WISP-3 User Guide

Version 1.2

Water Insight BV, the Netherlands

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1. INTRODUCTION

The WISP-3 is an easy-to-operate hand-held hyper-spectral radiometer for assessing surface water quality. The instrument derives water quality parameters from the colour of the water.

1.1 General Description

At the push of a button, the WISP-3 will store a set of three light measurements and instantly convert these into a number of water quality parameters. The collector on top measures the down-welling irradiance (E_d) that is incident on the water surface. The two channels at the front are used to determine the fraction of light that interacted with substances in the water. One of these collectors points downward at a 42-degree angle to capture upwelling radiance (L_u) that includes all light leaving the water as well as sky light reflected at the water surface. The collector that looks up at a 42 degree angle collects the downwelling radiance (L_d) or the sky light separately so that its influence on observed water color can be determined. The water color or subsurface irradiance reflectance (R(0-)) is immediately calculated after each measurement by combining the information from the three measurements.

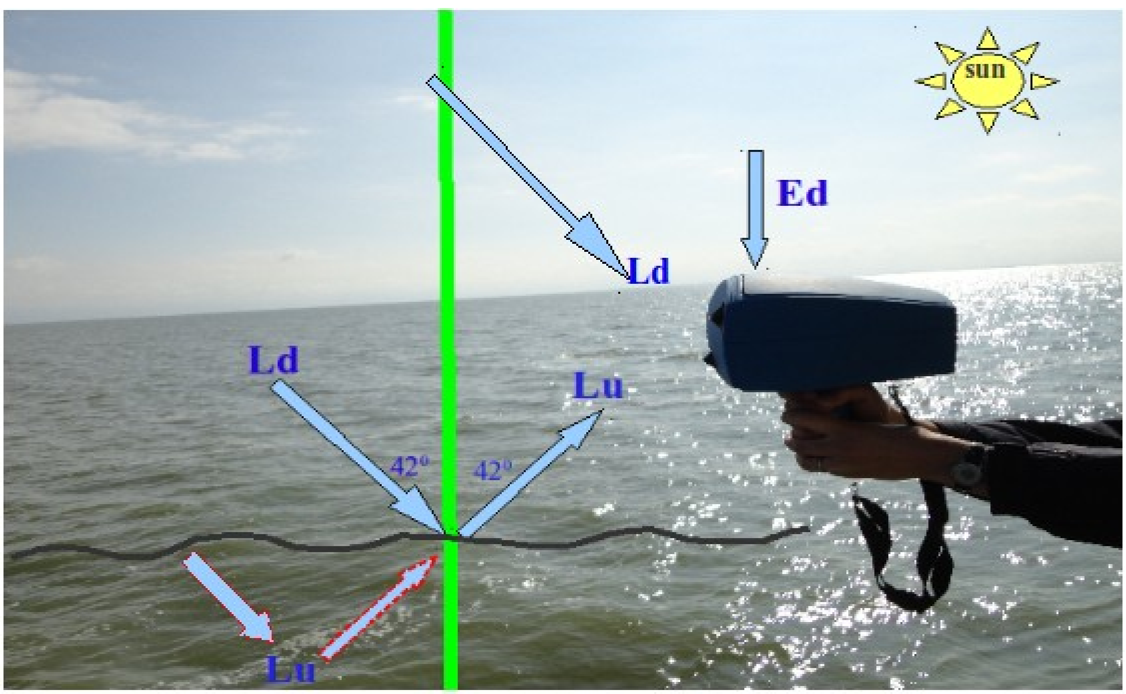


Figure 1: Schematic overview of measurement protocol. R(0-) is determined from three separate above-surface measurements of sky and water

When a hyper-spectral measurement of water colour is recorded, the WISP-3 applies built-in water quality algorithms on the reflectance spectrum, resulting in concentrations of phytoplankton biomass (as chlorophyll-*a*), cyanobacterial biomass and suspended sediments concentrations as well as the water transparency on its display. When you return from the field, insert the SD memory card of the WISP-3 into a computer to upload new measurements to our online measurement system WISPweb, hosted at Water Insight. The measurements will now be subjected to tuned optical models to improve the observations that the WISP-3 already provided in the field.

1.2 Major Features

- Instantaneous results: The algorithms for the retrieval of water quality parameters are embedded inside the WISP-3. Within seconds of taking a measurement, the results are displayed.
- User friendly: Its point and measure capability makes WISP-3 easy to operate.
- Diverse application: Its speed and flexibility of use combined with smooth upload and inspection of data on WISPweb enable day-to-day decision support in water quality management. Trends in algal blooms can be followed and preventive actions to protect water safety for drinking or recreation can be taken in time. The WISP-3 can also be used to collect reference measurements for interpretation of optical satellite imagery.
- Narrow field-of-view: The down-welling and the up-welling radiance sensors of the WISP-3 have a 3^0 angle of view making it suitable for point measurement by preventing unwanted signals.
- Adaptability to local algorithms: The algorithms that are built into the WISP-3 by default are considered suitable for a range of moderately to highly turbid water types, which includes a large number of lakes and other inland waters. But in rare optical conditions local algorithms can be applied to the WISP-3.
- Remote access over Ethernet: Upon a request the WISP-3 can be programmed to measure continuously.
- Data storage: Once the measure button is pressed, the raw data and calculated parameters will be automatically stored on the SD card inside the WISP-3. In addition the raw data will also be stored in our database if you upload your measurements to WISPweb and can be retrieved back if requested.
- Portability: The WISP-3 is most favoured especially by our woman communities because of its light weight and easy to transport.
- Long battery life: WISP-3 has a low power consumption ~2.5W. Once fully charged, the battery life is about 8 hours.
- Upgrading and software access: Subscription to WISPweb software is free for users. Water Insight continuously strives to adopt state-of-the-art reflectance data processing techniques, so that a measurement taken today will remain valuable for water quality monitoring in years to come.

2. INSTRUMENT OVERVIEW

Removing the protective cover reveals the three spectrometers that make up the WISP-3 (Figure 2). Replace the cover between measurements to keep the light collectors clean.

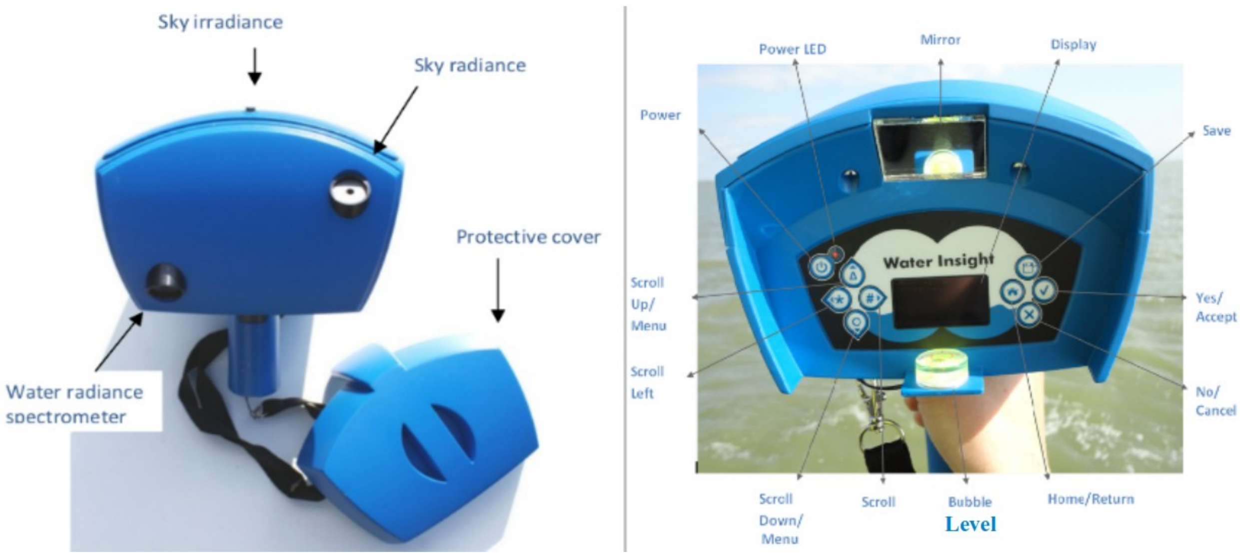


Figure 2: The front side of WISP-3 (left) and the backside of WISP-3 (right)

During a WISP-3 measurement the instrument should be held at the handle as shown in Figure 1. A mirror and the bubble level help to maintain the correct horizontal position during the measurement. The controls on either side of the display are used to navigate the menu and control basic settings such as time, location and measurement number or station names.

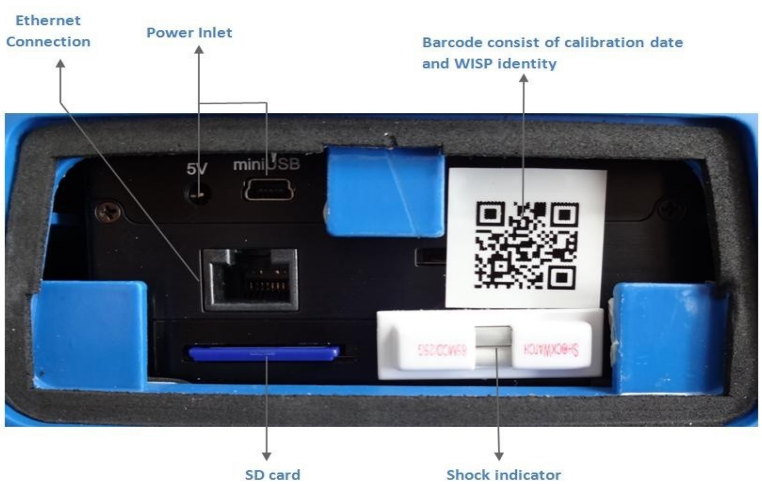


Figure 3: Bottom panel of WISP-3

The bottom panel (Figure 3) includes the power connector for recharging, SD card slot for data storage, and a QR code used to identify each spectrometer and its respective calibration dates.

3. SETUP

3.1 Checking the battery

To check the battery charge status, power on the WISP-3 and press cancel in the main menu to enter the spectrometer menu. Navigate up or down until **System tools** is highlighted and press yes/accept then scroll down to **Battery Info** which shows battery level and remaining charge time (see Figure 4). To return to the measurement menu, press cancel, navigate to **Jaz menu** and press the home button.

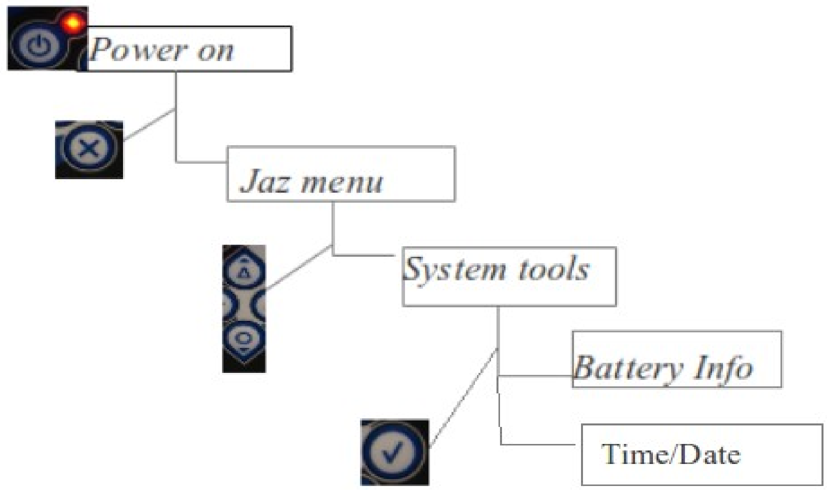


Figure 4: Steps to follow for checking battery status or setting date and time

To recharge the WISP-3 battery connect the AC adapter (Input: 100-240V, output +5V DC) to the power connector inside the bottom panel. Alternatively, a USB cable can be used to charge but this will take longer.

3.2 Setting the date and time (Optional)

The WISP system time should be kept on Coordinated Universal Time (UTC), so that measurement location and time stamp can be used with algorithms that require information on sun position. But if you want to adjust time and date, please follow the procedure shown in the Figure 4.

3.3 Adding station names

Turn the WISP-3 on and press configure to create a custom file name for your sample station within the settings menu ('configure' – 'base file name'). Navigate through the alphabet with the control buttons and accept characters by pressing accept/yes button. To accept the name, navigate to done and press home. All subsequent measurements will now be stored under this base name (*name*000, *name*001, etc.). The base file name is lost when the **WISP is turned off**. To go back to the main menu, press cancel.

4. PERFORMING WISP-3 MEASUREMENT

4.1 Preparing the WISP-3 for measurement

First, make sure the WISP-3 has sufficient battery power (Please refer to section 3.1 for details). To measure enough light reflected in the water column, we recommend to measure when the sun elevation is at least 30° above the horizon. The solar elevation at your latitude can be obtained from web-based solar height calculator such as “http://www.esrl.noaa.gov/gmd/grad/solcalc/” or estimated in the field by taking the angle from the horizontal to the sun. Also, keep an eye on the weather forecast. Sunny days are best, full cloud cover is usually fine, but low light due to thick rain clouds, as well as fog and rain are best avoided since the WISP-3 will give error.

4.2 Performing a measurement

Positioning WISP-3: It is very important to operate the WISP-3 at the intended horizontal and vertical angles. The bubble level will help to keep the instrument level during measurements. Equally important is the angle towards the sun and possible shadows. The WISP-3 should be positioned 135° away from the sun, or in other words at 45° away from where shadows cast by the sun reach. There are thus two suitable angles, measured either clockwise or anti-clockwise from the sun, as illustrated in Figure 5. Reflections of the sun and the sky on the water surface are kept to a minimum when measuring at these angles. According to literature [6], the angle from the sun should at least be 90°, although closer to 135° is optimal. Angles < 90° (towards the sun) and ~180° (opposite to the sun) should absolutely be avoided. The correct position (see Figure 5) should be kept during the measurement, until the display indicates the measurement is finished by flashing the screen. If the sky is fully overcast and shadows are not visible, the angle is less critical but measuring towards the position of the sun is still not advised.

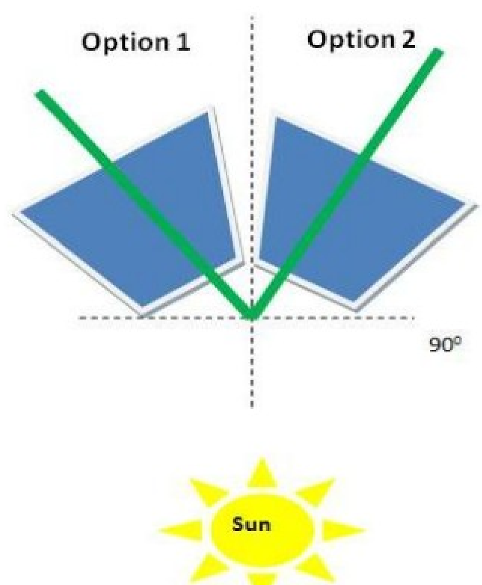


Figure 5: Correct positioning of the WISP-3 during the measurement

Measurement conditions: Make sure to stand close enough to the water so that the sensor looking down will actually be pointed at the water surface. Clear and completely overcast skies provide the best measurement conditions. Scattered clouds may hamper accuracy, because the light collector pointed at the sky might not represent the same light as reflected on the water surface and captured by the downward looking sensor. If clouds are moving in and out of view, try waiting a while for homogeneously open or closed cloud cover. Taking additional measurements is also recommended under doubtful conditions. Avoid areas with floating vegetation, leaves, garbage, bottom visibility and shadows cast from the boat or jetty you are on. Waves can also interfere with accuracy, although this is normally sufficiently reduced by measuring in the correct direction relative to the sun. The WISP-3 averages 5 measurements, which further reduces the effect of the darker and lighter wave slopes. Boats, jetties, rafts, and bridges without superstructures can provide ideal locations. A summary of conditions that should be avoided is illustrated in Figure 6.

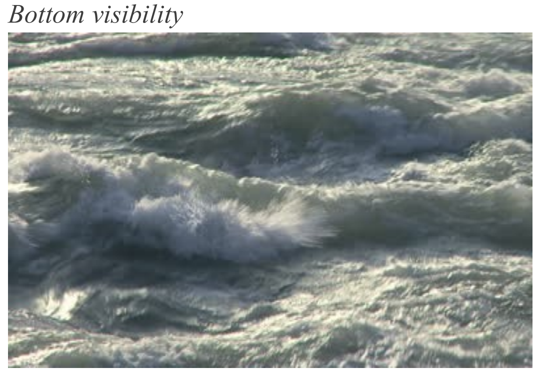
Trees (or buildings)

Shadows cast caused from/by e.g. a bridge or yourself

Mixed clear and clouded sky

Bottom visibility

Floating debris



Waves with whitecaps

Figure 6: Conditions that negatively influence the quality of WISP-3 measurements

Performing Measurement: From the main menu press Measure (#) to record a measurement. The display will show “adapting to light”, followed by the percentage completion of the current measurement. Keep the WISP-3 steady until the screen blinks several times and estimates of chlorophyll-*a* (Chl-a), phycocyanin (PC), light attenuation (K_d) and total suspended matter (TSM) are displayed. The measurement is automatically saved.
The message “not enough light” warns of low light conditions. Verify that the sensors are not blocked. If the WISP-3 is exposed to direct sunlight for some time on a warm day, the message 'too much light' may show. Place the instrument in the shade for a while to cool down. It is good practise to return the instrument to its case in a shaded spot when it is not in use. The WISP-3 will record measurements even when the solar elevation is not correct, when it is not kept horizontal, or pointed towards the sun. These considerations are the responsibility of the user, as with any measurement device.

4.3 Viewing measurements

The first results you will see on the display screen are the estimates of chlorophyll-*a* (Chl-a), phycocyanin (PC), light attenuation (K_d) and total suspended matter (TSM). To view the reflectance spectrum after a measurement, press cancel and select 'view graph'. The WISP-3 saves its measurements on an SD card. To retrieve the data, turn the WISP-3 off, open the bottom panel, press on the SD card to release it and place it in a suitable reader in your computer or an external card reader.
In the SD card folder you will find a folder called 'WISP' containing your measurements. In the folder 'WISP' you will find a folder for each time you created a new base file name. The names include the date of the measurements (year, month, day) and the base file name you gave it: 'yyyy mmdd_basefilename'.
Each folder contains two types of .txt files, one containing the spectral data of your measurements and one calculated water quality parameters (Chl-a, TSM, K_d, CPC) and subsurface irradiance reflectance $R(0^-)$ values equivalent to the bands of the ENVISAT/MERIS instrument which form the basis of the embedded algorithms. Both file-names include the date and the time (hour, minute, second) of the measurement, the base file name (yyyymmdd_hhmmss_basefilename) and end with “spec” and “conc.” for ‘spectrum’ and ‘concentration’ respectively. If you took several measurements under the same base file name, you can tell them apart by their timestamps. If you forget to give the basefilename, then the WISP-3 will automatically give default name ¨WISP001,WISP002,etc,”.
Note that concentration results may show as zero, ‘nan’ (not a number) or very high values in situations where the generic built-in algorithms are not suitable for the current water type, or if a measurement is not carried out according to proper protocol.
As a WISP-3 user you have access to WISPweb where you can store and analyse your data. The following chapter introduce you to the use of WISPweb.

5. INTRODUCTION TO WISPWEB

As a WISP-3 user you have access to WISPweb where you can store and analyse your data. In WISPweb your WISP-3 measurements are safe: backed up and only visible to you and if you want also to users you allow access. During uploading the measurements are calibrated and several algorithms for water quality parameters (Chlorophyll-*a*, Total Suspended Matter, Phycocyanin, and K_d) are run. In WISPweb, the analysis and comparison of measurements becomes easy. This chapter is a basic introduction to the use of WISPweb. The full manual for WISPweb is found at http://wispweb.waterinsight.nl/.

5.1 Login to WISPweb

With your WISP-3 you have received a user name and password for WISPweb. Go to http://WISPweb.waterinsight.nl, fill out your user name and password and click 'login'. If you have lost your login details, please write to info@waterinsight.nl, or directly to your contact at Water Insight.
By default, your login details will grant you access to your own measurements while these are hidden from everyone else. Various alternative sharing options can be provided.

5.2 Upload data

After login, you will find the 'Quick Up-loader' on the left. Here you can upload measurement files to the WISPweb system. Fill out meta-data, such as Region, Station, and Operator of the WISP-3 measurement for your own convenience. In the near future it will be possible to filter and select measurements based on this information.
Now click the 'Browse' button. Find the file you want to upload by clicking on the folder of the SD card, the folder 'WISP', and go to the folder 'yyyymmdd_basefilename' and select the file ' yyyymmdd_hhmmss_basefilename_spec. Text'.
Next, fill out the latitude and longitude of the measurements (in decimal degrees). These are used to plot the location of the measurement station on maps. Latitude is also important for some advanced algorithms, so provide these data whenever possible. You can add notes in the 'Comments' box. When done, click 'upload'. The measurement data are transferred to the WISPweb database, where they are safely stored. The raw data are converted to calibrated units and water quality parameters are derived using state-of-the-art processing methods. The measurement is added to your list of measurements displayed on the right.
The meta data of the last measurement remains in the up-loader, so it is easy to quickly upload more measurements with the same meta data: only select the next measurement and click 'Upload'. When the next measurement has other meta data, simply edit it.

5.3 Working with WISPweb

Following data upload, the main feature of WISPweb is a table that holds information on all measurements to which you have access. From this view, the user can review measurements in detail, compare between measurements, and select and download processed results. The features of WISPweb data view are briefly introduced below.

The Measurement overview page

Per page of the measurement table 20 measurements are listed. Use the arrow at the bottom of the table or click on the page numbers to proceed to the next page.

Clicking on the headers of the columns will sort the measurement table according to the values in that column. Click again to change from ascending to descending sorting.

The measurements table on the right side of the screen, shows (from left to right):

- Selection check boxes, allowing selection of one or multiple measurements.
- Location metadata (Region, Station)
- Date and time of the measurement (obtained from the measurement file)
- Derived water quality parameters:
  - Chlorophyll-a [Chl (µg/l)]
  - Phycocyanin [CPC (µg/l)]
  - Ratio of chlorophyll-*a* over Phycocyanin [Chl/CPC], a measure of the dominance of cyanobacteria with respect to the other phytoplankton;
  - Total Suspended Matter [TSM (mg/l)] or Suspended Particulate Matter (SPM) concentration.
  - Diffuse downwelling attenuation coefficient [Kd(1/m)] at 490 nm, a measure of water transparency used to model the penetration of sunlight in the water. Generally, a negative linear correlation exists between ln(K_d) and Secchi depth.
- A link ('Details') to the spectral measurement details of a single measurement. Described in more detail, below.
- A link ('Edit') to edit metadata of the measurement. After editing click 'Update' to save or use the 'Measurements' menu button or the browser 'back' button to return to the table without saving.

'Details' page

By clicking on 'Details' of any measurement in the 'Graph' column, a page opens containing graphs of the hyperspectral light measurements.

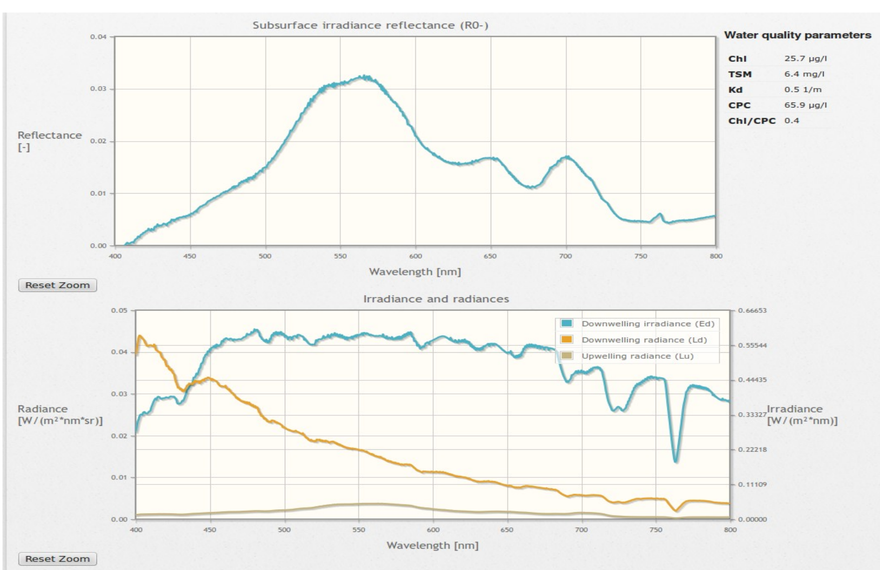


Figure 7: Preview of the details page

On the upper right you will find the derived water quality parameters for this measurement. The upper graph shows the reflectance just below the water surface, (R0-), which determines the colour of the water. The reflectance, which is calculated from the data in the lower graph, is used to derive water quality parameters. The lower graph presents the calibrated measurements of the three single radiometers within the WISP-3:

- The downwelling irradiance E_d (W/(m²*nm),
- The downwelling radiance L_d (W/(m²*nm*sr)
- The upwelling radiance L_u (W/(m²*nm*sr)

Irradiance (E_d) is plotted on the right vertical axis, both radiances on the left vertical axis of the lower graph. In above-surface reflectance spectrometry, the terms L_s or L_{sky} are sometimes used instead of L_d . Similarly, the water-leaving radiance (L_w), or transmitted radiance (L_t) are sometimes used instead of L_u. The quantities shown in this view are those recorded by the WISP-3 after calibration to physical units, without further conversions. The L_u signal plotted in the Details screen includes a fraction (usually between 2-8%) of sky radiance (L_d) directly reflected on the water surface. To compute Reflectance (upper graph), this fraction is estimated and removed.

Zooming in and out
All spectral data are presented over the 400-800 nm range (from blue to short-wave infra-red). By moving the mouse over the graphs, corresponding values are plotted in the lower left corner. Clicking and dragging the mouse allows you to zoom in on an area. The button 'reset zoom' will zoom out and show the complete graphs again.

Map
If you have filled out the station co-ordinates in decimal degrees, you will find a map on the bottom of the page, showing the location of the measurement. You can zoom in and out on the map by scrolling with the mouse or by using the + and – buttons. It is also possible to click-and-drag the map. To go back to the list of measurements, click on the 'Measurements' button or on the Water Insight logo.

Selecting multiple measurements
To view the reflectance spectrum of multiple measurements in one graph, go back to the measurements list and check the boxes of several measurements in the first 'select' column. After selecting the measurements, scroll to the bottom of the list and select 'Plot spectra in graph' from the pull down menu. Press 'Go' to view and compare the reflectance for the 400-800 nm region for the selected measurements. As with the graphs under 'view details' it is possible to zoom and read out the values. To go back to the list of measurements, click on the 'home' button or on the Water Insight logo.

Downloading data
To download the derived water quality parameters of one or several measurements in excel format, check the boxes of the measurement(s) in the first column. After selecting the measurements, three downloading option are given below each other in the pull down menu.
If you select 'Download parameters of selected measurements in Excel', the downloaded file will contain columns for Region, Station, Date and time, Chl, TSM, CPC, Chl/CPC, and Kd.
If you select 'Download parameters of all measurements in Excel', the downloaded file will contain all the measurements you upload including columns for Region, Station, Date and time, Chl, TSM, CPC,

Chl/CPC, and Kd.
If you select 'Download parameters and spectra of selected measurements in Excel' , the downloaded file will contain not only the above parameters but also the calibrated spectral data (E_d, L_d, L_u) and the reflectance (R0-), all for the 400-800 nm region.

How to interpret water colour using the reflectance (R(0-))?
The reflectance (R0-) is an accurate description of the intrinsic colour of the water, independent of illumination conditions. The reflectance is the ratio between downwelling and upwelling light in the water and therefore describes the fate of sunlight as it penetrates the water column.
Simply put, high reflectance (closer to 1) corresponds to bright (turbid) water. Low reflectance corresponds to a dark appearance of the water. When reflectance peaks at short wavelengths (e.g. 400-500 nm), the water will appear blue (e.g. clear oceanic water). For inland lakes that are more turbid, we usually see that the middle part (500 - 600 nm) of the reflectance spectrum is most pronounced. Light in this spectral region appears green to our eyes. A spectrum that peaks in the green wavelength range often corresponds to the presence of phytoplankton (algae or cyanobacteria), particularly when local depressions in the reflectance spectrum around the areas of high absorption by phytoplankton pigments (e.g. around 450 and 670 nm) are present. A reflectance spectrum that rises at longer wavelengths (> 700 nm) may indicate high turbidity, phytoplankton bloom, or floating vegetation. Water with these properties will appear more yellow-brown or even red.

Basic quality screening
The reflectance (R0-) is the ratio of the available sunlight that is reflected upward and can therefore not be lower than 0 or higher than 1. If the reflectance spectrum exceeds these limits this is an indication of a problem with the measurement (if all measurements turn out this way, instrument calibration should be checked). A common problem for negative reflectance is uncertainty in the correction of the signal for reflected sky radiance, which happens when measurements are carried out under suboptimal illumination conditions such as broken cloud cover, or with extensive waves. Taking repeated measurements often is sufficient to determine which measurements suffered from this problem, so that these can be deleted. Water Insight is working towards implementing algorithms that will be able to identify and sometimes recover some of these suboptimal measurements. If a measurement is obviously poor, it can be deleted. In all cases where reflectance is negative, treat the results of the water quality algorithms with care.
The irradiance (E_d) should always have the highest values of the three separate spectra (note the separate axes for L_u, L_d and E_d in the Details page graph). The downwelling radiance (L_d) is only a fraction of Ed and should therefore be much lower (in the order of 1-10% of Ed). Under clouded skies, the shape of L_d and E_d can be very similar. Under clear skies, L_d tends to be relatively higher at short (blue) wavelengths.
The upwelling radiance L_u (the 'water' signal) is generally lower than L_d in at least a large part of the spectrum. Again, this depends on the illumination conditions. Under a clouded sky, L_u will not typically rise above the intensity of L_d. Under blue skies, the peak of the L_u spectrum can exceed that of L_d outside the blue spectral range (e.g. > 500 nm). Water bodies that appear clear and dark should have L_u that is much lower than L_d along the whole spectrum. With increasing turbidity, L_u may approach or even exceed L_d. These rules-of-thumb are only valid when measurement angles and conditions were chosen according to the guidelines laid out in section 4.2 of this User Guide.

6. MAINTENANCE

As with any optical instrument the WISP-3 should be handled carefully. We strongly advise you to send your WISP-3 to Water Insight once a year for recalibration to ensure optimal performance.

6.1 Cleaning and storage

The WISP-3 conducts an above-surface measurement and is therefore not subject to fouling through direct water exposure. The instrument is designed to be used under either clear or fully overcast skies. The light collectors should be kept dry to obtain high-quality measurements. The protective cover should be kept on the WISP-3 at all times except during measurement. The front collectors (black tubes) form an open connection with the optical surfaces in the instrument. Hence water or dust entering these tubes could cause accumulation of dirt as well as oxidation of the internal optics, requiring re-calibration of the instrument. To ensure long-term stability the WISP-3 should be stored in a dry, dust-free place, preferably at room temperature. Humid air condition may damage the instrument when exposed for a prolonged period of time. It is recommended that the WISP-3 is stored in its carrying case.

To protect the WISP-3 from excessive vibration and shock, please use the hard carrying case with soft foam lining or field carrying case for transportation. If the WISP-3 is exposed to shock (e.g. when it is dropped), the shock indicator (see Figure 3) will turn red. If this is the case, the WISP-3 should be examined carefully and compared with another reference instrument or reference measurement. If the comparison indicates a problem, please send the WISP-3 back to Water Insight for recalibration as the optical fibre alignment could have been disturbed.

6.2 Battery maintenance

The WISP-3 operates on a rechargeable lithium-ion battery. If fully charged with a new set of batteries, it can last for 8 hours of continuous operation. But just like any other rechargeable battery its performance can drop with time and usage. Other factors that also influence the rate of degradation of Li+ batteries are high temperature and their self-discharge rate. The rate of degradation of lithium-ion batteries is strongly temperature-dependent; they degrade much faster if stored or used at higher temperatures.

In addition , Li+ batteries have self-discharge rate of approximately 5–10% per month[10] .As the battery self-discharges over time, its voltage gradually reduces. if stored fully discharged the battery may not last longer. It is recommended to store batteries at 40% charge level[1]. When you noticed that your WISP-3 battery is degrading, you can contact WaterInsight for replacement.

6.3 Calibration

The WISP-3 is sent from Water Insight fully calibrated. Calibration files for the three channels are used in the built-in (and WISPweb) software. Once a year, the WISP-3 needs to be re-calibrated at Water Insight. Opening the WISP-3 could disrupt the optical fibres alignment which reduces the calibration accuracy and requires re-calibration.

7. SPECIFICATIONS

Table 1: Specification of WISP-3. The spectrometers, light collectors and optical fibers connecting them are produced by Ocean Optics (www.oceanoptics.com) and custom-made for the WISP-3.

	Radiance UV/VIS (L_s, L_t)	**Irradiance UV/VIS (E_d)**
Calibrated spectral range	400-800 nm	
Detector	2048-element linear silicon CCD array	
Sampling Interval	0.3 nm, boxcar smoothing over 5 pixels	
Sampling Resolution	4.9 nm	3.9 nm
Slit width	100 µm	25 µm
Field-of-view	3º	180° cosine response
Stray light	< 0.05% at 600 nm ,< 0.1% at 435nm	
Signal-to-noise ratio	250:1 for the radiometers	
Dynamic range	1300:1	
Integration Time	870µs – 65sec, automatically set	
Communication		
Connector	mini-USB, Ethernet supported	
Data storage	SD-card	
Physical appearance		
Dimensions	Height: 15 cm + 10 cm handle (5.9 + 3.9”) Length: 25 cm(9.8”) Width: 20 cm (7.9”)	
Weight	2.2 kg (4.85 lbs.)	
Miscellaneous		
Battery type	Rechargeable lithium-ion	
Battery life	up to 8 hours on full charge	
Operating temperature	-5°C to 45°C (customized on request)	
Power consumption	250 mA @ 5 VDC	

8. THEORY OF OPERATION

The WISP-3 accurately records downwelling irradiance (E_d), upwelling radiance (L_u) and downwelling radiance (L_d). The following parameters are derived from the optical measurements:

- Concentration of chlorophyll-*a*, a proxy for phytoplankton biomass, 0 - 120 mg m^{-3};
- Concentration of phycocyanin, a proxy for cyanobacteria biomass, 0 - 1200 mg m^{-3};
- Concentration of Total Suspended Matter (TSM), 0 - 100 g m^{-3};
- Spectral attenuation of light, $K_d(\lambda)$

8.1 Algorithms

Reflectance spectroscopy relates the radiation reflected by an object to its material composition. The WISP-3 is developed specifically for reflectance spectroscopy of natural water bodies. The challenge in developing reflectance algorithms is to relate light absorption and scattering properties of the substances that are present in a water body (e.g. phytoplankton pigments, dissolved matter) to their influence on water colour, at varying concentrations of each substance. In addition, the bulk attenuation of light by the combined substances is of prime interest to define the penetration of sunlight into the water column, fuelling aquatic photosynthesis.

Various approaches to the inverse problem of water colour have been researched in the last decades, and it is important that the algorithms used to derive the concentrations of these substances from the measured reflectance are appropriately chosen. The algorithms that are built into the WISP-3 by default are considered suitable for a range of moderately to highly turbid water types, which includes a large number of lakes and other inland waters. The algorithms provided through WISPweb are more complex and can handle an even wider range of water types. If the WISP-3 measurement is carried out properly, it is likely that an algorithm exists that can derive the concentrations of dominant optical substances. If a suitable algorithm does not exist, some algorithms can be tuned or trained to handle rare optical conditions.

Most of the built-in WISP-3 algorithms target specific areas in the reflectance spectrum which correspond to wavelength ranges where the substance of interest has a large influence on the amount of reflected light, while other substances do not have much influence on the reflectance spectrum. The optical signals are extracted from differences between these spectral bands, or from band ratios against a reference bands. These algorithms typically targets one to four bands simultaneously to solve the inverse problem, and are computationally inexpensive so that they can be embedded on an instrument such as the WISP-3.

Advanced algorithms may use substantially more information from the reflectance spectrum, and use bio-optical models to match the full spectral absorption and scattering profiles of individual substances to the observed reflectance. The main advantage of these bio-optical models is that spectral information of individual substances can be easily changed to match locally expected conditions, such as red sediments or specific phytoplankton groups. However, the complexity of these models require more computing power. In the WISP-3 data processing chain, results from such algorithms become available only after uploading the measured data to WISPweb.

The preliminary data that appear on the WISP-3 display are calculated using the band algorithms adopted from the studies listed in Table 2.

Table 2: Default algorithms used with the WISP-3, which can be adapted on request. References are given in full in Chapter

Parameter	**Reference**
Chlorophyll-*a*	Gons *et al.* 2005[4]
Total Suspended Matter	Rijkeboer *et al.* 2000[7]
Light attenuation (K_d)	Gons *et al.*, 1997[2]
Phycocyanin	Simis *et al.* 2005[8], 2007[9]

8.2 Converting the raw data to physical units

The radiance and irradiance are calculated from raw instrument counts according to the following equations:

$$L_u\ (W\ m^{-2}\ nm^{-1}\ sr^{-1}) = 0.01 \times (counts \times cal/t)/(A \times d\lambda \times \Omega) \qquad (Eq.1)$$

$$L_d\ (W\ m^{-2}\ nm^{-1}\ sr^{-1}) = 0.01 \times (counts \times cal/t)/(A \times d\lambda \times \Omega) \qquad (Eq.2)$$

$$E_d\ (W\ m^{-2}\ nm^{-1}) = 0.01 \times (counts \times cal/t)/(A \times d\lambda) \qquad (Eq.3)$$

$$R(0\text{-}) = Q \times f\,(L_u - r_{sky} \times L_d)/E_d \qquad (Eq.4)$$

where *cal* is the calibration factor, *t* is the integration time of the measurement, *A* is the collection area (surface area of the optical fiber for radiance channels, and the surface of the cosine collector for the irradiance channel), $d\lambda$ is pixel width, and Ω corrects for the solid angle of the radiance measurement ($\Omega = 2\pi[1-\cos(FOV/2)]$, where FOV is the 3° field-of-view).
Q denotes the conversion coefficient for L_{wu} (upwelling radiance below water) to E_{wu} (upwelling irradiance below water), f is the conversion constant of L_u (upwelling radiance above water) to L_{wu} (upwelling radiance below water), r_{sky} is the radiance of skylight at zenith angle of 42^0.

8.3 Validation of WISP-3

The WISP-3 uses a unique configuration of fiber optics. To validate this approach, WISP-3 measurements were compared against other non-handheld or mounted spectroradiometers and laboratory concentrations.

Validation against non-handheld spectroradiometers

Sensors from TriOS, ASD FieldSpec as well as other sensors were included in this comparison. Figure 8 shows high correspondence between the sensor systems when operated in Lake Vänern, Sweden, after Hommersom et al., 2012.

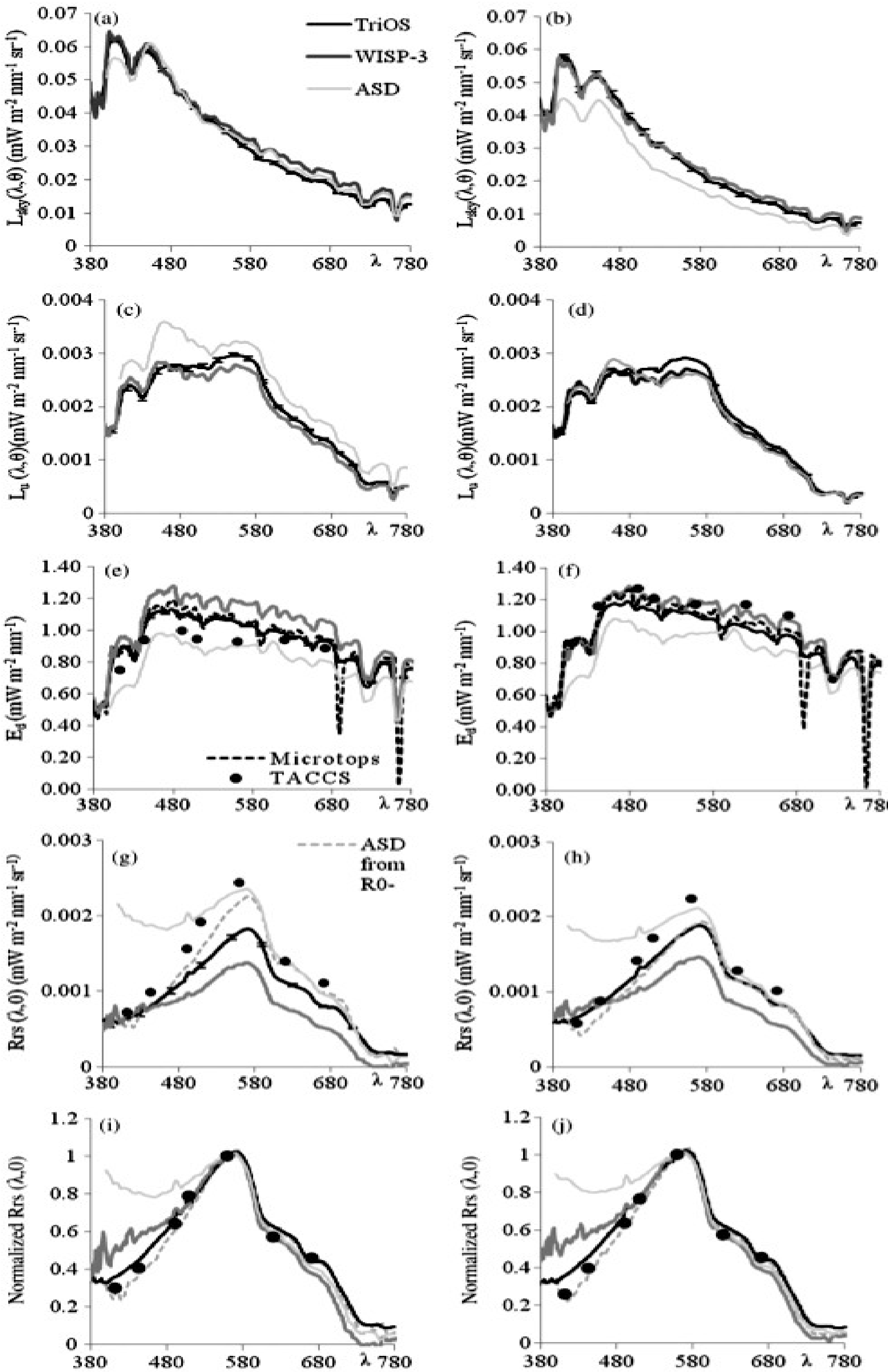


Figure 8: Comparison of spectroradiometer systems including the WISP-3 on Lake Vänern (plot taken from Hommersom et al., 2012)

Validation against laboratory concentrations

The performance of WISP-3 as compared to other radiometers delivers similar spectra measurements (see Figure 8). Nevertheless, efforts are constantly made to allow direct comparisons between WISP-3 estimates and laboratory measurements of the concentrations of targeted substances. To illustrate these efforts, Figure 9 shows comparisons between band ratio and band value algorithm results against concentrations of chlorophyll-a and suspended matter for measurements with various devices including the WISP-3, on Swedish and Estonian lakes (Hommersom et al., 2012).

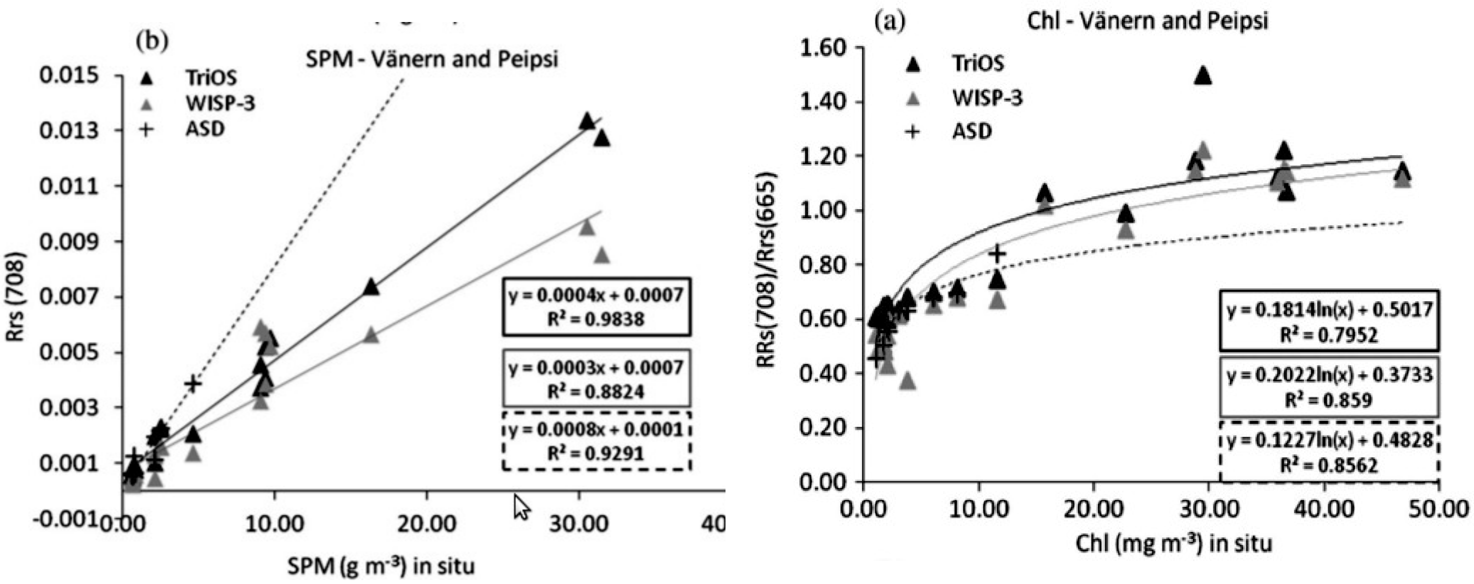


Figure 9: Band ratio and single band values obtained with TriOS RAMSES, WISP-3, and ASD Fieldspec spectroradiometers compared to concentrations of (left) chlorophyll-a and (right) suspended matter (from Hommersom et al., 2012)

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APPENDIX A. FAQ

1 . WISP-3 questions

1.1. Can I use the WISP-3 when it is cloudy?

Sunny days are best, full cloud cover is usually fine, but low light due to thick rain clouds, as well as fog and rain are best avoided because the WISP-3 will give error measurement. Scattered clouds may hamper accuracy, because the light collector pointed at the sky might not represent the same light as reflected on the water surface and captured by the downward looking sensor. If clouds are moving in and out of view, try waiting a while for homogeneously open or closed cloud cover. Taking additional measurements is also recommended under doubtful conditions.

1.2. My concentration values read nan, what does this mean?

'nan' stand for 'not a number'. The concentrations could not be calculated, either because it was not a good measurements (e.g. not measured in the right direction (135 degrees) away from the sun, or not kept straight), or because the algorithms used within the WISP-3 were not suitable for the type of water you were measuring. The algorithms were calibrated on Dutch inland but open waters, so for measurements taken in oceanic water, or in very turbid waters such as peat pots might be out of the calibrated concentration ranges. However, in these cases the spectral data is still expected to be valid, so do save these measurements and upload them to WISPweb.

1.3. My concentration values read zero

Either the concentrations were very low, or the algorithms used within the WISP-3 were not suitable for the type of water you were measuring. Also in the latter case the spectral data is expected to be valid, so do save these measurements and upload them to WISPweb. It could also be that the WISP-3 was not kept straight or in the right direction (135 degrees) away from the sun.

1.4. CPC (phycocyanin concentration) shows a very high value, while I'm sure there are no cyanobacteria in the water

The CPC algorithm is only calibrated for fresh waters where chlorophyll is present.

1.5. The WISP-3 takes long to adapt to light (and measure)

Most likely the water you are measuring is very dark (a lot of absorbing matter is available). If this is the case, the measurement will take longer, so that enough light is caught. It is also possible that the conditions are changing rapidly. For example, when the WISP-3 was adapting to high sunlight and suddenly the sun disappears behind a cloud, adapting starts again. Also small reflecting waves can cause such changing conditions. If none of this is the case, check the battery power. When the battery gets empty, adapting and measuring takes somewhat longer.

1.6. When my WISP-3 was delivered, the G-force button on the suitcase had changed colour

Please send the WISP-3 back for re-calibration.

1.7. My WISP-3 fell on the ground during fieldwork.

Please send the WISP-3 back for re-calibration.

1.8. My WISP-3 got wet due to rain.

No problem, just clean the CC3 collector on top with a tissue, preferably a special optical tissue.

1.9. Where can I find how much the battery is charged?

Go out of the WISP-software menu by pressing 'X'. Now navigate up or down with the arrows, choose 'system tools' and then 'battery info'.

1.10. The screen of the WISP-3 is hard to read in the sun

We know this, however, it is a trade off between visibility and battery lifetime after charging. The best is to hold the WISP-3 in your own shadow to set the 'base file name ', so you know you only need to press ' # ' to take a measurement while the screen is hard to read.

1.11. The time set in my WISP-3 is not correct

It is advised to keep it in UTC timestamps. although you can change the UTC time into your local time, The algorithms using sun elevation on WISPweb would not work. But if the UTC time is incorrect, you can change time and date settings in the main menu (go out of the WISP-software menu by pressing 'X'. Now navigate up or down with the arrows, choose 'system tools' and choose 'date/time').

2. WISPweb questions

2.1. Are my spectral measurements okay?

Please check R(0-) directly after measurement. The reflectance (R0-) is a ratio and should therefore never be lower than 0 or higher than 1. Reflectance spectra that are out of the 0-1 range should be erased. Because of sky glint correction, sometimes the reflectance around 400nm is negative. If this occurs only on the leftmost side of the graph and the values are just below zero,you can still use the data. But please treat this measurements with care.

The irradiance (E_d) should always have the highest values of the three separate spectra. The downwelling radiance (L_d) is a fraction of E_d and should therefore be much lower (e.g. a factor 10). However, both measure the sky and the spectral shape should therefore be relatively similar. The downwelling radiance (the 'water' signal) should be much lower than Ld. If not, check if there was a high sediment load (than the spectra might be correct), or if there were factors with a negative influence on the measurement, such as bottom visibility, macrophytes, floating plants or garbage, or wrong measuring angles.

2.2 I have a lot of data and single uploading is time consuming.

We are working on the implementation of this on the WISPweb. Water Insight can assist you in uploading large batches of data.

APPENDIX B. MERIS bands

Of the text files stored by the WISP-3 on the SD card, the one 'conc' contains both the calculated water quality parameters (Chl-a, TSM, K_d, CPC) and the calculated subsurface irradiance reflectance $R(0^-)$ values equivalent to the bands of the ENVISAT/MERIS instrument which form the basis of the embedded algorithms (see Table 3). These values are stored to reduce computation time of the embedded algorithms.

ID on SD card	MERIS band	Band width
M1	412.5	10
M2	442.5	10
M3	490	10
M4	510	10
M5	560	10
M6	620	10
M7	665	10
M8	681.25	7.5
M9	708.75	10
M10	753.75	7.5
M11	760.63	3.75
M12	778.75	15

Table 3: One of the outputs of WISP-3's embedded algorithms is irradiace reflectance value based on MERIS band

About Water Insight

Water Insight BV offers innovative products and services in the field of geoinformation and surface water quality monitoring. State-of-the-art remote sensing technologies are used from different platforms including boats, air planes and satellites, for our products and services. Water Insight was founded in 2005 by Dr. Steef Peters and Dr. Marnix Laanen. Besides water remote sensing products and services for insitu measurements and satellite data, Water Insight leads and participates in international research projects. Customers are national and regional water management authorities and national and international commercial enterprises.

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