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Innovations in aquatic monitoring

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1. INTRODUCTION

This report is in response to a request from SEPA via CREW to highlight examples of monitoring where personal monitors have the potential to be, or currently are, being used.

In recent years, the use of mobile phones and tablets for personal communication has increased dramatically. The infrastructure and technology lying behind these ubiquitous devices has expanded in scope and sophistication. It is now possible to integrate sensor technology directly into off-the-shelf systems and either acquire new readings or upload them directly to cloud-based storage. Given the resources that are available, and the number of technical challenges that have been overcome in order to allow this, it would seem like a natural progression to begin using mobile communication technology for field-based environmental monitoring. In this report, we review existing technology for acquiring, processing and reporting on environmental data in the field. The objective is to demonstrate whether or not it is possible to use off-the-shelf technology for water monitoring.

Many examples of existing technology in this area already exist. Lane et al. (2010) discuss the potential for using mobile phones for environmental sensing, although they focussed on sensors embedded into the mobile phone rather than augmentation with additional devices. Work at the James Hutton Institute on linking models to mobile phone apps with image analysis techniques has led to rapid field monitoring for soil (Aitkenhead, 2013). Here we identify and review a number of examples over a wide range of technological sophistication and level of user/device interaction, in order to provide a summary (with notable examples identified) of what is currently available.

2. TECHNOLOGICAL CATEGORIES

There are many different solutions available within the field of environmental monitoring, even if the focus is on water alone. Grouping the different technological and computing developments into specific categories allows us to more easily compare these different solutions, and allows the reader to focus on the category that is of greatest interest to them. There are several possible frameworks of categorisation of mobile environmental monitoring solutions. We have chosen to group them in two ways: by technological sophistication (which is closely related to cost) and by user/device interaction.

2.1 Technological sophistication

- Snappy apps – purely app-based, with no additional technology required and little or no interpretation of the information obtained. Commonly used to record imagery of events or specific features within the landscape, sometimes with the option to provide additional data from the user's visual interpretation (e.g. water quality, presence of a particular species).
- Smart apps – again, purely app-based but with more sophisticated interpretation of information obtained by the user. Image analysis and the use of additional knowledge available from knowing the user's geographical location are used to drive models or to provide information directly to the user from digital maps.
- Plug & play – off-the-shelf sensor devices that can be plugged into a mobile phone or tablet and used to augment the sensor technology of the device. These are ready to use and provide specific sensor readings.

- Clever kits – either for purchase or recently developed and for testing, this type of technology requires construction and a high degree of understanding from the user. Sensor devices of this kind are usually customisable and are designed to be used by researchers or professionals.

2.2 User/device interaction

- Crowd source – here, the user is not required to provide any interpretation of the results, but simply acts as a recorder of information (usually imagery, but sometimes audio recordings). The information is transmitted to a central location where it can be subjected to further interpretation by experts.
- Personal use – the user is provided with readings, usually interpreted automatically to make them more useful, about their environment. There is no expertise required in handling the equipment or interpreting the information obtained, but some experience in using the equipment properly might be necessary.
- Decision support – information is taken from the user, either in the form of imagery for interpretation or numerical values (or both). This information is integrated with information derived from knowledge of the user's position within the landscape, and is used to provide information that is of specific interest for land management etc. The outputs from this type of system tend to be less 'interpreted' than they would be for a member of the public.
- Tricorder – the user of this technology is a specialist, often a scientist or someone looking to answer a specific question that requires sophisticated monitoring. Use of this technology requires an understanding of the system being monitored, training in the use of the technology and the ability to interpret sophisticated monitor readings.

The following table shows how the above categorisation works, and lists the examples found which fall into each category, with links to a discussion of each example.

Table 1. Categorisation of mobile environmental monitoring solutions, with examples

	Snappy apps	**Smart apps**	**Plug & play**	**Clever kits**
Crowd source	What's invasive NatureWatch	Water Quality Reporter		
Personal use	PEIR		Lapka Ghana air quality Thermodo Luxi Alcohoot	
Decision support	SoilWeb SoilMapp mySoil	Soil Test Pro PrecisionEarth Aphid Speed Scout SIFSS SOCiT AWQS		Platforma SINC MoboSens
Tricorder		Optimizer EMAP SEPA/Geofield	H2020 tech transfer Tesla Microscope Proscope	Sensordrone WiMoto smarTROLL

3. EXAMPLES

The tables below list examples that have been found of apps, mobile phone-related equipment and associated systems for environmental monitoring. The relevance of these examples varies, and where necessary we have identified the concepts or ideas that are relevant to water monitoring and that could be extracted for future systems. In each case, we have identified the design function, the potential of the system for water monitoring, the level of technological sophistication, the level and type of user/device interaction, any limitations on the use of the system in question and its suitability (i.e. the level to which it achieves the stated purpose).

Name	**What's Invasive**
Website	http://whatsinvasive.com/
Designed function	Crowd-sourcing of invasive plant species.
Potential for water monitoring	Direct application of this app could achieve monitoring of rivers and water bodies for invasive species, such as Japanese Knotweed, often spread along river banks. Indirectly, this app and others similar to it can provide a template for capturing user observations of water body quality or features of interest (e.g. pollution, dumping).
Technological sophistication	The app is relatively simple and acts more as a mechanism for capturing user observations than anything else. Photographs can be geotagged automatically, as can observations, allowing databases to be populated with user observations and images. However, there is no automated interpretation of the information sent, neither is there much in the way of moderation – the quality or relevance of an observation varies with the user.
User/device interaction	This app can be used with the minimum of training or experience, and requires no sophisticated technical knowledge on the part of the user. However, they are expected to be able to identify the species or other feature of interest that they are describing.
Limitations on use	This is very much a 'what goes in is what comes out' app – all information of use is entered by the users, whose level of expertise in the subject area may vary. It is difficult therefore to produce statistical or numerical evaluations of the topic of interest.
Suitability assessment	Potentially useful for capturing the spatial location and distribution of qualitative observations. Not capable of capturing quantitative observations unless used in parallel with monitoring equipment. In order to make use of this app for monitoring water quality, it would have to be developed slightly differently to allow different observations to be entered; it is therefore only suitable for monitoring of invasive species in or near water bodies.

Name	**PEIR**
Website	http://www.cs.cornell.edu/~destrin/resources/conferences/2009-jun-Mun-Sheddy-PEIR.pdf
Designed function	An app developed at UCLA and demonstrated in 2009, which calculated exposure to particulate matter in cities based on positional information and mode of transportation.
Potential for water monitoring	None directly, but its application for assessing user risk exposure to airborne pollutants could be easily transferred to water-borne pollutant exposure assessment.

Technological sophistication	This app records the user's position and movement automatically, and integrates this information with existing datasets. The results are interpreted for the user and presented in an understandable form.
User/device interaction	Relatively simple user interaction is involved – the app presents the user with a set of results about air pollution exposure and also sends this information to servers for later data interpretation.
Limitations on use	Only designed for airborne pollution currently – could be reverse-engineered to be applicable to water pollution relatively easily.
Suitability assessment	This app is designed to integrate information about the user's position with existing spatial datasets and expert knowledge on transport systems and air pollution. As such, it requires existing datasets to be available, and in the case of water quality monitoring is more applicable for assessing the user's likely exposure to water-borne pollutants that have already been mapped. This is an app that is not directly applicable but which would provide useful ideas for water-related applications.

Name	**Water Quality Reporter**
Website	http://www.bristol.ac.uk/aquatest/in-action/aquatest-system/wqr/
Designed function	Transmits information from a water testing device to water supply companies.
Potential for water monitoring	This app is designed specifically to allow water monitoring results to be sent to a central system for processing, and has been extensively tested and used in the field. The measurements that are uploaded by the user are perhaps not the full range that could be applied.
Technological sophistication	Relatively easy to use and technologically unsophisticated – this app is designed to be used by anyone in the field who has access to the relevant water quality monitoring equipment and a mobile phone. However, the data recording side is well designed and provides a framework for later remediation and interpretation.
User/device interaction	Straightforward data input by the user – no connection between the monitoring device and the mobile phone.
Limitations on use	The user has to upload the measurements, rather than having a direct connection between the monitoring device and the mobile phone or tablet. This means that there is a time/effort constraint on uploading multiple measurements.
Suitability assessment	This app is quite suitable for water quality monitoring, but is fairly restrictive in that it requires user input rather than connection to the monitoring equipment, and limits the types of observations that can be entered. Could easily and rapidly be replicated for use in Scotland, with more functionality.

Name	**Aphid Speed Scout**
Website	http://real.unl.edu/iOS/AphidSpeedScout/
Designed function	Users provide information about aphid infestation rates on soybean, which is used in a decision support tool for treatment methods.
Potential for water monitoring	Not in the current form. Included in this report as it provides an example of expert system-based apps that provide a response to the user based on one or more inputs.
Technological sophistication	Relatively simple, the input data and processing chain are quite basic.

User/device interaction	The user provides information about aphid densities on a plant, and some limited locational information. A response is given based on an expert system built into the app.
Limitations on use	Currently only applicable for aphids infestations on specific crop types.
Suitability assessment	Could be related to climatic conditions that are good/bad for aphid numbers, or for giving an indication of current aphid counts that could then be used to model seasonal aphid population densities.

Name	**Optimizer**
Website	http://www.advancedagsolutions.com/optimizer.php
Designed function	Data management decision support tool for cropping, applies input data from farmers to data automatically downloaded about local weather conditions, and models crop growth, nitrogen uptake and other features.
Potential for water monitoring	In its current form, this system is not suitable for water monitoring. However, as an example of a system that can be used for recording and visualising data, and for using that data in 'background' models to produce new and useful information, it is extremely informative. The structure between pages within the app and the manner in which it takes data from the user and represents it could provide inspiration for more water-relevant monitoring apps.
Technological sophistication	This app displays a high level of technological sophistication, allowing users to input, organise and visualise their data and also linking this data along with existing weather data and models to produce new and potentially useful crop growth information.
User/device interaction	The user needs to know what they are doing when they are using this app, which is designed for technical specialists in the farming domain. There is a significant amount of data flow in both directions between the user, the app interface and the underlying models and data structures.
Limitations on use	In its current form, this app is limited to what it was designed to do, namely to provide decision support to farmers growing specific crops. It cannot provide water monitoring capabilities but as noted above, could well provide inspiration for a similar water monitoring tool.
Suitability assessment	Not suitable for water monitoring in its current form, but does provide some useful ideas.

Name	**Platforma SINC**
Website	http://www.alphagalileo.org/ViewItem.aspx?ItemId=128267&CultureCode=en
Designed function	Equipment that can be used to detect mercury concentrations in water, based on colour change in sensitive paper. Not fully implemented as a monitoring tool, but its use with mobile phones has been demonstrated.
Potential for water monitoring	Good potential, needs to be more fully developed to be an integrated package. Some kind of standardised detection mechanism (i.e. standardised chemosensitive paper in a mechanism that allows easy imaging) would improve the functionality.
Technological sophistication	Relatively low-tech, although the image analysis software requirements for detection and processing of the chemosensitive paper colour change are not trivial.
User/device interaction	Some activities required on the part of the user, in relation to sample preparation and acquisition of appropriate imagery.

Limitations on use	The limitations on this kind of application relate more to the chemosensitive paper (or whatever sensing mechanism is used that changes colour). If there is a chemical of interest and a reliable colour-change chemistry that can be implemented in the field, then there are no limitations on application.
Suitability assessment	Suitable for water pollution monitoring, if appropriate chemical-colour change mechanisms can be implemented that are cheap, rapid and accurate.

Name	**H2020 Tech Transfer**
Website	http://www.enterprise-europe-scotland.com/sct/services/enquire.asp?id=12%20RB%201B1N%203QG6&EnquiryType=BBS&reftype=RSS&refid
Designed function	A small Serbian company developed a device for real-time monitoring of environmental parameters using GPS/GPRS technology. It can be used in applications such as air quality monitoring. No further information is available, but it appears they have a device that can be plugged into mobile phones for monitoring a number of air quality parameters.
Potential for water monitoring	This device may be highly suited to water monitoring needs; unfortunately very little information is available. While the original description stated the purpose of air quality monitoring, the implication was that the device could be used for monitoring a host of parameters, including water-based measurements, based on the fact that it acted as an interface between the sensor and the mobile phone.
Technological sophistication	Unknown, but potentially sophisticated.
User/device interaction	Unknown.
Limitations on use	Possibly dependent on the interface mechanisms used – if it has been designed with specific sensors in mind, then it may be limited to those sensors due to hardware involved.
Suitability assessment	Potentially very suitable for direct monitoring of water quality, although there was no information given about how the readings were recorded, stored and presented for later use.

Name	**Ghana Air Quality**
Website	http://www.globalproblems-globalsolutions-files.org/unf_website/PDF/vodafone/tech_social_change/Environmental_Conservation_case3.pdf
Designed function	Carbon monoxide sensor linked to mobile phone technology, used as a pilot study.
Potential for water monitoring	The sensor that links to mobile phones was designed specifically to record atmospheric carbon monoxide levels. However, similar sensors could be developed with identical electronic interfaces to the mobile phone technology. Sensors that are relevant for water monitoring could therefore be developed.
Technological sophistication	The sensing device is the most sophisticated part of this system, with the recording app being relatively simple and low in 'options'.
User/device interaction	No user/device interaction, this is a portable recording device that the user (a taxi driver) transported in his vehicle and which recorded information on air quality over

	time. The recorded information is uploaded to servers for later processing.
Limitations on use	The limitations relate to the physical monitoring mechanisms – a water quality sensor that produces a translatable electronic signal could be linked to a mobile phone just as easily as a sensor that detects air pollution levels. However, such a sensor does need to exist in the first place.
Suitability assessment	Highly suitable for water monitoring, if the monitoring equipment is available. An app for recording readings could be produced rapidly and cheaply.

Name	**Sensordrone**
Website	http://www.kickstarter.com/projects/453951341/sensordrone-the-6th-sense-of-your-smartphoneand-be
Designed function	Multisensor device for mobile phones, for use in experimental environmental monitoring.
Potential for water monitoring	This system has a lot of potential for water monitoring, as it allows sensors that measure relevant parameters to be linked through Bluetooth technology to mobile phones, and provides a 'whole package' system for acquiring, storing and visualising logged data.
Technological sophistication	This is a relatively sophisticated system, as it includes sensors, connectivity to mobile phones for download and storage of measurements, and apps for visualising and controlling this information.
User/device interaction	While a lot of the information acquisition and storage is automated, there is still a degree of user/device interaction required in setting up the system for use and in ensuring that the observations are recorded properly.
Limitations on use	Currently, there are only a small number of sensors available, although this situation is changing rapidly. The user is therefore limited to using these specific sensors and cannot plug in a different sensor that may be of more relevance to their interests.
Suitability assessment	Highly suitable for water monitoring, within a restricted range of parameters. The system provides a complete package for rapid observation of the environment, although it does require quite a high level of understanding and implementation on the part of the user.

Name	**EMAP**
Website	http://www.aecom.com/What+We+Do/Environment/Practice+Areas/Impact+Assesment+and+Permitting/Environmental+Mobile+Application+for+Projects
Designed function	GIS package for mobile tablets, designed to allow information to be captured, edited and processed in the field. Designed as an all-in-one package that facilitates environmental monitoring at all stages from field data capture to reporting, all from a single mobile platform.
Potential for water monitoring	Potentially extremely useful for aiding water monitoring, as a mechanism for recording, processing and reporting. Not designed to allow monitoring devices to link directly to the tablet, so data entry still has to be carried out manually.
Technological sophistication	A very sophisticated package, requiring a high level of user understanding, but with a lot of tools to allow field monitoring to be carried out more rapidly.
User/device interaction	The user interacts with the software package in a similar manner to that in which a GIS package would be used on a desktop. Additional functionality for reporting and filling in of technical sheets is also built in.

Limitations on use	The technology is proprietary to AECOM, a large American technical and management support company. Licensing may or may not be possible.
Suitability assessment	Extremely suitable for a wide range of environmental monitoring applications.

Name	**SEPA/Geofield diffuse pollution assessment**
Website	http://www.sepa.org.uk/about_us/news/2013/sepa_wins_connect_ict_innovate.aspx?lang=en-gb
Designed function	Use of off-the-shelf tablets and sensor recording software in water monitoring. The application of this system is broad and has not been fully explored, as it allows users in the field to record a large number of different readings and to integrate these with existing spatial datasets.
Potential for water monitoring	Rather than useful for water monitoring directly, this system appears to have been designed to facilitate the recording and later interpretation of a wide range of environmental monitoring. Its potential for water monitoring lies therefore in assisting with the input, organisation and archiving of readings rather than the direct acquisition of the readings themselves.
Technological sophistication	High levels of technological sophistication are applied in the software that is used for the recording and organisation of sensor readings in the field. However, there is no mechanism for the user to integrate monitoring devices directly into the system and to record the readings without the human interface.
User/device interaction	The user must enter measurements into the system, which does not provide any feedback or processing but which does allow visualisation of the data entered.
Limitations on use	The main limitation here is the user themselves – if a system could be developed to accept data directly from a number of recording devices, then the user could act in a more effective 'oversight' capacity rather than having to be directly involved in the measurements and their recording.
Suitability assessment	Highly suitable for monitoring of water and environmental pollution, and for a number of other monitoring requirements. The suitability lies more with the system's facilitation of data entry and recording, and with allowing later assessment, than with the direct recording of sensor readings or the integration of readings with existing data to provide 'added value'.

Name	**NatureWatch**
Website	http://www.eea.europa.eu/mobile
Designed function	Allows citizen scientists to identify and report invasive species
Potential for water monitoring	As with "*What's Invasive*" this app could achieve monitoring of rivers and water bodies for invasive species.
Technological sophistication	Similar to "*What's Invasive*", but the user can also submit video and audio clips that could be of value in recording moving water.
User/device interaction	This app can be used with the minimum of training or experience, and requires no sophisticated technical knowledge on the part of the user. Additionally guidance is given on recognising invasive species.
Limitations on	This is very much a 'what goes in is what comes out' app – all information of use is

use	entered by the users, whose level of expertise in the subject area may vary. It is difficult therefore to produce statistical or numerical evaluations of the topic of interest.
Suitability assessment	Potentially useful for capturing the spatial location and distribution of qualitative observations. Not capable of capturing quantitative observations unless used in parallel with monitoring equipment. In order to make use of this app for monitoring water quality, it would have to be developed slightly to allow different observations to be entered; it is therefore only suitable for monitoring of invasive species in or near water bodies.

Name	**SIFSS**
Website	http://sifss.hutton.ac.uk/
Designed function	Allows a user to find information about soil at their location (using the unit's GPS or interactive map) and all over Scotland
Potential for water monitoring	Potentially useful in assessment of nutrients and eutrophication – soil N & P are available in the app. Future developments are likely to include reporting on whether the user is in an Nitrate Vulnerable Zone and the HOST (Hydrology of Soil Type) class.
Technological sophistication	The most comprehensive of existing UK soils apps (albeit with information for Scotland only). Detailed information on up to 15 soil characteristics from the Soil Survey of Scotland are provided for each soil horizon, for both cultivated and semi-natural land covers (where they exist). The app accesses James Hutton databases, so always points to the most up to date data.
User/device interaction	This app can be used with the minimum of training or experience, and requires no sophisticated technical knowledge on the part of the user. Where several soil series are present at a location the user is given a description of the appearance of the soil as a guide to selecting the correct series. No user information is incorporated in the app.
Limitations on use	Currently uses only the national soil mapping at 1:250,000, but future versions will incorporate higher resolution mapping where it is available.
Suitability assessment	At present this is a soil information tool with limited relevance to water, but potentially significant use in the riparian zone.

Name	**SOCiT**
Website	http://www.hutton.ac.uk/research/groups/information-and-computational-sciences/esmart
Designed function	SOCiT provides the user with a near instantaneous field assessment of soil organic matter content using image analysis and modelling.
Potential for water monitoring	None directly, but potentially very useful conceptually – the integration of sensor information and environmental data sets in near-realtime.
Technological sophistication	From the perspective of the user and in hardware terms low, using only the device's camera (and a shovel), but computationally highly sophisticated, integrating automated image analysis and neural network environmental data analysis.
User/device interaction	The user has to dig a hole, drop an image normalisation card in it, take a photo and click a button for the soil organic matter to be calculated.
Limitations on use	Currently Scotland only (due to access to environmental data sets), potentially extending to rest of UK in the future, subject to collaboration with other data holders.

Suitability assessment	At present this is a soil information tool with limited relevance to water, but potential use in the riparian zone. However, this app could provide a template for other apps integrating image and environmental data analysis which could be used in the water environment.

Name	**SoilWeb**
Website	http://casoilresource.lawr.ucdavis.edu/soilweb/
Designed function	Provide access to soil mapping information from the United States. This includes drainage class, water table depth and available water storage (in soil).
Potential for water monitoring	None in Scotland, but some potential in the US as detailed soil mapping is used in addition to the soil hydrology information.
Technological sophistication	This appears to be similar to SIFSS, but with more restricted user control of location selection – this app permits only input by the device GPS.
User/device interaction	Minimal "Get My Location".
Limitations on use	US only - blocked for Android distribution outside US and while available for Apple devices the only input is via the device's GPS, so it is effectively impossible to explore the app.
Suitability assessment	Limited.

Name	**SoilMapp**
Website	http://www.csiro.au/soilmapp
Designed function	Provides access to soil mapping information from Australia. This includes maps, photographs, satellite images, tables and graphs of data about nearby soils. Also includes soil's physical and chemical characteristics, including acidity (pH), soil carbon, available water storage, salinity and erodibility.
Potential for water monitoring	Potentially useful due to the large number of attributes linked to soil hydrology, but only in Australia.
Technological sophistication	This is essentially an interactive map, but gives access to very large amounts of data in a convenient manner.
User/device interaction	The user interacts with the soil map displayed on the device to obtain information. Information on site conditions can also be uploaded to CSIRO by users for subsequent use in map validation.
Limitations on use	Available for iPad only, data for Australia only.
Suitability assessment	Limited, but a good example of what can be done, and potentially useful in guiding future developments of existing apps.

Name	**mySoil**
Website	http://www.bgs.ac.uk/mysoil/home.html
Designed function	To provide access to soil mapping information from the majority of Europe. This app provides extensive coverage of soil information, but with a limited number of

	attributes, and low precision (e.g. Organic Matter: “Medium” and pH: “Slightly Acidic”)
Potential for water monitoring	With current information available in the app quite low, however, it is likely that more data sets will be added in the future.
Technological sophistication	Fairly limited, a clickable interactive map.
User/device interaction	Uses a clickable interactive map with web mapping services. Users can also upload their observations which are subsequently displayed as pushpins.
Limitations on use	While the extent of the cover is comprehensive, the depth of information being provided is low.
Suitability assessment	The app contains information from the Countryside Survey and the Land Cover Map (2007). It is possible that other aspects of the data from these surveys, if incorporated in future versions (or new apps), could make this app more useful in water monitoring or assessment.

Name	**Soil Test Pro**
Website	http://www.soiltestpro.com/video/
Designed function	To manage soil fertility data and assist in collection of soil samples. Once registered, the app gives users access to satellite imagery of their farm/site. It allows them to demarcate their own field boundaries on foot/by vehicle, create a custom sampling grid at user specified intervals, then when they walk the field the app will guide them to each of the grid points, and assign it a unique sample id. It is assumed the user will send the soil sampled at each point to a lab for analysis and this unique id will allow them to trace the results from each sample. Details of all samples are automatically synced to their web account with the app developer (also the lab that analyses the samples). Results can be sent back with geolocation information suitable for uploading to GPS-enabled farm machinery.
Potential for water monitoring	Although the sampling frame for soils and waters are different, the ability to delineate boundaries and create sampling locations on the fly is a powerful and useful ability, especially when combined with the automatic ID creation for samples. At the linked web account it is possible to automatically print shipping address sheets, specify the type of analyses to be done, and download results. This technology would be particularly useful when taking sediment samples from standing waters or when sampling soils in the riparian zone.
Technological sophistication	Similar to SIFSS but with the added on the fly polygon and point creation.
User/device interaction	Very easy for a non-specialist to work out suitable sampling locations. Combined with a robust set of sampling protocols, it would allow anyone to take a set of samples with a high-degree of quality control. A possible addition would be to expand on the simple grids generated e.g. ‘W’ patterns, transects, more sophisticated statistical sampling algorithms.
Limitations on use	Current version only in US. Access to suitable source of satellite/aerial imagery would allow it to be modified for use in other locations.
Suitability assessment	Given the fluid nature of water, unlikely to be useful in moving waters or in measurement of dissolved water chemistry in standing waters. Great potential for sediment sampling.

Name	**Precision Earth**
Website	http://precisionearth.com/
Designed function	Similar to Soil Test Pro, designed to record farm sample locations.
Potential for water monitoring	See above.
Technological sophistication	Seems to have more flexibility in output file formats – supports various GIS and image packages. Also allows viewing of cropping history, can integrate weather data, can work where no access to 3G/wifi.
User/device interaction	See above
Limitations on use	Not free
Suitability assessment	See above.

Name	**Lapka**
Website	https://mylapka.com/
Designed function	Lapka Personal Environment Monitor is a collection of sensors (which fit together in a stylishly designed wood and moulded plastic block) which interface with an iPhone via the associated app. The sensors are individual devices which plug into the audio jack of the phone and measure electrical conductivity (which they claim is highly correlated to nitrate concentration so is billed as a 'food quality' monitor), humidity and temperature, radiation, and electromagnetic fields.
Potential for water monitoring	Depending on how sensitive the sensors actually are, having the capability of measuring electrical conductivity and temperature in one device which interfaces directly to the phone (thus allowing records to be associated with geotagged photographs) is appealing. How the device would compare against purpose built sensors is unknown without further testing. The package is sold for $220 (USD) which the makers claim compares favourably with the cost of a single humidity sensor at around $200, but puts it outside the range of most citizen scientists unless provided by a third party.
Technological sophistication	The various sensors are all available in other forms (e.g. Thermodo for temperature), but the package appears to be much more about style than function.
User/device interaction	Simply plug each sensor into the phone and the app records the appropriate measurement.
Limitations on use	Cost, sensors not especially sensitive or measuring different things to other devices. As usual with this type of add-on device, the practicality of using it in or near water needs to be carefully assessed.
Suitability assessment	Moderate/Low. Limited range of useable information, although having multiple sensors in one device is a plus.

Name	**Tesla Microscope**
Website	http://tesla.dma.ucla.edu/TEST6/?q=research/fluorescent-microscope-cell-phone-attachment

Designed function	This device is a 'matchbox-sized attachment that converts a mobile phone's camera into a fluorescent microscope. The device utilizes an inexpensive lens and battery-powered, light-emitting diodes to create a field of view two orders of magnitude larger than previous cell-phone fluorescent microscopy technology. It is more than five times smaller than previous cell phone microscopes'.
Potential for water monitoring	The device is designed to be able to quickly and accurately analyse large sample sizes. The proposed use is in testing medical samples in remote areas, but the technology would easily lend itself to analysis of water samples. The inventors state that while it does not have the resolution of conventional microscopes, it is high enough to screen for pathogens in drinking water or food and to image various body fluid samples to search for disease marker.
Technological sophistication	Extremely high, although it appears to have been designed for size and robustness in the field. No indication if it being mass-produced or if it is still at the experimental design stage.
User/device interaction	Relies on a high degree of user input and interpretation.
Limitations on use	Some other equipment required (e.g. a colour filter) although this device is designed to be able to work with cheaper alternatives to the usual filters.
Suitability assessment	Potentially very suitable. Individual users would need suitable training before it could be rolled out.

Name	**Proscope**
Website	http://www.bodelin.com/proscope/proscope-micro-mobile
Designed function	A professional quality microscope which attaches to an iOS (such as iPhones or iPod) device. This relatively inexpensive device (c$150 (USD)) fits onto an iOS device and provides 20X to 80X magnification, with high quality optics. Includes stand, integrated LED lighting, and allows photographs of the subjects to be taking using the devices' native camera.
Potential for water monitoring	Potentially extremely useful for in the field monitoring of invertebrate and other biological specimens. Adding of geotagged photographs has potential for extremely rapid biological field assessments.
Technological sophistication	High. Produced by a company with a track record for portable and/or internet enabled microscopes. Robust design specifically designed for field operation.
User/device interaction	Some familiarization with the equipment required (as well as the specific skills required to carry out the task in question).
Limitations on use	Interpretation skills of user
Suitability assessment	Wide range of potential applications in aquatic/riparian monitoring and measurement

Name	**Thermodo**
Website	http://thermodo.com/
Designed function	An external temperature sensor for a smartphone, tablet
Potential for water	The device (which interfaces with an app from the same developer) is a very small temperature sensor which plugs into the audio jack of the phone. While it is designed

monitoring	to measure air temperature, there seems to be no reason why you could not plug an extension into the audio jack, and dangle the sensor itself in water. While it offers no real benefit over using a standard thermometer, as the app will (presumably) geotag the locations where the measurements are made, it would cut down on data processing time in the office plotting temperature readings spatially/temporally.
Technological sophistication	Medium/Low. The sensor itself is the most sophisticated part, although affordable (c$30 USD))
User/device interaction	Simply plug in the device, start the app and record.
Limitations on use	No better than a standard thermometer. Even if solution for working in water proposed above is workable, phones are not very robust so care would have to be taken in the field not to damage it.
Suitability assessment	Limited, but also shows the capability for developing small sensors which plug into smart device and can interface with a simple app.

Name	**Luxi**
Website	http://www.kickstarter.com/projects/jamesflynn/luxi-incident-light-meter-adapter-for-iphone http://www.esdevices.com/collections/all/products/luxi
Designed function	An incident light meter which clips onto an iPhone camera to help determine best exposure setting for a (D)SLR camera.
Potential for water monitoring	None directly. Due to the nature of the device and the way it fits over the phone it interferes with the camera so apps which require the user to take a photograph and upload it if done via an iPhone cannot be used directly (e.g. SoCit, iDee etc). Where it could be of benefit is in tandem with applications where image post-processing is used on a photo of water as it helps ensure that the photograph is properly exposed, meaning the image sent for analysis is of the 'best' quality.
Technological sophistication	Medium. The device is comparable in function to a professional light meter, but somewhat cheaper, and is very small and portable.
User/device interaction	Requires a good knowledge of photography and the camera being used so the settings suggested by the app which comes with the device can be properly implemented.
Limitations on use	Impairment of iPhone camera
Suitability assessment	None directly. Some testing would be needed to determine if the improved quality of images taken after using the app is actually of any benefit to a post-processing application.

Name	**Agricultural Water Quality Self Assessment 1.0 (AWQS)**
Website	http://appfinder.lisisoft.com/app/agricultural-water-quality.html
Designed function	To help a user (a farmer) assess the risk of adverse impact on water quality of their growing practices.
Potential for water monitoring	This iPad app is intended more as a decision support system to identify potential diffuse pollution risks than monitor water quality per se. The user is asked to supply information on a property basis. There are a total of 43 questions which gather information about location, whether the property is near a watercourse, management of potential pollution sources etc. A final assessment for each category ranks the risk

	into low/med/high categories, and gives an indication of the cost/difficulty/time required to implement recommended mitigation options.
Technological sophistication	Low. App is a simple questionnaire.
User/device interaction	User works through screens, selecting options from menus or adding free text.
Limitations on use	Currently only option for crop type is 'tree crops', based in US so some of the management options and legislative background not immediately relevant to UK/Scotland
Suitability assessment	Only as a risk assessment, no monitoring option

Name	**Alcohoot**
Website	http://www.getalcohoot.com/
Designed function	Measurement of blood alcohol concentration (BAC)
Potential for water monitoring	This is a small sensor device which attaches to a smartphone (compatible with iPhone, iPad and Android devices currently) via a 3.5mm jack. Its intended purpose is to measure the user's blood alcohol content in the same way as a conventional breathalyzer. It uses a fuel cell sensor (similar to the type used in police breathalysers) as opposed to a semi-conductor sensor, which allows it to be specific to alcohol (and unaffected by other solvents or chemicals such as hairspray, deodorant etc), as well as a patented air sensor to detect airflow into the device. If the sensor could be replaced with a different kind, then it may be possible to use as a relatively sophisticated air quality detector. It would not be useable directly in water, or to measure water chemistry, but the possibility for measuring point source gas emissions which might help in tracing of chemical leaks, spillages etc might be explored.
Technological sophistication	The internal sensors are quite sophisticated, although the device itself retails for $75 (USD) so is still affordable. For the BAC measurements, the sensor needs to be periodically recalibrated which would either require return to base (RTB) or provision of some method for the user to do it in the field.
User/device interaction	The user simply connects the device to the phone and blows into the mouthpiece.
Limitations on use	Need for periodic calibration (see above)
Suitability assessment	Not directly suitable, but shows the capability of designing and implanting add-on sensors for specific applications. The challenge would be to create small, accurate and reliable enough versions of other gas sensors for this to be a useable technology for pollution monitoring

Name	**WiMoto**
Website	http://www.wimoto.com/
Designed function	A variety of small wireless sensors which can measure ambient temperature, humidity, light, soil moisture, soil temperature, object temperature, human presence and movement.
Potential for	Unlike a number of the other sensor add-ons in this review, these can send their data

water monitoring	wirelessly via Bluetooth. Assuming they are robust enough for deployment in the field, they could replace the need for manual download of temperature loggers and/or allow placement of the sensors in locations where accessing loggers frequently would be hazardous or time-consuming. The example use suggested for the temperature sensor on their crowdfunding page is to monitor a swimming pool.
Technological sophistication	The sensors themselves appear no more complex than others mentioned here but the addition of battery powered Bluetooth is different.
User/device interaction	All data collected via a smartphone or tablet, which can then be uploaded to a cloud server. Potentially allows data to be collected more quickly and easily than traditional in-situ loggers.
Limitations on use	Battery powered, the makers claim that batteries last for about a year. Uses Bluetooth SMART technology so receiving device needs to be capable of acquiring signal.
Suitability assessment	Potentially very high, especially for light and temperature in water. Still at the crowdfunding stage, but could possibly be used to develop other sensors using similar infrastructure e.g. dissolved oxygen, specific chemicals.

Name	**MoboSens**
Website	http://nanobionics.mntl.illinois.edu/mobosens/#
Designed function	A smartphone based sensor add-on which can accurately measure nitrate concentrations in water due to be released by end of 2013. Development of arsenic sensor underway, with plans in place to expand to sensors covering other pollutants (specifically heavy metals).
Potential for water monitoring	Specifically designed to tackle a major diffuse pollution issue.
Technological sophistication	Sensor prototype has been developed at Illinois University. Further development and testing at the crowdfunding stage.
User/device interaction	Unsure – still at testing stage with pilot citizen science group/crowdfunders, but assumed to be simple given purpose.
Limitations on use	Unsure. Some training presumed, and no information given about where data would be uploaded and analysed beyond the pilot area.
Suitability assessment	Very high. If the technology can be expanded to detect a wider range of determinands, then it would be the ideal device for large scale, crowdsourced water chemistry data collection.

Name	**smarTROLL**
Website	http://www.in-situ.com/products/water-quality/handheld-systems/smartroll-multiparameter-handheld
Designed function	This app is designed to interface with the smarTROLL water quality probe produced by 'in-situ'. The probe can measure dissolved oxygen, pH, ORP, conductivity (actual or specific), salinity, total dissolved solids, resistivity, and density, as well as physical parameters such as air and water temperature, barometric pressure, water level, and water pressure. The phone app replaces the need to have a handheld meter or logger attached to the probe, and allows data to be sent instantly to the office or uploaded to the cloud subject to having a phone signal.
Potential for	Specifically designed for this purpose

water monitoring	
Technological sophistication	Low for the app itself as it only records readings made by the probe.
User/device interaction	Very simple, no real user knowledge required as the probe (assuming correct calibration) can be put in water and readings taken without any assumed skill or technical expertise. Eliminates need to download separate logger and potential transcription errors from manually adding data.
Limitations on use	Specific to the sensor, which is expensive. No capability for expansion as it would require the probe itself to have extra sensors added.
Suitability assessment	Very high for the specific attributes measured.

4. DISCUSSION

Most of the examples given above do not relate directly to water monitoring. Instead they provide examples where monitoring of the environment is being carried out, and where the technology and software developed could be altered for use in water quality monitoring. Only a small number of the examples found are immediately and directly applicable to water monitoring without a level of investment. We emphasise that this investment is low in nearly every case – there are a lot of solutions available that would be very appropriate with a small amount of tweaking. In each case most, if not all, of the technological barriers have been overcome through earlier development work.

The examples found in this search demonstrate a trend whereby the more sophisticated and/or expensive the technological application, the more likely it is to be used for scientific or industrial research. Complex equipment, requiring experienced users does not appear to be used in citizen science. Conversely, purely app-based recording of simple observations does not occur with sophisticated monitoring of complex environmental conditions.

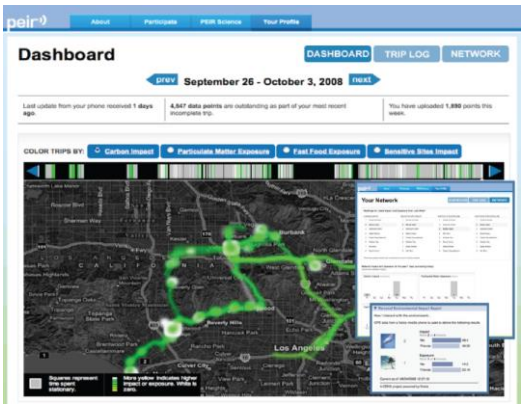
A notable example is the application of SEPA's existing framework for recording, organising and later processing of environmental monitoring readings using tablets and geospatial software developed by Geofield. This example facilitates a wide range of environmental monitoring. In order to take this system a step further, it is necessary to remove the human element, or to at least reduce the amount of human data input required. Automated sensor acquisition using Bluetooth technology or wifi download would require a fair degree of further development in the data recording interface, but would enable measurements to be made more rapidly and would remove the risk of human error.

The examples found in this search which may provide this 'missing element' are the Sensordrone, WiMoto and smarTROLL. While lacking the sophistication in terms of presentation and immediate user ease of the Lapka, these systems are highly flexible and generalizable. Furthermore they are to a certain degree 'programmable', i.e. the sensor readings can be controlled by the user in a manner that is not available through other systems. The developers of Sensordrone have produced a system with a wide range of potential applications that integrates well with mobile phone technology and produces useful information. It is however, contained within an unattractive and poorly-marketed package. Comparison of the Sensordrone webpage with that of Lapka is the first sign that here we have something designed

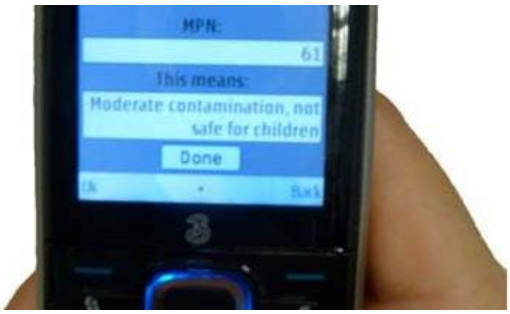
with scientists and 'early adopters' in mind, rather than the trendy consumer market. The other two systems, WiMoto and smarTROLL, are somewhat more professionally presented.

Additional systems of note include the following:

- PEIR – a useful example of integrating automatically recorded sensor data with position and existing spatial datasets of relevance. The image below is extracted from the referenced link, as is the case with images relating to the other examples given.



- Water Quality Reporter – an example of a relatively simple, widely applicable app for uploading observations. This concept could be readily and rapidly applied to almost any kind of water-related monitoring.



- Platforma SINC – cleverly applies colour interpretation from the mobile phone camera of sensor strips. A relatively low-tech but potentially rapid and simple tool.

- H2020 Tech Transfer (no imagery available) – this is a good idea that needs to be developed further before field application is possible, but worth watching out for. Very little detail has currently been made available.
- EMAP (no imagery available) – this tablet-based GIS package is similar in concept to the system currently being used by SEPA and developed by Geofield. A very useful system for facilitating monitoring in the field. The next step (removing the human input requirements and connecting directly to sensors) needs to be made.
- Lapka – a visually pleasing but relatively restricted set of sensors, the most relevant of which is for nitrate concentration. Possibly not rugged enough for field-based research purposes.

- Tesla microscope (no imagery available) – a microscope attachment for mobile phones that could be used for monitoring water-borne bacteria, requires user expertise in identification but potentially extremely useful.
- Proscope – similar to the example above, with a few additional features including geotagging of images and easier recording of video.

- Sensordrone – the ability to link multiple sensors to mobile phone technology through Bluetooth, in a small and robust package. Potentially extremely useful for a wide range of environmental monitoring.

- WiMoto – same as for Sensordrone and smarTROLL.

- smarTROLL – same as for Sensordrone and WiMoto. In relation to these, smarTROLL appears to have the edge in functionality and usefulness for water monitoring, but is likely to be more expensive.

- MoboSens (no imagery available) – this system is not available yet and few details are provided. It promises a wide range of specific sensors that can connect to mobile phones.

5. CONCLUSIONS

There are a number of different systems available on the market that are at least partially relevant for water monitoring, or that can inform developments in that direction. We have identified a number with particular promise, as well as categorising the examples found within a conceptual framework that enables comparison. Field-based environmental monitoring using off-the-shelf components is an area that is developing extremely rapidly, and trends in what is available would seem to indicate that more functionality and integration between sensors and mobile phone technology is highly likely in the near future.

6. REFERENCES

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