UPDATING THE SMART DISPERSANT MONITORING PROTOCOL:
Review of Commercial-Off-The-Shelf Instruments

Final Report

For

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And

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By

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Executive Summary

This is a brief review of commercial, off-the-shelf (COTS) instruments to monitor the in-water behavior of oil during dispersant operations, as described in the SMART protocol (USCG et al. 2006). A recent workshop convened to review the SMART protocol concluded that technologies that might be used for this purpose in the immediate future included fluorometry and particle-size analysis. A search conducted to identify suitable submersible and field-portable fluorometers and particle-size analysers identified a number of instruments described below. Potentially suitable products have been identified and certain key technical information has been reported for each. All meet the minimum usefulness criteria described in the report, but no attempt has been made to comment on the instruments' relative capabilities.

Among the instruments detecting oil by fluorescence, the Turner 10AU is still available, as are several newer devices, including Wetlabs WetStar CDOM (the instrument included in the BUBA Buster[1] package), Turner Cyclops-7 (crude oil module) / C6 platform, Chelsea UV AQUA tracka, and Seapoint Ultraviolet Fluorometer. Among the particle-size instruments, a number of manufacturers produce instruments that measure particles in water samples. However, most are laboratory or industrial instruments and are neither submersible, nor field-portable, nor configured for flow-through operation as required by SMART. Only the following are suitable for the present application: Sequoia LISST – 100X (field-portable in-situ particle-size analyser); and LISST Streamside – (field-portable particle-size analyser, with flow through capability). In addition, Sequoia Scientific Inc. produces the LISST SL, a LISST-100X-like instrument, suitable for towing. It is currently configured only for use in freshwater, but can be adapted for the marine environment.

[1] The integrated real time GPS-fluorometer data acquisition system (BUBA Buster) developed by the Shoreline Environmental Research Facility (SERF) of the Civil Engineering Department of Texas A&M University (College Station, TX) permits the user to simultaneously collect hydrocarbon plume data that is automatically referenced both temporally and spatially. The unit includes a Wetlabs WetStar fluorometer and Garmin GPS whose output are integrated on a laptop.

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1 Introduction

This is a brief review of commercial, off-the-shelf (COTS) instruments to monitor the in-water behavior of oil during dispersant operations, as described in the SMART protocol (USCG et al. 2006)[2]. The report contains the results of research to identify commercially available instruments and sensors that might be used to monitor the in-water behavior of oil under dispersant-treated oil slicks. A recent workshop convened to review the SMART protocol concluded that technologies that might be used for this purpose in the immediate future included fluorometry, that could provide an index of the amount of oil present, and particle-size analysis that could provide an indication of the amount of particulate oil present as well as the size of those particles (SL Ross 2008a). A search has been conducted to identify suitable submersible and field-portable fluorometers and particle-size analysers. This work included a search of the Internet and the recent marine science literature followed by direct contact with instrument manufacturers. The research has identified a number of instruments that are described below. For purposes of this report, the potentially suitable products have been identified and certain key technical information has been reported, but no attempt has been made here to comment on potential usefulness.

The intent of the original authors of SMART was that effectiveness could be assessed reliably by visual means under many, if not most circumstances (Tier I), but the ability to make in-situ measurements (Tier II) would be useful for two purposes (Henry, pers. comm., 2007):

1. To aid in decision making if two visual monitors disagreed on whether an application was effective; and
2. To gather information on the actual concentrations of dispersed oil generated in the upper water column under dispersant treated slicks.

The authors of SMART called for using the Turner 10-AU Fluorometer (T-10AU) in flow-through configuration to measure in-water oil concentrations under treated slicks. Coast Guard Strike Teams still use the T-10AU for this purpose. Since the 2006 revision, the SMART

[2] The SMART procedure involves deploying the instrument system at sea by boat. The monitoring team samples at a depth of 1 to 2 m along transects through sections of the slick before and after dispersant spraying. Water samples are pumped continuously to the instrument for analysis through a 1-inch hose from under untreated and dispersant-treated slicks. Grab samples are taken from the water stream at intervals for purposes of post-event calibration of the Turner for the actual oil spilled. Dispersant applications are judged to be effective if oil concentrations under treated slicks are at least 5 times greater than under untreated slicks (i.e., under the slick prior to treatment). Instrumental outputs are recorded continuously digitally and manually at regular intervals. The monitor summarizes the results and communicates them to the Incident Command Team via the Technical Specialist after each sortie.

Protocol allows discretion in selecting the type of instrument used. In the 15 years since its first development, SMART operators have gained experience with the Protocol and the T-10AU. In addition, our understanding of dispersants has improved and a wide variety of new instruments that might replace the T-10AU for this application have come on the market. For this reason, the United States Coast Guard and the Minerals Management Service of the United States Department of the Interior have undertaken a review of the SMART protocol. The first step in this process was to hold a workshop in September 2007 to review the SMART process as a whole and operators' input regarding the challenges and limitations of the T-10AU (SL Ross 2008a). As part of that review, this project surveyed the COTS instruments that could replace the T-10AU for monitoring in-water oil behavior in the Tier II part of SMART operations.

Participants in the 2007 workshop to update SMART recognized that there were two types of sensors that might replace or augment the Turner 10AU field-portable fluorometer currently in use. These included:

a) New generation fluorometry-based systems (e.g., WET Labs CDOM in-situ fluorometer, Turner Cyclops-7 (crude oil sensor); and

b) Systems using particle-analysis technology to measure oil in water (e.g., Sequoia LISST-100X system).

All of the systems identified below meet the absolute minimum requirement to produce an estimate or index of the amount of total oil present in the water column on a continuous basis in real-time. Some have the capability of measuring the droplet size distribution, a capability that was flagged as useful both in the 2007 workshop and in the assessment of Ohmsett monitoring data (SL Ross 2008b). In addition, all are capable of interfacing with a laptop to aid real-time data display and interpretation in the field. The sections that follow contain: a) information regarding users feedback on experience of working with the Turner 10AU and their guidance regarding selection of a suitable replacement instrument; and b) technical data on potentially suitable COTS instruments based on results of the 2007 SMART Workshop.

1.1 Input from the 2007 SMART Workshop

1.1.1 Challenges with the Turner 10AU Field Portable Fluorometer

Operators from the US Coast Guard Strike Teams provided the following feedback concerning the operation of the Turner -10AU field portable fluorometer (T-10AU).

1. The Turner requires a complex, multi-step set-up and calibration procedure each time it is deployed.
2. The current standardization procedure for the Turner requires a standard fluoroscein dye solution that operators regard as problematic (large volumes required).
3. This set-up and standardization challenge is exacerbated because some versions of the Turner 10AU appear to be unstable and require frequent recalibration. This problem is avoided in more modern models of the Turner that are solid-state and are less prone to instability.
4. There may be losses in precision due to the lag between the time that the sample enters the sampling tube at depth and the time that it reaches the fluorometer. This is a feature of the Turner that could be avoided in instruments where the sensor is in-situ. (This question was raised in the workshop, but participants agreed that this consideration was not significant in considering new instrumentation.)
5. Participants suggested that regardless of the instrument used, all USCG Strike Teams should have exactly the same version of the instrument, so that they would be completely interchangeable.
6. The package of Turner equipment is very large. The instrument itself is bulky and much support gear (e.g., pump, hoses, cables) is required. This poses a number of logistics challenges in transporting the gear to a spill site and deploying it on an emergency basis.
7. Providing power to different components of Turner gear (Turner, pump, laptop) is sometimes a challenge, as the different components require different types of power sources.
8. Purchase/Replacement/Repairs. If the Turner breaks down, backup or repairs can be a significant issue in isolated areas and can be very expensive (e.g. $1800 rehab/$15k repair). Leasing this equipment may be a better option since Turner Designs Hydrocarbon Instruments, Inc. services the equipment within the continental U.S.

1.1.2 Considerations in Choosing a New Analytical Instrument

If a new system is considered to replace the Turner, regardless of type, operators recommend that it must include the following.

1. In-situ versus ex-situ – In-situ sensors should be the priority.
2. Analytical characteristics – Must meet the following operating sensitivity characteristics - required detection limits and ranges:
    a. Lower detection limit - 0.1 – 1 ppm
    b. Upper detection limit at least 100 ppm)

3. Note that operators are willing to sacrifice a little if the equipment were more easily deployable. However, minimum performance standards must be set by the technical specialists.
4. Simplicity of use– Instrument should be simpler to use than Turner, that is, be easier to set up and standardize.
5. Reliability – Turner setup may vary from day to day and is sensitive to rough handling. New instrument must be robust.
6. Easier Logistics – New system must have fewer components and must be lighter and require less logistics than the current system that requires two large boxes weighing 75-100 lbs each.
7. Maintenance – Replacement system must require less maintenance and lower maintenance costs.
8. Features – Must be capable of being integrated with Windows operating systems and GPS Software.

In addition, the selection process must include a multiple unit exercise at-sea to compare instruments with – Turner 10-AU as the baseline.

1.1.3 Fluorometry vs. Particle Size

As discussed above, fluorometry produces an index of oil concentration rather than an absolute measurement of oil concentration. Particle-size analysis (particle system) also provides an index of in-water oil concentration and droplet size distribution, though existing instruments are limited in that they can measure only droplets that fall in the size range 2 to 500 μm. The latter measures particles of all types present, but information on oil droplets can be estimated from measurements in areas of high oil concentration under slicks and subtracting the background particles. Some participants in the 2007 SMART workshop questioned whether SMART planners should be choosing between the capability to measure particle size and the ability to take grab samples. Decisions about grab samples and particle size analysis must recognize that particle-size analysis is used to improve real-time decision-making capability about dispersant effectiveness, while grab samples are used to support the post-event damage assessment process. As such, particle-sizing capability is of greater value for the primary mission of SMART. In addition, the recent review of monitoring data gathered during dispersant experiments at OHMSETT showed that particle-size analysis, though not without drawbacks, provides a near unambiguous indication of effectiveness.

2 Survey of Instruments

This survey considered COTS instruments that:

1. Monitor oil concentrations in the water column at sea in the upper mixing zone under slicks;
2. Monitor continuously;
3. Provide interpretable output in real-time;
4. Produce continuous digital output that is compatible with Windows software on a laptop; and
5. In some cases, provide information concerning oil particle size distribution.

Two families of instruments met these criteria: instruments that monitor using fluorometry or particle-size analysis. A number of instruments of each type are available off the shelf. Among the instruments detecting oil by fluorescence, the Turner 10AU is still available, as are several newer devices designed for detecting oil at sea, including Wetlabs WetStar CDOM (the instrument included in the BUBA Buster package), Turner Cyclops-7 (crude oil module) / C6 platform, Chelsea UV AQUA tracka, and Seapoint Ultraviolet Fluorometer. Among the particle-size instruments, a number of manufacturers produce instruments that measure particles in water samples. However, most are laboratory or industrial instruments that are neither submersible nor field-portable, nor are they configured for flow-through operation as required by SMART. Only the following are suitable for the present application: a) Sequoia LISST – 100X (field-portable in-situ particle-size analyser); and b) LISST Streamside – (field-portable particle-size analyser, with flow through capability). In addition, Sequoia Scientific Inc. produces the LISST SL, an isokinetic river and stream sediment concentration and size distribution analyser. This instrument is similar to a LISST – 100X, housed in a streamlined body to minimize drag in flowing-water or towed applications. It is currently configured only for use in freshwater, but according to manufacturers could be easily adapted for the marine environment.

2.1 Fluorometry Instruments

There are several field-deployable instruments that might be useful for monitoring oil conditions in the water column for purposes of SMART monitoring (see Appendix Table A1). Their characteristics, as well as those of the Turner 10AU, are summarized below.

2.1.1 Turner 10AU Field Fluorometer

The 10-AU-005-CE Field Fluorometer is a rugged, field-portable instrument that can be set up for continuous-flow monitoring or discrete sample analysis. The instrument features a watertight case, internal data logging, automatic range changing, and watertight quick-change filter paddles. A variety of compounds can be easily measured on-site using operator changeable application-specific optical filters. It is currently in use for SMART Tier 2 monitoring.

Detection method: Fluorescence

Output: Raw fluorescence or direct concentration

Sensitivity: 10 parts per billion of crude oil in pure water.

Range: 0 to 9999.99 fluorescence units

Continuous Measurement/Output: Instrument sits on deck processing samples continuously pumped to it from sample depth through tubing. Discrete sample averaging: Sample averaging period 2 to 60 seconds, with pre-averaging delay of 1 to 60 seconds.

Oil Detection Kit: Two oil kit configurations possible, short and long wave lengths: Excitation Wavelength, nm short wave length = 254 nm, long wavelength = 400 nm; Detection Wavelength, nm short wave length = 300-400 nm, long wavelength = 410-600 nm

Lamp: Low Pressure Mercury Vapor Lamp, 4 watts,

Detector: Factory installed photomultiplier tube.

Digital Output: ASCII format through a 9-pin RS-232 serial cable at 4800 or 9600 bits per second (bps).

Software: Menu-driven microprocessor-controlled.

Analog Output: Full scale voltage: 0.1, 1, 2, or 5 volts (user selected).

Calibration and Zero: Several steps before every use

Standard: No solid standard or easy-to-use liquid standard. Large volumes of fluorescein standard needed for each use.

Mechanical: Width- 13.39 in., Length - 21.65 in., Weight - 34.5 lbs, plus pump hoses, cables, power supply, standardization gear and laptop.

Unit Cost: $15k, plus cost of pumps, hoses, power, standardization kit and crating.

Post-calibration: Grab sample can be taken and related to instrument measurements.

Other Applications: Chlorophyll a - Extracted and In Vivo, Blue Green Algae – Phycocyanin, Blue Green Algae – Phycoerythrin, Rhodamine WT, Fluorescein, Ammonium , Histamine, colored dissolved organic matter (CDOM)

Manufacturer: Turner Designs, Inc., 845 W. Maude Avenue, Sunnyvale, CA 94085, Toll Free: (877) 316.8049, Local: (408) 749-0994, Fax: (408) 749.0998, Web: http://www.turnerdesigns.com

2.1.2 WETLabs WETStar (CDOM)

The WETLabs WETStar fluorometers are small, low power optical instruments that provide comparable performance to other available fluorometers at a fraction of their power requirements and size. The unit employs an optical flow tube design that lends itself to both pump-through and flow-through operation. The WetStar (colored dissolved organic matter unit (CDOM)) is the sensor currently in use in the "BUBA Buster"[3].

Detection method: Fluorescence

Output: Raw fluorescence or direct concentration

Sensitivity: Sensitivity: 0.100 ppb quinine sulphate dihydrate (QSD)

Range: Dynamic range: 100, 250, or 1000 ppb QSD

Continuous Measurement/Output: operates in-situ with continuous measurement

Oil Detection Kit: Excitation Wavelength: 370 nm, Detection Wavelength EM: 460 nm

Lamp: Two UV LEDs centered at 370 nm

Detector: Silicon photodiode

Digital Output: RS232 output with digital output ranging from 0 to 4095 counts.

Software: Connects via a test cable and DB-9 connector to a PC running a terminal communications program such as HyperTerminal.

Analog Output: 0 to 5 VDC

Operating Standard: Fluorescent plastic test stick

Standard: Requires standardization

Calibration and Zero: Minimal

Mechanical : Width 2.7 in, Length 6.7 in, Weight 1.7 lbs, plus power and cable

Unit Cost: $4.2K

Post-calibration: Not possible without additional sampling equipment

Other Applications: Colored dissolved organic matter (CDOM)

Manufacturer: WETLabs, Inc., 620 Applegate St., Philomath, OR 97370, Phone: 541-929-5650; Fax 541-929-5277, www.wetlabs.com

[3] The integrated real time GPS-fluorometer data acquisition system (BUBA Buster) developed by the Shoreline Environmental Research Facility (SERF) of the Civil Engineering Department of Texas A&M University (College Station, TX) permits the user to simultaneously collect hydrocarbon plume data that is automatically referenced both temporally and spatially. The unit includes a Wetlabs WetStar fluorometer and Garmin GPS with output being integrated on a laptop.

2.1.3 Turner Cyclops-7 Submersible Sensor (crude oil) / C6 Multi-Sensor Platform

Cyclops-7 Submersible Sensors are compact submersible units for turbidity or fluorescence applications, including crude oil. Up to six sensors can be integrated into the C6 Multi-sensor platform that supplies power and provides automatic gain control, calibration, digital data reporting and data logging for each Cyclops sensor. The C6 Windows™ based user interface allows for intuitive calibration, data logging set up, and file downloading.

Detection method: Fluorescence

Output: Raw fluorescence

Sensitivity: Lower Detection Limit for crude oil = 20 ppb, Upper Limit = 250 ppm

Continuous Measurement/Output: Operates in-situ with continuous measurement

Oil Detection: Excitation Wavelength = 300 to 400 nm,
Detection Wave Length = 400 to 600 nm

Digital Output: Cyclops-7 output is analog only. The C6 Multi-sensor platform processes the Cyclops signal producing an RS232 signal through a test cable connected to a PC via a USB connector.

Software: C6 Windows™ based user interface allows for intuitive calibration, data logging set up, and file downloading.

Analog Output: Cyclops out put in 0 to 5 VDC

Operating Standard: A solid secondary standard is available for use in checking the stability of the instrument. The correlation between the primary (crude oil, fluorescein dye) and secondary standards must be established in advance.

Calibration and Zero: See operating standard.

Mechanical: C6 Multi-Sensor Platform = Width 4.0 in, Length 10.2 in, Weight 6.0 lbs
Cyclops-7 Sensors = Width 0.9 in, length 4.3 in, 5.0 oz

Cost: C6 Multi-Sensor Platform = $3K, Cyclops-7 Sensors (crude oil) = $2K

Post-calibration: Not possible without additional sampling equipment

Other Applications: Other C6-compatible sensors detect chlorophyll-A in vivo, blue green algae – phycocyanin, blue green algae – phycoerythrin, rhodamine dye, fluorescein dye, turbidity, CDOM, and optical brighteners. Custom optics are available.

Manufacturer: Turner Designs, Inc., 845 W. Maude Avenue, Sunnyvale, CA 94085, Toll Free: (877) 316.8049, Local: (408) 749-0994, Fax: (408) 749.0998, Web: http://www.turnerdesigns.com

2.1.4 Chelsea UV AQUAtracka

The UV AQUA - Tracka is a submersible fluorometer to monitor the concentration of hydrocarbons (360nm) in a wide range of oceanographic applications. The in-situ module is designed for use in conjunction with a deck unit that interfaces with Windows software on a laptop. The in-situ module can be mounted on a shuttle that can be towed at speeds of up to 5 knots. It is currently used to monitor sub-sea pipelines for leaks.

Detection method: Fluorescence

Output: Raw fluorescence or direct concentration

Sensitivity/Range: 0.001to 10 μg/l carbazole

Oil Detection Kit: Excitation Wavelength = 239 nm, Detection Wavelength = 360 nm

Digital Output: Analogue output is conditioned by deck unit for compatibility with Windows software on a laptop PC.

Calibration and Zero: Available calibration kit

Mechanical: Width- 3.5 in., Length – 15.9 in., Weight – 12.1 lbs.

Unit Cost: Chelsea AQUA-Tracka (configured for hydrocarbons) - $23.9K

NuShuttle – $52.5K

Real-time bridle $4.4K Cable - no data

Deck unit for real time display and storage (with GPS) - $6,000

Post-calibration: Not possible without additional sampling equipment

Other Applications: see also Chelsea AQUA – Shuttle

Manufacturer: Chelsea Technologies Group, 55 Central Avenue, West Molesey, Surrey, KT8 2QZ, UK, Tel: +44 (0) 20 8481 9000, Fax: +44 (0) 20 8941 9319, Email: sales@chelsea.co.uk

2.1.5 Seapoint Ultraviolet Fluorometer[4]

The Seapoint Ultraviolet Fluorometer (SUVF) is a high-performance, low power instrument for in-situ measurement of chromophoric dissolved organic matter (CDOM). The SUVF uses modulated ultraviolet LED lamps and an excitation filter to excite photophores. The fluorescent light emitted by photophores passes through a blue emission filter and is detected by a silicon photodiode. The low level signal is processed to produce an output voltage proportional to photophores (hydrocarbon) concentration. The SUVF may be operated with or without a pump. Two control lines allow the user to set the range to one of four options. The sensor is easily interfaced with data acquisition packages. A 5 ft. pigtail is supplied, but custom configurations are available.

Detection method: Fluorescence

Measurement Units: Raw Fluorescence

Sensitivity/Range: Four operating ranges allow instrument to span from 0.1 to 1500 μg/l as CDOM. No data on oil concentrations.

Detection Kit (CDOM): Excitation Wavelength, nm wave length = 370 nm, Detection Wavelength, nm wavelength = 440 nm (custom filter sets available, but chosen filter set is permanently fixed inside sensor)

Digital Output: Custom output connections are available. Sensor can interface with data acquisition packages.

Analog Output: 0 to 5.0 VDC

Calibration and Zero: no data

Mechanical: Width- 2.5 in., Length – 6.6 in., Weight – 2.2 lbs.

Unit Cost: $2950 for standard SUVF (presumably signal conditioning module and cables would be extra)

Post-calibration: Not possible without additional sampling equipment

Other Applications: Other units are available including wastewater discharge

Manufacturer: Seapoint Sensors Inc., P.O. Box 368Exeter, NH 03833, USA,E-mail: seapoint@seapoint.com <mailto:seapoint@seapoint.com-> - Sales: (603) 642-4921 - Support: (603) 775-7707.

[4] Manufacturer's Note: Please note that this sensor is designed for CDOM measurement, not hydrocarbon detection. We are unaware of any use of the Seapoint SUVF for hydrocarbon detection and I suspect it may not work very well. There are now some LEDs available that emit deeper in the UV, 270 nm and may work better for hydrocarbons. The problem with these is that they have much lower output than the 370nm LEDs, plus the optical filters and silicon photodiode are also less efficient at lower wavelengths, so the overall performance in terms of optical power output and detection Signal/Noise would be significantly less than the SUVF. However, since you would be operating at the correct wavelengths, I still think this would work better than our regular SUVF.

2.2 Particle-size Instruments

This review considered a range of manufacturers and products that might be suitable for monitoring particle abundance and size-distribution on a continuous basis in the water under dispersant-treated slicks at sea. A number of technologies are currently in use for automated measurement of particles, including: a) laser diffraction; b) impedance; and c) size-shape analysis. The most common is laser diffraction. At least seven manufacturers produce instruments to analyse particle size and abundance for medical, industrial, environmental or research purposes (Appendix Table A2). By far the majority of instruments identified are configured for laboratory bench use, not for either in-situ or flow through use and are not hardened for at sea use. One instrument, Malvern Insitec LPS, is configured for flow through use, but is a very large industrial instrument (not portable) and was not considered here. For two instruments very little information was available and manufacturers did not respond to repeated requests for information. Only one manufacturer, Sequoia Scientific Inc produces instruments with suitable analytical capabilities that are sufficiently rugged for the present application. Latter et al. (1997) conducted an inter-comparison of three instruments for use in analysing suspended particulate matter at sea. These included a LISST-100B, Galai (Porotec) CIS-100 and Partec Lasentec P100. Of these instruments, only the LISST-100B was suitable for *in-situ* deployment. Repeated requests for information concerning the Galai and Partec instruments, both of European manufacture, have received no response.

2.2.1 Sequoia LISST- 100X

The LISST-100X instrument is a multi-parameter system for in-situ observations of the particle size distribution. It uses small-angle laser scattering principles (laser diffraction) and obtains particle size distribution and particle volume concentration data.

Detection method: Laser diffraction

Output: Total concentration of droplets present (volume/volume), volume droplets in each of 32 size bins, volume mean diameter of droplets present.

Operating Range of Particulate Concentrations: 1-600 mg/l, (Note: Concentration range varies with the size of particles. The range give is reflects the range for the dispersed oil particle-size range.)

Continuous Measurement/Output: Operates in-situ with continuous measurement, but limited amenability to towing.

Oil Detection Kit: Two size-ranges are available: 1.25-250 microns (Type-B) and 2.5-500 microns (Type-C).

Lamp: Red 670 nm diode laser

Detector: Custom silicon detector

Digital Output: Direct download to laptop by test cable. RS232 output of time average particle-size distribution information, as well as overall particle concentrations and volume mean diameter data.

Software: Excel compatible software for data processing is provided.

Analog Output: No

Operating Standard: No

Calibration and Zero: Standardization using distilled water.

Mechanical: Length = 34.25 in., Diameter = 5.25 in. Weight = 25 lbs.

Post-calibration: Not possible without additional sampling equipment

Other Applications or Sensors: no

Cost: $US 29.5K

Manufacturer: Sequoia Scientific, Inc. Sequoia Scientific Office, 2700 Richards Road, Suite 107, Bellevue, WA 98005, Phone: (425) 641-0944, Fax: (425) 643-0595, info@sequoiasci.com, www.sequoiasci.com.

2.2.2 Sequoia LISST Streamside

The LISST-Streamside is an ex-situ flow-through version of the LISST-100X meant for use in streams or rivers. The instrument is designed to be enclosed in a shed, with power provided. A pump is inserted in-situ to deliver water. This device displays the size distribution in real time on a plasma display and stores processed data for subsequent download.

Detection method: Laser diffraction.

Output: Total concentration of droplets present (volume/volume), volume droplets in each of 32 size bins, volume mean diameter of droplets present.

Operating Range of Sediment Concentrations: 1 to 3000 mg/l

Continuous Measurement/Output: Operates as described above with continuous measurement

Oil Detection Kit: Two size-ranges are available: 1.25-250 microns and 2.5-500 microns.

Lamp: red 670 nm diode laser

Detector: custom silicon detector

Digital Output: Direct download to laptop by test cable. RS232 output of time average particle-size distribution information, as well as overall particle concentrations and volume mean diameter data.

Software: See LISST-100X

Analog Output: No

Operating Standard: Standardized with distilled water prior to use.

Calibration and Zero: Standardized with distilled water prior to use

Mechanical: Height = 11.5 in., Depth 6.5 in., Width = 10 in, Weight = 10 lbs.

Post-calibration: Not possible without additional sampling equipment

Other Applications or Sensors: No

Cost: $15K

Manufacturer: Sequoia Scientific, Inc. Sequoia Scientific Office, 2700 Richards Road, Suite 107, Bellevue, WA 98005, Phone: (425) 641-0944, Fax: (425) 643-0595, info@sequoiasci.com, www.sequoiasci.com

2.2.3 Sequoia Scientific LISST SL

The LISST SL is configured for in-situ particle-size measurement, but features a streamlined body suitable for use in flowing water or undertow. The streamlined body is a minimum drag shape with twin fins below the body to orient the LISST-SL into current. Diffracted light is measured in an enclosed electro-optics test section. Data are transmitted up the USGSB-reel to a control box that is interfaced with a laptop. Depth, velocity, and temperature are stored with each sample. This system is currently configured for use in freshwater only, but could be produced in marine format.

Detection method: Laser diffraction.

Output: Total concentration of droplets present (volume/volume), volume droplets in each of 32 size bins, volume mean diameter of droplets present.

Operating Range of Sediment Concentrations: 1 to 3000 mg/l

Continuous Measurement/Output: Operates in-situ with continuous measurement

Oil Detection Kit: 2-400 microns

Lamp: red 670 nm diode laser

Detector: custom silicon detector

Digital Output: Direct download to laptop by test cable. RS232 output of time average particle-size distribution information, as well as overall particle concentrations and volume mean diameter data.

Software: See LISST-100X

Analog Output: No

Operating Standard: Standardization with distilled water prior to use.

Calibration and Zero: Standardization with distilled water prior to use.

Mechanical: Length = 29.5 in., Dia. = 5.1 in., Weight = 35 lbs.

Post-calibration: Not possible without additional sampling equipment

Cost: $US35K

Other Applications or Sensors: No

Other Applications or Sensors: Depth, velocity, and temperature are stored with each sample

Manufacturer: Sequoia Scientific, Inc. Sequoia Scientific Office, 2700 Richards Road, Suite 107, Bellevue, WA 98005, Phone: (425) 641-0944, Fax: (425) 643-0595, info@sequoiasci.com, www.sequoiasci.com

3 References

Latter, R.J., A.J. Bale, S.E. Jones and C. Jago. 1997. Comparison of three suspended particle analysers under field and laboratory conditions. Marine Geology 140: 47-59.

SL Ross Environmental Research Limited. 2008a. Report on Project to Update SMART Protocol for Monitoring Efficacy of Oil Spill Dispersant Operations: Proceedings from Stakeholder Workshop. Prepared for USCG Research and Development Center, Groton, CT and U.S. Department of the Interior, Minerals Management Service, Herndon, VA.

SL Ross Environmental Research Limited. 2008b. Updating the SMART Dispersant Monitoring Protocol: Review of OHMSETT Results 2001-2007. Prepared for USCG Research and Development Center, Groton, CT and U.S. Department of the Interior, Minerals Management Service, Herndon, VA, February 2008

U.S. Coast Guard, National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, Centers for Disease Control and Prevention, and Minerals Management Service. 2006. Special Monitoring of Applied Response Technologies (SMART). Developed by U.S. Coast Guard, National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, Centers for Disease Control and Prevention, and Minerals Management Service, 43 pp.

Appendix 1 – Table of Fluorometry Instruments

Table A1 Summary of Submersible Fluorometer Equipment					
					Manufacturer
Turner 10AU Field Portable Fluorometer	Various	Two oil kit configurations: Short wave lengths: Excitation = 254 nm, Detection = 300-400 nm, Long wavelength Excitation= 400 nm; Detection = 410-600 nm	Flow-through	$15K	Turner Designs Hydrocarbon Instruments 2023 North Gateway, Suite 101 Fresno, CA 93727 (559) 253-1414 Local (559) 253-1090 Fax
WetLabs WetStar CDOM	CDOM	Excitation Wavelength: =370 nm, Detection Wavelength = 460 nm	In-situ	$4.2K	WetLabs PO Box 518 • Ship to: 620 Applegate St. • Philomath, OR 97370 • 541-929-5650 • Fax: 541-929-5277
Turner Cyclops-7 Crude Oil	Crude oil detection	Excitation Wavelength = 300 to 400 nm, Detection Wave Length = 400 to 600 nm	In-situ	C6 Platform = $3K, Cyclops-7 Sensor (crude oil) = $2K	Turner Designs, Inc. 845 W. Maude Avenue Sunnyvale, CA 94085 Local: (408) 749.0994 Fax: (408) 749.0998 Web: http://www.turnerdesigns.com
Submersible fluorometer	Phytoplankton	No data	No data	No data	Photon Systems Instruments Hogrova 20 612 00 Brno Czech Republic Tel: +420 541 269 004, +420 541 269 006 Fax: +420 541 269 005
Chelsea AQUA-Tracka	Hydrocarbon detection	Excitation Wavelength= 239 nm, Detection Wavelength = 360 nm	In-situ	No Data	Chelsea Technologies Group 55 Central Avenue, West Molesey, Surrey, KT8 2QZ, UK. Tel: +44 (0)20 8481 9000 Fax: +44 (0)20 8941 9319 Email: sales@chelsea.co.uk
Seapoint Ultraviolet Fluorometer	Dissolved organic matter	Excitation Wavelength = 239 nm, Detection Wavelength = 360 nm	In-situ	$2.9	Seapoint Sensors Inc. P.O. Box 368 Exeter, NH 03833 • USA seapoint@seapoint.com Sales: (603) 642-4921 Support: (603) 775-7707 Fax: (603) 642-4922 • (801) 729-8280

Appendix 1 – Table of Fluorometry Instruments

Table A2. Summary of Particle Size Measuring Instruments						
						Manufacturer
Coulter LS 13 320[a,]	0.4 to 2000	Laser diffraction	No	Height 17.5 in, Width 40 in Depth 10 in, Weight 71.5 lb	No data	Beckman Coulter, Inc. Bioresearch Information 4300 N. Harbor Boulevard P. O. Box 3100 Fullerton, CA 92834-3100 Tel: (800) 742-2345
Particle Measuring Systems LiQuilaz E	2 to 125	Laser diffraction	In-line 70 ml/min	Not Available	$7.5	Particle Measuring Systems 5475 Airport Blvd Boulder, CO 80301 Tel: 303-443-7100 or 1-800-238-1801 Fax: 303-449-6870 Email: info@pmeasuring.com
Malvern Insitec LPS	0.1 to 1000	Laser diffraction	Flow through	Very large specifics not available	No data	Malvern Instruments Inc Contact Sales Department Address 117 Flanders Road Westborough ,MA 01581-1042 Telephone +1 508 768 6400
Malvern Mastersizer 2000	0.02 to 2000	Laser diffraction	No	Laboratory bench instrument	No data	Malvern Instruments Inc Contact Sales Department Address 117 Flanders Road Westborough ,MA 01581-1042 Telephone +1 508 768 6400
Mictrotrac S3500	0.024 to 2800	Laser diffraction	No		No Data	Microtrac Support Team (727) 507-9770 (FAX 9774) 12501A - 62nd Street North Largo, FL 33773
Sequoia LISST 100X	Type B =1.25-250 Type C =2.5-500	Laser diffraction	In-situ	Length = 34.25 in., Diameter = 5.25 in. Weight = 25 lbs.	$29K	Sequoia Scientific, Inc.,2700 Richards Road, Suite 107, Bellevue, WA 98005, Phone: (866) 212-2226 Fax: (425) 643-0595, info@sequoiasci.com, www.sequoiasci.com
Sequoia Streamside	Type B =1.25-250 Type C =2.5-500	Laser diffraction	Flow-through	**Height = 11.5 in., Depth 6.5 in., Width = 10 in, Weight = 10 lbs.**	$15K	Sequoia Scientific, Inc.,2700 Richards Road, Suite 107, Bellevue, WA 98005, Phone: (866) 212-2226 Fax: (425) 643-0595, info@sequoiasci.com, www.sequoiasci.com
Sequoia LS	2-400	Laser diffraction	In situ	Length = 29.5 in., Dia. = 5.1 in., Weight = 35 lbs.	$35K	Sequoia Scientific, Inc.,2700 Richards Road, Suite 107, Bellevue, WA 98005, Phone: (866) 212-2226 Fax: (425) 643-0595, info@sequoiasci.com, www.sequoiasci.com
Symantec Helos BF	0.1 to 875	Laser diffraction	No data available	No data Available	?	No data Available
a. also applies to Coulter LS 2, similar for Coulter LS 100Q except that size range for 100Q is 0.4 to 948 um diameter						

Appendix 3 – Addendum

This addendum includes information concerning two Turner Designs instruments that have been added to the list of possible replacements for the Turner 10AU fluorometer since the technical review of this report was completed. These include a new instrument, the C-3, which has only recently appeared on the market and an older instrument, the SCUFA, which was omitted as it was soon to be discontinued, but is currently being tested by Oil Spill Response Limited in the UK as a possible replacement for the Turner 10AU.

A1.1 Turner C-3 Submersible Fluorometer Platform

The Turner C-3 Submersible Fluorometer platform is new and is an improvement on the Cyclops-7 fluorometry platform. It uses the same sensors and optics as the Cyclops-7 mounted in a housing that supports only three sensors, but includes a temperature sensor and optional pressure sensors and self-cleaning attachment, as well as on-board auto-gain feature and signal processing.

Detection method: Fluorescence

Output: Raw fluorescence

Sensitivity: Lower Detection Limit for crude oil = 20 ppb, Upper Limit = 250 ppm

Continuous Measurement/Output: Operates in-situ with continuous measurement

Oil Detection: Excitation Wavelength = 300 to 400 nm,
Detection Wave Length = 400 to 600 nm

Digital Output: Sensor output is processed to produce raw fluorescence

Software: C6 Windows™ based user interface allows for intuitive calibration, data logging set up, and file downloading. The system is capable of onboard data logging or real-time data output to laptop via cable.

Analog Output: Sensor output in 0 to 5 VDC is processed onboard

Operating Standard: There is no solid standard available for hydrocarbon detection.. Standardization is achieved using user-prepared quinine sulphate standard.

Calibration and Zero: See operating standard.

Mechanical: C3 Platform = Diameter = 3.9 in., Length 9.1in., Weight 3.6 lbs

Cost: **Option A** – Platform only, plus one hydrocarbon sensor + $5.2 K, plus signal booster and cable = $2.2 K. **Option B** – Platform plus three sensors, pressure sensor and wiper = $6.9K, plus signal booster and cable = $2.2K

Post-calibration: Not possible without additional sampling equipment

Other Applications: Other sensors chlorophyll-A in vivo, blue green algae – phycocyanin, blue green algae – phycoerythrin, rhodamine dye, fluorescein dye, turbidity, CDOM, and optical brighteners.

Manufacturer: Turner Designs, Inc., 845 W. Maude Avenue, Sunnyvale, CA 94085, Toll Free: (877) 316.8049, Local: (408) 749-0994, Fax: (408) 749.0998, Web: http://www.turnerdesigns.com

A1.2 Turner Self-Contained Underwater Fluorescence Apparatus (SCUFA) Submersible Fluorometer Platform

The Turner Self-Contained Underwater Fluorescence Apparatus (SCUFA) Submersible Fluorometer Platform is a self-contained submersible fluorometer for chlorophyll and dye tracing. It comes with a single, factory-mounted sensor, cable and SCUFA-Soft Windows-based software. The instrument is included here because the Oil Spill Response Limited in the UK is currently testing it. Note, however, that this instrument will be discontinued by Turner Designs, Inc. after November 2008, but will be supported until 2013.

Detection method: Fluorescence

Output: Raw fluorescence

Sensitivity: Lower Detection Limit for crude oil = 100 ppb, Upper Limit = 250 ppm

Continuous Measurement/Output: Operates in-situ with continuous measurement

Oil Detection: Excitation Wavelength = 300 to 400 nm,
Detection Wave Length = 410 to 600 nm

Analog Output: **Out put is 0 to 5 VDC**

Digital Output and Software: The analog output can be converted to raw fluorescence units using the SCUFA-Soft, Windows-based software provided. The unit communicates via cable to a labtop computer.

Operating Standard: There is no solid standard available. Standardization is achieved using user-prepared quinine sulphate standard.

Calibration and Zero: See operating standard.

Mechanical: SCUFA Sensor/Platform, Diameter = 2.5 in., Length = 10 in., Weight = 2.0 lbs.

Cost: Unit cost is $6.5K, plus $0.9K for 20-m cable.

Post-calibration: Not possible without additional sampling equipment

Other Applications: No data

Manufacturer: Turner Designs, Inc., 845 W. Maude Avenue, Sunnyvale, CA 94085, Toll Free: (877) 316.8049, Local: (408) 749-0994, Fax: (408) 749.0998, Web: http://www.turnerdesigns.com