Project	MONOCLE H2020 (grant 776480)	Start / Duration	1 February 2018/ 48 Months
Dissemination	PUBLIC	Nature	OTHER
Date	20/11/2018	Version	1.1

MONOCLE

Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries

Deliverable 4.1

Report on performance criteria for field testing

Project Description

Funded by EU H2020 MONOCLE creates sustainable *in situ* observation solutions for Earth Observation (EO) of optical water quality in inland and transitional waters. MONOCLE develops essential research and technology to lower the cost of acquisition, maintenance, and regular deployment of *in situ* sensors related to optical water quality. The MONOCLE sensor system includes handheld devices, smartphone applications, and piloted and autonomous drones, as well as automated observation systems for e.g. buoys and shipborne operation. The sensors are networked to establish interactive links between operational Earth Observation (EO) and essential environmental monitoring in inland and transitional water bodies, which are particularly vulnerable to environmental change.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776480

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Document History:

Release	Date	Reason for Change	Status	Distribution
0.1	22/06/2018	Initial document	Draft	Internal
0.2	29/06/2018	Internal Review	Draft	Internal
1.0	29/06/2018	Final review and approval	Completed	Public
1.1	20/11/2018	Digital Object Identifier added	Released	Public

To cite this document:

Riddick, C.A.L., *et al.* (2018). D4.1 Report on performance criteria for field testing. *Deliverable report of project H2020 MONOCLE (grant 776480)*, doi: 10.5281/zenodo.1492178

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776480

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Executive Summary

This document constitutes Deliverable 4.1 of the MONOCLE project and provides an overview of the key performance indicators (KPIs) for each sensor or system as defined at the start of the project, briefly summarised as follows.

Prosumer units of a Remote Piloted Aircraft System (RPAS), either DJI Phantom 4 pro or DJI M200, equipped with a range of cameras (RBG, Micasense Red-edge or Multispectral) are intended to be deployed by professionals and citizen science groups. These sensors measure radiance of the water surface and convert this to water-leaving reflectance, which will be validated by a TriOS Ramses, ASD Field Spec or WISP system. Concentrations of total suspended matter (TSM) and chlorophyll-a (Chl-*a*) derived from the camera imagery will be validated against laboratory measurements. Target measurement precision and performance accuracy for all parameters will be tested and are expected to depend on illumination conditions.

The HSP1 is a fixed installation that will collect global and diffuse irradiance measurements, to be validated against a sun photometer (e.g. Cimel) in the field. Measurement precision is in the range of 3-5%, while target performance accuracy is 5% uncertainty/offset.

The CLAM is presently a bench top flow-through system which measures *in situ* Chl-*a* concentrations. Measurements will be validated against accredited laboratory analysis of Chl-*a* (e.g. High Performance Liquid Chromatography (HPLC)). Measurement range and precision are to be tested and feed back into the development cycle, while target performance accuracy will be 10% uncertainty/offset.

The sun tracking radiometer platform is a ship-mounted device for control of the azimuth viewing angle of radiometers with respect to the sun and ship heading. Reference values can be calculated from ship compass and solar position. Measurement precision is 1°, while target performance accuracy is <1% uncertainty assuming the viewing angle is consistently >90° and a ship heading is available.

The iSPEX is a smartphone add-on for citizen science measurements of aerosol optical thickness (AOT), which will be adapted for MONOCLE to measure water colour. Measurements of AOT will be validated against groundSPEX, MODIS or AERONET measurements. AOT measurement precision is >5% per individual measurement and <1% when stacking >50 measurements, and target performance accuracy is <10% uncertainty/offset.

The KdUINO is a profiling device from a surface buoy that measures the light extinction coefficient (K_d). It will be adapted for MONOCLE with a new sensor and hardware, improved accuracy and temperature sensors. Measurements will be validated in the laboratory against TriOS radiometers, and precision and accuracy will be defined during the MONOCLE campaigns to feed back into the development cycle.

The WISPStation is a fixed installation which measures remote sensing reflectance ($R_{rs}(\lambda)$). Measurements will be validated against other high-end calibrated field spectroradiometers (e.g. TriOS Ramses). Measurement precision is 2%, depending on the ambient light and wave conditions) and target performance accuracy will be determined during the MONOCLE campaigns.

FreshWater Watch is an established citizen science method for monitoring of global freshwaters, which includes assessments of water colour, turbidity (Secchi tubes) and colourimetric phosphate measurement using inosine enzymatic reactions. Phosphate measurements will be validated in the laboratory (Skalar SAN++ system autoanalyzer with ammonium molybdate). Measurement precision is 43% (Relative Standard Deviation - to be confirmed) and performance accuracy will be defined during the MONOCLE campaigns.

The system KPIs described in this deliverable will inform planning of the forthcoming MONOCLE field campaigns as well as the novel development activities (WP2 & WP3) and innovation activities (WP5, WP6 & WP7).

Scope

The aim of this document is to provide performance criteria for each MONOCLE system, including measurement and deployment requirements defined with each stakeholder (notably end-user) audience in WP8. Specific focus is given to in situ performance, operational characteristics and sustainability in terms of measurement performance and robustness. This document translates these requirements into a framework for testing and feedback for modification and assessment of suitability for each sensor.

1. Introduction

The MONOCLE project aims to develop a range of in situ sensors for support of Earth Observation (EO) of inland, coastal and transitional waters. This will be undertaken by development of sensor systems and networks that aim to lower EO product uncertainty as well as the overall in situ system cost. Introduction of complementary low-cost systems can help fill observation data gaps in order to improve satellite data processing, validate operational satellite services in near real-time, and resolve existing uncertainties in EO application over inland and transitional waters.

The MONOCLE sensors are presently at relatively low technological readiness levels (TRLs), therefore these systems will be developed and improved over the course of this project to better support EO water quality observations. As these systems are at various phases of development, it is important to define their present capabilities and outline the future target capabilities over the course of each MONOCLE field campaign. Moreover, we need to define the reference against which each sensor will be validated, as well as what levels of accuracy and precision are acceptable to achieve measurements to the highest possible standard.

The MONOCLE systems include sensors for measurement of biogeochemical parameters, inherent optical properties (IOPs) and radiometric measurements. These include measurement of water-leaving reflectance for use in validating the atmospheric correction of satellite sensors (e.g. WISPStation, drones, HSP1, iSPEX). Consideration is also given to the development of platforms in order to support collection of radiometric measurements (e.g. sun tracking radiance platform). Sensors for measurement of aerosol properties will also be tested during this project (e.g. HSP1, iSPEX) for improved atmospheric correction of satellite data. Also included are sensors for characterisation of the underwater light climate (KdUino). Other systems will be tested for their ability to directly measure water quality parameters such as chlorophyll-a (CLAM), water colour, turbidity and phosphate (FreshWater Watch). Finally, the capacity of sensors to be used over a broad network of non-professionals will be investigated (e.g. drones, KdUino, iSPEX, FreshWater Watch).

These sensors will be validated against reference instruments and methods during a series of coordinated field campaigns, with increasing levels of sensor and data integration. Prior to the field campaigns it is vital to outline the key performance indicators for each MONOCLE system in order to define the standards against which each sensor will be evaluated. This document details the instrument characteristics and key performance indicators (KPIs) for each MONOCLE system.

2. Overview of MONOCLE systems

Eight MONOCLE systems will be tested during the field campaigns (Table 1). Testing of some of these systems (e.g. the drone systems, KdUino and iSPEX systems) will also include testing by non-professional users, along with the FreshWater Watch method for citizen science measurements of water quality.

The TRLs for each MONOCLE system are listed in Table 2, indicating anticipated improvements for all sensors over the series of campaigns. The exception is the drone systems, as different sensors with different TRLs will be tested during each campaign.

Table 1. List of MONOCLE sensors and systems

System	Developer	Measurement
Prosumer RPAS drone systems	VITO/Sitemark	Water-leaving reflectance, Total Suspended Matter (TSM) and Chlorophyll-*a* (Chl-*a*)
HSP1	Peak Design Ltd	Global and diffuse spectral irradiance
CLAM	PML	Chl-*a*
Sun tracking radiance platform	PML	Water-leaving reflectance under optimal viewing angles
iSPEX	University of Leiden/DDQ	Aerosol optical thickness (AOT) and water contents (TBD)
KdUino	CSIC	Light attenuation coefficient (K_d)
WISPStation	Water Insight	Remote sensing reflectance (R_{rs})
FreshWater Watch	Earthwatch	Water colour, turbidity and phosphate

Table 2. Technology readiness levels (1-9) for each MONOCLE system, by campaign

Sensor	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Prosumer RPAS drone systems	DJI PH 4 + RGB 9	DJI PH4 + Micasense Red-edge 6	M200 + Multispectral Docking Station 5	DJI PH 4 + multispectral (with reservation) TBD	DJI PH 4 + multispectral (with reservation) TBD
HSP1	6	7	8	9	9
CLAM	4	5	6	6	7
Sun tracking radiometer platform	N/A	4	5	6	6
iSPEX	AOT: 9 Water quality parameter(s):	AOT: 9 Water quality parameter(s):	AOT: 9 Water quality parameter(s):	AOT: 9 Water quality parameter(s):	AOT: 9 Water quality parameter(s):

Sensor	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
	1 (pilot)	7	9	9	9
KdUino	4	5	5	6	7
WISPStation	8	TBD	TBD	TBD	TBD
FreshWater Watch	N/A	N/A	N/A	N/A	N/A

2.1. Prosumer Remotely Piloted Aircraft System (RPAS) drone systems

The Prosumer systems comprise imaging sensors on board drones for the observation of water-leaving reflectance and water quality parameters including total suspended matter (TSM) and chlorophyll-a (Chl-a; Figure 1) (Raymaekers et al. 2016). MONOCLE will investigate and define protocols on how those systems should be operated by local pilots or citizen science groups in order to obtain useful data for water quality mapping. These systems operated by pilots and will also be investigated for potential use by citizen science groups. The drones can be deployed manually and will be developed for automated deployment of flights from a docking station for a specific test case.

(a)

(b)

(c)

Figure 1. The Prosumer RPAS drone systems, including the (a) DJI PH 4 and (b) DJI M200 waterproof systems (www.dji.com), and (c) the drone docking station.

A summary of the drone systems for each campaign is detailed in Table 3. These include the two RPASs (Consumer DJI Phantom 4 pro and Professional DJI M200) with either a default RGB or multispectral MicaSense camera (+ irradiance at Lake Balaton, M17). Operation will vary from manual to autonomous, with citizen involvement in the latter campaigns (Lower Danube Delta and Black Sea, M32; Lake Tanganyika, M38).

Table 3. Details of Prosumer RPAS drone systems, by campaign

Details	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
System	Consumer DJI Phantom 4 pro (DJI PH 4)	Consumer DJI Phantom 4 pro	Professional DJI M200 (with reservation)	Consumer DJI Phantom 4 pro (with reservation)	Consumer DJI Phantom 4 pro
Camera	Default RGB	Multispectral MicaSense + irradiance	Multispectral MicaSense (with reservation)	Multispectral MicaSense (with reservation)	Multispectral
Operation	Manual	Manual	Autonomous (with supervision)	Manual, with citizen involvement	Manual, with citizens
Take-off and landing method	From shore	From boat	From shore	From boat	TBD
Measurements	Water-leaving reflectance and TSM	Water-leaving reflectance, TSM and Chl-*a*	Water-leaving reflectance, TSM and Chl-*a*	Water-leaving reflectance, TSM and Chl-*a*	Water-leaving reflectance, TSM and Chl-*a*

The drone cameras measure digital numbers (DN), which are converted to water-leaving reflectance, from which total suspended matter (TSM) and chlorophyll-a (Chl-a, for multispectral cameras only; Table 4) are again derived. Water-leaving reflectances will be validated with those from a calibrated TriOS Ramses, ASD Field Spectrometer or WISP (Water Insight), while TSM and Chl-a will be validated with laboratory measurements. The RGB and multispectral data from the prosumer system will also be intercompared and checked against a high-end professional RPAS system (M17 or M29) with a hyperspectral camera. The exact precision (measured reproducibility) and accuracy (offset between sensor value and reference value) will be tested in the field campaigns.).

There is available battery power for approximately 1200 images per charge, with a maximum of 4000 images per memory card (Table 5). Calibration is either by reference targets in field or irradiance sensor on drone, with the best option selected for latter campaigns. The length of time before service is to be determined.

The drone systems range from 1.388 kg (DJI PH4 + RGB camera) to approximately 3.800 kg (DJI M200 + multispectral camera; Table 6). The DJI PH4 drone is shockproof, while the DJI M200 system is drop and shockproof. The drone systems can be carried in a box (50 x 30 x 30 cm), while the docking station for the Stockholm lakes campaign (MS29) requires an additional larger container (2.5 x 2.5 x 1 m). Insurance costs are approximately €125-150 per year per instrument, and purchase costs range from €1,300 (DJI PH4) to €8,000 (DJI M200) with an additional €5,000 for the multispectral + irradiance camera (MicaSense). Annual maintenance and calibration costs are currently unknown.

Deployment conditions are summarised in Table 7. The DJI M200 can be operated over a slightly broader range of environmental conditions (-20-45°C, 95% humidity, 12 m/s wind speed) than the DJI PH4 drone system (1-40°C, 75% humidity, 10 m/s wind speed). However, both systems are neither waterproof nor tolerant to rain. Observation height for all systems is limited to 100 m due to regulations. Illumination conditions can be variable, however the cameras must be positioned to look away from the sun (>90°). Deployment is either manual (human operator, whether professional or citizen) or in the case of the Stockholm Lakes campaign (M29) deployment is autonomous from the drone docking station. Flight regulations and environmental restrictions must be considered on a site-by-site basis.

Mains power is required for all campaigns (220V AC) for recharging of drone batteries (Table 8). Battery charge time is one hour, with live time from full charge varying from 14-32 minutes, depending on payload.

Both professionals and citizens are the target users of the drone systems, therefore training duration will vary accordingly at 1-2 days (Table 9). Pilot supervision will be required for the campaigns with automated systems (Stockholm Lakes, M29) or citizen operation of drones (Lower Danube Delta and Black Sea, M32 and Lake Tanganyika, M38). Rates of success of citizen science measurements and voluntary follow-up are to be determined. A user operational manual will be drafted, with a final document produced by the last campaign.

Table 4. Measurement Parameters – Prosumer RPAS drone systems

Variable 1	
Parameter	Water-leaving reflectance
Units of Measurement	Digital Number (DN) converted to water-leaving reflectance (sr^{-1})
Measurement range	440-650 nm (RGB) 400-720 nm (multispectral)
Precision of measurement (%)	TBD
Standard / high performance reference measurement against which accuracy is being assessed	TriOS Ramses, ASD Field Spectrometer, WISP
Target performance accuracy (%)	TBD
Variable 2	
Parameter	Total Suspended Matter (TSM)

Units of Measurement	DN converted to g/m^3
Measurement range	Expected saturation 50-100 g/m^3 (RGB) Switch from red band to NIR band for TSM retrieval when saturation occurs (multispectral)
Precision of measurement (%)	TBD
Standard / high performance reference measurement against which accuracy is being assessed	Lab measurement (gravimetric)
Target performance accuracy (%)	TBD
Variable 3	
Parameter	Chlorophyll-*a* (multispectral only, not RGB)
Units of Measurement	DN converted to mg/m^3
Measurement range	TBD
Precision of measurement (%)	TBD
Standard / high performance reference measurement against which accuracy is being assessed	Lab measurement (spectrophotometry or HPLC)
Target performance accuracy (%)	TBD

Table 5. Measurement Reproducibility – Prosumer RPAS drone systems

Parameter	**M7 Loch Leven (Scottish Lochs, UK)**	**M17 Lake Balaton (Hungary)**	**M29 Stockholm Lakes (Sweden)**	**M32 Lower Danube Delta and Black Sea (Romania)**	**M38 Lake Tanganyika (Tanzania)**
Number of Measurements per charge	Approx. 1200 images	Approx. 1200 images	Approx. 1200 images	Approx. 1200 images	Approx. 1200 images
Number of measurements for available memory	Max 4000 (32Gb card)	Max 4000 (32Gb card)	Max 4000 (32Gb card)	Max 4000 (32Gb card)	Max 4000 (32Gb card)
Number of measurement before service requirements/disposal	TBD	TBD	TBD	TBD	TBD
Calibration requirements	Reference targets in field	Irradiance sensor on drone	Best option	Best option	Best option

Table 6. Instrument characteristics and costs – Prosumer RPAS drone systems

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Weight (kg)	1.388 kg	1.900 kg	~ 3.800 kg	1.900 kg	1.900 kg
Durability (drop/shock proof)	Shockproof / not drop proof	Shockproof / not drop proof	Shockproof & drop proof	Shockproof / not drop roof	Shockproof / not drop proof
Transport requirements	Carry-on box (50 X 30 X 30 cm)	Carry-on box (50 X 30 X 30 cm)	Large container to transport docking station (2.5 x 2.5 x 1 m)	Carry-on box (50 X 30 X 30 cm)	Carry-on box (50 X 30 X 30 cm)
Insurance required? If so, approximate Cost (€)	Yes - Approx. €125/year	Yes - Approx. €125/year	Yes – Approx. €150/year	Yes - Approx. €125/year	Yes - Approx. €125/year
Approximate Purchase Cost (€)	€1300	€1300 + €5000 (camera + irradiance sensor)	€8000	€1300+ €5000 (camera + irradiance sensor)	€1300 + €5000 (camera + irradiance sensor)
Annual Maintenance Cost (€)	TBD	TBD	TBD	TBD	TBD
Calibration costs (€) and frequency (months)	TBD	TBD	TBD	TBD	TBD
Target users	Citizen	Prosumers	Professional	Citizen	Citizen

Table 7. Conditions for deployment – Prosumer RPAS drone systems

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Temperature range (°C)	DJI PH 4: 0 – 40° C	DJI PH 4: 0 – 40° C	DJI Matrice M200: -20 – 45° C	DJI PH 4: 0 – 40° C	DJI PH 4: 0 – 40° C
Humidity (0-100%)	Max 75%	Max 75%	Max 95%	Max 75%	Max 75%
Wind speed	10	10	12	10	10

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
maximum (m/s)					
Rainfall intensity (1: Drizzle to 5: Torrential rain)	1				
Immersion in water (1: Splash proof 2: state depth in m)	Not Waterproof				
Depth of Water (m)	N/A				
Water flow velocity	N/A				
Altitude/height of observation	Variable Up to 100m (regulation limitations)	Variable Up to 100m (regulation limitations)	Variable Up to 100m (regulation limitations)	Variable Up to 100m (regulation limitations)	Variable Up to 100m (regulation limitations)
Illumination conditions	Can be variable	Can be variable	Can be variable	Can be variable	Can be variable
Position of sun to the observation	Camera positioned away from sun	Camera positioned away from sun	Camera positioned away from sun	Camera positioned away from sun	Camera positioned away from sun
Platform deployment requirements	Human operator	Human operator	Automated system monitored by human operator	Human operator	Human operator/citizen
Deployment from shore/boat	Shore	Boat	Autonomous	Boat	Whichever is more relevant
Other operational constraints	Regulations, Environmental conservation considerations				

Table 8. Power requirements for deployment – Prosumer RPAS drone systems

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
External Power requirements	220V AC				
Battery Charge Time	1 hour				

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Battery live time from full charge	28 min	14 min	20-32 (depending on payload	14 min	14 min

Table 9. Operator training and response/uptake – Prosumer RPAS drone systems

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Training required	N/A	N/A	Professional (2 days)	Citizen training (1 day) Flying with drone according to instructions	Citizen training (1 day) Flying with drone according to instructions
Supervision requirements	N/A	N/A	Yes, pilot supervising automated system.	Yes, pilot supervision.	Yes, pilot supervision.
Number of operators required	N/A	N/A	1	1	1
Success rate (% of valid samples recorded)	N/A	N/A	TBD	TBD	TBD
Voluntary follow-up (does operator wish to continue using the sensor right away)	N/A	N/A	TBD	TBD	TBD
Clarity of instruction materials (score on evaluation form)	Draft document	Draft document	User Operational Manual Version 1	User Operational Manual Version 1 - update	Final user operational Manual

2.2. HSP1

The HSP1 (Peak Design Ltd.) uses a novel optical design to measure global, direct and diffuse spectral irradiance without moving parts and at significantly reduced cost compared to existing methods. This prototype is a hyperspectral sensor based on a previous broadband radiometer, the SPN1 (Wood et al., 1999; Wood et al., 2017). The measurements can be used for estimation of aerosol and other atmospheric constituents, and also for correcting and improving on satellite retrievals of surface reflectance by removing the confounding effects of atmospheric absorption. Deployment is primarily by fixed installation, however use on a buoy or Autonomous Surface Vehicle (ASV) will be investigated. The HSP1 will also be used as a reference sensor for other instruments in the MONOCLE project.

(a) (b)

Figure 2. Prototype HSP1 mounted on the (a) James Clark Ross research vessel and (b) roof of the Plymouth Marine Laboratory.

The HSP1 will be calibrated against a laboratory radiometer (National Physical Laboratory), with field measurements assessed against a sun photometer (Table 10). Measurement precision is in the range of 3-5%, while target performance accuracy is 5%.

There is available memory for collection of 1 year of measurements at 1-minute intervals, and calibration is required every 2 years by the manufacturer (Table 11).

The sensor weighs 6 kg and is not drop/shock proof, however is suitable for all ground weather conditions (Table 12). For the Stockholm lakes campaign (MS29), the instrument will be suitable for all surface water conditions as well. The instrument is transported in a standard pelicase or similar, with insurance required for a value of €10,000-15,000. Approximate purchase cost is €10,000-15,000, with calibration costs of €500 every 2 years. Maintenance is minimal, consisting of periodic cleaning & desiccant replacement.

Deployment conditions are summarised in Table 13. The platform can be operated over a broad range of climate conditions, including temperatures of 0-50°C (Loch Leven, M7) and this range will be extended to -20-60°C for Lake Balaton (M17). Deployment wind speeds can be up to 20 m/s (Loch Leven, M7) evolving to up to 30 m/s (Lake Balaton, M17). The sensor is splash proof (Loch Leven, M7) and will be able to be immersed to 1m depth for the Lake Balaton campaign (M17). Deployment will be shore based on a fixed mounting platform (Loch Leven, M7), and possibly by boat or buoy (Stockholm Lakes, M29). Observations are possible in all illumination conditions and sun positions.

Power requirements for deployment are 12V 1A (Loch Leven, M7) or <12V 0.3A (Lake Balaton, M17) direct to mains or large solar panel and battery. Battery is external, and the sensor is intended for permanent long-term operation.

Professionals are the target users of the sensor, therefore the expected training duration is short.

Table 10. Measurement parameter – HSP1

Variable 1	
Parameter	Global and diffuse spectral irradiance
Units of Measurement	W m^{-2} nm^{-1}
Measurement range	Spectral range 350nm – 1050nm
Precision of measurement (%)	3% - 5%
Standard / high performance reference measurement against which accuracy is being assessed	Lab calibration to NPL, comparison to sunphotometer (limited wavelengths).
Target performance accuracy (%)	5%

Table 11. Measurement Reproducibility –HSP1

Parameter	**M7 Loch Leven (Scottish Lochs, UK)**	**M17 Lake Balaton (Hungary)**	**M29 Stockholm Lakes (Sweden)**	**M32 Lower Danube Delta and Black Sea (Romania)**	**M38 Lake Tanganyika (Tanzania)**
Number of Measurements per charge	N/A				
Number of measurements for available memory	1 Yr @ 1-min sampling				
Number of measurement before service requirements/disposal	N/A				
Calibration requirements	2 Yr (return to manufacturer)				

Table 12. Instrument characteristics and costs – HSP1

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Weight (kg)	6				
Durability (drop/shock proof)	Not drop/shock proof. All ground weather conditions	TBD	All water surface conditions	TBD	TBD
Transport requirements	Large Peli case or similar.				
Insurance required? If so, approximate Cost (€)	Insure for value of €10k – €15k				
Approximate Purchase Cost (€)	€10k – €15k				
Annual Maintenance Cost (€)	Minimal – periodic cleaning & desiccant replacement				
Calibration costs (€) and frequency (months)	€500 at 2 years				
Target users (professional/citizen)	Professional				

Table 13. Conditions for deployment – HSP1

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Temperature range (°C)	0° - 50°	-20 ° - 60°	TBD	TBD	TBD
Humidity (0-100%)	0 – 100%				
Wind speed maximum (m/s)	20 $m.s^{-1}$	30 $m.s^{-1}$	TBD	TBD	TBD
Rainfall intensity (1: Drizzle to 5: Torrential rain)	5				
Immersion in water (1: Splash proof 2: state depth in m)	1	2 (1m)	TBD	TBD	TBD
Depth of Water	N/A				

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
(m)					
Water flow velocity	N/A				
Altitude/height of observation	Near water surface				
Illumination conditions	All conditions				
Position of sun to the observation	All conditions				
Platform deployment requirements	Fixed mounting platform	TBD	Possibly buoy or boat	TBD	TBD
Deployment from shore/boat	Shore	TBD	Possibly buoy or boat	TBD	TBD
Other operational constraints	N/A				

Table 14. Power requirements for deployment – HSP1

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
External Power requirements	12V 1A Direct to mains, or large solar panel & battery	<12V 0.3A Direct to mains, or small solar panel & battery	TBD	TBD	TBD
Battery Charge Time	External battery - TBD				
Battery live time from full charge	Intended for permanent long-term operation.				

2.3. CLAM

The CLAM is designed to provide accurate, high-frequency measurements of chlorophyll-a concentration at a relatively low cost. At present, the CLAM is a bench top instrument with flow-through setup, however the ultimate goal is for submersible deployment.

CLAM in situ measurements will be validated against accredited measurements of extracted Chl-a (e.g. High Performance Liquid Chromatography (HPLC), Table 15). Measurement range and precision are to be tested, while target performance accuracy will be <10%.

Using mains power for CLAM operation, integration time is set to 1 second and measurements are saved to a data logger, currently a laptop (Table 16). Available memory depends upon the laptop used (e.g. 10's of thousands), and the number of measurements before service and the calibration requirements are to be determined.

The sensor weighs 1-5 kg and is not drop or shock proof (Table 17). The instrument is transported by peli-case, and insurance is not required. The target purchase cost for the final product is €1,000 - €10,000, depending on sensitivity, for the sensor and €1,000 for the laptop, with minimal annual maintenance or calibration costs.

Deployment conditions are summarised in Table 18. The sensor can be operated over a broad range of climate conditions (5-40°C and 1-100% humidity), however the prototypes are not waterproof or splashproof and for bench-top deployment only. The sensor is independent of the ambient light climate (illumination and sun position), and is deployed with a human operator from the shore or a lab setting. A key limitation for use of the CLAM is the availability of the prototype from the manufacturer.

Power requirements for CLAM deployment are direct to mains only (
Table 19).

Professionals are the target users of the sensor, therefore the expected training duration is short. A success rate of 95% valid samples is anticipated.

Table 15. Measurement parameter– CLAM

Variable 1	
Parameter	Chlorophyll-*a*
Units of Measurement	mg m^{-3}
Measurement range	TBD
Precision of measurement (%)	TBD
Standard / high performance reference measurement against which accuracy is being assessed	Total Chl-*a* (e.g. from HPLC)
Target performance accuracy (%)	10%

Table 16. Measurement Reproducibility – CLAM

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Number of Measurements per charge	N/A (integration time currently set to 1 second but variable)	TBD			
Number of measurements for available memory	N/A (depends on storage device e.g 10's of thousands for a laptop)	TBD			
Number of measurement before service requirements/disposal	TBD				
Calibration requirements	TBD				

Table 17. Instrument characteristics and costs – CLAM

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Weight (kg)	1-5kg	TBD			
Durability (drop/shock proof)	none	TBD			
Transport requirements	Peli-Case	TBD			
Insurance required? If so, approximate Cost (€)	no	TBD			
Approximate Purchase Cost (€)	€1k - €10k	TBD			
Annual Maintenance Cost (€)	N/A				

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Calibration costs (€) and frequency (months)	N/A				
Target users (professional/citizen)	Professional				

Table 18. Conditions for deployment – CLAM

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hugary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Temperature range (°C)	5-40	TBD			
Humidity (0-100%)	0-100	TBD			
Wind speed maximum (m/s)	N/A				
Rainfall intensity (1: Drizzle to 5: Torrential rain)	N/A				
Immersion in water (1: Splash proof 2: state depth in m)	0	TBD			
Depth of Water (m)	0 - currently lab deployment only	TBD			
Water flow velocity	N/A				
Altitude/height of observation	N/A				
Illumination conditions	N/A				
Position of sun to the observation	N/A				
Platform deployment requirements	Human operator				
Deployment from shore/boat	Shore/lab	TBD	TBD	TBD	TBD

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hugary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Other operational constraints	Availability of prototype from manufacturer				

Table 19. Power requirements for deployment – CLAM

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
External Power requirements	Mains Power				
Battery Charge Time	N/A				
Battery live time from full charge	N/A				

2.4. Sun-tracking radiometer platform

The sun tracking radiometer platform is being designed by Plymouth Marine Laboratory for control of the azimuth viewing angle during radiometer deployment on moving vessels. The platform is ship mounted for the purpose of maintaining azimuth orientation of radiometers with respect to the sun and ship heading.

The accuracy of the platform can be determined against records of ship heading and solar position, from GPS and compass records (Table 20). The precision of the measurement will be 1° which is determined by the stepper motor geometry and not subject to degradation. The key test is for the viewing azimuth angle to be kept consistently around 135° and at least >90° with respect to solar azimuth, while ship heading information is available.

Measurements will be continuous at least every 10 seconds (depending on sensor choice rather than the sun-tracking platform) by the Sweden campaign (M29), and no calibration is required (Table 21). 1 year of data for the platform viewing angle and associated sensors can be acquired for the available memory, and the expected lifetime of the platform is 5 years.

The platform weighs 10 kg without sensors (Lake Balaton, MS17) or 5 kg with printable parts (Lower Danube Delta and Black Sea, M32; Table 22). The platform is drop/shock proof, however the impact on the motor axle is unknown. Transport is by standard shipping, with no insurance required. Approximate purchase cost is €5,000 however a lower cost of €2,000 will be obtained using printable parts. There are no known maintenance or calibration costs.

Deployment conditions are summarised in

Table 23. The platform can be operated over a broad range of climate conditions, and is built to IP65 (dust proof and resistant to water projected from a nozzle). The platform should be optimally placed anywhere on the ship, except where the sun is expected to occur straight in front of centre of axial movement (Lake Balaton, M17), however operational protocols will be developed for Lower Danube Delta and Black Sea (M32) to define the optimal positioning. Deployment is by boat, and 2 operators are likely required for installation for health and safety purposes (lifting, handling).

Power requirements for deployment are direct to mains or converter (Lake Balaton, M17), however the possibility of solar power operation will be investigated (Stockholm Lakes, M29; Table 24). Battery charge and live time are currently not determined.

Professionals are the target users of the platform, and it is expected that training duration is short (15 minutes) with no supervision or operators required. Success rate shall be 100%.

Table 20. Measurement parameter – Sun tracking radiometer platform

Variable 1	
Parameter	Azimuth viewing angle
Units of Measurement	Degrees
Measurement range	-170 to 170°
Precision of measurement (%)	1°
Standard / high performance reference measurement against which accuracy is being assessed	Calculated from ship heading and solar position
Target performance accuracy (%)	viewing angle kept always >90° from solar azimuth (100% of time when a heading is available), therefore <1% uncertainty expected.

Table 21. Measurement Reproducibility – Sun tracking radiometer platform

Parameter	**M7 Loch Leven (Scottish Lochs, UK)**	**M17 Lake Balaton (Hungary)**	**M29 Stockholm Lakes (Sweden)**	**M32 Lower Danube Delta and Black Sea (Romania)**	**M38 Lake Tanganyika (Tanzania)**
Number of measurements per charge	N/A	N/A	continuous every 10 seconds	TBD	
Number of measurements for available memory	N/A	at least 1 year of data from azimuth control and attached sensors (gps, compass, radiometers, weather station)			
Measurements before service requirements / disposal	N/A	Expected life time 5 years. Maintenance protocol not yet known.			
Calibration requirements	N/A	Free of calibration			

Table 22. Instrument characteristics and costs – Sun tracking radiometer platform

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Weight (kg)	N/A	10kg (without sensors)	N/A	5 kg with printable parts	TBD
Durability (drop/shock proof)	N/A	drop/shock proof except for impact on motor axle (unknown)	N/A	TBD	TBD
Transport requirements	N/A	Standard shipping < 25 kg with sensors			
Insurance required? If so, approximate Cost (€)	N/A	No	N/A	TBD	TBD
Approximate Purchase Cost (€)	N/A	€5000		€2000 when using printed components	
Annual Maintenance Cost (€)	N/A	TBD	N/A	TBD	TBD
Calibration costs (€) and frequency (months)	N/A	None	N/A	TBD	TBD
Target users (professional/citizen)	Professional				

Table 23. Conditions for deployment – Sun tracking radiometer platform

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Temperature range (°C)	N/A	0-70 (commercial range)			
Humidity (0-100%)	N/A	0-100%			
Wind speed maximum (m/s)	N/A	20 + ship speed			
Rainfall intensity (1: Drizzle to 5: Torrential rain)	N/A	5			
Immersion in water (1: Splash	N/A	IP65			

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
proof 2: state depth in m)					
Depth of Water (m)	N/A				
Water flow velocity	N/A				
Altitude/height of observation	N/A				
Illumination conditions	N/A				
Position of sun to the observation	N/A	optimally anywhere except straight in front of centre of axial movement N/A		operational protocols developed to check optimal positioning TBD	
Platform deployment requirements	N/A	2 operators likely required for H&S (lifting, heights)			
Deployment from shore/boat	N/A	on boat / ship			
Other operational constraints	N/A				

Table 24. Power requirements for deployment – Sun tracking radiometer platform

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
External Power requirements	N/A	Direct mains / converter	Direct to mains or converter, Possibly solar power operated		
Battery Charge Time	N/A	TBD	TBD	TBD	TBD
Battery live time from full charge	N/A	TBD	TBD	TBD	TBD

2.5. iSPEX

The iSPEX is a smartphone add-on which measures the aerosol optical thickness (AOT) in the atmosphere and concentrations of chemical substances in water (Figure 3). It is a low-cost extension of the smartphone camera and was successfully deployed for a large-scale citizen science campaign in the Netherlands for measurement of AOT (Snik et al., 2014).

Figure 3. iSPEX smarphone add-on for measurement of aerosol optical thickness and water quality parameters.

The iSPEX measurements of AOT will be validated against a groundSPEX, MODIS or AERONET measurements (Table 25). AOT measurement range is <0.8, with precision >5% per individual measurement and <1% when stacking >50 measurements. Target performance accuracy is <10%. The iSPEX will also be investigated for its ability to retrieve water quality parameters, however these details are to be determined following the pilot study at Loch Leven (M7).

The iSPEX measurement reproducibility is dependent on the smartphone used (Table 26). Generally, >10-100 measurements can be anticipated per charge and for the available memory. There is no limit to the number of measurements before servicing is required, and no calibration is required for measurement of AOT. For water quality parameters, 1-2 calibration measurements are anticipated per session by the Lake Balaton campaign (M17).

The sensor is small and durable, weighing <50g (Table 27). The approximate purchase cost is €10 for the existing iSPEX for AOT measurement, and approximately €10 for the new hardware to measure water quality parameters. No insurance is required and there are no annual maintenance costs. There are no calibration costs for AOT, and calibration for water quality parameters are estimated as <€10.

Deployment conditions are summarised in Table 28. The sensor can be operated over a broad range of climate conditions, however dry clear sky conditions are required for measurement of AOT (TBD for water quality parameters). The sensor is for use above-water only and is not waterproof. The sun position needs to be 90° to either side for AOT (TBD for water quality parameters). Deployment is by attachment to smartphone, using a human operator from the boat or shore.

The iSPEX itself requires no external power, however the smartphone it attaches to must be charged by mains power (Table 29). The battery charge time and live time from full charge are dependent on the smartphone and will vary.

Citizens are the target users of the iSPEX, however the sensor is simple to use and training takes approximately 10 minutes to complete (Table 30). No supervision is required, with one operator required per sensor. The success rate for AOT measurements is 100%, however this is yet to be determined for water quality parameters.

Table 25. Measurement parameters - iSPEX

Variable 1	
Parameter	Aerosol Optical Thickness (AOT)
Units of Measurement	Dimensionless
Measurement range	0-0.8
Precision of measurement (%)	>5% per individual measurement; <1% when stacking >50 measurements
Standard / high performance reference measurement against which accuracy is being assessed	groundSPEX, MODIS, AERONET
Target performance accuracy (%)	<10% offset
Variable 2	
Parameter	Water quality parameters (to be determined following M7 Loch Leven campaign)
Units of Measurement	TBD
Measurement range	TBD
Precision of measurement (%)	TBD
Standard / high performance reference measurement against which accuracy is being assessed	TBD
Target performance accuracy (%)	TBD

Table 26. Measurement Reproducibility – iSPEX

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Number of Measurements per charge	Smartphone-dependent; generally >10 at least, >100 likely				
Number of measurements for available memory	Smartphone-dependent; generally >10 at least, >100 likely				

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Number of measurement before service requirements/ disposal	Unlimited				
Calibration requirements	AOT: None	AOT: None Water: 1-2 calibration measurements per session (TBD)	AOT: None Water: 1-2 calibration measurements per session (TBD)	AOT: None Water: 1-2 calibration measurements per session (TBD)	AOT: None Water: 1-2 calibration measurements per session (TBD)

Table 27. Instrument characteristics and costs – iSPEX

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Weight (g)	<50 g				
Durability (drop/shock proof)	Very durable				
Transport requirements	No requirements				
Insurance required? If so, approximate Cost (€)	No				
Approximate Purchase Cost (€)	~10€ (current iSPEX)	~10€ (new hardware)	~10€ (new hardware)	~10€ (new hardware)	~10€ (new hardware)
Annual Maintenance Cost (€)	None				
Calibration costs (€) and frequency (months)	None (AOT)	<10€ total (water), re-usable	<10€ total (water), re-usable	<10€ total (water), re-usable	<10€ total (water), re-usable
Target users (professional/citizen)	Citizen				

Table 28. Conditions for deployment – iSPEX

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Temperature range (°C)	Any				
Humidity (0-100%)	Any				
Wind speed maximum (m/s)	Any				
Rainfall intensity (1: Drizzle to 5: Torrential rain)	AOT: 0 (need clear sky)	AOT: 0 (need clear sky) Water: 1? (TBD)	AOT: 0 (need clear sky) Water: 1? (TBD)	AOT: 0 (need clear sky) Water: 1? (TBD)	AOT: 0 (need clear sky) Water: 1? (TBD)
Immersion in water (1: Splash proof 2: state depth in m)	0, above-water only				
Depth of Water (m)	Any				
Water flow velocity	Any				
Altitude/height of observation	Any				
Illumination conditions	AOT: clear sky	AOT: clear sky water: TBD	AOT: clear sky water: TBD	AOT: clear sky water: TBD	AOT: clear sky water: TBD
Position of sun to the observation	AOT: 90 deg to either side	AOT: 90 deg to either side water: TBD	AOT: 90 deg to either side water: TBD	AOT: 90 deg to either side water: TBD	AOT: 90 deg to either side water: TBD
Platform deployment requirements	Smartphone operated by human				
Deployment from shore/boat	Either				
Other operational constraints	None				

Table 29. Power requirements for deployment – iSPEX

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
External Power requirements	Add-on itself requires no power, smartphone needs to be charged				
Battery Charge Time	Smartphone-dependent				
Battery live time from full charge	Smartphone-dependent				

Table 30. Operator training and response/uptake – iSPEX

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Training required	Simple, ~10 minutes, citizens				
Supervision requirements	None				
Number of operators required	1				
Success rate (% of valid samples recorded)	AOT: 100%	AOT: 100% Water: TBD	AOT: 100% Water: TBD	AOT: 100% Water: TBD	AOT: 100% Water: TBD
Voluntary follow-up (does operator wish to continue using the sensor right away)	TBD				
Clarity of instruction materials (score on evaluation form)	TBD				

2.6. KdUINO

The KdUINO (Kdu-stick) is a low-cost device to estimate the light extinction coefficient (Kd) (Bardaji et al., 2016). It is based on an array of quasi-digital sensors (light to frequency converters) that estimate light intensity at different depths. The instrument is inspired by the design developed for a previous FP7 project (CITCLOPS). However, taking into account new power requirements, this version will employ a new sensor and hardware. Additionally, a second version will be developed with improved accuracy and the addition of temperature sensors. Deployment is manually by submerging the sensor to desired depth using a surface buoy (Figure 4).

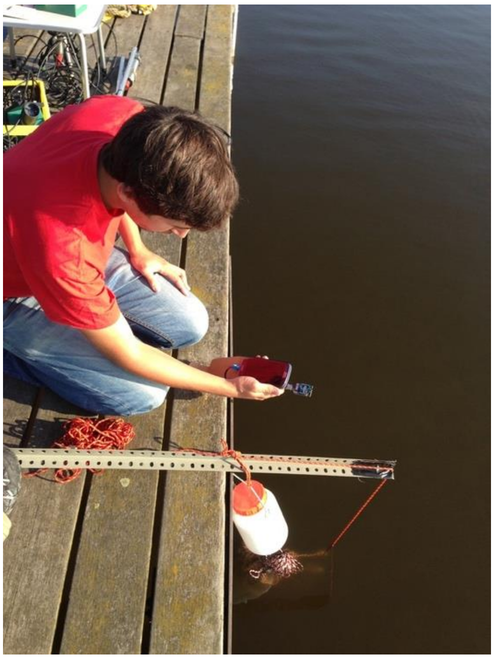


Figure 4. KdUINO deployment for the FP7 project CITCLOPS (taken from http://www.citclops.eu/transparency/measuring-water-transparency)

The KdUINO measurements of the light extinction coefficient will be validated in the laboratory against TriOS radiometers (Table 31). The measurement range is 0-10 m-1, with precision and target performance accuracy to be tested during the MONOCLE campaigns.

There is available memory for collection thousands of measurements at 1-second intervals (Table 32). Calibration and servicing requirements are to be determined.

The KdUINO weight and durability are to be determined, and the sensor can be shipped with no insurance required (Table 33). Approximate purchase cost of the KdUINO is €150 + €800 for laptops (as compared to €30,000 for a CTD and €10,000 for TriOS Ramses). There are no calibration costs and maintenance costs are to be evaluated during the MONOCLE project.

Deployment conditions are summarised in Table 34. The KdUINO can be operated over a broad range of climate conditions, including temperatures of 0-40°C and humidity of 0-100%, however maximum wind speed is to be tested during the project campaigns. The sensor can be deployed in all rainfall conditions, is waterproof and can be used up to 30 m depth. The sensor can be deployed in sun and cloudy conditions, and must be positioned between 0-50° from the sun. Deployment is with a buoy from the shore or a boat.

Mains power is required for recharging (5-12V), and battery charge time is 4 hours (Table 35). Live time from full charge is to be tested during the MONOCLE campaigns.

Citizens are the target users of the KdUINO, and operator training requirements and success rates are to be determined during the project.

Table 31. Measurement parameter – KdUINO

Variable 1	
Parameter	Light extinction
Units of Measurement	m^{-1}
Measurement range	0-10 m^{-1}
Precision of measurement (%)	To be tested.
Standard / high performance reference measurement against which accuracy is being assessed	Lab measurement against TriOS Ramses instrumentation
Target performance accuracy (%)	To be tested.

Table 32. Measurement Reproducibility – KdUINO

Parameter	**M7 Loch Leven (Scottish Lochs, UK)**	**M17 Lake Balaton (Hungary)**	**M29 Stockholm Lakes (Sweden)**	**M32 Lower Danube Delta and Black Sea (Romania)**	**M38 Lake Tanganyika (Tanzania)**
Number of Measurements per charge	1 measurement per second				
Number of measurements for available memory	Thousands				
Number of measurement before service requirements/disposal	TBD				
Calibration requirements	TBD				

Table 33. Instrument characteristics and costs – KdUINO

Parameter	**M7 Loch Leven (Scottish Lochs, UK)**	**M17 Lake Balaton (Hungary)**	**M29 Stockholm Lakes (Sweden)**	**M32 Lower Danube Delta and Black Sea (Romania)**	**M38 Lake Tanganyika (Tanzania)**
Weight (kg)	TBD				
Durability (drop/shock proof)	TBD				

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Transport requirements	Shipped				
Insurance required? If so, approximate Cost (€)	No				
Approximate Purchase Cost (€)	KdUINO - €150 Laptops - €800				
Annual Maintenance Cost (€)	TBD				
Calibration costs (€) and frequency (months)	0				
Target users (professional/citizen)	Citizen				

Table 34. Conditions for deployment – KdUINO

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Temperature range (°C)	0 – 40				
Humidity (0-100%)	0 – 100%				
Wind speed maximum (m/s)	TBD				
Rainfall intensity (1: Drizzle to 5: Torrential rain)	5				
Immersion in water (1: Splash proof 2: state depth in m)	Waterproof				
Depth of Water (m)	1 – 30 meters				
Water flow velocity	TBD				
Altitude/height of observation	N/A				
Illumination conditions	Sun and cloud				

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Position of sun to the observation	0 – 50 °				
Platform deployment requirements	Buoy				
Deployment from shore/boat	Shore and boat				
Other operational constraints	N/A				

Table 35. Power requirements for deployment – KdUINO

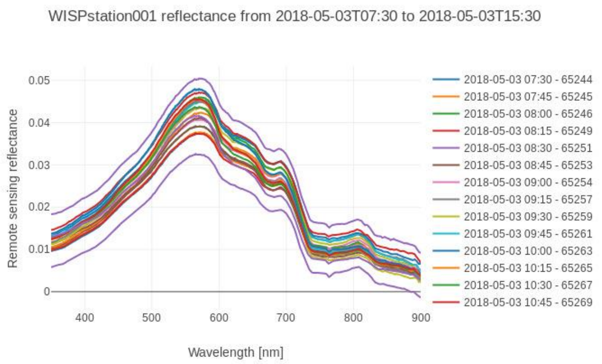
Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
External Power requirements	5-12V for recharging only				
Battery Charge Time	4 hours				
Battery live time from full charge	TBD				

2.7. WISPStation

The WISPStation (Water Insight Spectrometer Station) is a fixed spectroradiometer setup which measures the water-leaving reflectance (as remote sensing reflectance, Rrs(λ); Figure 5). From the measurements of Rrs(λ), the concentrations of water quality parameters (e.g. Chl-a, TSM, phycocyanin (PC), Kd and coloured dissolved organic matter (CDOM)) can be derived, while Rrs(λ) is directly useful in satellite system vicarious calibration. The measured (ir)radiances can also be used to validate the atmospheric correction of satellite images. The WISPStation is fixed to a pole or frame and is powered by a solar panel. It therefore operates autonomously, taking measurements every e.g. 15 minutes. Data are sent by the 3G network to WISPCloud, a cloud storage database and processing server operated by Water Insight.

The WISPStation technology is based on the handheld version of the instrument (WISP-3), which has been validated over inland and coastal waters with TriOS Ramses, ASD FieldSpec and TACCS field measurements of Rrs(λ) (Hommersom et al., 2012).

a



b

Figure 5. (a) Fixed WISPStation installation and (b) example output of $R_{rs}(\lambda)$ spectra.

The WISPStation will be internally vicariously calibrated by Water Insight against a reference instrument (gold standard instrument with calibration certification; Table 36). Reflectance spectra from the WISPStation will also be validated with other measurements during the MONOCLE field campaigns (e.g. TriOS Ramses). Measurement precision is 2%, depending on the ambient light variability and wave conditions), and target performance accuracy will be determined during the MONOCLE campaigns.

There is unlimited available memory for collection measurements, as data are uploaded directly to the WISPCloud (Table 37). The number of measurements before servicing will be tested for continuous operation for at least 3 months during the Loch Leven (M7) campaign. At present, calibration is expected to be once per year.

The sensor weighs approximately 20 kg and durability is to be determined during the MONOCLE campaigns (Table 38). The instrument is shipped in original cardboard box only, with local transport to site with sensors covered. The approximate purchase price is €40,000, with insurance and maintenance costs unknown. Calibration costs are expected to be €1,500 (excluding shipping) every 12 months.

Deployment conditions are summarised in Table 39. The platform can be operated over a broad range of temperatures (0-50°C), and humidity and wind speed tolerances will be determined during MONOCLE. The instrument is tolerant to high rainfall intensity and immersion to less than 1 m depth (although the instrument is not intended for use underwater). The depth of water where the WISPStation is installed should be greater than one optical depth (will be site dependent). The station should be optimally placed 1-5 m above the water level and away from any potential obstructions of the downward looking lens. The instrument should be north facing and is operational in all illumination conditions, but ideally requires a solar elevation of >30° and clear sky conditions. Deployment is possible from the shore on a fixed position pole, however a buoy deployment is currently being tested in Loch Leven. Other operational constraints include 3G network coverage, the presence of a stable platform, and the need to protect the installation from vandalism or theft.

The instrument is powered by its own solar panel, therefore there are no external power requirements for deployment (Table 40). The battery charge time is 2 hours (solar panel charges on a continuous basis), and the battery live time is approximately 3 days from full charge.

Professionals are the target users of the WISPStation. Although no training is required for instrument use, some training is recommended for retrieval of data from the WISPCloud API. Installation will be completed by Water Insight, and no maintenance is expected (although visual inspection is recommended when possible, and some cleaning may be required).

Table 36. Measurement parameter – WISPStation

Variable 1	
Parameter	Remote sensing reflectance, $R_{rs}(\lambda)$
Units of Measurement	sr^{-1}
Measurement range	At least 400-850 nm
Precision of measurement (%)	2% (depends on the ambient light variability and wave conditions)
Standard / high performance reference measurement against which accuracy is being assessed	Internally vicariously calibrated against reference instrument (gold standard instrument that is absolutely calibrated with certification)
Target performance accuracy (%)	TBD

Table 37. Measurement Reproducibility – WISPStation

Parameter	**M7 Loch Leven (Scottish Lochs, UK)**	**M17 Lake Balaton (Hungary)**	**M29 Stockholm Lakes (Sweden)**	**M32 Lower Danube Delta and Black Sea (Romania)**	**M38 Lake Tanganyika (Tanzania)**
Number of Measurements per charge	N/A				
Number of measurements for available memory	Unlimited as data are uploaded to WISPCloud				
Number of measurement before service requirements/disposal	TBD – will be tested for continuous operation over at least 3 months				
Calibration requirements	expected 1x per year				

Table 38. Instrument characteristics and costs – WISPStation

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Weight (kg)	Approx. 20 kg				
Durability (drop/shock proof)	TBD - Up to 1 m expected, but sensor casings are sensitive				
Transport requirements	Shipping in original cardboard box only. Local transport to site with sensors covered.				
Insurance required? If so, approximate Cost (€)	TBD				
Approximate Purchase Cost (€)	€40,000				
Annual Maintenance Cost (€)	TBD				
Calibration costs (€) and frequency (months)	€1,500 excluding shipping every 12 months (expected)				
Target users (professional/citizen)	Professionals				

Table 39. Conditions for deployment – WISPStation

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Temperature range (°C)	0 – 50				
Humidity (0-100%)	TBD				
Wind speed maximum (m/s)	TBD				
Rainfall intensity (1: Drizzle to 5: Torrential rain)	5				
Immersion in water (1: Splash proof 2: state depth in m)	Immersion to less than 1 m tested				
Depth of Water (m)	Preferably the water is deeper than the optical depth (site dependent)				
Water flow	N/A				

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
velocity					
Altitude/height of observation	Optimally 1-5 m above water level (considering access for maintenance and potential obstruction of the downward looking lens)				
Illumination conditions	All, but needs ideally a solar elevation >30° and clear sky conditions				
Position of sun to the observation	Ideally facing North				
Platform deployment requirements	Buoy installation is being tested	Preferably on a fixed position pole	Preferably on a fixed position pole	Preferably on a fixed position pole	Preferably on a fixed position pole
Deployment from shore/boat	Boat	TBD	TBD	TBD	TBD
Other operational constraints	Unobstructed view for irradiance sensor, 3G network coverage, stable platform, Protection from vandalism / theft.				

Table 40. Power requirements for deployment – WISPStation

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
External Power requirements	Provided by solar panel, no external requirements.				
Battery Charge Time	2 hrs (continuous)				
Battery live time from full charge	About 3 days without charging				

2.8. FreshWater Watch

The FreshWater Watch (FWW) methodology has been developed and used across the globe in more than 3000 freshwater ecosystems (https://freshwaterwatch.thewaterhub.org/). It is based on the use of a standard methodology by trained citizen scientists and requires the presence of the citizen scientist on location and the sampling of approximately 1 litre of lake/river water. Citizens follow a specific methodology to acquire a representative sample.

(a)

(b)

Figure 6. Measurement of (a) turbidity (Secchi tube) and (b) phosphate (P-PO_4) concentrations as part of the FreshWater Watch Citizen Science method.

The first step includes the acquisition of a number of ecosystem contextual observations including local land use, presence of pollution sources, followed by a number of optical and chemical measurements. Turbidity is determined using a calibrated Secchi tubes (14 – 240 NTU; Figure 6a). Water colour is measured as categorical data, recorded as the colour perceived by the citizen scientists using a dropdown menu. Algae presence is recorded by selection in the following categories: no algae, evenly dispersed algae, floating mats, attached algae or blue-green scum. The use of citizen science measurements of turbidity, water colour and algal presence has been shown to correlate well with phytoplankton density (Castilla et al., 2015). Chemical measurements are usually limited to dissolved nutrient concentrations, but microbial concentrations (coliforms) have also been measured in several projects, requiring additional logistics and infrastructure (Farnham et al., 2017). Nitrate concentrations are estimated colourimetrically using N-(1-Naphthyl)ethylenediamine in seven specific ranges from 0.2 mg/L to 10 mg/L N-NO3. Phosphate concentrations are also estimated colourimetrically using inosine enzymatic reactions in seven specific ranges from 0.02 mg/L to 1.0 mg/L P-PO4. All datasets include geographical coordinates and sampling time obtained using the FWW smartphone application or online tools.

The parameters included in the FreshWater Watch citizen science for MONOCLE will be water colour, turbidity and phosphate (Table 41). Phosphate measurements will be validated against a laboratory measurement (Skalar SAN++ system autoanalyzer with ammonium molybdate). Measurement precision is 43% (to be confirmed), and performance accuracy will be defined during the MONOCLE project.

There are no power or memory requirements for this data collection method. The FreshWater Watch measurement kit weighs 200g, is drop/shock proof and costs approximately €30 (Table 42).

Deployment conditions are summarised in Table 43. For phosphate measurement (Variable 3), water temperature and humidity can vary over a broad range (10-100°C, 0-100%). For assessment of water colour (Variable 1), the bottom must not be visible during assessment. Readings for phosphate must be undertaken in the shade. FreshWater Watch measurements are undertaken by human operators, and advance permission from the land/water owner is required.

Citizens are the target users of FreshWater Watch. For the Loch Leven (M7) and Lake Tanganyika (M38) campaigns, citizen scientists will be trained and equipped to take measurements under a project framework. For the Stockholm Lakes campaign (M29), citizen scientists already trained and active using FreshWater Watch will be engaged. Training requirements will vary according to each campaign, as outlined in Table 44.

Table 41. Measurement parameters – FreshWater Watch

Variable 1	
Parameter	Turbidity
Units of Measurement	NTU
Measurement range	14-240
Precision of measurement (%)	-
Standard / high performance reference measurement against which accuracy is being assessed	-
Target performance accuracy (%)	-
Variable 2	
Parameter	Water colour
Units of Measurement	Colourless, yellow, brown, green, other
Measurement range	-
Precision of measurement (%)	-
Standard / high performance reference measurement against which accuracy is being assessed	-
Target performance accuracy (%)	-
Variable 3	
Parameter	Phosphate concentration
Units of Measurement	mg/L P-PO_4
Measurement range	0.02-1.0
Precision of measurement (%)	Relative Standard Deviation = 43% (to be confirmed)
Standard / high performance reference measurement against which accuracy is being assessed	Skalar SAN++ system autoanalyzer with ammonium molybdate

Target performance accuracy (%)	TBD

Table 42. Instrument characteristics and costs – FreshWater Watch

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Weight (kg)	200g				
Durability (drop/shock proof)	Drop/shock proof				
Transport requirements	-				
Insurance required? If so, approximate Cost (€)	-				
Approximate Purchase Cost (€)	€30				
Annual Maintenance Cost (€)	-				
Calibration costs (€) and frequency (months)	-				
Target users (professional/citizen)	Project framework created that includes citizen scientists to be trained and equipped in August 2018.	-	Citizen scientists trained and active using FreshWater Watch	-	Project framework created that includes citizen scientists to be trained and equipped in coming months.

Table 43. Conditions for deployment – FreshWater Watch

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Temperature range (°C)	Phosphate: 10-100°C				
Humidity (0-100%)	Phosphate: 0-100%				

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Wind speed maximum (m/s)	N/A				
Rainfall intensity (1: Drizzle to 5: Torrential rain)	N/A				
Immersion in water (1: Splash proof 2: state depth in m)	N/A				
Depth of Water (m)	Water colour: bottom not visible				
Water flow velocity	N/A				
Altitude/height of observation	N/A				
Illumination conditions	Phosphate: reading in shade				
Position of sun to the observation	N/A				
Platform deployment requirements	Human operator				
Deployment from shore/boat	N/A				
Other operational constraints	Land/water owner permission				

Table 44. Operator training and response/uptake – FreshWater Watch

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
Training required	*Online training (required): 20 minutes *Face-to-Face training community leader	-	*Existing community – no additional training required.	-	*Before campaign (M9-17): Face-to-face training adapted to local community (as part of PhD

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
	(optional): Length 3 hrs *Available to non-technical users *Audiences: general public (e.g. members river trusts, outdoor groups, local community members), business employees, students				project) – 0.5 day at each of the 5 sites (village leaders, beach management units, fisheries officers, fishers, farmers and riparian communities in Kigoma) followed by quarterly F2F for quality check and feedback session. *Available to non-technical users
Supervision requirements	*Measurement: None *Management involved in sampling design, reporting, order kits, quality control by community group leader *Earthwatch team: Follow-up with community leader * Repetition of 10% of measurements by community leader or staff	-	*Measurement: None *Management involved in sampling design, reporting, order kits, quality control by community group leader *Earthwatch team: Follow-up with community leader	-	*Before: Regularly led by local PhD student, and community managers *Earthwatch team: Follow-up with community leader * Repetition of 10% of measurements by community leader or staff
Number of	Minimum one,	-	Minimum one,	-	Minimum one,

Parameter	M7 Loch Leven (Scottish Lochs, UK)	M17 Lake Balaton (Hungary)	M29 Stockholm Lakes (Sweden)	M32 Lower Danube Delta and Black Sea (Romania)	M38 Lake Tanganyika (Tanzania)
operators required	recommended two (related to safety)		recommended two (related to safety)		recommended two (related to safety). Planned groups of five.
Success rate (% of valid samples recorded)	From experience: > 95% of the records	-	From experience: > 95% of the records	-	From experience: > 95% of the records
Voluntary follow-up (does operator wish to continue using the sensor right away)	Possible	-	Possible	-	Possible
Clarity of instruction materials (score on evaluation form)	N/A	-	N/A	-	N/A

3. Exploitation and Dissemination

The information in this deliverable can be used in WP8 for dissemination and exploitation of the results from the field campaigns and to formulate initial reference specification sheets of the MONOCLE instrument set. Field training materials for citizen science measurements using iSPEX, KdUINO and the FreshWater Watch method will similarly be made available via the project website. In WP8, these documents will be structured for specific target audiences, including executive summaries and practical guides for the acquisition and deployment of the sensor systems (leading to factsheets in WP9). Protocols for use of the instruments following the field campaigns are also made available, including sensor/platform details and documented test results from the field campaigns (e.g. for installation/operation of drones, CLAM, sun tracking radiometer platform, HSP1 and WISPStation). All data collected during the MONOCLE field campaigns, including sensor observation data, metadata, calibration data files and data processing pathways will be openly accessible through the WP5 infrastructure (including data servers and an interactive web visualisation portal). This will be an ongoing process throughout during sensor development after each planned field campaign.

4. Future activities/recommendations

This deliverable describes the sensors and systems to be tested during the MONOCLE field campaigns, indicating the technology readiness levels and key performance indicators (KPIs) against which each system will be assessed. There are a range of sensors and methods which will be tested and improved over the course of the project following each validation campaign. The systems and KPIs described in this deliverable will directly feed into the novel development activities (WP2 – Novel Sensors and Sensing Methods & WP3 – Acquisition and Deployment Techniques) and the innovation activities (WP5 – Sensor Interoperability and Data Integration, WP6 – Signal and Image Analysis & WP7 – In situ Data Operationalisation for EO). The information in this deliverable will also inform and guide the forthcoming joint validation campaigns, alongside the information on validation site characteristics that will be detailed in D4.2 Report compiling test and validation site characteristics. Several KPIs need to be further specified as the prototypes become available, and may be revised in an updated document.

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