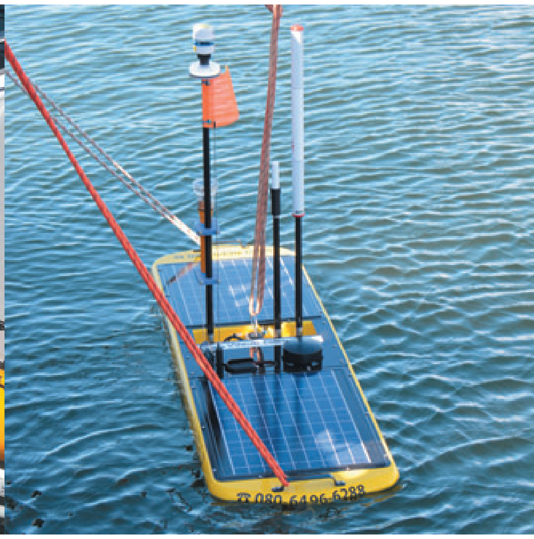
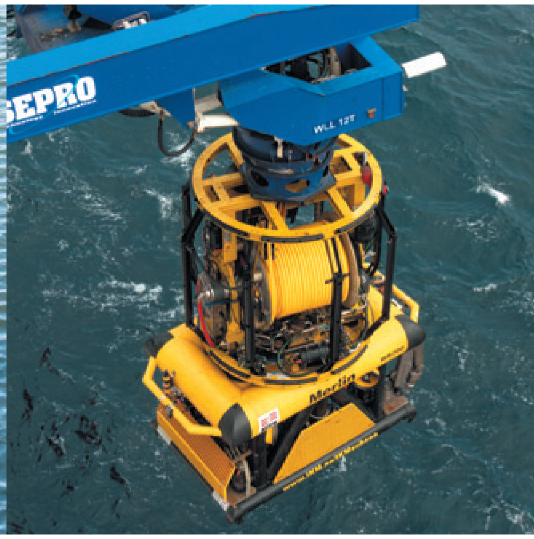
In-water surveillance of oil spills at sea

Good practice guidelines for incident management and emergency response personnel





IPIECA

The global oil and gas industry association for environmental and social issues

14th Floor, City Tower, 40 Basinghall Street, London EC2V 5DE, United Kingdom
Telephone: +44 (0)20 7633 2388   Facsimile: +44 (0)20 7633 2389
E-mail: info@ipieca.org   Website: www.ipieca.org

IOGP International Association of Oil & Gas Producers

International Association of Oil & Gas Producers

Registered office
14th Floor, City Tower, 40 Basinghall Street, London EC2V 5DE, United Kingdom
Telephone: +44 (0)20 3763 9700   Facsimile: +44 (0)20 3763 9701
E-mail: reception@iogp.org   Website: www.iogp.org

Brussels office
Boulevard du Souverain 165, 4th Floor, B-1160 Brussels, Belgium
Telephone: +32 (0)2 566 9150   Facsimile: +32 (0)2 566 9159
E-mail: reception@iogp.org

Houston office
10777 Westheimer Road, Suite 1100, Houston, Texas 77042, United States
Telephone: +1 (713) 470 0315   E-mail: reception@iogp.org

IOGP Report 550

Date of publication: 2016

In-water surveillance of oil spills at sea

Good practice guidelines for incident management and emergency response personnel

Cover photographs reproduced courtesy of the following: (left) Suzanne Long/Alamy Stock Photo; (centre) OIST; (right) Navin Mistry/Shutterstock.com.

Preface

This publication is part of the IPIECA-IOGP Good Practice Guide Series which summarizes current views on good practice for a range of oil spill preparedness and response topics. The series aims to help align industry practices and activities, inform stakeholders, and serve as a communication tool to promote awareness and education.

The series updates and replaces the well-established IPIECA 'Oil Spill Report Series' published between 1990 and 2008. It covers topics that are broadly applicable both to exploration and production, as well as shipping and transportation activities.

The revisions are being undertaken by the IOGP-IPIECA Oil Spill Response Joint Industry Project (JIP). The JIP was established in 2011 to implement learning opportunities in respect of oil spill preparedness and response following the April 2010 well control incident in the Gulf of Mexico.

Note on good practice

'Good practice' in this context is a statement of internationally-recognized guidelines, practices and procedures that will enable the oil and gas industry to deliver acceptable health, safety and environmental performance.

Good practice for a particular subject will change over time in the light of advances in technology, practical experience and scientific understanding, as well as changes in the political and social environment.

Contents

About this guide

This Good Practice Guide (GPG) builds on two technical reports prepared for IOGP and IPIECA on behalf of the Oil Spill Response (OSR) Joint Industry Project (JIP). The first of these reports was prepared by Battelle (2014), entitled *Capabilities and Uses of Sensor-Equipped Ocean Vehicles for Subsea and Surface Detection and Tracking of Oil Spills*. The second was prepared by Oceaneering (2015), entitled *Capabilities and Uses of Sensor and Video-Equipped Waterborne Surveillance-ROVs for Subsea Detection and Tracking of Oil Spills*.

In addition, work by the American Petroleum Institute (API) has been reviewed, including:

- API (2013a), *Industry recommended subsea dispersant monitoring plan*; and
- Arthur *et. al.* (2013), *Monitoring hydrocarbon releases in deep water environments: A review of new and emerging technologies* (API Report 13-01).

Information in the US National Response Team guidance on dispersant operations (NRT, 2013) has also been reviewed.

The objective of this GPG is to synthesize and summarize the content of these reports and provide an overview of the strategic and operational application of in-water surveillance. In addition, recommendations are made on incorporating in-water surveillance data and information into the overall situational awareness picture within the Incident Management System (IMS), as part of a 'common operating picture' (COP).

Where relevant, reference is made to other GPGs which have been developed within the Oil Spill Response JIP, including:

- *Incident management system for the oil and gas industry* (IPIECA-IOGP, 2016a);
- *Tiered preparedness and response* (IPIECA-IOGP, 2015a);
- *Dispersants: subsea application* (IPIECA-IOGP, 2015b); and
- *Response strategy development using net environmental benefit analysis (NEBA)* (IPIECA-IOGP, 2015c).

This guide aims to provide stakeholders such as responders, regulators, statutory consultees, industry, NGOs, oil spill response organizations and academia with an overview and guidance on good practice with regard to the fundamental principles of using in-water surveillance. It should be noted, however, that in-water surveillance of oil spills at sea is a fast-moving, technology-based subject for which the definition of good practice will change over time. The recommendations provided in this document should not, therefore, be construed as always being applicable for each situation described, and both the selected technology and most appropriate actions to be taken will ultimately depend on the wider circumstances at the time of a spill.

The guide focuses on sensor-based detection and observation and as such is designed to obviate, to the extent possible, the need for physical diving procedures, which are not covered in this document. If diving is undertaken for any reason, it should be carried out according to established good practice using operating procedures laid down for the specific purpose, in compliance with local regulations, and supervised by qualified personnel.

The IOGP Diving Operations Subcommittee has published material which may provide additional references in this regard.

Introduction

In-water surveillance is of critical importance for the effective monitoring of a subsea release of hydrocarbons. During the Macondo spill in the Gulf of Mexico in 2010, subsea dispersant injection (SSDI) was applied for the first time. This response tool involves adding dispersant directly into the oil plume in the immediate vicinity of the release point, either via a remotely controlled underwater vehicle or by using a fixed injection system associated with a capping stack.

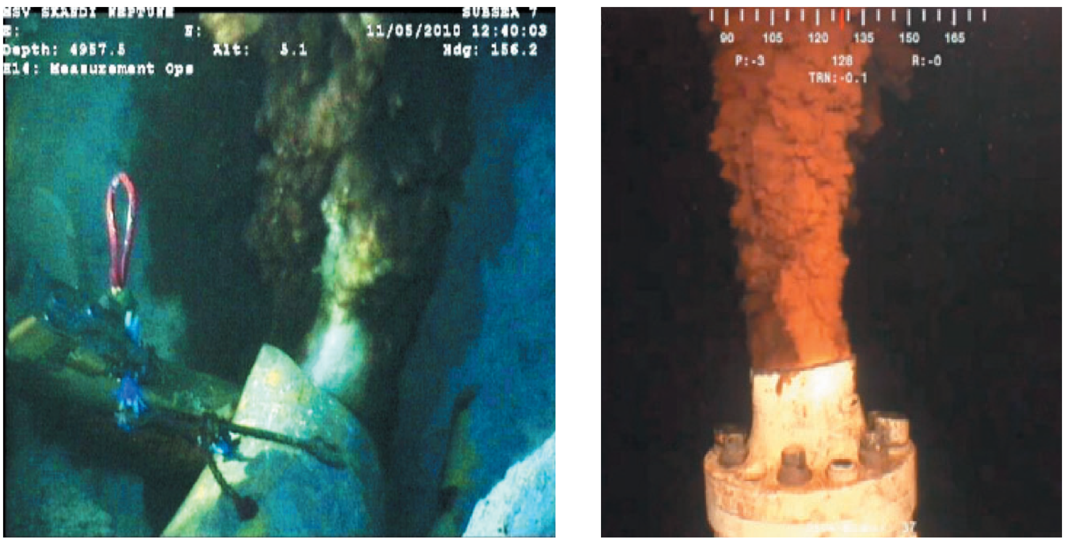
Surveillance of the oil plume, and the dispersant injected into it, are of critical importance for assessing:

- the nature, behaviour and extent of the hydrocarbon plume dispersed into the water column;
- dispersant efficacy;
- potential ecological effects as they relate to operational decision making;
- the flow rate of hydrocarbons released into the water column; and
- the ambient environmental conditions and constituents present.

Surveillance can also help to ascertain whether other possible sources of hydrocarbons, such as those released from natural seeps, might be mistakenly attributed to the accidental release that is being studied.

The rapid deployment of in-water surveillance equipment, and the sustained operational monitoring of hydrocarbons in the water column, are fundamental to the success of SSDI activities. The selection, deployment and operation of appropriate in-water surveillance tools should draw on the principles of net environmental benefit analysis (NEBA), details of which can be found in IPIECA-IOGP, 2015c.

To maximize the usefulness of the data generated by in-water surveillance, it should be incorporated within the common operating picture (COP) of the response operations. Once available in the COP it can be turned into actionable information that can be used by the response team for planning future operations and surveillance activities. The delivery of this information within the required time frame is of critical importance in providing accurate situational



Photos modified from BP video from ROVs

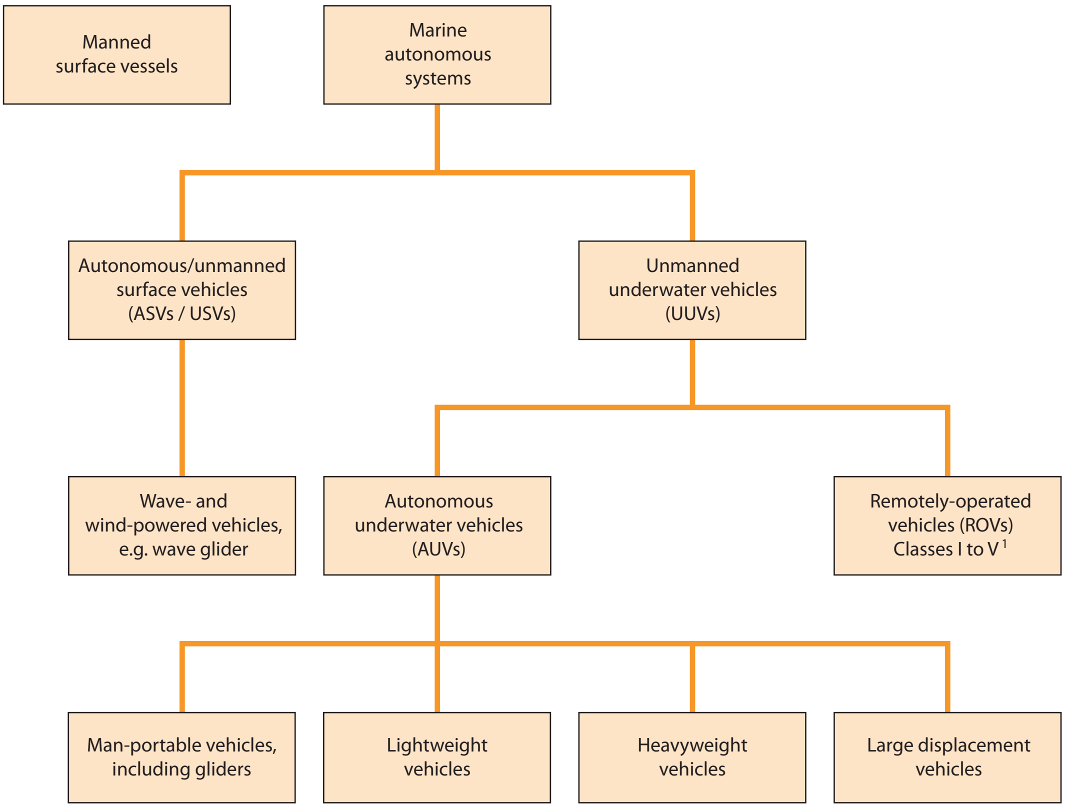
These images, captured using remotely operated vehicles (ROVs), show hydrocarbons (oil and natural gas) escaping from the broken riser tube during the Macondo incident in the Gulf of Mexico in 2010. Surveillance data gathered during the response operation were critical to the success of the mission.

awareness, as well as helping operational planning and communication. It is also invaluable in providing information to validate numerical models of the plume and its trajectory.

In-water surveillance, which for the purposes of this guide includes the use of systems deployed at the sea surface and in the water column, can be performed using a wide range of vehicles and platforms as hosts for the sensing systems. These range from manned surface vessels to autonomous oceanographic vehicles (AOVs) and remotely operated vehicles (ROVs).

A hierarchical schematic of the different classes of oceanographic vehicles is shown in Figure 1.

Figure 1 *Host vehicles and platforms for in-water surveillance*



[1] The term ROV covers a wide range of unmanned submersible equipment and no single vehicle can be described as 'typical' of its classification. The International Marine Contractors Association (IMCA, 2016) has identified the following five vehicle classifications for ROVS:
- Class I—Observation ROVS
- Class II—Observation ROVS with payload option
- Class III—Work-class vehicles
- Class IV—Towed and bottom-crawling vehicles
- Class V— Prototype or development vehicles

Underwater vehicles

Autonomous underwater vehicles

An autonomous underwater vehicle (AUV) is a robotic vehicle that travels underwater without requiring constant input from an operator. AUVs range in size from lightweight, portable devices to large-diameter vehicles over 10 m in length. AUVs can carry a wide range of sensors, including compasses, depth sensors, sidescan sonars, magnetometers, thermistors and conductivity probes, to allow them to navigate autonomously and map features of the ocean.

Table 1 provides information of the sizes of AUVs in the various classifications used in this guide.

Table 1 *AUV classification*

Classification	Diameter (m)	Weight (kg)	Endurance (hrs)	Payload (m^3)
Portable	0.15–0.3	80	< 10–20	0.007
Lightweight	0.3	225	10–40	0.03–0.08
Heavyweight	0.5	1,350	20–80	0.11–0.17
Large displacement	0.55+	up to 9,000	100+	0.4–0.8

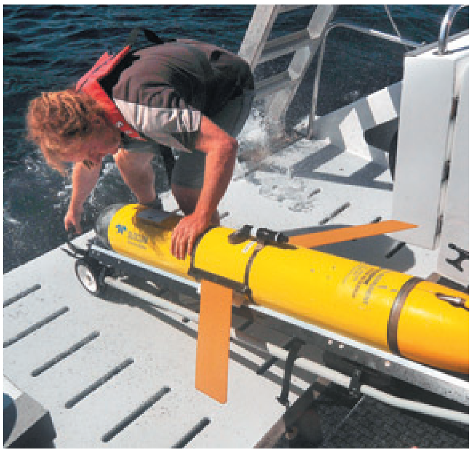
The portable class includes gliders. These use an engine or pump to generate small changes in buoyancy, in conjunction with wings to convert vertical motion to horizontal motion. This is in contrast to most AUVs that use propeller-based systems. Some key characteristics of gliders are:

- they are slower than propeller-based AUVs (0.2 to 0.35 m/s versus 1.5 to 2.5 m/s);
- they benefit from increased endurance and range (hours to weeks or months and potentially thousands of km);
- they follow an up-and-down, saw tooth-like profile;
- while at the surface, they use satellite transmissions for navigation and communication; and
- there is no requirement for a supervising vessel at the surface.

Typically, four basic modes of sampling are used, as follows (adapted from Davis *et al.,* 2002):

- Forward motion can be used to counter ambient currents and maintain the glider's position, allowing it to collect data while gliding back and forth between the sea surface and the seabed in a specific area, effectively acting as a virtual array of vertically moored instruments.
- Moving from place to place yields a highly resolved section, although the slow speed of advance mixes temporal and spatial variability.
- Multiple gliders controlled remotely from a vessel or shore base can form an array to describe the temporal and spatial context for more intensive measurements.
- The long operating durations and ability to carry out dense sampling make gliders suitable for seeking out unusual events (e.g. spill plume boundaries) by constantly modifying the glider path to collect a wide range of useful data (adaptive sampling).

Below: deployment of a portable subsea glider, commonly known as a 'Slocum glider', which uses on-board battery power for communications, sensors and navigational computers.



Suzanne Long/Alamy Stock Photo

AUVs can be operated from a nearby vessel or from the shore, or in many cases can operate completely autonomously. The different modes of operation are summarized in Table 2; a combination of these modes may be used for certain AUV missions to facilitate the required tasks.

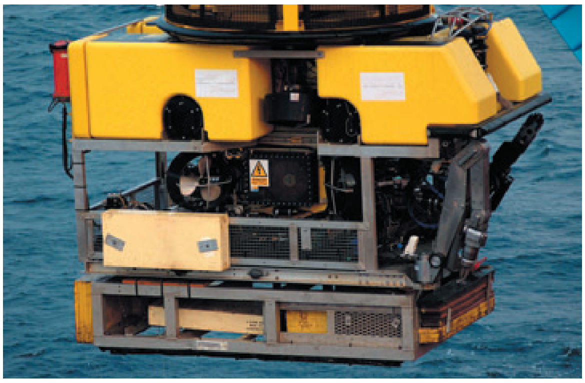
Table 2 *Monitoring options for different types of AUVs*

Type of AUV	Mode of operation
Portable	AUV mission executed with no interaction
Lightweight	AUV in intermittent contact with support vessel which is free to perform other tasks
Heavyweight	AUV in near-continuous contact
Large displacement	AUV uses underwater acoustic positioning for navigation

Remotely-operated vehicles

A remotely-operated vehicle (ROV) is a tethered underwater vehicle. It incorporates a high strength frame, buoyancy material, propulsion systems, power and telemetry systems and a sensor interface which includes electrical, hydraulic and mechanical systems to support the specific requirements of the mission. Five classes of ROV are recognized based on their size, depth capability, power and payload capacity (IMCA, 2016). ROVs are typically powered and controlled from the surface by an operator/pilot via an umbilical.

Examples of two different types of ROVs being launched from an offshore support vessel to collect subsea surveillance data.



Ingvar Tjostheim/Shutterstock.com

Navin Mistry/Shutterstock.com

Surface vehicles and vessels

Both manned and unmanned surface vehicles and vessels are potentially useful in a spill response effort. Manned vessels may include small boats, rigid-hull inflatable boats (RHIBs), fishing and research vessels, and oil supply and support ships. Autonomous surface vehicles (ASVs) cover a range of sizes (masses) from 100 kg or less, up to several thousand kilogrammes. The information in Tables 3, 4 and 5 on the following pages is derived from Battelle's report on the capabilities and uses of sensor-equipped vehicles (Battelle, 2014) which reviews the parameters and status of different types of autonomous surface vehicles. ASVs with masses less than 100 kg are deemed 'small' and can be launched and recovered manually.

Table 3 *Small autonomous vehicle parameters*

	Vehicle parameters									
Manufacturer/platform	**Length (m)**	**Width (m)**	**Weight dry (kg)**	**Max. mission duration (hrs)**	**Available payload power**	**Payload volume (m^3)**	**Payload weight (kg)**	**Power source**	**Mission turnaround time**	**Communications**
CMR Instrumentation Sailbuoy	2		60	1 yr		0.06	10			Iridium
EvoLogics SonoBot	0.45	0.92	30	10 (@2 kts)						WiFi
Robotic Marine Systems Scout	3			8						RF WiFi
Sea Robotics USV-1000 High Speed Timaram	3	1.2	40	12 (@2.4 kts) 6 (@4.37 kts)			80	Ni-MH batteries; Li-polymer batteries operational	In-field battery swaps	2402 MHz Ethernet
Sea Robotics USV-2600 Mission Reconfigurable USV (catamaran)	3.25	1	75–100	8 (@2.4 kts) 3 (@4.37 kts)				Ni-MH batteries; Li-polymer batteries operational	In-field battery swaps	2403 MHz Ethernet
Sea Robotics USV-450 Heavy Payload Catamaran	1.9	1.2	40	8 (@2.4 kts) 2 (@4.37 kts)			80	Ni-MH batteries; Li-polymer batteries operational	In-field battery swaps	2400 MHz Ethernet
Sea Robotics USV-5000 Self Righting Mono-Hull	4.25	0.5	60	12 (@2.4 kts) 6 (@4.37 kts)			50	Ni-MH batteries; Li-polymer batteries operational	In-field battery swaps	2404 MHz Ethernet
Sea Robotics USV-600 Mission Reconfigurable USV	1.25	0.66	15	8 (@2.4 kts) 3 (@4.37 kts)			8	Ni-MH batteries; Li-polymer batteries operational	In-field battery swaps	2401 MHz Ethernet

Table 4 *Large autonomous vehicle parameters*

	Vehicle parameters									
Manufacturer/platform	**Length (m)**	**Width (m)**	**Weight dry (kg)**	**Max. mission duration (hrs)**	**Available payload power**	**Payload volume (m^3)**	**Payload weight (kg)**	**Power source**	**Mission turnaround time**	**Communications**
ASV C-Enduro	4.2		350–500	3 months				Solar and wind		LOS Radio Satellite
SIEL Advanced Sea Systems UAPS 20: RHIB 500	5.05		320	12 continuous			810	4 stroke outboard engine, 60 to 110 Hp		
ASV C-Cat 5	5		650–1,000	diesel genset: 48 Battery alone: 8			500	2 x DC electric motors (3.6 kW each), diesel Genset or direct drive diesel options		UHF S-Band L-Band Xbee Option
ASV C-Hunter	6.3		2,000	50+ (@6 kts) 96+ (@4 kts)			300	1 x Yanmar 3YM30 diesel engine (30 Hp)		UHF up to 8 km or satellite/GSM communication options
ASV C-Worker	5.85		3,500–5,000	720 (@4 kts) 240 (@6 kts)				2 x diesel generator sets 13 kW each		LOS radio satellite
C&C Technologies ASV 6300 Hydrographic Survey Vehicle (semi-submersible)	6.3		2,000	96 (@4 kts) 50+ (@6 kts)			300	30 HP Yanmar diesel engine		
C&C Technologies ASV 9500 Multi Role (semi-submersible)	9.5			720				Diesel engine		
C&C Technologies SASS-Q (semi-submersible)	6						200			

Table 4 Large autonomous vehicle parameters (continued)

	Vehicle parameters									
Manufacturer/platform	**Length (m)**	**Width (m)**	**Weight dry (kg)**	**Max. mission duration (hrs)**	**Available payload power**	**Payload volume (m^3)**	**Payload weight (kg)**	**Power source**	**Mission turnaround time**	**Communications**
ECA Robotics INSPECTOR MK2 Imagery and Bathymetric Survey	8.4		4,700	20 (@6 kts)			1,000	2 x diesel hydro jets (2 x 170 to 215 kw)		
ISE Dorado (semi-submersible)	8.23	2.28	6,600	28		0.6	210	Marine diesel engine	1–2 hours (refuel)	RF Ethernet
Maritime Robotics USV Mariner	5.8	2	1,700	50 (@5 kts)		1		Volvo Penta D3 Engine		VHF/UHF GPRS/Iridium opt.
QinetiQ Blackfish	3.2		470	1			150			VHF/UHF WiFi Iridium
SIEL Advanced Sea Systems UAPS 20: RHIB 750	7.5		850				2,160	4 stroke outboard engine, 110 to 250 Hp		
SIEL Advanced Sea Systems UAPS 20: RHIB 900	8.8		1,500				2,160	4 stroke outboard engine, 500 Hp		
ZyCraft Vigilant	16.5		6,000–13,000	720		18	2,700			

Recent additions to the class of ASVs include the 'AutoNaut' and the 'wave glider'. These are wave-propelled devices that can maintain continuous satellite communication links allowing them to be remotely controlled in real time.

Table 5 *Wave and wind powered ASVs*

	Vehicle parameters									
Manufacturer/ platform	**Length (m)**	**Width (m)**	**Weight dry (kg)**	**Reserve buoyancy**	**Max. mission duration (hrs)**	**Available payload power**	**Payload volume (m^3)**	**Payload weight (kg)**	**Typical cruise speed knots**	**Communications**
Liquid Robotics Wave Glider SV2	Float: 2.1 Glider: 1.9	1.07 (wing)	90	Displacement 150 kg	Up to 1 year	10 W Payload ports (3): 3 A/13.2 V PEP port: 5 A/13.2 V Glider port: 1 A/13.2 V System max. 10 A/13.2 V	0.04	18	0.5–1.6	Iridium Satellite RF modem WiFi
Liquid Robotics Wave Glider SV3	Float: 2.9 Glider: 1.9	1.4 (wing)	90	Displacement 150 kg	Up to 1 year	10 W Payload ports (3): 3 A/13.2 V PEP port: 5 A/13.2 V Glider port: 1 A/13.2 V System max. 10 A/13.2 V	0.09	45	1–2 w/o thruster 1.5–2.3 w/ thruster	Iridium Satellite RF modem WiFi
MOST AutoNaut	3.5			3 months (@2–3 kts)	20 W @ 50% duty cycle for 90 days			Battery: 720 Wh lead gel Solar PV: 125 Wp Generator: 45 watt methanol fuel cell, 20 litres fuel (22 kWh of power)		UHF XBEE PRO Iridium
Saildrone Saildrone	5.8	2.1			5,000 hrs	5–10W		100	5	Satellite

Sensors

Hydrocarbons present in seawater may take the form of a multiphase mix consisting of liquid, dissolved, gaseous or solid phases. The liquid phase contains significant amounts of polycyclic aromatic hydrocarbons (PAH) whereas the gaseous phase consists mostly of lighter alkanes such as methane.

Hydrocarbons can be detected directly using suitable sensors to measure gaseous and dissolved methane and PAH. They can also be detected indirectly by measuring an associated anomaly in the environmental baseline, e.g. changes in temperature, salinity and other parameters. Certain sensing systems can also monitor the flow of fluids underwater. Such systems are immersed in the water and rely on contact or very close proximity to the hydrocarbons.

Both direct and indirect detection systems are discussed below. It should be noted that, while direct systems may provide more timely information for the response, indirect systems can provide, with some latency, suitable samples with which to calibrate and validate other detection methods and models.

Direct detection systems

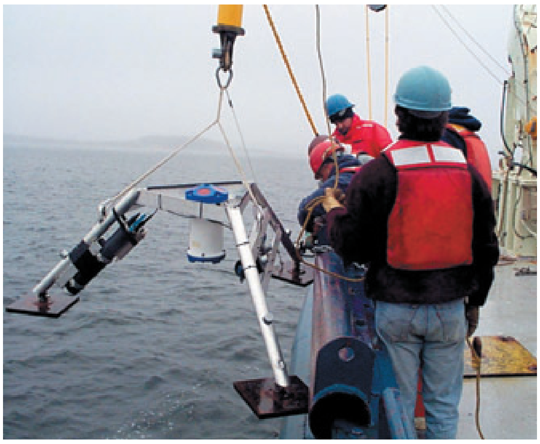
Direct hydrocarbon detection systems employ one or more of the following methods:

- Non-dispersive infrared (NDIR) spectrometry measurement of methane (CH_4), using a high precision optical analysing NDIR system.
- Fluorometric measurement of PAH using a fluorometer to measure the intensity and wavelength distribution of the emission spectrum after excitation by a known spectrum of light.
- Fluorometric measurement of refined and crude hydrocarbons using a chromophoric dissolved organic matter (CDOM) fluorometer to measure the concentration of refined hydrocarbons (360 nm) or crude hydrocarbons (440 nm).
- In-situ measurement of particle size distribution using a laser in-situ scattering and transmissometry (LISST) instrument or other particle sizing instrument.
- Use of acoustic doppler current profilers (ADCPs) which measure the speed at which water is moving across the water column.
- Use of in-water communication and geospatial data acquisition technology.
- Use of subsea camera/video technology, including the recently-developed SINTEF silhouette camera (SilCam), to characterize dispersed hydrocarbons in the water column.

Many of these sensors can be configured for either pumped or open flow-through deployment, with the sensor deployed on the host vehicle such that it is exposed to the water column.

Below: (upper) deployment of the LISST-100X submersible laser sensor; (lower) deployment of an acoustic doppler current profiler (ADCP) mounted on a tripod system.

Sequoia Scientific



Woods Hole Oceanographic Institution

Indirect detection systems

Indirect hydrocarbon detection systems rely on the identification of changes in the properties of the baseline local seawater environment that may potentially be due to the presence of hydrocarbons. Indirect detection techniques include measurement and analysis of the following properties:

- Conductivity, temperature, depth (CTD): separate sensors monitor the individual parameters. Salinity is derived from conductivity, and depth from hydrostatic pressure measurements.
- Turbidity: measured using optical light scattering.
- Dissolved oxygen concentration: measurement may be carried out using electrodes, electrochemical sensors or optodes (optical sensors).
- Dissolved CO_2 concentration: measured using NDIR spectrometry.

Flow characterization sensors provide the capability to monitor the flow of water, and often the entrained constituents in the flow. Such information can be used to support decisions on the use and potential effectiveness of subsea dispersant injection techniques. The parameters of interest are:

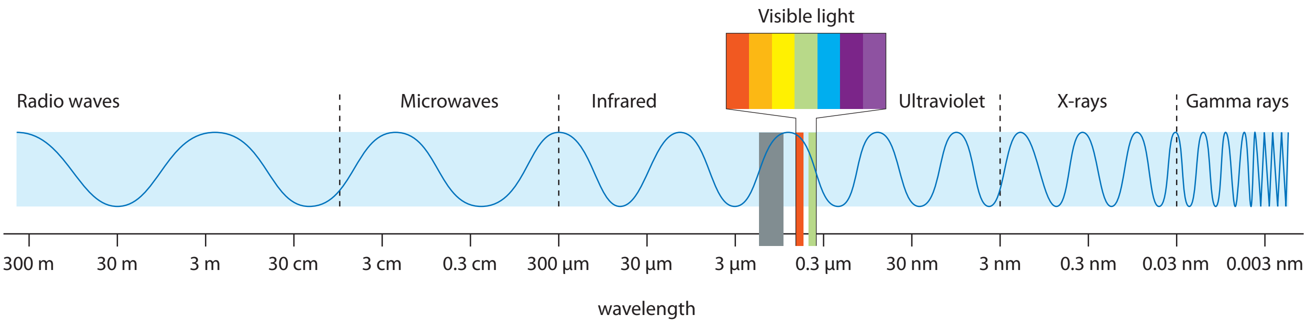
- total volume flow;
- flow composition;
- particle size; and
- particle density.

To determine total flow volume, both macro- and micro-area sensors are required. Macro-area sensors, such as high-resolution forward looking sonar and parallel laser systems, measure the total size of the flow stream at the point of interest. Micro-area sensors provide specific details related to the dimensions and quantities of suspended particles in the water column. Both underwater microscopy and optical light diffraction systems are in use.

Surface-deployed sensing systems

In addition to the immersed sensing systems discussed above, a range of surface-deployed sensing systems are available which can remotely detect the presence of hydrocarbons on, or near, the sea surface. Such systems are normally deployed from manned and unmanned surface vehicles. Four main types of technology are used, classified according to the part of the electromagnetic spectrum from which the sensing is performed. Figure 2 (below) shows the electromagnetic spectrum.

Figure 2 *The electromagnetic spectrum*



Sensing systems are either 'passive' or 'active'. Passive systems detect radiation emitted by the target whereas active systems emit their own energy and measure the signal that is reflected back from the target.

Table 6 *Sensors and the electromagnetic spectrum*

Sensor type	Active/ passive	Wavelength	What does it measure?	Typical sensor systems
Ultraviolet	Passive	100–400 nm	Reflected sunlight	UV cameras and line scanners
Visible	Passive	400–700 nm	Reflected sunlight	Still and video cameras
Infrared	Passive	0.74–14.0 µm	Naturally emitted radiation and surface temperature	Thermal imaging cameras and scanners
Radar	Active	2.5–3.75 cm	Radar backscatter	Marine (X-band) radar

A wide variety of surface sensing systems are available. These range from the human eye, supported with binoculars to assist response personnel in detecting surface sheens, through to complex radar-based systems.

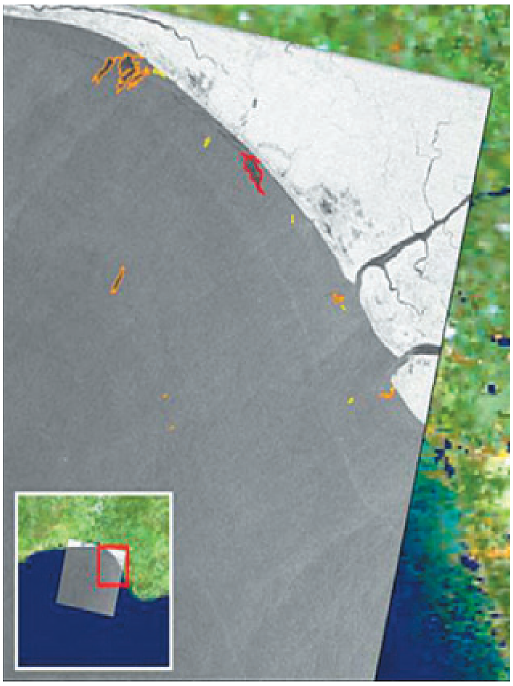
Detailed descriptions of these surface-deployed sensing systems and the vehicles used to deploy them can be found in API's review of new and emerging technologies (Arthur *et al.*, 2013), and the Oil Spill Response JIP reports by Battelle (2014) and Oceaneering (2015).

SMART protocols

During the late 1990s, representatives from a number of US health and environmental agencies collaborated to produce the Special Monitoring of Applied Response Technologies (SMART) protocol (NOAA, 2006). SMART provides guidance on establishing a monitoring system for rapid collection and reporting of real-time, scientifically-based information to assist responders with decision making during controlled in-situ burning and/or dispersant operations.

When hydrocarbons are present at the surface, a wider range of surveillance technologies are available, including aerial and satellite systems. However, the in-water surveillance technologies covered in this GPG are also important for assessing and monitoring hydrocarbons on the sea surface. The use of unmanned surface vehicles has the potential to provide significant safety and cost benefits, when compared to manned systems, by removing or minimizing the exposure of human responders to the potential harmful effects of volatile organic compounds (VOCs) from the spilled hydrocarbons. This is the case for dispersants applied subsea and at the surface, and particularly for dispersants applied from aerial platforms such as helicopters and aircraft. As noted by the American Petroleum Institute (API, 2013a), the surface application of dispersant has utilized the tiered SMART protocol for dispersant effectiveness monitoring. When using SMART protocols, monitoring begins with visual observations to determine dispersant efficacy, and decisions to escalate to higher tiers of the monitoring plan are based on operational needs and the time available to implement additional monitoring systems, including in-water surveillance.

SMART provides guidance on establishing a monitoring system including all types of surveillance—i.e. satellite (near right), aerial (far right) and in-water techniques—for rapid collection and reporting of real-time, scientifically-based information to assist response personnel with the oil spill response operation.



MacDonald Dettwiler and Associates

OSRL

As noted in the introduction to this GPG, in-water surveillance is a critically important, technology-driven approach to monitoring the subsea release of hydrocarbons. It enables the collection of suitable water samples that are required to assess the efficacy of dispersant application in subsea releases, and to monitor the flow rate of hydrocarbons released into the water column.

Surveillance (including all types—i.e. satellite, aerial and in-water) is crucial to providing effective support to the response team and other stakeholders during a response operation. It provides an understanding of the pollution situation, enables an assessment of response actions under way and facilitates the planning of future response activities. Surveillance, together with appropriate predictive modelling, reporting, display and documentation of the data and information gathered, is recognized as being a vital tool for enabling 'situational awareness', i.e. the knowledge of what is taking place during the spill (see Box 1 on page 18).

The use of in-water and surface surveillance for oil spills

The use of surveillance during an oil spill response can serve a range of purposes. In particular, those responsible for organizing the response operations can use surveillance to enhance their situational awareness of the spill. In addition, the outputs from surveillance—including imagery and video, maps, spreadsheets and calculations—can be used for planning operations, monitoring and assessing the impact of recovery methods, validating and calibrating numerical models of the spill, and as a communication tool for briefing external parties, such as the media and the public. Furthermore, real-time surveillance can provide tactical support during a response, e.g. by using aircraft to 'spot' oil slicks and direct the dispersant application vessels to the appropriate area.

Surveillance information that has been recorded and documented can be used post-spill for a variety of other purposes, e.g. providing support for training courses and exercises, and for educational and academic reference. The information may be critical to addressing any legal issues and regulatory requirements that have arisen from the spill.

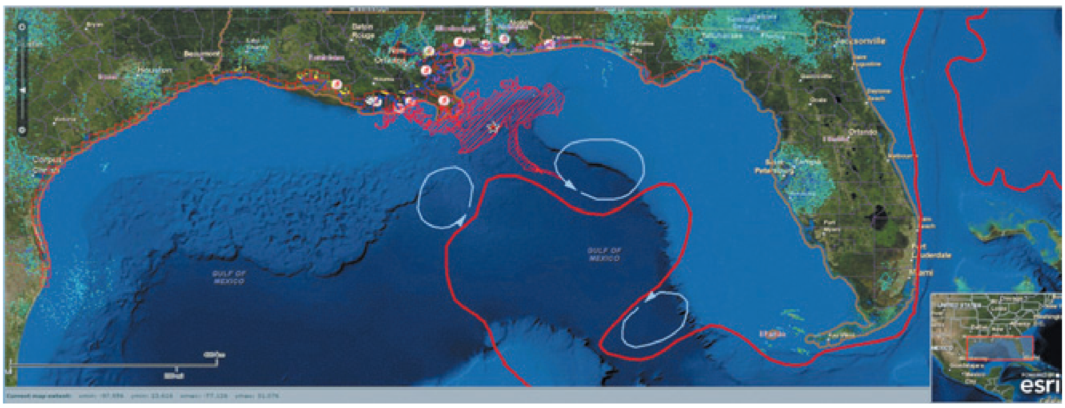
In addition to being used during oil spill response operations, surveillance can also be used as a preparedness measure to monitor areas at potential risk from oil spills (e.g. areas near installations, shipping routes, pipelines) on a routine or even a continuous basis.

The role of surveillance during an oil spill response

Surveillance is an essential part of the oil spill response toolkit, and provides valuable information on the evolving scenario during a response operation. Oil spill surveillance should provide the response team with:

- an initial detection (or confirmation) and assessment (characterization and quantification) of an oil spill *within a specified time frame*;
- ongoing assessment and synoptic monitoring of an oil spill **and** the response operations *at regular intervals;* and
- tactical support (constant visual monitoring) for operations and missions *at the required time and location.*

The delivery of information within the required time frame is critical for ensuring an adequate level of situational awareness, as well as helping with operational planning and communication.



Waypoint Mapping/Esri

Surveillance data gathered during a response operation is fed into the GIS-based common operating picture (see page 42) to ensure that all stakeholders are operating from a common situational awareness standpoint.

Box 1 *What is situational awareness?*

Situational awareness is 'knowing what is going on around you'. For an oil spill response, situational awareness requires a holistic yet comprehensive understanding of the spill scenario; this is achieved by identifying, processing and comprehending critical elements of the information provided. Obtaining the right types of information, and ensuring that all information is correct and up to date is thus intrinsic to gaining an accurate situational awareness of an oil spill. Table 7 (below) details the key types of information and its data that are required to provide situational awareness for an oil spill.

How does surveillance contribute to situational awareness?

Surveillance is used primarily to detect, characterize and preferably quantify spilled oil that may be present in on-water, in-water and onshore settings. Furthermore, surveillance can be used to gather information on the environment surrounding the oil spill. Surveillance can therefore provide much of the key information needed to inform the response about the evolving spill scenario, such as the locations of spilled oil (absolute and relative), estimates of the quantity of spilled oil, characterization of the oil, and even information on the operating conditions (weather forecasts, local terrain or hydrography, environmental sensitivities)—all of which are of critical importance for situational awareness.

Table 7 *Information required for situational awareness*

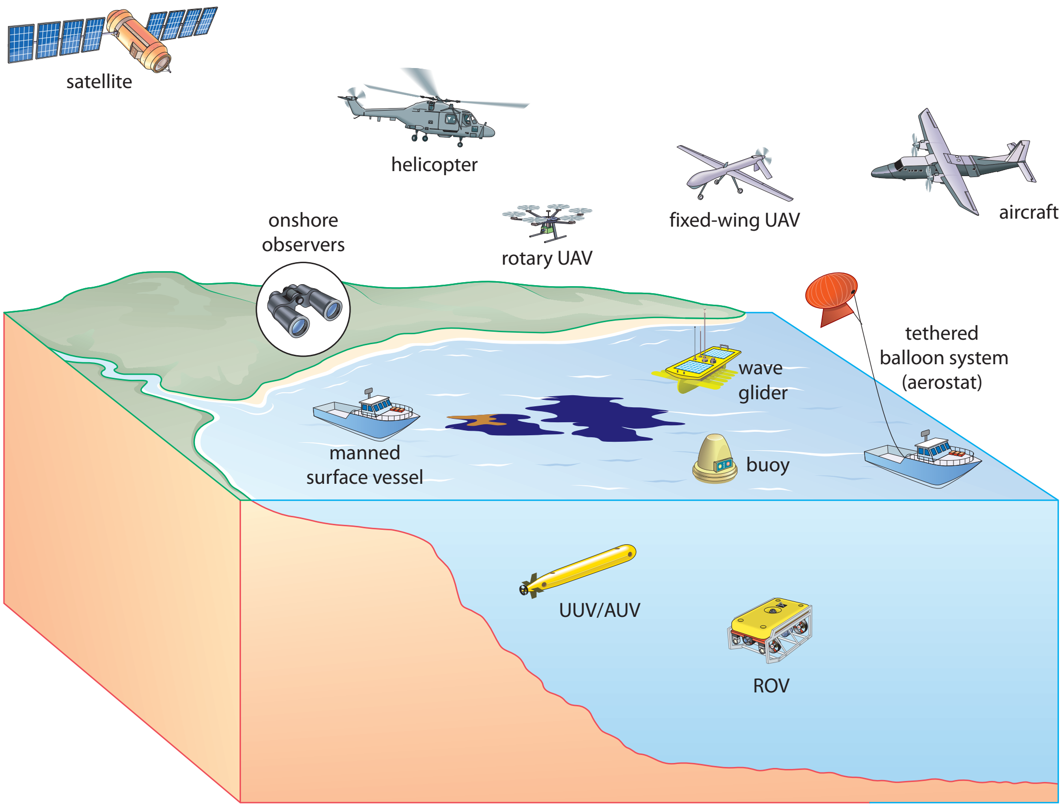
Type of information	Examples
Oil spill measurements and characteristics	• Geographical location of the oil spill and individual slicks • Extent of the oil spill • The number of slicks • Quantity of oil spilled (estimate) • Type of oil spilled
Location of the oil spill	• Physical location (on-water, in-water, onshore, inland) • Associated physical characteristics (ocean currents, surface type, ice coverage) • Environmental sensitivities in the area (mangroves, nesting areas)
Operating conditions	• Weather conditions • Associated physical characteristics that could impede operations
Socio-economic factors	• Areas of habitation/urbanization nearby • Economic vulnerabilities (fishing zones, farmland)
Political factors	• Stakeholders involved in the response (i.e. who is responsible for what) • Regulations and laws that may affect response operations • Boundaries/zones involved if response is multinational
Ongoing operations	• Response operations and methods in progress and planned • Location of resources and assets, and number deployed
Response impact	• The amount or percentage of oil recovered • The mitigations in place to prevent further spills (if necessary) • The amount of shoreline, land, etc. cleaned

The tools and approaches used for surveillance during a response

To ensure that the most appropriate information is provided efficiently during a response, an oil spill surveillance and monitoring programme should be put in place that uses a variety of surveillance approaches and tools to gather the information needed and support the ongoing response (Figure 3). Surveillance tools include:

- unmanned underwater vehicles (UUVs), including autonomous underwater vehicles (AUVs) (e.g. gliders) and remotely operated vehicles (ROVs);
- unmanned surface vessels (USVs), including autonomous surface vehicles (ASVs) (e.g. AutoNaut and wave gliders);
- surface vessels (using techniques including optical and radar, photography and video, and human eye);
- buoys, trackers and mounted systems (e.g. instruments mounted on rigs or moored independently);
- onshore observers (using human eye, photography and video);
- aerial platforms such as fixed-wing aircraft and helicopters (using techniques including human eye, optical and radar surveillance, photography and video);
- unmanned aerial vehicles (UAVs—using optical and radar techniques);
- tethered balloon systems (i.e. aerostats, using optical and infrared techniques); and
- satellites (using optical, infrared and radar techniques).

Figure 3 *Examples of surveillance tools that may be used in a response operation*



Each tool has its advantages and limitations when used to gather information for an oil spill response; these characteristics are outlined in the API report on remote sensing (API, 2013b). For information on surveillance tools other than in-water surveillance technologies see IPIECA-IMO-IOGP, 2015 and IPIECA-IOGP, 2016b.

The advantages and disadvantages of in-water surveillance technologies need to be considered in conjunction with the oil spill scenario, as a variety of different factors may affect the overall suitability of a particular tool. Factors that may need to be taken into account include:

- the size of the spill (and predicted duration);
- the location of the spill (both geographical position and type, e.g. offshore, inland);
- the environmental conditions;
- the operating conditions;
- the type of oil spilt and its behaviour during weathering (e.g. tendency to spread);
- logistical issues (e.g. access to deploy the technology);
- regulatory and political constraints (including control and regulation of airspace and the ocean, and local governance of technology);
- the type of response operations;
- when the information will be needed; and
- the ease of integrating and organizing different sources and types of information.

As an example, a localized small spill may only require human observers, while poor weather conditions could prevent aircraft from being deployed. In general, to gather all the information required, a surveillance programme should utilize a combination of the surveillance tools that are appropriate for the response.

As an incident progresses, the demands on a surveillance programme will generally increase, and the programme often divides into strategic (situational awareness, operations planning and impact monitoring) and tactical (supporting operations) roles. Any tool used should be capable of meeting at least one of these roles and their requirements.

In general, to gather all the information required, a surveillance programme should utilize a combination of the surveillance tools that are appropriate for the response.

Andrej Polivanov/Shutterstock.com

As noted in the introduction to this GPG, in-water surveillance is of critical importance for monitoring the subsea release of hydrocarbons, characterizing the nature and extent of subsea dispersed oil plumes, and determining the efficacy of dispersant operations. Such monitoring activities support the decision making process concerning dispersant application, and will inform decisions on whether to continue applying dispersant to a release and when it would be appropriate to cease the dispersant operation. Much was learned on such topics during the Macondo incident in 2010, and later sections of this guide include recommendations based on findings developed during and since that event. These recommendations have been incorporated into other industry guidance documents including API Report 1152 on subsea dispersant monitoring (API, 2013a) and the IPIECA-IOGP Good Practice Guide on subsea dispersant application (IPIECA-IOGP, 2015b).

Measuring the effectiveness of an oil spill response surveillance programme

The overall effectiveness of the surveillance programme will be most visible within the response's common operating picture (COP). The COP is a shared view of the incident and its operating conditions, and has been defined as '*a computing platform based on geographic information system (GIS) technology, which provides a single source of data and information for situational awareness, coordination, communication and data archival to support emergency management and response personnel and other stakeholders involved in, or affected by, an incident*' (IPIECA-IOGP, 2015d). The COP is used to support strategic and tactical decision making within the Incident Management System (IMS) used to manage the response.

The COP allows response personnel and other stakeholders to view any data and information generated within the response, including surveillance data. Much of the information in the COP is static and therefore can be developed and pre-populated during the response planning phase for the location in question. If any surveillance-relevant information required by users is 'missing' from the COP, the surveillance programme will need to be improved and updated to ensure that this need is met. Detailed guidance on the elements that should be included in the COP can be found in IPIECA-IOGP, 2015d.

In the ongoing advancement of oil spill response strategies, technologies and practices, the COP and its incorporation into an IMS as described above is a relatively recent development, and there remains no widespread agreement on its place in the IMS hierarchy or even whether it should inevitably form part of the IMS structure in every case (for example in small-scale responses). Wherever the COP is placed, it must nonetheless define accountability for the operation of the surveillance function to ensure that the surveillance programme is capable of accurately answering key operational questions (e.g. on the condition, fate and behaviour of oil) on a timeline that is meaningful for the response decision makers.

Determining the appropriate technologies

Selection of the in-water surveillance platforms and vessels required to host the sensing systems will depend on the nature of the spill. Where the spill is confined to the surface, conventional manned and unmanned surface vessels and vehicles may be sufficient. Where spills have both surface and subsurface impacts it is recommended that a mix of surface and subsea vehicles are deployed for spill detection and tracking. The selection is likely to vary as the spill scenario develops and the oil propagates and spreads.

Selecting and prioritizing the appropriate sensing technologies requires an understanding and knowledge of the hydrocarbons involved. Different oils have different physical, chemical and weathering characteristics, and the prioritization of sensing technologies will therefore vary for gaseous hydrocarbons versus liquid hydrocarbons, crude oil versus refined products, waxy crude versus asphaltene crude, etc.

Surface vessels

A wide range of surface vessels is potentially available to support a response. Features that should be taken into account when considering whether a particular vessel is suitable for deploying surveillance technologies include:

- vessel size (i.e. can the vessel support the size, weight and power requirements of the selected sensing system(s));
- vessel range and duration;
- operability in the response area, given the prevailing and forecast weather and sea conditions;
- personnel capacity (for manned vessels)—i.e. for crew and responders;
- sensor deployment height—higher elevations increase sensing range and projected areal coverage; this could be on the bridge, a mast, A-frame, boom or crane;
- communications technology (cell and/or satellite) available to provide real-time information to the COP via the Internet; and
- vessel availability, whether on contract or spot hired, or made available through a pre-agreed reciprocal arrangement with another operator.

Alan Smillie/Shutterstock.com

Michael Grant Travel/Alamy Stock Photo

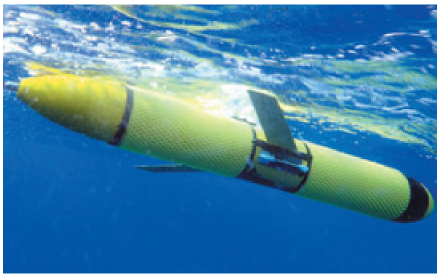
Autonomous oceanographic vehicles (AOVs)

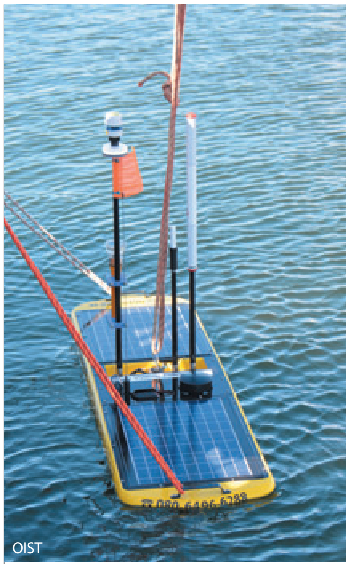
When considering AOVs of any type it should be borne in mind that not all currently available commercial systems have a proven track record of successful deployment in oil spill response exercises and operations. Some units are produced as research systems only and may not be manufactured in sufficient quantities to provide a commercially available resource, while others are only applicable for military operations. However, a number of new vessels are now available which have a variety of different capability packages and could therefore meet the requirements for surveillance of oil spills.

Vehicle compatibility considerations that should be borne in mind include the following (adapted from Battelle, 2014):

- In most locations manned surface vehicles are likely to be readily available, while deployment of AOVs to the incident area will likely require several days or longer.
- Larger AOVs become more desirable for extended missions as the spill duration increases, and as spills get deeper and farther from the shore.
- Portable AOVs become less useful in deeper water due to limited operational duration, depth and manoeuvrability.
- AOVs are generally preferred over manned vessels as they reduce the risks of personnel being exposed to hazards during a spill response operation.
- Gliders have limited on-board power and therefore may not be able to operate active sensors continuously.
- Gliders are 'release-and-forget' vehicles that are likely to be useful for monitoring spill boundaries and extents, particularly with adaptive sampling and control systems in place.
- Gliders may have a minimum operating water depth.
- ASVs using wind and wave power are designed as open water vehicles and are therefore less likely to be useful close to the shore.
- Small ASVs can operate in protected bodies of water such as ports and harbours but are not designed for open seas.
- ASVs, such as wave gliders, are more useful than AUVs when the majority of the spill is at, or near, the water surface.
- AUVs are not practical or economical close to the shore where the water is shallow and a range of surface vessels are likely to be readily available.


Free Wind 2014/Shutterstock.com


NOAA

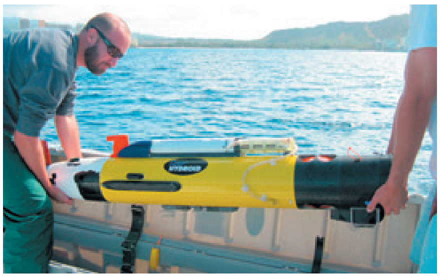

OIST

Examples of different types of AOVs (clockwise from top left): recovery of a lightweight portable glider; wave glider being deployed from a support vessel; and an underwater glider close to the surface.

Sensor systems and compatibility with the range of sensing platforms

As hydrocarbons in the water column exist as a multiphase mix, reliable detection usually requires a combination of direct and indirect sensing methods. Direct methods benefit from the fact that the oil phase contains significant amounts of PAH, whereas the gas phase contains mainly methane. Indirect methods focus on determining appropriate parameters in the environmental baseline and detecting anomalies.

Typical oceanographic parameters monitored in the water column are water temperature, dissolved oxygen (DO), pH, salinity and turbidity. Establishing a baseline set of oceanographic conditions is important as this can then be used to detect potential changes in the water column which may be related to the presence of oil plumes. Measurements of DO are particularly important as levels of


UHM/SOEST

Example of an AUV equipped with sensors that measure salinity, temperature, currents, bathymetry and water quality.


MBARI

A water sampling system installed in the mid-body of an AUV.

oxygen below reference or baseline levels may indicate the presence of polluting substances (e.g. hydrocarbons) that are being biodegraded by microbial organisms in the water column.

Multiple detection methods can cover a broad range of hydrocarbon phases and reduce the potential for false positives from a single method. An example would be to employ a DO sensor and a CTD probe to indirectly detect oil in the water column. Such monitoring will also assist the response team in determining the fate and transport of any subsea plume over the course of the release. This in turn allows the effectiveness of dispersant application to be monitored, and provides information to assess potential environmental impacts.

Consideration should be given to including an acoustic method to also monitor the true flow velocity.

Details of the compatibility of different types of AOVs with the available hydrocarbon sensing systems is presented in the form of a series of matrices in Battelle, 2014. An example of one such matrix is shown in Table 8 on page 25 of this Good Practice Guide.

The API review of sensing technologies (Arthur *et al.,* 2013) contains a summary of the monitoring capabilities of current, new and emerging technologies.

Logistical and deployment considerations

Weather and other conditions (e.g. maritime regulations) may limit the operation of more traditional, vessel-based surveillance technologies, depending on a number of factors including:
- the size of the vessel;
- the type of vessel required for operations; and
- whether a dedicated launch and recovery system (LARS) is required.

Portable USVs and AUVs can be transported by most vehicles and can be deployed from the shore but are normally deployed by a small number of personnel in inflatable boats or RHIBs. Deployment from small boats will be highly dependent on the sea state. These technologies will need to be appropriately packaged using ruggedized field cases, which can often incorporate additional operational items such as PCs, removable storage media, power/data cables and spares. Details of a range of different types of AUVs are presented in Battelle, 2014.

Table 8 *Glider AUV and direct detection sensor compatibility matrix*

1 Sensor is not expected to be compatible.
2 Sensor is compatible but may require external mounting; or sensor is expected to consume almost all of the available payload volume.
3 Sensor fits readily and allows for additional payloads to be carried.
NR = Not rated.

	Direct detection																					
Vehicle	ASD Sensortechnik BackScat 1	Bowtech Leak Detection System	Chelsea Technologies Subsea Pipeline Leak Detection	Chelsea Technologies UniLux Fluorometer	Chelsea Technologies UV AquaTrack Fluorometer	Contros HydroC CH_4 Hydrocarbon and methane	Contros HydroC PAH Fluorometer sensor	Contros Mobile Leak Detection System	Hach FP 360 SC Oil-in-Water Sensor	Neptune Oceanographic SNIFFIT	Ocean Tools OceanSENSE Leak Detection	Phaze Hydrocarbon Leak Detector	Sea & Sun Technology UV Fluorometer	Seapoint UV Fluorometer	Smart Light Devices LDS3 Laser Leak Detection System	Sonardyne Automatic Leak Detection Sonar (ALDS)	Teledyne TSS MELDS System	TriOS enviroFlu-DS	TriOS enviroFlu-HC	Turner Designs C3 Submersible Fluorometer	Turner Designs Cyclops 6K customizable	Turner Designs Cyclops 7 customizable	Weatherford BigEars Passive Acoustic Leak Detection System
ACSA SeaExplorer	NR	1	1	3	1	1	2	1	2	NR	1	NR	2	2	1	NR	NR	1	2	1	2	2	NR
Bluefin Robotics Spray Glider	NR	2	1	3	2	2	2	1	2	NR	2	NR	2	2	2	NR	NR	2	2	2	3	3	NR
Exocetus Costal Glider	NR	3	2	3	3	3	3	3	3	NR	3	NR	3	3	3	NR	NR	3	3	3	3	3	NR
Kongsberg 1KA Seaglider	NR	1	1	3	1	1	2	1	2	NR	1	NR	2	2	1	NR	NR	1	2	1	2	2	NR
Teledyne Webb Research Slocum Thermal Glider	NR	1	1	3	1	1	2	1	2	NR	1	NR	2	2	1	NR	NR	1	2	1	2	2	NR
Teledyne Webb Research G2 Slocum Glider	NR	1	1	3	1	1	2	1	2	NR	1	NR	2	2	1	NR	NR	1	2	1	2	2	NR
Teledyne Webb Research Slocum Electric Glider (aka Battery Glider)	NR	1	1	3	1	1	2	1	2	NR	1	NR	2	2	1	NR	NR	1	2	1	2	2	NR

Both lightweight and heavyweight AUVs (sometimes referred to as LWVs and HWVs, respectively) are typically launched using an A-frame or boom-style crane system, a launch and recovery ramp, or a specialized launch and recovery system developed specifically for a particular type of AUV. Normal recovery operations consist of the AUV swimming or drifting at the surface. AUVs typically have lifting points to which recovery straps can be attached, and/or a nose recovery bail to which a hook system, deployed from a crane or davit, can be attached. This method requires both dexterity with equipment and sufficient available manpower. Because many of these operations require personnel to be in close proximity to the AUV, relatively calm sea conditions are required for safe launch and recovery operations. Some systems allow the attachment of the recovery system by a long (approx. 10 m) carbon fibre pole.

Most AUVs can also use a dedicated LARS that eliminates the close proximity 'pole hooking' approach. When launching an AUV, the vehicle is released from the recovery cradle and slides down (tail first) into the water. The AUV releases the recovery line and float (from the nose) on command, which are then captured by the crew using a grapple. Such techniques are proven in open ocean operation.

USVs are typically launched either from a slipway in an adjacent port, after which they self deploy to the operational area, or from a support vessel using a davit/crane or A-frame in a similar manner to AUVs. USVs have lifting points, usually fore and aft (lightweight vessels may have just a single lifting point). Weather constraints on the use of USVs are currently similar to those for AUVs. Attachment of the recovery system also mirrors that of AUVs although USVs are much more controllable, using a local control mode, when alongside a support ship.

Recommendations for different spill scenarios

Tables 9 to 14 provide priority recommendations for sensor and vehicle combinations to be used in each of the following five spill scenarios:

1. Release at a coastal terminal—small spill at the surface.
2. Oil tanker in transit offshore—medium spill 25 km offshore at 10 m depth.
3. Offshore platform release—small spill 50 km offshore at the surface, and at 300 m depth.
4. Offshore pipeline rupture—small spill 50 km offshore at 50 m depth for 5 days.
5. Deepwater well blowout—extensive spill 100 km offshore at 2,000 m depth.

The compatibility scoring is rated on the following point scale:

3 = High priority combination of vehicle and sensor for this scenario.
2 = Medium priority combination of vehicle and sensor for this scenario.
1 = Low priority combination of vehicle and sensor for this scenario.
- = Vehicle and sensor combination incompatible.

Ratings containing an asterisk (*) indicate that the sensors and vehicles are compatible but are not likely to be available without further investment for integration and software/algorithm development.

Tables 9 to 14 are adapted from Battelle, 2014.

Table 9 *Sensor/vehicle recommendations for a release at a coastal terminal—small spill at the surface*

Scenario 2: Release at a coastal terminal										
Sensor group	Sensor	Subsurface vehicles				Surface vehicles				
		AUV Classes			Glider	ASV Classes			Manned vessels	
		Man-portable AUV	LW/HW AUV	Large displacement AUV		Wave-/wind-powered ASV	Small ASV	Large ASV	Vessel of opportunity	Large vessel
Subsea direct sensors	Fluorometer	1*	1*	1*	1*	1*	2	2	2	2
	NDIR (CH_4)	1*	1*	1*	1*	1*	1	1	1	1
Subsea indirect sensors	CTD	1	1	1	1	1	2	2	2	2
	DO (electro-chemical)	1	1	1	1	1	1	1	1	1
	DO (optical)	1	1	1	1	1	2	2	2	2
	NDIR (CO_2)	1	1	1	1	1	1	1	1	1
	Turbidity meter	1	1	1	1	1	2	2	2	2
Surface vessel sensors	Fluorescence LiDAR	-	-	-	-	-	-	-	-	1*
	Radar	-	-	-	-	-	-	1	2	2
	Thermal IR imagers	-	-	-	-	-	2	2	3	3
	UV imagers	-	-	-	-	-	1	1	2	2
	Visible light imagers	-	-	-	-	-	2	2	3	3

Spill = Light sweet crude. Priority: 3 = high, 2 = medium, 1 = low, – = Incompatible.
*Technology exists but resources are required for integration and software/algorithm development.

Table 10 *Sensor/vehicle recommendations for an oil tanker in transit offshore—medium spill, 25 km offshore at 10 m depth*

Scenario 3: Oil tanker in transit offshore										
Sensor group	Sensor	Subsurface vehicles				Surface vehicles				
		AUV Classes			Glider	ASV Classes			Manned vessels	
		Man-portable AUV	LW/HW AUV	Large displacement AUV		Wave-/wind-powered ASV	Small ASV	Large ASV	Vessel of opportunity	Large vessel
Subsea direct sensors	Fluorometer	1*	2*	1*	1*	3*	1	3	3	3
	NDIR (CH_4)	1*	1*	1*	1*	1*	1	1	1	1
Subsea indirect sensors	CTD	1	2	1	1	3	1	3	3	3
	DO (electro-chemical)	1	1	1	1	1	1	1	1	1
	DO (optical)	1	2	1	1	3	1	3	3	3
	NDIR (CO_2)	1	1	1	1	1	1	1	1	1
	Turbidity meter	1	2	1	1	3	1	3	3	3
Surface vessel sensors	Fluorescence LiDAR	-	-	-	-	-	-	-	-	2*
	Radar	-	-	-	-	-	-	3	3	3
	Thermal IR imagers	-	-	-	-	-	1	3	3	3
	UV imagers	-	-	-	-	-	1	2	2	2
	Visible light imagers	-	-	-	-	-	1	3	3	3

Spill = Light sweet crude. Priority: 3 = high, 2 = medium, 1 = low, – = Incompatible.
*Technology exists but resources are required for integration and software/algorithm development.

Table 11 *Sensor/vehicle recommendations for an offshore platform—small spill, 50 km offshore at 0 m depth*

Scenario 4a: Offshore platform (0 m depth)										
		Subsurface vehicles				Surface vehicles				
		AUV Classes				ASV Classes			Manned vessels	
Sensor group	**Sensor**	**Man-portable AUV**	**LW/HW AUV**	**Large displacement AUV**	**Glider**	**Wave-/wind-powered ASV**	**Small ASV**	**Large ASV**	**Vessel of opportunity**	**Large vessel**
Subsea direct sensors	Fluorometer	1*	1*	1*	1*	2*	1	2	2	2
	NDIR (CH_4)	1*	1*	1*	1*	1*	1	1	1	1
Subsea indirect sensors	CTD	1	1	1	1	2	1	2	2	2
	DO (electro-chemical)	1	1	1	1	1	1	1	1	1
	DO (optical)	1	1	1	1	2	1	2	2	2
	NDIR (CO_2)	1	1	1	1	1	1	1	1	1
	Turbidity meter	1	1	1	1	2	1	2	2	2
Surface vessel sensors	Fluorescence LiDAR	-	-	-	-	-	-	-	-	1*
	Radar	-	-	-	-	-	-	3	2	3
	Thermal IR imagers	-	-	-	-	-	1	3	2	3
	UV imagers	-	-	-	-	-	1	2	2	3
	Visible light imagers	-	-	-	-	-	1	3	2	3

Spill = Light sweet crude. Priority: 3 = high, 2 = medium, 1 = low, – = Incompatible.
*Technology exists but resources are required for integration and software/algorithm development.

Table 12 *Sensor/vehicle recommendations for an offshore platform—small spill, 50 km offshore at 300 m depth*

Scenario 4b: Offshore platform (300 m depth)										
Sensor group	Sensor	Subsurface vehicles				Surface vehicles				
		AUV Classes			Glider	ASV Classes			Manned vessels	
		Man-portable AUV	LW/HW AUV	Large displacement AUV		Wave-/wind-powered ASV	Small ASV	Large ASV	Vessel of opportunity	Large vessel
Subsea direct sensors	Fluorometer	2*	3*	2*	2*	2*	1	3	2	3
	NDIR (CH_4)	1*	1*	1*	1*	1*	1	1	1	1
Subsea indirect sensors	CTD	2	3	2	2	2	1	3	2	3
	DO (electro-chemical)	1	1	1	1	1	1	1	1	1
	DO (optical)	2	3	2	2	2	1	3	2	3
	NDIR (CO_2)	1	1	1	1	1	1	1	1	1
	Turbidity meter	2	3	2	2	2	1	3	2	3
Surface vessel sensors	Fluorescence LiDAR	-	-	-	-	-	-	-	-	1*
	Radar	-	-	-	-	-	-	3	2	3
	Thermal IR imagers	-	-	-	-	-	1	3	2	3
	UV imagers	-	-	-	-	-	1	2	2	3
	Visible light imagers	-	-	-	-	-	1	3	2	3

Spill = Light sweet crude. Priority: 3 = high, 2 = medium, 1 = low, – = Incompatible.
*Technology exists but resources are required for integration and software/algorithm development.

Table 13 *Sensor/vehicle recommendations for an offshore pipeline rupture—small spill, 50 km offshore at 50 m depth for 5 days*

Scenario 5: Offshore pipeline rupture										
		Subsurface vehicles				Surface vehicles				
		AUV Classes				ASV Classes			Manned vessels	
Sensor group	Sensor	Man-portable AUV	LW/HW AUV	Large displacement AUV	Glider	Wave-/wind-powered ASV	Small ASV	Large ASV	Vessel of opportunity	Large vessel
Subsea direct sensors	Fluorometer	1*	3*	1*	1*	2*	1	3	2	3
	NDIR (CH_4)	1*	1*	1	1*	1*	1	1	1	1
Subsea indirect sensors	CTD	1	3	1	1	2	1	3	2	3
	DO (electro-chemical)	1	1	1	1	1	1	1	1	1
	DO (optical)	1	3	1	1	2	1	3	2	3
	NDIR (CO_2)	1	1	1	1	1	1	1	1	1
	Turbidity meter	1	3	1	1	2	1	3	2	3
Surface vessel sensors	Fluorescence LiDAR	-	-	-	-	-	-	-	-	1*
	Radar	-	-	-	-	-	-	3	2	3
	Thermal IR imagers	-	-	-	-	-	1	3	2	3
	UV imagers	-	-	-	-	-	1	2	2	3
	Visible light imagers	-	-	-	-	-	1	3	2	3

Spill = Light sweet crude. Priority: 3 = high, 2 = medium, 1 = low, – = Incompatible.
*Technology exists but resources are required for integration and software/algorithm development.

Table 14 *Sensor/vehicle recommendations for a deep water well blowout—extensive spill, 100 km offshore at 2,000 m depth*

Scenario 6: Deep water well blowout (Macondo type)										
		Subsurface vehicles				Surface vehicles				
		AUV Classes				ASV Classes			Manned vessels	
Sensor group	Sensor	Man-portable AUV	LW/HW AUV	Large displacement AUV	Glider	Wave-/wind-powered ASV	Small ASV	Large ASV	Vessel of opportunity	Large vessel
Subsea direct sensors	Fluorometer	1*	3*	3*	3*	3*	1	3*	1	3
	NDIR (CH_4)	1*	1*	1*	1*	1*	1	1*	1	1
Subsea indirect sensors	CTD	1	3	3	3	3	1	3	1	3
	DO (electro-chemical)	1	1	1	1	1	1	1	1	1
	DO (optical)	1	3	3	3	3	1	3	1	3
	NDIR (CO_2)	1	1	1	1	1	1	1	1	1
	Turbidity meter	1	3	3	3	3	1	3	1	3
Surface vessel sensors	Fluorescence LiDAR	-	-	-	-	-	-	-	-	2*
	Radar	-	-	-	-	-	-	3	1	3
	Thermal IR imagers	-	-	-	-	-	1	3	1	3
	UV imagers	-	-	-	-	-	1	3	1	3
	Visible light imagers	-	-	-	-	-	1	3	1	3

Spill = Light sweet crude. Priority: 3 = high, 2 = medium, 1 = low, – = Incompatible.
*Technology exists but resources are required for integration and software/algorithm development.

Establishing in-water and surface surveillance capabilities

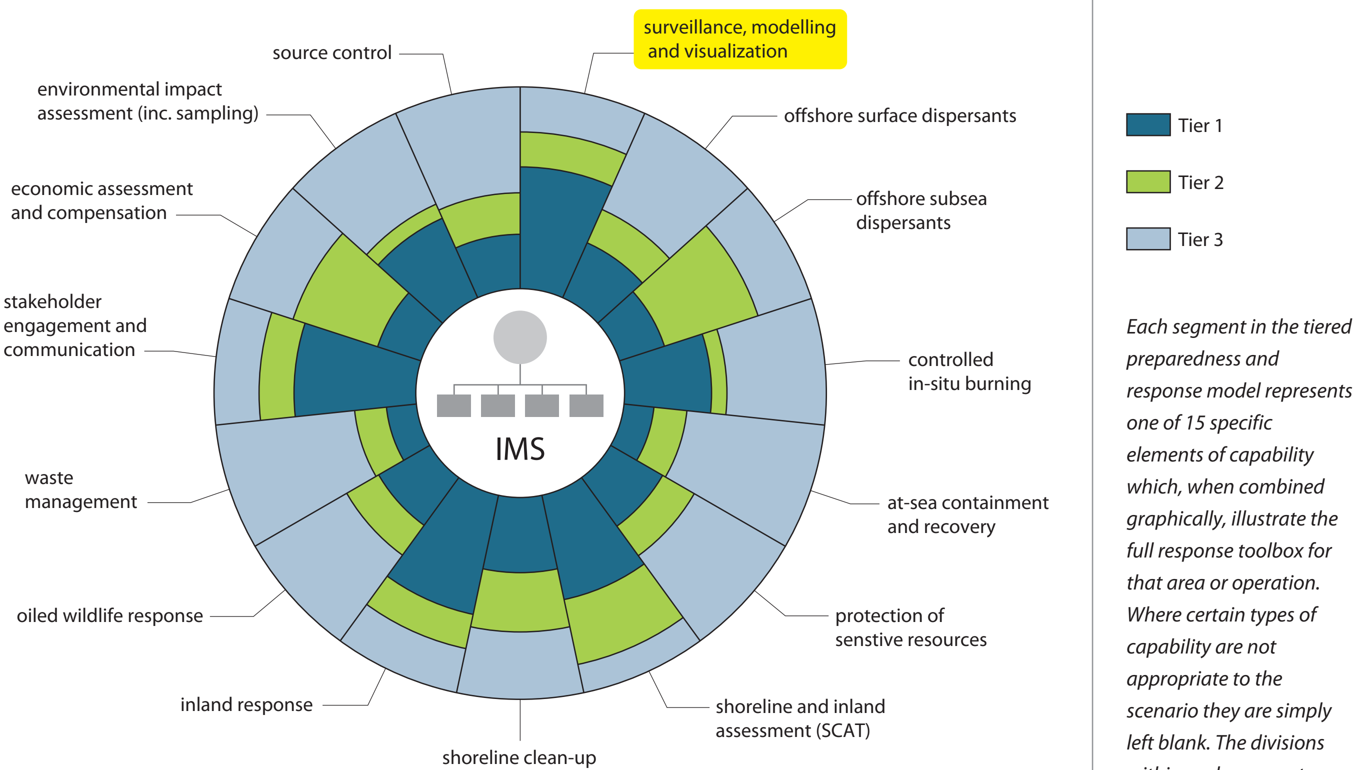
The role of surveillance in the Incident Management System

Surveillance is a key part of one of the 15 areas of capability that combine to provide an integrated tiered preparedness and response system. Further details can be found in the IPIECA-IOGP Good Practice Guides on tiered preparedness and response (IPIECA-IOGP, 2015a) and the Incident Management System (IPIECA-IOGP, 2016a). The information in those GPGs will help to frame decision making concerning the resources and capabilities required for in-water and surface surveillance within an organization and for a given event (or exercise).

Figure 4 is reproduced from the tiered preparedness and response GPG and shows the 15 areas of capability, including surveillance, modelling and visualization.

In addition to the surveillance element within a tiered response, there is also a requirement for modelling and visualization. Surveillance data, together with the prediction of oil spill movements, need to be converted into useful, well-presented, timely information to enable informed decision making during the response.

Figure 4 *The tiered preparedness and response model*



Each segment in the tiered preparedness and response model represents one of 15 specific elements of capability which, when combined graphically, illustrate the full response toolbox for that area or operation. Where certain types of capability are not appropriate to the scenario they are simply left blank. The divisions within each segment represent the relative proportions of Tier 1, 2 and 3 resources required to address the current scenario.

In-water surveillance resources in a tiered response

The decision on what (if any) in-water or surface surveillance technology to hold in-house should be made as part of the planning phase for any oil spill response activity.

The OSR JIP has addressed the issue of response planning more generally, using a risk-based approach. Full details, including a range of planning scenarios and risk assessments, can be found in IPIECA-IOGP, 2013 together with a discussion on the determination of oil spill response resources, including equipment, personnel and logistics.

The following questions may assist in the decision making process for in-water surveillance operations:

- Is there a regulatory requirement for such surveillance technologies, and if so, how will this be addressed?
- Does appropriate technology already exist at a local or national centre that can be readily mobilized as part of a response effort (i.e. Tier 2 and Tier 3 capabilities)?
- Do these resources meet the requirements of the local regulations?
- Are pre-approvals or processes in place should the need arise to import the technologies?
- Are contracts or user agreements in place to access this support?
- Are robust risk management plans and safety cases in place for the safe deployment of marine autonomous systems, as well as for the wider in-water surveillance programme?
- In addition to the surveillance technologies (e.g. AUVs and possibly ASVs and USVs) what other logistic support (e.g. vessels) will be required?
- Are suitable vessels already contracted or available through existing reciprocal agreements to deploy the technologies?
- Are competent and appropriately trained personnel available to deploy the equipment?
- Are these personnel employed by the operator or provided with the equipment?
- Are the instruments calibrated, and is the calibration documented?
- Are the instruments available for deployment?
- Given the nature of the spilled oil, are the appropriate sensors included with the in-water and surface surveillance platforms?
- Does the range of resources available suit the environment and water depths at the location of the potential incident?
- Are pre-approvals required for the deployment of the surveillance systems? This may be a particular requirement in the case of autonomous systems that have extended ranges.
- Is a science team required to accompany the equipment and support the monitoring operation? Are the science team's objectives compatible with the response objectives? Does the organization's IMS have the capability to manage the science team?
- How will the data from the various sensing systems and platforms be relayed in real time or near real time to the IMS?
- Does the organization's IMS have the capability to integrate the potential information from in-water and surface surveillance into the COP in a timely fashion?
- Have tests been performed in exercises and/or drills to ensure that the equipment will function as planned and that the data can be communicated to, and displayed by, the COP?

The importance of planning for surveillance capabilities cannot be overemphasized. An oil spill response based on unplanned and opportunistic availability of platforms and sensors is not a viable option.

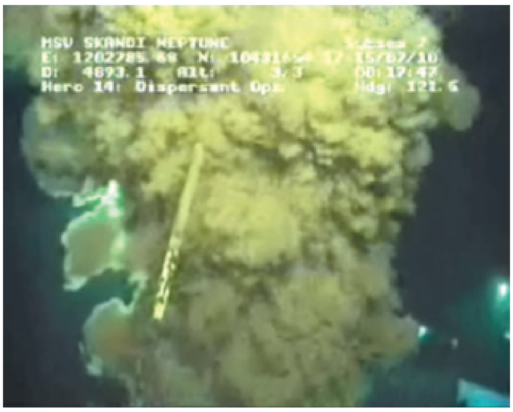
In-water surveillance and subsea dispersant injection monitoring

One of the major roles for in-water surveillance is to monitor the effectiveness of subsea dispersant injection (SSDI). Many of the questions above will form part of a wider review at the response planning stage when assessing the potential use of SSDI. A detailed in-water and surface surveillance monitoring plan helps to identify the supplies, equipment, personnel and activities necessary to effectively use and assess SSDI in the event of a spill. Addressing these requirements through response planning helps to produce more efficient and effective results during the response effort.

These issues are discussed further in the IPIECA-IOGP Good Practice Guide on subsea dispersant injection (IPIECA-IOGP 2015b). The publication provides an overview of the subsea monitoring and assessment carried out during the Macondo spill in the Gulf of Mexico in 2010—the first time SSDI had been used in an oil spill response operation. Details of the water column monitoring performed during the Macondo response are also discussed.

Three main operational response objectives for subsea monitoring are to (see also pages 37–40):
- monitor the subsea dispersant application and assess its effectiveness;
- characterize the behaviour and extent of dispersed hydrocarbon plumes in the water column; and
- carry out an initial assessment of potential ecological effects as they relate to operational decision making.

Whenever a subsea release of oil occurs there is a likelihood that some of the oil will rise to the surface where more traditional monitoring techniques can be deployed. This may involve surface-deployed manned and unmanned vessels and vehicles, as well as the use of aerial and satellite surveillance systems. The IPIECA-IOGP Good Practice Guides on aerial observation (IPIECA-IMO-IOGP, 2015) and satellite remote sensing (IPIECA-IOGP, 2016b) provide further information on these topics. It should be noted that surface surveillance can use the technologies associated with the Special Monitoring of Applied Response Technologies (SMART) protocols (NOAA, 2006).



Modified from BP video from ROVs

The images on the left show dispersant being injected directly into the plume of oil and gas flowing from the broken well head during the Macondo incident in 2010. Dispersant was injected into the plume through a 'lance' or 'wand' held by a ROV and guided by the ROV operator.

The integration of such a wide range of potential surveillance information within the IMS is covered under the COP. The OSR JIP has developed a recommended practice for the COP (IPIECA-IOGP, 2015d), which is discussed further on pages 42–43 this guide.

In-water surveillance may also be used to monitor physical and chemical parameters in the water column to gain a better understanding of the environmental effects of a spill. Data on physical parameters such as temperature, conductivity (salinity), and ocean currents can provide invaluable inputs to hydrodynamic and oil spill plume models. To maximize these benefits for operational decision making, the data need to be retrieved and transmitted in real time (or very near real time). Data assimilation into oil spill models can significantly improve their performance in providing predictions of oil spill motion, and hence can improve response decision making. Planning for the integration of spill models into the COP needs to be considered well in advance of an actual spill, and should be tested during exercises or drills.

Should the decision be made to establish an in-house capability (i.e. platforms and sensors) for in-water surveillance, planning the organization of these response assets will require careful consideration. This should include regular maintenance of the systems and calibration of the sensors. Appropriate procedures should be in place for ensuring that the battery packs used in the vehicles and the sensors required are ready for deployment at short notice during an exercise or a spill response. When establishing such an in-house capability it will be important to establish from the outset whether the equipment will:

- be dedicated (i.e. not used for other activities) or shared (e.g. across industry);
- be fit-for-purpose (to underscore its operational intent); and
- have a unique maintenance cycle and/or rapid deployment capability (to underscore the enhanced state of readiness).

In addition to the equipment required for in-water surveillance, suitably trained personnel will also be required. Clear job descriptions, responsibilities and chain of command should be identified, together with an appropriate communication strategy between the various groups such as the monitoring and science teams, planning and logistics group, COP and GIS staff, etc. The key stakeholders in the incident command group should be fully aware and supportive of these in-water surveillance technologies and personnel to maximize the benefits of their recruitment and retention.

An alternative approach is to look at regional provision of in-water surveillance assets and personnel. An example is the regional response programme operated in the Gulf of Mexico under the auspices of the Marine Well Containment Company (MWCC). This provides suitable equipment and personnel to enable the application of the SSDI monitoring guidelines recommended by API (2013a).

Deploying the technologies in a subsea response

The API has developed guidance for industry that is concerned primarily with operational monitoring during SSDI implementation (API, 2013a). Monitoring data are used to help decide whether to continue or modify subsea dispersant use during a spill response. Much of the API guidance has general relevance for in-water surveillance. The focus for SSDI monitoring is to collect real-time or near real-time monitoring data that can be used to inform operational response decisions for the current operational period.

Monitoring data that are not readily available to the IMS through the COP cannot support operational decisions, but may be useful for post-spill assessments. Monitoring strategies designed for environmental assessments may also use many of the platforms and sensors discussed in this guide, although much of the data gathered will require more detailed analysis and interpretation if it is to be used for environmental assessments resulting from the spill. This subject is not covered further in this guide.

Framepool

Monitoring data are useful in helping to determine whether to continue, or modify, the application of subsea dispersants during a spill response. In the image on the left, three ROVs can be seen monitoring the oil and gas plume released from the well head during the Macondo incident in 2010.

Depending on the location and nature of the oil spill, it may take several days to have in-water and surface surveillance assets available in the field. Local regulations may require such monitoring assets to be in place before SSDI can take place. Although the protection of worker health and safety, and environmentally-sensitive surface and shoreline areas requires SSDI as soon as possible after a subsea release, in most cases it should be possible to have monitoring assets in position to initiate more sophisticated monitoring procedures concurrently with dispersant injection.

Subsea dispersant monitoring

As noted by API (2013a) and the IPIECA-IOGP Good Practice Guide on subsea dispersant application (IPIECA-IOGP, 2015b), there are three main goals in monitoring SSDI:

1. monitoring the subsea dispersant application and assessing its effectiveness;
2. characterizing the behaviour and extent of dispersed hydrocarbon plumes in the water column; and
3. initial assessment of potential ecological effects as they relate to operational decision making.

These phases are organized chronologically and increase in complexity with time. In ideal circumstances, all phases would be concurrent but logistical considerations may necessitate the phased approach detailed and advocated by API. Each phase is discussed further below.

Phase 1: Assessment of subsea dispersant effectiveness

Prior to the initiation of SSDI, monitoring at the proposed injection point is required to establish baseline conditions and to guide the selection of dispersant injection methods and application rates. This initial monitoring is used to:

- characterize the spatial and temporal distribution of the subsea hydrocarbon release;
- estimate the oil and gas flow rates; and
- determine the properties and behaviour of the released oil.

The in-water monitoring comprises the following:

- Visual assessments from ROVs equipped with video cameras: the imagery can be analysed to ascertain whether the visible cloud of oil is changing colour, density and/or shape.
- Sonar-based, acoustic assessments using backscatter data from an ROV-mounted device: sonar at the appropriate frequency should give a stronger signal prior to injection of dispersant and a weaker signal after injection.
- Recent work by API and SINTEF has resulted in the development of the SilCam (silhouette camera) which has demonstrated the ability to more accurately determine the droplet size distribution and oil-to-gas ratio.

In addition to the in-water monitoring, surveillance from surface and aerial sources are incorporated into the assessment, as follows:

- Aerial imaging is used to assess the surface expression and extent of the oil: comparing aerial images before and after SSDI has been initiated will allow an assessment of whether the amount of oil reaching the surface has diminished.
- Surface vessels in close proximity to the spill source can be used to monitor VOCs and percentage lower explosive limit (LEL). Significant reductions in VOCs might be expected if the SSDI were effective, but evidence from the response to the 2010 Macondo incident in the Gulf of Mexico suggests that the process is complex and the correlation may not be as strong as theory might suggest.

It is recommended that a formal VOC/LEL monitoring programme is put in place, which should include an appropriate numerical modelling component. This 'safety first' approach is recommended during both incidents and exercises where the use of dispersants may enhance the ability to safely control the source.

One of the issues associated with monitoring from manned surface vessels is the potential exposure of personnel to the harmful effects of VOCs. Appropriate monitoring of permissible exposure levels (PELs) can be facilitated by having offshore personnel wear vapour monitoring badges. Ideally, this type of VOC monitoring would take place using appropriately equipped unmanned marine systems and/or aerial drones, thereby reducing the health and safety risk to response personnel and others in the area.

Phase 2: Characterization of the behaviour and extent of dispersed hydrocarbon plumes in the water column

The purposes of this phase of the in-water monitoring are to:

- determine the location, extent and characteristics of the dissolved and dispersed hydrocarbons within the water column;
- characterize the lateral and vertical movement of the dissolved and dispersed hydrocarbons; and
- document changes in the concentration of hydrocarbons as they move away from the source.

The primary monitoring strategy involves the use of an appropriate surface vessel. This should be equipped with an A-frame and winch system to deploy a CTD system to measure conductivity, temperature and depth. Typically, the CTD system will also be accompanied by a water-sampling rosette with Niskin bottles, a fluorometer and a dissolved oxygen sensor. Water samples are collected from depths determined by the analysis of the CTD casts for selected stations, and are stored for subsequent detailed analysis. Water samples for dissolved oxygen measurements should be collected at depths above, in and below any observed increase in fluorometric response. Following recovery of the instruments, the water samples should be transferred into suitable containers, with the appropriate metadata, and stored for subsequent analysis.

In addition to the CTD system, a deep-water particle size analyser (e.g. LISST, SilCam) can be deployed to provide real-time in-situ measurements of dispersed oil droplet size distribution. A significant shift from larger to smaller droplet sizes is indicative of the dispersion of the oil.

Local oceanographic data, together with hydrodynamic models, if available, will determine the likely direction of movement of the subsurface oil. The determination of water sampling site locations should be based on information from a reliable 3D subsea oil spill model. Such models are being continually developed and improved, and care should be taken to ensure that the most up-to-date version is employed. Ideally, the selected model should be validated as part of the planning process. Guidance on hydrodynamic model validation was developed as part of the OSR JIP (Actimar, 2015a).

An oil spill model will only be as reliable as the input atmospheric and hydrodynamic conditions used in its initialization and operation. Therefore, wherever possible, real-time or near real-time metocean data from the area of the spill should be assimilated into the modelling system. The Global Ocean Observing System (GOOS) provides oceanographic data on a global basis and much of this is readily accessible. A recent worldwide survey of ocean-observing systems can be found in Ocean News & Technology (2015). The role of assimilation in ocean models has been the focus of significant research in the UN's Global Ocean Data Assimilation Experiment (GODAE). A summary of this research work and its latest findings can be found in a recent special issue of the *Journal of Operational Oceanography* (IMarEST, 2015).

A review of the available metocean databases and resources by ocean basin can be found in the work performed for the OSR JIP by Actimar (2015b). In addition, this report provides a comprehensive review of a wide range of atmospheric and hydrodynamic models. These range from global models to those designed for use in specific basins, and recommendations are made as to which model is likely to be the most appropriate for use in each basin.

The outputs from the oil spill model(s) can also be assessed against the in-situ observations of the locations of the plumes in the water column and at the surface. It may be necessary to run a suite of different models, or a single plume model with multiple hydrodynamic boundary conditions, to obtain a 'consensus' prediction of the most likely location of the plume and to guide the optimum locations for future sampling.

Where no models are available to assist with the selection of sampling locations, a sampling grid should be developed and centred on the spill location. Stations should be established in a radial pattern located at fixed distances from the centre, and fluorometer readings from CTD casts and LISST measurements should be used to determine the path of the dispersed oil. As well as using a fixed array, adaptive sampling stations or arrays can be used to complement the fixed stations as the spill scenario changes over time.

However the sampling pattern is determined, care must be taken to ensure that monitoring vessel and ROV operations are commensurate with other logistical activities taking place around the spill site. Decisions on simultaneous operations (SIMOPS) will form an integral part of the IMS. Detailed and up-to-date knowledge of the locations of the vessels, platforms and sensors performing the in-water surveillance and monitoring operations will be required in the COP to facilitate such decision making.

Phase 3: Initial assessment of the potential for ecological effects

This phase of the monitoring seeks to fully characterize all water samples collected by CTD casts, using state-of-the-art laboratory techniques for petroleum analytes and dispersant marker analysis. The water samples will need to be returned to land for rapid transfer to a certified accredited laboratory, and appropriate chain-of-custody procedures should be followed while samples are in transit. Vessel transit time, sample transfer time and laboratory processing can equate to a minimum of five days to process a sample, depending on the incident location. In the case of a larger spill event where significant numbers of samples are collected, it could take at least 7 to 10 days to receive detailed analytical results that meet quality assurance and control standards. It is unlikely that many locations in the world would have sufficient laboratory facilities to sustain the level of toxicology and analytical chemistry required during the water sampling and monitoring phase of the dispersant response to the Macondo incident.

In any surveillance activity or data gathering exercise, it is important to understand and agree on the standards, thresholds and reasons for collecting the data that will be returned as part of the surveillance exercise. This will ensure that the data collected are meaningful in terms of guiding the response, and/or that the data will confirm the presence or absence of any negative impact compared to an established and agreed baseline.

Quality assurance planning

A suitable quality assurance project plan (QAPP) is required which addresses sample collection methodology, handling, chain of custody and decontamination procedures, to ensure that the highest quality data are collected and maintained. The QAPP should include:

- an introduction identifying the project objectives and project staff;
- the site description and background, including bathymetry, ocean currents and other relevant sediment and geological features; the description should identify any relevant oil seeps and/or natural gas infrastructure in the area;
- a description of the sampling and monitoring protocols, data quality objectives, and health and safety implementation strategies; and
- quality assurance to address chain-of-custody procedures, field records and qualitative data handling, including images and videos.

Using and communicating the data and information

Significant volumes of surveillance data from a vast range of sources were generated during the response to the Macondo incident in 2010. The challenge of turning such large amounts of data into information that could assist the responders became a key issue for the response effort. The value of existing surveys (e.g. environmental sensitivity assessments) and baseline data should, therefore, not be overlooked, and should be captured in the COP as part of the pre-planning phase. This will facilitate timely decision making during an incident when significant volumes of new data and information from an actual incident or exercise arrive at the Incident Command Centre.

Accurate, timely and geo-referenced information is vital for both operational and strategic decision making. The barriers to synchronized and total situational awareness identified during the Macondo response included (USCG, 2011):

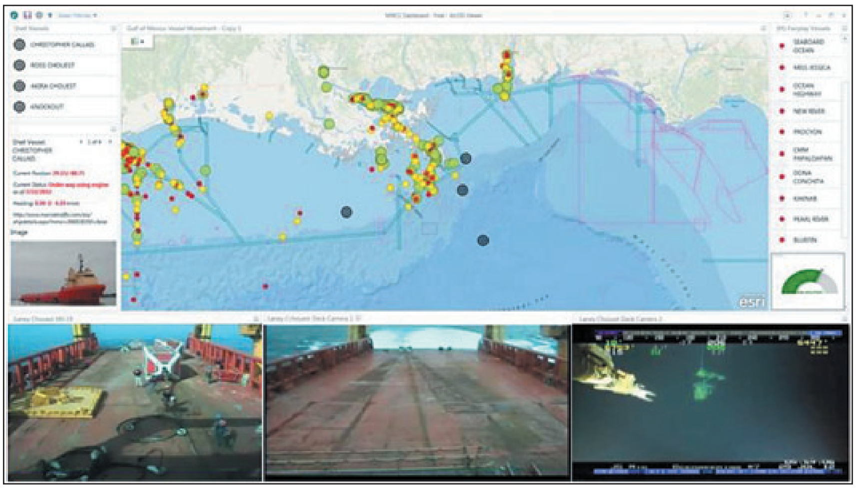
- lack of agreement on what data needed to be tracked and transmitted;
- the vast geography of the response area of operations;
- lack of availability of appropriate interoperable communications technology;
- limited ability to push real-time data, both vertically and laterally, throughout the response organization; and
- different computing standards.

Common operating picture (COP)

The lessons learned from reviewing these barriers within the OSR JIP have led to the development of a recommended practice for common operating picture (COP) architecture (IPIECA-IOGP, 2015d). By following the guidance in this recommended practice, many of the issues that prevented timely decision making during the Macondo incident can be addressed. Not least of these is the development of an information management plan (IMP) that should include:

- agreed data standards;
- field reporting requirements;
- media formats;
- access control policy; and
- data archiving requirements.

Example of an oil spill response COP geospatial dashboard.



Esri

The following are of particular importance for in-water surveillance:

- Accurate geo-referencing of surveillance data to a common coordinate reference system.
- A vertical reference datum appropriate for the location (e.g. mean sea level, chart datum).
- Metadata that describe the source, location, sampling, and output units and formats of the incoming data streams, including video sources.
- OGC[1]-compliant data formats: it is notable that many of the existing in-water sensing systems use proprietary output formats that are not compliant with OGC standards (Battelle, 2014).
- The tagging of operational assets to facilitate identification and tracking of equipment and asset use, e.g. the use of automatic identification system (AIS) transmitters on surface vessels.
- Systems and procedures for the processing and analysis of the incoming data to generate information that can be used for operational decision making by the response team; this is likely to include integration with other data and information available within the COP, and will require appropriate experts to perform the overall assessments.
- The processing and workflow history of the generated information and products should be retained for post spill assessments.

Modelling of oil spills

Modelling of an oil spill as part of the response has three main components:

1. modelling the trajectory of an oil spill/plume;
2. hydrodynamic and atmospheric modelling of parameters such as waves, currents and winds that drive the spill and plume models; and
3. atmospheric modelling for VOCs and LELs.

The selection of the appropriate model(s) will require expertise from both environmental and metocean specialists within the industry. As noted previously, oil spill models will only be as reliable as the input atmospheric and hydrodynamic conditions used in their initialization and operation. The results of any model should be validated against in-situ observations and surveillance information. If a suite of models is used, the selection of the one with the most accurate output may vary from day to day, depending on the specific hydrodynamic and atmospheric conditions.

The COP is likely to receive model output in a variety of formats. In addition, the integration of the model output with in-situ metocean and surveillance data may be challenging due to the wide variety of formats that are in use. Wherever possible, these should be agreed and codified during the planning phases and then tested in drills and exercises to ensure that the information is readily usable in a timely fashion by the response team.

[1] The Open Geospatial Consortium (OGC) is an international consortium of more than 480 companies, government agencies, research organizations and universities participating in a consensus process to develop publicly available geospatial standards. OGC standards support interoperable solutions that 'geo-enable' the web, wireless and location-based services, and mainstream IT. OGC standards empower technology developers to make geospatial information and services accessible and useful with any application that needs to be geospatially enabled. www.opengeospatial.org

Innovations and future technological developments

In-water surveillance is one of several oil spill response areas that are currently undergoing rapid technological development, including advances in sensor technology, host platforms, software systems and battery technologies. In addition, the associated modelling and visualization tools that are required to provide surveillance intelligence to the response teams are also advancing rapidly.

In the USA, the Interagency Coordinating Committee on Oil Pollution Research (ICCOPR) recently published their six-year plan for research and development in oil spill response (ICCOPR, 2015). This includes sections related to oil spill detection and surveillance. A similar type of forward-looking report has also been produced by an expert team for the Royal Society of Canada (Lee *et al.*, 2015).

Host platforms

The Saab Sabretooth represents a new development in hybrid AUV/ROV water surveillance technology; it combines hovering technology with deep water capability, extended autonomous endurance and increased thrust for high speed surveys in high current environments.

The development of technology for in-water surveillance platforms is evolving rapidly. Innovations cover a range of different aspects. Some of these are discussed briefly below and, with appropriate development and testing, have the potential to significantly improve the capabilities of oil spill response in the coming years.

Hybrid vehicles, which combine some of the features of AUVs and ROVs, are also under development. This technology was initially developed for military markets and oil and gas offshore inspection and intervention roles, but could be adapted for oil spill surveillance missions. Examples include the Saab Sabretooth which comprises a hovering AUV/ROV with deep water capability. Operations can be controlled by an operator via a thin fibre-optic tether, or the unit can be untethered and under autonomous operation. The AUV functionality includes obstacle avoidance, behaviour-based control, hovering and the capability for underwater docking. The latter enables battery recharging and data download, and allows for sustained deployment for more than six months without maintenance, eliminating both the need for, and associated costs of, an accompanying surface vessel.

©Saab

Marine robotics is a field that is now receiving significant attention (and funding) in certain countries. The European Union is funding work through their Horizon 2020 programme to develop deep ocean gliders with depth capabilities from 2,400 to 5,000 metres. In the UK, the Marine Robotics Innovation Centre is attached to the National Oceanography Centre in Southampton which receives significant government investment. Much of the work carried out at the Marine Robotics Innovation Centre is aimed at improving the ability and cost-effectiveness of global ocean marine monitoring, whether for scientific, military or commercial purposes. In the marine science field, the potential for using autonomous systems for certain marine observations, rather than using research vessels which require expensive manpower, maintenance and running costs, is being assessed.

Many of the developments currently taking place at the Marine Robotics Innovation Centre and other marine research centres could be applicable for in-water surveillance of oil spills, as the following examples show:

- Work is ongoing to improve the monitoring of ocean parameters using intelligent and adaptive sampling systems for ephemeral events. This has the potential to be applied for in-water surveillance of oil spill plumes, etc.
- Research is being carried out to investigate the potential for real-time communication between AUVs to allow them to work in teams rather than as individual autonomous units.
- The role of ASVs is being enhanced to allow communication between the surface vehicle and a fleet of AUVs working in the same area; there are plans to have an ASV acting as a launch system for AUVs and to provide the command and communications hub to integrate the signals from subsea and surface sensing systems deployed on the ASV, and on AUVs and ROVs.

Developments such as these offer the potential for improving the simultaneous operation of monitoring assets in the event of a spill. There are, however, regulatory issues pertaining to the use of marine autonomous systems generally. These are currently under discussion in international forums, including the International Maritime Organization (IMO).

The UK Maritime Autonomous Systems Regulatory Working Group (MASRWG) is currently preparing an industry-led Code of Conduct and a Code of Practice for the safe operation of USVs, and are working with a number of international partners to achieve consensus for the inclusion of USVs in IMO instruments, such as COLREGS, SOLAS, STCW and MARPOL.

Communications and batteries

The limitations of wireless subsea data transfer rates are under review, and a range of technologies other than acoustic transmission are being developed. One example is BlueComm, a short-range, optically-based system developed by Lumasys, Inc., which is capable of providing high-bandwidth, broadband-speed data transmission over distances of up to 200 metres.

AOVs of all types are typically powered by battery technology. Many use lithium ion (Li-ion) batteries but these have some limitations, including:

- they degrade over time, even when not in use;
- transportation restrictions—shipments are likely to be subject to import/export controls; and
- they require a protection circuit to maintain voltage and current within safe operating limits.

Over the past 10 years, development of the next generation of lithium-based batteries has been taking place using lithium sulphur (Li-S) technology. Li-S batteries potentially offer up to five times the theoretical energy density of Li-ion batteries. In addition, they are maintenance free, safer, lighter and neutrally buoyant, unlike Li-ion batteries which require syntactic foam flotation to be used in AUV deployments to maintain their buoyancy. However, recent high-profile incidents involving fires caused by lithium batteries have given rise to safety concerns related to the transportation of these power sources by air; this presents a major challenge for international response.

The increased power of Li-S batteries offers the following advantages, individually or in combination, over conventional Li-ion batteries in AUV systems:
- higher speeds;
- increased endurance; and
- greater payload.

Li-S batteries are not yet being produced on a commercial scale, but the technology is expected to become more widely available over the next few years.

Sensors

Work by the API and SINTEF has led to the development of a system for real-time monitoring of droplet sizes, especially near the well head. This is a backlit silhouette camera system known as the SilCam which is capable of measuring oil droplets and gas bubbles simultaneously—something that had not previously been possible. The ability to measure both droplets and bubbles is critical in optimizing the dosage of subsea dispersant. SINTEF (2014) provides further details. Similar instruments are available from Sequoia Scientific, Inc., with their LISST range of multi-parameter systems for in-situ observations of particle size distributions and volume concentrations.

The Interagency Coordinating Committee on Oil Pollution Research (ICCOPR) recommends the use of acoustic systems and LiDAR technology, both individually and as a packaged suite, for investigation of submerged oil (ICCOPR, 2015). They also recommend the development of new or improved chemical sensors for submerged oil detection.

Experience using AUVs for monitoring during the response to the Macondo incident suggests that the use of innovative methods combining advanced in-situ chemical sampling/tracking, robotic sampling and acoustic positioning with AUV control systems can provide efficient characterization and localization of water column hydrocarbons. A useful review of these technologies has been published by the International Research Institute of Stavanger (IRIS, 2013). Underwater sensor payloads recommended by IRIS for additional in-situ chemical sampling include:
- fluorometers, including hyperspectral and time-resolved fluorescence sensors;
- mass spectrometers;
- surface-enhanced Raman spectrometry;
- immunosensors;
- sniffers;
- multi-parameter electronic tongue; and
- 'lab-on-a-chip' technology.

Modelling

Significant developments are taking place in the area of numerical modelling, both of oil spill plumes and the hydrodynamic and atmospheric models that are used to drive them. Work undertaken by the API has focused on improving the plume characterization in oil spill models. A summary of API's efforts in this and other related spill research activities can be found in Socolofsky *et al.*, 2015.

In the field of ocean observation and data assimilation, current and future research is discussed in a special issue of the *Journal of Operational Oceanography*, edited by Bell *et al.* (IMarEST, 2015).

It is clear that in-water surveillance in its own right, and especially when integrated with other surveillance technologies and appropriate modelling and visualization schemes, will play an increasingly important role in marine spill response efforts. Technological developments are advancing rapidly in many of the key areas of importance to responders, e.g. vehicles, sensors, batteries, models, visualization software, etc. It is therefore vital that these technologies are reviewed at regular intervals to ensure that the most appropriate and up-to-date combination of technologies is used in an oil spill response operation. To facilitate such a review, the websites of the principal sensor and platform manufacturers are listed on pages 51 and 52 of this guide.

List of acronyms

AIS	Automatic identification system
AOV	Autonomous oceanographic vehicle
API	American Petroleum Institute
ASV	Autonomous surface vehicle
AUV	Autonomous underwater vehicle
CDOM	Chromophoric dissolved organic matter
COLREGS	International Regulations for Preventing Collisions at Sea
COP	Common operating picture
CTD	Conductivity, temperature, depth
DO	Dissolved oxygen
GIS	Geographic information system
GOOS	Global Ocean Observing System
GPG	Good Practice Guide
HWV	Heavyweight vehicle
ICCOPR	Interagency Coordinating Committee on Oil Pollution Research
IMCA	International Marine Contractors Association
IMO	International Maritime Organization
IMP	Information management plan
IMS	Incident Management System
IOGP	International Association of Oil and Gas Producers
IPIECA	Global oil and gas industry association for environmental and social issues
IR	Infrared
IRIS	International Research Institute of Stavanger
JIP	Joint Industry Project
LARS	Launch and recovery system
LEL	Lower explosive limit
LiDAR	Light detection and ranging
LISST	Laser in-situ scattering and transmissometry
LWV	Lightweight vehicle
MARIC	Marine Robotics Innovation Centre, UK
MARPOL	International Convention for the Prevention of Pollution from Ships
MASRWG	Maritime Autonomous Systems Regulatory Working Group, UK
µm	Micrometre
MWCC	Marine Well Containment Company
NDIR	Non-dispersive infrared
NEBA	Net environmental benefit analysis
NGO	Non-governmental organization
PAH	Polycyclic aromatic hydrocarbons
QAPP	Quality assurance project plan
RHIB	Rigid hull inflatable boat
ROV	Remotely operated vehicle
SilCam	Silhouette camera
SMART	Special Monitoring of Applied Response Technologies
SOLAS	International Convention for the Safety of Life at Sea
Sonar	A system for the detection of objects under water by emitting sound pulses and detecting or measuring their return after being reflected. (From SOund NAvigation and Ranging.)
SSDI	Subsea dispersant injection
STCW	Standards of Training, Certification and Watchkeeping for Seafarers
UOV	Unmanned oceanographic vehicle
USV	Unmanned surface vehicle
UUV	Unmanned underwater vehicle
VOC	Volatile organic compound

References

Actimar (2015a). *Recommendations on validation techniques.* IOGP-IPIECA Oil Spill Response Joint Industry Project (OSR-JIP) Report MOC-0970-02, Version 3.1. February 2015. 52 pp. http://www.oilspillresponseproject.org/wp-content/uploads/2016/02/RR-WP3-and-WP4-RECOMMENDATIONS-ON-VALIDATION.pdf

Actimar (2015b). *Review of models and metocean databases.* IOGP-IPIECA Oil Spill Response Joint Industry Project (OSR-JIP) Report MOC-0970-01 Version 1.2. February 2015. 75 pp. http://www.oilspillresponseproject.org/wp-content/uploads/2016/02/RR-WP3-and-WP4-REVIEW-OF-MODELS-AND-METOCEAN-DATABASES.pdf

API (2013a). *Industry recommended subsea dispersant monitoring plan, Version 1.* American Petroleum Institute (API) Technical Report 1152. September 2013. 20 pp.

API (2013b). *Remote sensing in support of oil spill response – planning guidance.* American Petroleum Institute (API) Technical Report 1144. September 2013. 79 pp.

Arthur, M., G. Coelho and P. Twomey. (2013). *Monitoring hydrocarbon releases in deep water environments: A review of new and emerging technologies.* HDR Ecosystem Management & Associates, Inc. Lusby, MD. API Technical Report 13-01. 55 pp.

Battelle (2014). *Capabilities and Uses of Sensor-Equipped Ocean Vehicles for Subsea and Surface Detection and Tracking of Oil Spills; IOGP-IPIECA Oil Spill Response Joint Industry Project (OSR-JIP) Surveillance, Modelling and Visualization Work Package 1: In Water Surveillance.* 233 pp. www.oilspillresponseproject.org/wp-content/uploads/2016/02/RR-Battelle.pdf

ICCOPR (2015). *Oil Pollution Research and Technology Plan, Fiscal Years 2015–2021.* Interagency Coordinating Committee on Oil Pollution Research (ICCOPR). September 2015. 294 pp.

Davis, R. E., Eriksen, C. C. and Jones, C. P. (2002). Autonomous Buoyancy-driven Underwater Gliders. In *The Technology and Applications of Autonomous Underwater Vehicles*. G. Griffiths (ed), Taylor and Francis, London.

IMCA (2016). Guidance for The Safe and Efficient Operation of Remotely Operated Vehicles. International Marine Contractors Association. Report no. IMCA R 004 Rev. 4. May 2016. http://www.imca-int.com/remote-systems-and-rov-division/code-of-practice-for-the-safe-and-efficient-operation-of-remotely-operated-vehicles.aspx

IPIECA-IMO-IOGP (2015). *Aerial observation of oil spills at sea.* IPIECA-IOGP Good Practice Guide Series, Oil Spill Response Joint Industry Project (OSR-JIP). IOGP Report 518. 56 pp. http://oilspillresponseproject.org

IPIECA-IOGP (2013). *Oil spill risk assessment and response planning for offshore installations.* Report of the IOGP Global Industry Response Group (GIRG) response to the Macondo incident in the Gulf of Mexico in April 2010. IOGP-IPIECA Oil Spill Response Joint Industry Project (OSR-JIP). http://oilspillresponseproject.org

IPIECA-IOGP (2015a). *Tiered preparedness and response.* IPIECA-IOGP Good Practice Guide Series, Oil Spill Response Joint Industry Project (OSR-JIP). IOGP Report 526. http://oilspillresponseproject.org

IPIECA-IOGP (2015b). *Dispersants: subsea application.* IPIECA-IOGP Good Practice Guide Series, Oil Spill Response Joint Industry Project (OSR-JIP). IOGP Report 533. http://oilspillresponseproject.org

IPIECA-IOGP (2015c). *Response strategy development using net environmental benefit analysis (NEBA).* IPIECA-IOGP Good Practice Guide Series, Oil Spill Response Joint Industry Project (OSR-JIP). IOGP Report 527. http://oilspillresponseproject.org

IPIECA-IOGP (2015d). *Work Package 5: Common Operating Picture. Recommended practice for Common Operating Picture architecture for oil spill response, release 2.1. Final Report.* Oil Spill Response Joint Industry Project (OSR-JIP). http://oilspillresponseproject.org

IPIECA-IOGP (2016a). *Incident management system for the oil and gas industry.* IPIECA-IOGP Good Practice Guide Series, Oil Spill Response Joint Industry Project (OSR-JIP). IOGP Report 517. 56 pp. http://oilspillresponseproject.org

IPIECA-IOGP (2016b). *Satellite remote sensing.* IPIECA-IOGP Good Practice Guide Series, Oil Spill Response Joint Industry Project (OSR-JIP). IOGP Report 549. http://oilspillresponseproject.org

IRIS (July, 2013). *NDP State of the art study – Deep water remote sensing and monitoring.* International Research Institute of Stavanger (IRIS), Report 2013/103. 66pp.

IMarEST (2015). *GODAE OceanView Part 2.* Special issue of the Journal of Operational Oceanography, Official Journal of the Institute of Marine Engineering, Science & Technology (IMarEST), Volume 8, Supplement 2, 2015. Pages s189-s271. Guest Editors: M. Bell, K. Haines, A. Schiller, N. Smith and Z. Willis.

Lee, K. (chair), Boufadel, M., Chen, B., Foght, J., Hodson, P., Swanson, S. and Venosa, A. (2015). *Expert Panel Report on the Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments.* Royal Society of Canada, Ottawa, Ontario, Canada.

NOAA (2006). *Special monitoring of applied response technologies (SMART).* National Oceanic and Atmospheric Administration (NOAA), Office of Response and Restoration. Seattle, Washington, USA. http://response.restoration.noaa.gov/smart

NRT (2013). *Environmental monitoring for atypical dispersant operations.* U.S. National Response Team, May 2013. 25 pp.

Oceaneering (2015). *Capabilities and Uses of Sensor and Video-Equipped Waterborne Surveillance-ROVs for Subsea Detection and Tracking of Oil Spills. IOGP-IPIECA Oil Spill Response Joint Industry Project Surveillance, Modelling and Visualization. Work Package 1: In Water Surveillance.* 89 pp. http://oilspillresponseproject.org

Ocean News and Technology (2015). A Worldwide Survey of Recent Ocean Observatory Activities: 2015 Update. In *Ocean News and Technology*, September 2015, pp. 18-29. http://digital.oceannews.com/publication/?i=270944

Socolofsky, S. *et. al.* (2015). Intercomparison of oil spill prediction models for accidental blowout scenarios with and without subsea chemical dispersant injection. In *Marine Pollution Bulletin,* Vol. 96, Issue 1–2, pp. 110-126. www.sciencedirect.com/science/article/pii/S0025326X15002969

SINTEF (2014). Combining technology to extend the limits of particle measurements in subsea blowouts. In *Particles in Europe (PiE): Program and Abstracts.* Proceedings of the PiE Conference held in Esbjerg, Denmark, 7–9 October, 2014. www.sequoiasci.com/wp-content/uploads/2014/07/Program-Particles-in-Europe-WITH-abstracts.pdf

USCG (2011). *BP Deepwater Horizon Oil Spill: Incident Specific Preparedness Review (ISPR).* United States Coast Guard. Final Report, January 2011.

Useful websites and resources

- Oil Spill Response JIP:
  http://oilspillresponseproject.org

- Arctic Response Technology—Oil Spill Preparedness website:
  www.arcticresponsetechnology.org

- American Petroleum Institute (API) Oil Spill Prevention and Response website:
  www.oilspillprevention.org

- Sensor and AOV reference material:

  Aanderaa Data instruments (AADI): www.aadi.no

  ALSEAMAR: www.alseamar-alcen.com

  AML Oceanographic: http://amloceanographic.com

  ASV: www.asvglobal.com

  Atlas Elektronik: www.atlas-elektronik.com/en/

  Atlas Maridan: www.maridan.atlas-elektronik.com/

  AutoNaut: http://www.autonautusv.com

  Autonomous Underwater Vehicle Applications Center: http://auvac.org

  Bluefin Robotics: www.bluefinrobotics.com/

  Canon U.S.A. Inc.: http://canon.com

  C&C Technologies: www.cctechnol.com

  Chelsea Technologies Group: www.chelsea.co.uk

  Deep Ocean Engineering: www.deepocean.com

  ECA Group: www.ecagroup.com

  Exocetus: http://exocetus.com

  Falmouth Scientific, Inc.: www.falmouth.com

  FLIR Systems, Inc: www.flir.com

  Fluidion: http://fluidion.com

  GoPro, Inc.: http://gopro.com

  Hamamatsu Photonics K.K.: http://hamamatsu.com

  INFRATEC GmbH: http://infratec.com

  International Submarine Engineering: www.ise.bc.ca

  JAI: http://jai.com

  JENOPTIK AG: http://jenoptik.com

  Kongsberg Maritime: http://www.km.kongsberg.com

  Laser Diagnostic Instruments: www.ldi.ee

  Liquid Robotics: http://liquidr.com

  Lockheed Martin: http://lockheedmartin.com/us/products/marlin.html

  Lumasys (BlueComm communications products): www.lumasys.com

Miros: http://miros.no

Mitsui Engineering & Shipbuilding Co. Ltd: www.mes.co.jp/english

Nikon Corporation: http://nikon.com

Nortek USA: www.nortekusa.com

OceanServer (Iver range of vehicles): http://iver-auv.com

OPTIMARE Systems GmbH: http://optimare.de

Oxis Energy (battery technology): http://oxisenergy.com

Rutter: http://rutter.ca

Saab: www.seaeye.com

Sea & Sun Technology: www.sea-sun-tech.com

Sea Robotics: http://searobotics.com

Sea-Bird Electronics: www.seabird.com

Seapoint Sensors, Inc.: www.seapoint.com

Sequoia Scientific: http://sequoiasci.com

SIEL Advanced Sea Systems: www.sielnet.com

Sony Corporation: http://sony.com

Teledyne Gavia: www.teledynegavia.com

Teledyne RD Instruments: www.rdinstruments.com

Teledyne Webb Research: www.webbresearch.com

Trios Optical Sensors: www.trios.de

Turner Designs: www.turnerdesigns.com

WetLabs: www.wetlabs.com

Acknowledgement

The original text for this guide was prepared by Colin Grant, CG Metocean Consulting, on behalf of the OSR-JIP.

IPIECA

IPIECA is the global oil and gas industry association for environmental and social issues. It develops, shares and promotes good practices and knowledge to help the industry improve its environmental and social performance; and is the industry's principal channel of communication with the United Nations. Through its member led working groups and executive leadership, IPIECA brings together the collective expertise of oil and gas companies and associations. Its unique position within the industry enables its members to respond effectively to key environmental and social issues.

www.ipieca.org

IOGP International Association of Oil & Gas Producers

IOGP represents the upstream oil and gas industry before international organizations including the International Maritime Organization, the United Nations Environment Programme (UNEP) Regional Seas Conventions and other groups under the UN umbrella. At the regional level, IOGP is the industry representative to the European Commission and Parliament and the OSPAR Commission for the North East Atlantic. Equally important is IOGP's role in promulgating best practices, particularly in the areas of health, safety, the environment and social responsibility.

www.iogp.org