

The last code in the BAOAC is Code 5 - Continuous True Oil Colour. Code 5 is defined by only a minimum thickness value of 200 microns.

There is no maximum thickness value for Code 5 since it is not possible by visual observation from above to estimate the thickness of oil layers above 200 microns. A spilled oil layer on water that is 0.5 mm thick will look, from the top, exactly the same as an oil layer that is several millimetres thick. The light is reflected from the top surface of the oil; this gives information about the colour and texture of the surface of the oil, but cannot give any direct information about the thickness of the oil layer.

The very high viscosity residual fuel oil that was spilled from the *Prestige* floated on the sea in layers that were many centimetres thick (up to 50 cm or more) and highly weathered and emulsified crude oils frequently form layers that are many millimetres thick.

One aspect of the BAOAC that should be appreciated is the fact that, in wave conditions on the sea, the thickness of a layer of oil on water at a particular location will not remain constant. The sea surface is not static and is often a dynamic environment.

As a non-breaking wave passes underneath the oil slick, the oil layer will be:

- Stretched and thinned on the wave crest
- Compressed and thickened in the wave trough

An area of oil that is of a thickness that is close to the minimum or maximum thickness of a particular BAOAC Code may therefore appear to alternate between two BAOAC Codes.

If there are breaking waves, the situation is more extreme. As the breaking wave passes through the oil slick, the area of oil affected by the wave will be temporarily dispersed below the surface as large oil droplets. The area of water surface will be temporarily cleared of oil. The large oil droplets will then rapidly re-surface and, as they reach the water surface, will rapidly spread out to form a layer of oil of rapidly diminishing thickness.

The oil layer thickness, and the BAOAC Codes associated with the particular thicknesses, will therefore not be constant when waves are present.

1.2 Subsequent work with the BAOAC

After the initial development of the BAOAC, several further studies were conducted and the BAOAC was used at several experimental oil spills.

- <u>Bonn OTSOPA Discussions</u>

  The designation of each Code by a minimum and maximum oil thickness value for each Code, with the maximum of one Code being the minimum of the next Code, and being the same for all oils, was considered in discussions at Bonn OTSOPA.

  Experimental work has shown that there is a degree of ‘overlap’ between each of the Codes and its neighbouring Codes and that these ‘overlaps’ vary with oil type. The maximum oil layer thickness value of one Code was found – in some cases – to be higher than the minimum oil layer thickness value of the next. The results can be presented as a series of overlapping ‘bell curves’.

  However, introducing overlapping minima and maxima – with the maximum of one Code being higher than the minimum of the next Code, or introducing separate BAOACs for different oil types, were rejected as being unnecessarily complex.

- Use of the Bonn Agreement Colour Code at the DeepSpill Experiments, Norwegian Sea, June 2000

  The objective of the work was to validate the BAOAC in comparison to the then existing Bonn Agreement Colour Code. This objective was only partially met because of the very poor observation conditions that prevailed during the DeepSpill experiments.

  From the limited observations that were made, it was concluded that the BAOAC did provide a more accurate estimate of total slick volume than the Colour Code within the range for which it has been calibrated i.e. slick thickness up to 200 microns thickness.

- BONNEX 2002 Results analysis November 2002

  The analysis of the results indicated that using the BAOAC produced spilled volume estimates that were reasonably close to the actual spill volumes, but there were exceptions of both over- and under-estimates. The inaccuracies were principally due to inaccurate estimations of the areas of BAOAC within the oil slicks.

- Field validation for improving Codes 4 and 5 of the Bonn Agreement Oil Appearance Code (BAOAC) A report to the Norwegian Coastal Administration by Alun Lewis and Per Daling, September 2006

  The poor visibility and low cloud at the NOFO 2006 Oil on Water Exercise prevented the planned programme of work for validating Codes 4 and 5 of the BAOAC from being conducted. The limited amount of work that was conducted did **not** unambiguously validate the currently used oil layer thickness intervals for DCTC, Code 4 (50 to 200 microns) or for CTC, Code 5 (greater than 200 microns).

  In particular, the distinction between Code 4 - DCTC and Code 5 - CTC was not visible from the surveillance aircraft, but was visible from the sampling boats. The more intensely coloured area of the crude oil slicks was observed from the aircraft as generally being Code 5 - CTC, but contained oil layers of thickness equivalent to both Code 4 - DCTC and to Code 5 - CTC. For the purposes of estimating spilled oil volume, some observers in aircraft elected to consider the entire area as being DCTC, Code 4, while other observers elected to consider the entire area to be CTC, Code 5. On the basis of the very limited amount of data available, neither assumption is absolutely correct.

  It is not obvious whether the poor visibility conditions with poor contrast and the low altitude that the surveillance aircraft had to operate at was the primary cause of this lack of discrimination between DCTC, Code 4 and CTC, Code 5. The viewing conditions certainly made any distinction more difficult than would have been possible in bright, sunny conditions, but it may be that the distinction would not be clear even under optimum viewing conditions.

2. Purpose of the BAOAC

Aerial surveillance plays an essential role in the task of preventing and combating oil pollution of the North Sea. The purpose of surveillance flights is to detect, investigate, gather evidence and monitor oil spills, whether the spill is a result of:

- an accident that may require response actions;
- or has been caused deliberately in contravention of International conventions such as MARPOL.

The primary objective in routine aerial surveillance patrols is to detect combatable oil slicks in an early stage, and to encounter ships and platforms in the act of discharging oil illegally, and to gather sufficient evidence for a prosecution. Visual observation of the pollution and polluter provides essential information about the size, appearance and coverage of the slick that are used to calculate the initial estimate of volume. The application of remote sensing equipment and techniques is also of great value.

As stated in the Bonn Agreement Aerial Surveillance Handbook Part 3, Oil Pollution Detection, Investigation and Analysis:

"1.1 The primary task for marine pollution surveillance aircrew is to detect, investigate, evaluate and report oil pollution. Assessing the volume of an oil slick is the result of a calculation using parameters recorded during the detection (remote sensing instruments) and observation (visual) of related circumstances and conditions. The result of the calculation is only an estimation; an indication of quantity.

1.2 In flight, all detections should be treated in the same way regardless of whether they are considered legal or illegal, from whatever the source, known or unknown. All detections should be investigated and the fullest data set possible collected and recorded using the available remote sensing and photographic equipment together with visual observation. The data should be evaluated and a volume calculated. The estimated quantity of oil forms the basis for the decision to respond together with other essential information such as location and weather.

1.3 Post flight, an independent and detailed analysis / evaluation of the size and volume of the oil should be made using the recorded data set, visual observation and photographs. The 'post flight' assessment of size and volume should be used for any follow up legal action."

The BAOAC is used by:

1. Estimating the total area of oil on the sea surface (by visual estimates or more accurately by using measurements of a SLAR image for larger oil slicks, or of a UV camera image for smaller oil slicks). When determining the oiled area coverage it is essential to remember that the main body of an oil slick may have 'areas' of clear water, especially near the trailing edge of the slick.

2. The 'oiled' area should be sub-divided into areas that relate to a specific oil appearance according to the BAOAC. This part of the volume estimation is mainly subjective so great care should be taken in the allocation of coverage to appearance, particularly the appearances that relate to higher thicknesses (Code 4, Discontinuous True Oil Colour and Code 5, Continuous True Oil Colour).

3. The areas of the oil slick for each of the different BAOAC Codes are calculated and the estimated volumes, both minimum (using the lower thickness limit for each BAOAC Code) and maximum (using the upper thickness limit for each BAOAC Code) are calculated for each BAOAC Code. These are then totalised to produce two estimates of spilled oil volume:
    - a maximum volume.
    - a minimum volume.

   As stated in the Bonn Agreement Aerial Surveillance Handbook Part 3, Oil Pollution Detection, Investigation and Analysis, Section 9: Oil Volume Estimate Usage:

   - *"It is suggested that in general terms the **maximum quantity** should be used together with other essential information such as location **to determine any required response action**.*
   - *It is suggested that the **minimum volume** estimate should be used **for legal purposes.***

   Reference is made to Bonn Agreement Contracting Parties Meeting Summary Record 2003 Page 5, Para. 2.4 (f) which states "When the BAOAC is used to estimate the quantity of oil released at sea, the lower limit of the range in the code for each coded appearance should be used for estimating the amount of oil present in the slick for enforcement purposes and for statistical reporting". However, it is emphasised that each national authority will determine how to use the BAOAC volume data within its own area."

The use of the BAOAC is illustrated in *"L'Observation Arienne des Pollutions Petrolieres en Mer – Guide Operationel"* published by CEDRE in July 2004.

3. Difficulties with Codes 4 and 5

Although the previous work with the BAOAC has demonstrated that it is valid for the thinner oil thickness (Codes 1 to 3), some problems remain with using it to estimate spilled oil volumes on the sea if thicker oil layers are present.

3.1 BAOAC Code 4 - Discontinuous True Oil Colour

BAOAC Code 4 is intermediate between Code 3 and Code 5; it is a hybrid of Codes 3 and 5. “Discontinuous” refers to the Code being used to describe patches of Code 5 - Continuous True Oil Colour against a background of Code 3 - Metallic.

As noted in Section 1.1 Code 4 of this report, The size of the thicker oil (Code 5 - Continuous True Oil Colour) patches that can be seen will depend on the distance from which they are observed and the visual acuity of the observer.

Visual acuity refers to the clarity or clearness of one’s vision, a measure of how well a person sees. The word “acuity” comes from the Latin “acuitas,” which means sharpness. A person with normal, or average, visual acuity, can correctly identify a 9 mm high black letter on a white background on a standard Snellen eye-chart that subtends 5 minutes of arc (0.04167°) at a distance of 6 metres (the standard distance for eye tests). They can discriminate the shape of the letter and can therefore easily see a black line or dot that subtends half this angle, 2.5 minutes of arc (0.0208º). A person with normal visual acuity would therefore have no difficulty in seeing individual 4 mm diameter black dots on a white background from a distance of 6 metres.

As was demonstrated at the BONNEX 2002 and NOFO 2006 Oil on Water Exercise, observers in small boats, who looked at the spilled oil from a distance of a metre or so, were able to easily see small patches of Code 5 in a background of Code 3 and reported this as Code 4 - Discontinuous True Oil Colour (Figure 3).

Surveillance aircraft conducting visual observations of oil slicks on the sea surface normally operate at altitudes of approximately 500 ft, 1500 ft or 2500 ft. The equivalent sizes of a black dot that could be seen on a white background by a person with normal acuity vision would be 110 mm, 330 mm and 550 mm from these altitudes. In addition, the contrast between black and white will normally be a lot more than the contrast between the true colour of an oil (black or brown) and the metallic, almost mirror-like effect, appearance of oil of the Code 3 thickness. Observers in aircraft will not be able to see small patches of Code 5 in a background of Code 3, but should be able to see much larger patches of Code 5, perhaps 0.5 to 1 metre across, in a background of Code 3.

From an aircraft, the appearance of a slick containing a large area of Code 4 - Discontinuous True Oil Colour – composed of individually small areas of Code 5 - Continuous True Oil Colour against a background of Code 3 – Metallic - will therefore be a function of the concentration of the Code 5 patches. At low concentrations (5 to 10% of the total area) they will probably be invisible and the area will be observed as Code 3 – metallic. At some increased concentration (perhaps 40 or 50% of the total area), the appearance of that area of the slick will probably ‘flip’ from being **all** Code 3 – Metallic to being **all** Code 5 - Continuous True Oil Colour.

Figure 3 *Patches of Code 5 - Continuous True Oil Colour against a background of Code 3 – Metallic, as seen from a sampling boat.*

Experiments at the BONNEX 2002 sea trials showed that many observers in aircraft chose not to use Code 4, preferring to use Code 3 and then Code 5 in varying proportion.

At the NOFO 2006 Oil on Water Exercise, it was difficult to distinguish between DCTC, Code 4 and CTC, Code 5 from the air and some observers interpreted most intensely coloured area as **all** Code 4 - Discontinuous True Oil Colour, while other observers interpreted **all the area** as Code 5 - Continuous True Oil Colour. Analysis of the data suggested that the reality lays between these two options; the observed slick area must have contained **both** Code 4 - Discontinuous True Oil Colour and Code 5 - Continuous True Oil Colour. The limited results that were obtained are indicative that the above explanation based on visual acuity is probably correct, but the poor visibility and low cloud at the NOFO 2006 Oil on Water Exercise prevented the planned programme of work from being conducted.

3.2 BAOAC Code 5 - Continuous True Oil Colour - > 200 microns

The current definition of Code 5 **-** Continuous True Oil Colour is an average oil layer thickness of greater than 200 microns (0.2 mm). No upper limit is given for Code 5 since it is known that some very high viscosity oils, such as those spilled from the *Erika* or *Prestige*, floated as layers that are many centimetres, or even tens of centimetres, thick. However, it is also known that many oils of lower viscosity will form much thinner oil layers (typical in the mm range) even when they have emulsified.

The absence of an upper limit for Code 5 produced distorts the results of using the BAOAC to estimate spilled oil volume. The minimum and maximum estimated spill volumes become similar if there are relatively large areas of Code 5. This causes an apparent increase in the accuracy of the BAOAC, but is misleading because both the minimum and maximum volume estimates are based on ‘greater than’ oil thickness.

The actual terminal (equilibrium) thickness of an oil layer on the sea will probably be highly dependent on the rheological properties of the spilled oil or emulsified oil. This would vary with individual oil types. It might be feasible to assign different maximum oil thicknesses for Code 5 on the basis of a limited number of oil type groupings. For example, the maximum Code 5 oil thickness could be; 200 microns for an IFO-80 grade fuel oil and non-emulsified crude oils; 600 microns for an IFO-380 grade fuel oil and emulsified crude oils, and 1000 microns for an IFO-380 grade fuel oil in temperate seas and highly weathered crude oils or particularly heavy crude oils.

These possibilities have not yet been explored. Bonn OTSOPA has accepted that the estimation of oil layer thickness by visual means alone cannot ever be successful for thick oil layers. If areas of thicker oil (particularly Code 5) are visually observed, further evidence for their existence should be sought by the use of remote sensing such as IR (Infra-Red), although these methods are known to be ambiguous under some circumstances.

4. The need for Code 4 (DCTOC)

4.1 The problem of Code 4 - Discontinuous True Oil Colour not being observed

The apparent inability of observers in aircraft to easily discriminate between Code 4 - Discontinuous True Oil Colour from Code 5 - Continuous True Oil Colour is a potential problem in the use of the BAOAC.

The transition from Code 3 - Metallic, through Code 4 and on to Code 5 may not be visible to an observer in an aircraft if the patches of Code 5 - Continuous True Oil Colour in a background of Code 3 - Metallic (that constitute Code 4 - Discontinuous True Oil Colour) are too small to be seen from the aircraft altitude.

Instead, there will be an apparent transition directly from an area of the slick observed as Code 3 to the same area being observed as Code 5, without any intervening observation of the same area of slick as being Code 4.

The point of this apparently abrupt transition between Code 3 and Code 5 will depend on the relative concentration of the Code 5 patches in the Code 3 background:

- If the individual patches of Code 5 in a background of Code 3 are too small for the observer in the aircraft to see and are of a relatively low concentration, the area will be described as Code 3 – Metallic.

- If the concentration of these small patches of Code 5 in a background of Code 3 is high enough for them to dominate the appearance the same slick area (without being visible as individual patches) the appearance will change and the same area will then be observed Code 5 - Continuous True Oil Colour.

The transition from an appearance of an area of a slick from Code 3 to Code 5 will not necessarily be abrupt. At intermediate concentrations of Code 5 patches in a Code 3 background, it might just be impossible to decide whether the area is Code 3 or Code 5.

4.1 Consequences of Code 4 not being observed on volume estimates

The likely effects of this effect, in terms of a somewhat unrealistic example, are contained in the calculations contained in Annex A. The final results of these calculations are presented here in Table 2.

		Minimum volume m^3	Maximum volume m^3
A.1	Base case (considered as the ‘truth’)	>51.07	>91.06
A.2	Code 4 observed as Code 3	>42.07	>61.06
A.3	Code 4 observed as Code 5	>81.07	>91.06
A.4	Code 4 and Code 5 observed as Code 3	3.07	31.06
A.5	Code 4 and Code 5 observed as Code 5	>120.07	>121.06

Table 2. Volume estimates from calculations in Annex A

The base case (Case A.1) for the calculations is a 1 km^2 slick with five equal (20% coverage) of each of the five Codes. This is considered to be the ‘truth’; the calculations based on this assessment would represent the correct minimum and maximum volume estimates. The correct minimum volume estimate is >51.07m^3 and the correct maximum volume estimate is >91.06m^3. The volume of the spilled oil is presumed to be around 70m^3, although it should be noted that both minimum and maximum volume estimates are “greater than” values.

If Code 4 cannot be observed from the aircraft, because the individual patches of Code 5 set in a background of Code 3 are too small to be seen and their concentration is relatively low, the ‘true’ area of Code 4 will be identified as Code 3. The minimum volume estimate would be >42.07m^3 and the maximum volume estimate would be >61.06m^3. Both the minimum and maximum volume estimates are lower than the ‘correct’ estimates, by 82% and 67% respectively. The probable volume of spilled oil would therefore be considered to be about 50 m^3, about 70% of the true value.

If the patches of Code 5 in a background of Code 3 cover a higher proportion of the Code 4 area, the area would be identified as Code 5. The minimum volume estimate would be >81.07m^3 and the maximum volume estimate would be >91.06m^3. The minimum estimated volume is 159% of the correct minimum, but the maximum is the same because it is a “greater than” value. The ‘average’ estimated spill volume would be a spuriously accurate 85 m^3, about 120% of the true value. The spurious accuracy is caused by the Code 5 contribution being based on a greater than 200 micron thickness in both minimum and maximum estimated volume cases.

This transition from the all Code 3 case (A.2: Code 4 identified as Code 3) and the all Code 5 case (A.3: Code 4 identified as Code 5) would be abrupt. The minimum volume estimate would ‘jump’ from >42.07m^3 to >81.07m^3, while the maximum estimated volume would ‘jump’ from >61.06m^3 to >81.07m^3 when the concentration of patches of Code 5 in Code 3 became visible and the identification of the area ‘jumped’ from Code 3 to Code 5.

Although the volume estimates calculated from these examples may not appear to be too far from the supposed ‘truth’, there are some implications. If the minimum volume estimates were to be used in a legal case, their inherent accuracy could easily be questioned. The observer in the aircraft could not know whether (in this example) the correct minimum estimated volume was about 40m^3 or about 80m^3. No intermediate estimated volumes could be calculated from the observations that exclude Code 4.

The minimum and maximum volume estimates only become very inaccurate if the thicker oil in the slick (Codes 4 and 5) are mis-identified as being Code 3 (Case A.4) or the Code 3 and Code 4 areas are misidentified as being thick oil, Code 5 (Case A.5). In the former case, both the minimum and maximum volume estimates are below the correct volume and in the latter cases both the minimum and maximum volume estimates are much higher than the correct volume.

5. Conclusions on the current status of the BAOAC

Previous work has indicated that the BAOAC is valid and useful for estimating the volumes of spilled oil where only Codes 1, 2 and 3 are observed. This is most often the case for illegal discharges. There is no need for this part of the BAOAC to be altered or revised.

There is still some doubt about the use of Code 4 - Discontinuous True Oil Colour and Code 5 - Continuous True Oil Colour.

At a meeting of the Bonn Contracting Parties held on December 11th, 2006 it was concluded that using the term *"Discontinuous True Oil Colour"* to describe Code 4 is not a very good description. However, as detailed in this report, it is difficult to devise a better description for an oil thickness range that is intermediate between Code 3 – Metallic and Code 5 - Continuous True Oil Colour and, in fact, consists of patches (of variable size) of thicker oil that appears as Code 5 - Continuous True Oil Colour oil thickness set in a background of thinner oil that appears as Code 3 – Metallic.

The fact that smaller patches of Code 5 - Continuous True Oil Colour in a background of Code 3 – Metallic can be observed from sampling boats than can be observed from surveillance aircraft has been established. The consequences of this for estimating spilled oil volumes is explained in this report.

The difficulty in identifying Code 4 - Discontinuous True Oil Colour, or distinguishing the transition from Code 3 – Metallic to Code 5 - Continuous True Oil Colour at the NOFO 2006 Oil on Water Exercise was undoubtedly made more difficult by the poor visibility and low cloud. It had been intended to carry out much more work on this topic by getting observations from observers in aircraft at various altitudes. This was not possible and only 10 to 15% of the planned programme was conducted and the results were of lower quality than desired. Nevertheless, the limited results that were obtained indicated that it can be very difficult for observers in aircraft to make an unambiguous identification. This may have been exacerbated by the very calm conditions; the spilled oil spread out in a way that would not have happened in conditions of even light wind when the thicker oil would have been concentrated at the 'head' of the slicks.

Further experience of using the BAOAC to observe thicker oil layers in good viewing conditions needs to be obtained. This is obviously difficult in circumstances where no surface vessels are present to obtain pad samples, so such experience is unlikely to be gained during routine surveillance flights.

Opportunities presented at oil-on-sea exercises, or at other oil releases in controlled conditions, should be used to carry out systematic studies. These are needed to clarify the exact status of Code 4 - Discontinuous True Oil Colour.

If such studies conclude that the Code 4 classification should be re-defined, or that the Code 3 maximum should be extended to meet a lowered Code 5 minimum, this should be considered. However, in the current absence of any firm evidence, it would be premature to consider further modification to the BAOAC.

ANNEX A

Calculations of estimated slick volumes

A.1 Base Case

Taking a somewhat unrealistic example, if an oil slick of 1 km^2 were to have five equal areas of 20% of each Code, as shown in Table A.1, the volume estimates would be:

- minimum volume of greater than 51.07 m^3
- maximum volume of greater than 91.06 m^3

BAOAC Code	Description	Minimum m^3/km^2	Maximum M^3/km^2	1 km^2 slick	Minimum volume m^3	Maximum volume m^3
1	SHEEN	0.04	0.3	20%	0.01	0.06
2	RAINBOW	0.3	5	20%	0.06	1.00
3	METALLIC	5	50	20%	1.00	10.00
4	DCTOC	50	200	20%	10.00	40.00
5	CTOC	>200	>200	20%	>40.00	>40.00
				100%	**>51.07**	**>91.06**

Table A.1. Base case example: 1 km^2 slick with all 5 Codes at 20% of area

Both the minimum and maximum volume estimates are "greater than" estimates because of the inclusion of Code 5 with a minimum thickness value of greater than 200 microns.

A.2 Code 4 observed as Code 3

If the 20% of area of Code 4 in the slick could not be discriminated from the 20% of area of Code 3, because the small patches of Code 5 in the area cannot be seen, the area would be designated Code 3 and the combined area was reported as 40% of Code 3 (Table A.2) the volume estimates would be:

- minimum volume of greater than 42.07 m^3
- maximum volume of greater than 61.06 m^3

BAOAC Code	Description	Minimum m^3/km^2	Maximum m^3/km^2	1 km^2 slick	Minimum volume m^3	Maximum volume m^3
1	SHEEN	0.04	0.3	20%	0.01	0.06
2	RAINBOW	0.3	5	20%	0.06	1.00
3	METALLIC	5	50	40%	2.00	20.00
4	DCTOC	50	200	0%	0.00	0.00
5	CTOC	>200	>200	20%	>40.00	>40.00
				100%	**>42.07**	**>61.06**

Table A.2 Code 4 observed as Code 3

The minimum estimated volume is reduced to 82% of the base case (greater than 51.07 m^3) to greater than 42.07 m^3. The maximum estimated volume is reduced to 67% of the base case (greater than 91.06 m^3) to greater than 61.06 m^3

A.3 Code 4 observed as Code 5

If the 20% of area of Code 4 in the slick could not be discriminated from the 20% of area of Code 5 and the combined area was reported as 40% of Code 5 (Table A.3) the volume estimates would be:

- minimum volume of greater than 81.07 m^3
- maximum volume of greater than 91.06 m^3

BAOAC Code	Description	Minimum m^3/km^2	Maximum m^3/km^2	1 km^2 slick	Minimum volume m^3	Maximum volume m^3
1	SHEEN	0.04	0.3	20%	0.01	0.06
2	RAINBOW	0.3	5	20%	0.06	1.00
3	METALLIC	5	50	20%	1.00	10.00
4	DCTOC	50	200	0%	0.00	0.00
5	CTOC	>200	>200	40%	>80.00	>80.00
				100%	**>81.07**	**>91.06**

Table A.3 Code 4 observed as Code 5

The minimum estimated volume is increased to 159% of the base case (greater than 51.07 m^3) to greater than 42.07 m^3. The maximum estimated volume is the same as the base case (greater than 91.06 m^3).

A.4 Code 4 and Code 5 observed as Code 3

If the both the 20% of area of Code 4 and the 20% of area of Code 5 cannot be discriminated from the 20% of area of Code 3 and the combined area was reported as 60% of Code 3 (Table A.4) the volume estimates would be:

- minimum volume of 3.07 m^3
- maximum volume of 31.06 m^3

BAOAC Code	Description	Minimum $m^{3/}km^2$	Maximum m^3/km^2	1 km^2 slick	Minimum volume m^3	Maximum volume m^3
1	SHEEN	0.04	0.3	0.2	0.01	0.06
2	RAINBOW	0.3	5	0.2	0.06	1.00
3	METALLIC	5	50	0.6	3.00	30.00
4	DCTOC	50	200	0	0.00	0.00
5	CTOC	>200	>200	0	0.00	0.00
				1	**3.07**	**31.06**

Table A.4. Code 4 and Code 5 observed as Code 3

The absence of Code 4 and Code and there substitution as Code 3 produces much lower volume estimates; the minimum estimate is only 6% of the base case and the maximum estimate is 34% of the base case, although both base case estimates are “greater than” values.

A.5 Code 3, Code 4 and Code 5 observed as Code 5

If the both the 20% of area of Code 4 and the 20% of area of Code 5 cannot be discriminated from the 20% of area of Code 3 and the combined area was reported as 60% of Code 5 (Table A.4) the volume estimates would be:

- minimum volume of 120.07 m^3
- maximum volume of 121.06 m^3

BAOAC Code	Description	Minimum m^3/km^2	Maximum m^3/km^2	1 km^2 slick	Minimum volume m^3	Maximum volume m^3
1	SHEEN	0.04	0.3	20%	0.01	0.06
2	RAINBOW	0.3	5	20%	0.06	1.00
3	METALLIC	5	50	0%	0.00	0.00
4	DCTOC	50	200	0%	0.00	0.00
5	CTOC	>200	>200	60%	>120.00	>120.00
				100%	**>120.07**	**>121.06**

Table A.4. Code 4 and Code 5 observed as Code 3

The mis-identification of Codes 3 and 4 as Code 5 produces very high volume estimates; the minimum estimate is 235% of the base case and the maximum estimate is 133% of the base case.