Water Quality Snapshots: Accurate Surface Water Monitoring using Optical Spectroscopy Techniques

The European Union underlines the availability and quality of water as a precondition for human, animal and plant life as well as an indispensable resource for the economy. The sustainability of aquatic ecosystems is therefore considered a priority within the EU. The Water Framework Directive (WFD) entails environmental reporting obligations to EU Commission, where each member state shall regularly report on the environmental state of the aquatic ecosystems. Any activities impacting these ecosystems are bound to monitoring requirements.

The water quality of the most important surface waters is monitored regularly by means of sampling. Monitoring frequency varies but is usually not higher than once per two weeks. Many small surface waters are not monitored at all. In order to monitor the effects of eutrophication on the water quality some parameters are measured: Algal biomass is approximated by a standard measurement of Chlorophyll-a, turbidity is measured by Secchi-disk and the amount of cyanobacteria is determined by microscope cell-counts. If there are indications for cyanobacterial blooms then e.g. the microcystine concentration can be measured, although recent publications indicate that this is a quite unreliable measurement because of high heterogeneity. Furthermore, collecting this data is costly and time consuming. Blooms can be missed because of the low time resolution. Therefore management of the water system is always out of phase with the actual developments.

Recent developments in portable spectroscopy enabled the development of a new instrument enabling automatic, instantaneous and continuous measurements of most of the controlling parameters relevant to authorities responsible for monitoring water quality. The low-cost, high quality and continuous information delivered by a portable (or fixed position) instrument, can play an important role in real-time warning for water quality deterioration. Because of its unique set of measured parameters, the instrument is also eminently suitable to monitor the effect of water quality improvement programs and to act as a controlling device for restorative measures such as water inlet, bubble screens (to prevent layer formation), etc.

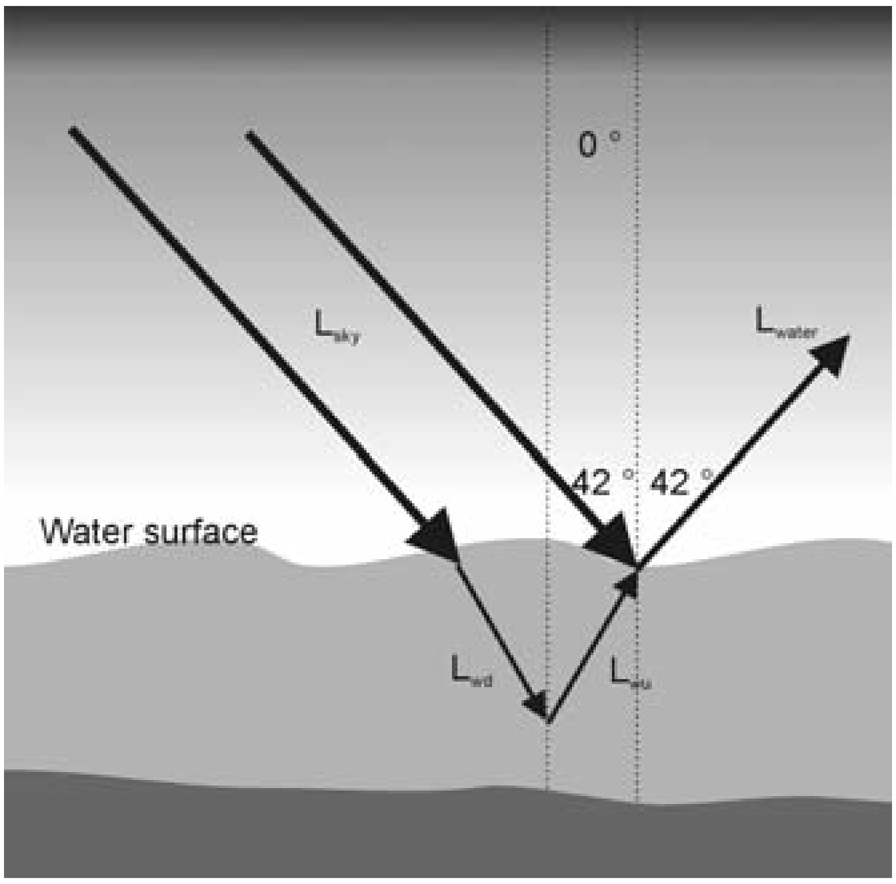

Figure 1: A schematic overview of the Gons protocol measurements. The R(0-) is determined by three separate measurements of L_{water}, L_{sky} and Ed."

Water remote sensing

The optical spectroscopy measurement technique was made operational by Water Insight, based in Wageningen the Netherlands, after more than 20 years of research at NIOO, NIOZ and VU/IVM.

The technique is based on combining simultaneous spectroradiometric measurements from 3 directions to characterize how sunlight interacts with water and its coloured constituents. This type of measurement originates from lake and coastal waters research in 1980s. Because of a need to amongst others validate high resolution satellite measurements, enormous progress has been made in the last 10 years.

As a basis, the (Gons 1999) protocol is used which calls for a series of consecutive measurements, beginning with the water-leaving radiance L_{water}, then the downward skylight radiance L_{sky}, both at an angle of 42° (respectively at nadir and zenith viewing direction), followed by measurements on a calibrated Lambertian reflectance panel, first sunlight-exposed (L_{rs}) and then shaded (L_{dif}). The consecutive measurements of the Gons protocol are shown in Figure 1. While the water leaving radiance term contains the water quality information that we are looking for, the other terms are required to correct for additionally observed sky reflectance at the water surface. The measurements on the reference panel are used to approximate the downwelling irradiance (in case of a radiance sensor).

The corrected water leaving radiance observation (often expressed as the subsurface reflectance) is a quantitative measurement of the total colour of the water. This colour is determined by the spectral characteristics and the concentrations of coloured compounds inside, either in solution or in suspension. Qualitative and quantitative relationships between the water colour and the concentrations of coloured compounds are expressed in bio-optical simulation models and inverse relationships (usually called algorithms). Three of such water compounds usually dominate the water colour: Total Chlorophyll (CHL), Total Suspended Matter (TSM) and Coloured Dissolved Organic Matter (CDOM).

Total Chlorophyll (approximately the same as Chlorophyll-a) is a proxy for algal biomass and is used as an indicator for eutrophication. TSM is a major influence on the transparency of water and CDOM is an indicator of stagnant water and organic pollution. Spectral observations also allow the determination of the vertical extinction coefficient K_D, a measure of the transparency of the water. The K_D is related to the Secchi Disk depth *SD*, a simple transparency measurement performed routinely by water managers all over the world as a quick indicator of general water quality. Recently also an algorithm was developed for determining the Phycocyanin pigment of cyanobacteria, making it possible to measure cyanobacteria (blue algae) concentrations. Chlorophyll-a, transparency and the ratio green algae / blue algae are Water framework Directive required monitoring parameters that can be directly measured by optical techniques.

In order to illustrate the concept of optical water remote sensing and bio-optical modelling a number of example spectra is given below. Using Bio-Opti, a tool developed at VU/IVM, a number of spectra is simulated. First, the effect of the individual water quality parameters is demonstrated, starting with TCHL. The effect of the concentration of chlorophyll on the reflectance spectrum is shown in figure 2A. At the lowest concentration (top line) of the series, the reflectance peaks at over 5%. Because of the light absorbing properties of chlorophyll, the reflectance peak decreases with increasing chlorophyll concentration. Another notable feature is the ratio between the dip at 676 nm (chlorophyll pigment absorption maximum) and the peak at 704 nm. At low TCHL concentrations the dip and peak are almost at the same level, but the 676 nm dip lowers with increasing TCHL concentrations.

The effect of TSM on the subsurface reflectance is demonstrated in figure 2B. The increase in TSM concentration results in an increase in reflectance at all wavelengths, which is caused by the fact that TSM particles are mostly scattering rather than an absorbing light. Finally, an increase in the CDOM concentration has an effect mostly on the reflectance values in the blue and green light region of the spectrum (figure 2C). With increasing CDOM concentrations, the peak at 550 nm also increases.

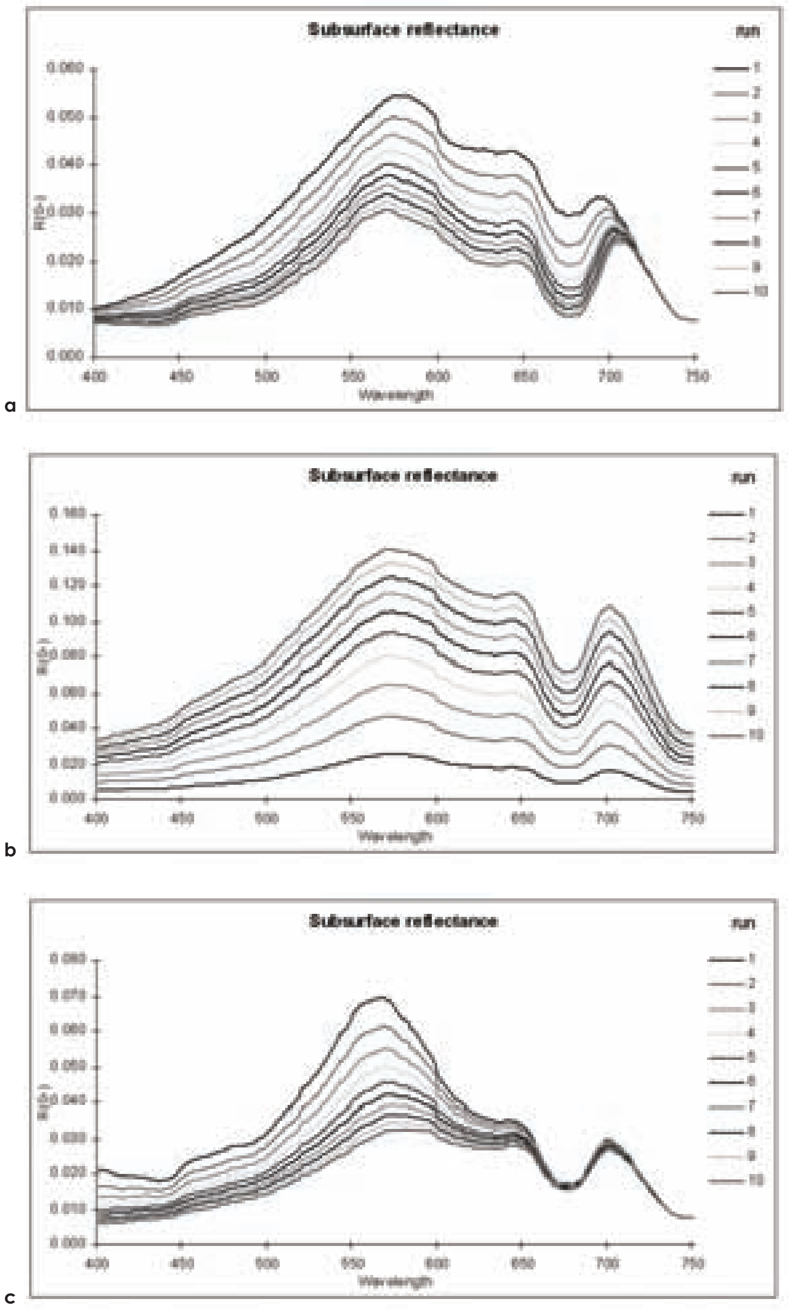

Figure 2: Simulated subsurface reflectance showing the effect of increasing concentrations (using Bio-Opti): A) increasing TCHL (10 – 100 µg l^{-1}) at fixed TSM (9 mg l^{-1}) and CDOM (2,4 m^{-1}) concentrations (top line is series 1) B) increasing TSM (5 – 50 mg l^{-1}) at fixed TCHL (40 µg l^{-1}) and CDOM (2,4 m^{-1}) concentrations (top line is series 10) and C) increasing CDOM (0.5 – 4 m^{-1}) at fixed TSM (9 mg l^{-1}) and TCHL (40 µg l^{-1}) concentrations (top line is series 1)

The Instrument setup

Based on the above described techniques Water Insight has developed a handheld system called the WISP-3 (Water Insight Spectrometer 3). To simultaneously acquire the three required spectra and analyse the data in real-time, the instrument is based on the Ocean Optics Jaz optical sensing platform (www.oceanoptics.eu/jaz).

This platform allows for multichannel spectrometer operation and includes a powerful microprocessor to handle the user interface and calculate and display the results on the OLED display of the WISP3. The WISP-3 also contains a battery module for 8 hours operations and Ethernet for remote control. One of the interesting features of the integrated microprocessor in the Jaz (image 3) is that it can adapt the measurement automatically to environmental light conditions, thus guaranteeing a wide range of application settings. Providing an instant reading of CHL, TSM, cyanobacteria and Kd on the screen, is unique in water quality monitoring. By collecting this data in an online information management system, water management authorities now have real time access to a decision support system to monitor situations where e.g. algal blooms influence: drinking water safety, general ecological status and e.g. swimming water safety. Vice versa, real time optical monitoring can be an economically interesting tool to shorten periods of prohibiting recreational use of water bodies in cases where there is a suspicion of cyanobacteria invasion. Above water measurement devices (like the WISP-3), do not suffer from bio-fouling as is the case in e.g. fluorimeter measurements.

Image 4: WISP-3 in action

Conclusions

New advances in miniature spectroscopy and long term research on water quality monitoring algorithms have resulted in the development of a hand portable water quality system, called the WISP-3 (image 4). Based on the real time observations of the WISP-3 system, decisions can be made in early stages of water quality deterioration and in early stages of water quality improvement. Continuous observations will also allow for tracking short and long term trends of the various water quality parameters.

Image 3: The modularity of the Jaz platform allows users and OEM customers to configure the system with the modules they need

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