



# Global Lakes Sentinel Services

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## GLaSS Training material, Lesson #10

### Assessing ecological status according to the WFD

How remote sensing could support Water Framework Directive implementation in lakes?

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## Lesson summary

Lakes and reservoirs provide essential ecosystem services, but are subject to significant pressure from agriculture, economical development, and climate change. Monitoring changes in the environmental status of lakes is regulated by the European Union in the Water Framework Directive (WFD). The WFD requires that the Member States systematically monitor all natural and artificial lakes with a surface area larger than 0.5 km<sup>2</sup> based on multiple components and parameters. As some of these parameters can be determined by remote sensing, this lesson exemplifies how we can use satellite data to assess the ecological status of lakes using data from a number of lakes in southern Sweden and Lake Vänern.



## GLaSS training material outline

This lesson is part of the GLaSS training material. The complete training material outline is listed on [http://data.waterinsight.nl/GLaSS/trainingmaterials/GLaSS\\_lesson\\_outline.pdf](http://data.waterinsight.nl/GLaSS/trainingmaterials/GLaSS_lesson_outline.pdf).

Note that the lessons logically follow up on each other, the later lessons might require skills that can be acquired during the earlier lessons.

## Table of contents

|   |    |
|---|----|
| Lesson summary .....  | 2  |
| GLaSS training material outline .....                         | 2  |
| Table of contents .....                                       | 3  |
| List of abbreviations .....                                   | 3  |
| 1 Introduction .....  | 4  |
| 2 This lesson .....   | 5  |
| 2.1 Research question .....                                   | 5  |
| 2.2 Training objectives / skills to gain in this lesson.....  | 5  |
| 2.3 Required software and data .....                          | 5  |
| Software and tools.....                                       | 5  |
| Downloadable files .....                                      | 5  |
| 3 Exercise .....  | 7  |
| Part 1 Visualization of MERIS L2 products.....                | 7  |
| Activities .....  | 7  |
| Part 2 Characterization of Swedish lakes status .....         | 8  |
| Part 3 WFD analysis of Lake Vänern on MERIS time series ..... | 10 |
| Activities.....   | 10 |
| 4 More information and further reading.....                   | 11 |
| References.....   | 12 |
| Colophon.....   | 13 |

## List of abbreviations

| Abbreviation | Description                                   |
|--------------|---|
| Chl          | Chlorophyll                                   |
| EO           | Earth observation                             |
| FUB          | Freie Universität Berlin                      |
| MERIS        | Medium Resolution Imaging Spectrometer        |
| MODIS        | Moderate Resolution Imaging Spectroradiometer |
| WFD          | Water Frame Directive                         |

## 1 Introduction

Lake water is an essential renewable resource for the environment and it is important for civil industrial and recreational purposes. Sustainable use of water resources requires the coupling of surface waters assessment monitoring programs and decision making and management tools. The Water Framework Directive (WFD, Directive 2000/60/EC, 2000) is the major reference in Europe to guide efforts to “*establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater*”. This means that the Member States have to achieve good water status (in the scale of High, Good, Moderate, Poor, and Bad) in terms of chemical and ecological parameters (e.g. chlorophyll-a concentration and transparency). WFD forces the member states to systematically monitor all natural and artificial lakes with surface area  $\geq 0.5 \text{ km}^2$ ; then the number of samplings during the year is a compromise between the need of describing the seasonal ecological variability and the required efforts/cost.

Over the past decade, latest generation of ocean colour sensors such as MODIS and MERIS have provided unique information for collecting consistent/homogeneous spatial and temporal data to assess water quality in lakes. Satellite imagery allows us to monitor large water areas (from local to global scale) with systematic and cost-effective acquisitions providing a powerful tool for supporting the WFD implementation (e.g. Bresciani et al., 2011; Koponen et al., 2004).

This work relies on the availability of a 10-years long dataset of MERIS-derived maps of water quality parameters at a spatial resolution of 300 m. The images allow to classify the water quality status according to the WFD limits in more the hundred lakes in southern Sweden. MERIS images are further investigated to capture the spatial and temporal variability of water quality status of Lake Vänern, one of the largest ( $5,650 \text{ km}^2$ ) Europe's lakes.

## 2 This lesson

### 2.1 Research question

How remote sensing supports the WFD implementation in Sweden?

### 2.2 Training objectives / skills to gain in this lesson

The aim of this lesson is to demonstrate how of remote sensing can support the implementation of the WFD.

- To be informed about the WFD
- Visualization of MERIS-derived products
- Checking differences in southern Sweden lakes based on WFD limits
- Analyzing differences among the Lake Vänern sub-basins depending on WFD regulation
- Checking water quality status of Lake Vänern during time

### 2.3 Required software and data

#### Software and tools

To complete this lesson tasks, the following tools and software are required or suggested:

- BEAM/SNAP 2.0 (required, see Lesson #1).  
Figures and buttons position in this document are referred to the BEAM-VISAT interface. Some slight difference may occur in SNAP interface.

#### Downloadable files

- GLaSS\_Training\_Lesson10.pdf  
The main document of the lesson including exercises and questions.
- GLaSS\_Training\_Lesson10\_Answers.pdf  
A document containing answers to all questions proposed in the exercises.
- GLaSS\_Training\_Lesson10\_DataAndTools.zip  
Supplied data and tools, described below.

The zip-file with supplied data and tools contain:

A 'Sample\_data' directory containing:

- a MERIS level-1 product in NetCDF format acquired on June 3<sup>rd</sup> 2011 ('MER\_FRS\_1PPBCM20110603\_102245\_000001413103\_00123\_48413\_0001.N1').
- a subset of FUB product of the same scene in BEAM-DIMAP format ('MERIS\_FUB\_20110603\_SouthSweden.dim' and the respective directory containing band products '.data').
- a text file ('In\_situ.txt') containing WFD classification retrieved from *in situ* measurements of Chlorophyll (Chl) concentration in five stations in Lake Vänern,

harvested during MERIS operational period, in August.

- 'insitu\_measurements\_coordinates.txt' containing the *in situ* stations coordinates.
- 'WFD\_sample\_lakes.shp' shapefile, containing some sample Regions of Interest (ROIs) in humic and non-humic Swedish lakes.
- 'WFD\_VÄNERN.shp' a shapefile of points, representing sample stations for Vänern sub-basin. In the file, the name of each station and humic condition are indicated.
- 'WFD\_VÄNERN\_coord.txt' containing the list of coordinates corresponding to 'WFD\_VÄNERN.shp' points.
- In addition, the subdirectory 'Vänern' contains Chl maps obtained averaging for each year all August available products, in BEAM-DIMAP format.

A 'Tools' directory containing:

- The *xml* file 'Extract\_chl.xml' for the extraction through BEAM batch-mode of Chl values from time series.

### 3 Exercise

#### Part 1 Visualization of MERIS L2 products

In the GLaSS project framework, FUB (Schroeder et al., 2007) processor was exploited for the retrieval of water quality parameters of Swedish lakes. In this first part, a FUB product derived from a MERIS image of southern Sweden territories is used to assess the trophic status of large and small lakes. Some sample lakes are then classified according to WFD limits.

#### Activities

- Start VISAT, the BEAM interface (find it in ...\\beam-5.0\\bin).
- Open the Level 1 MERIS product of June 3<sup>rd</sup> 2011 *File>Open Product...* and choose 'MER\_FRS\_1PPBCM20110603\_102245\_000001413103\_00123\_48413\_0001.N1' file in 'Sample\_data' directory.
- To get a *True Colour* visualization, in *Product* tab, right click on the product name and choose *Open RGB Image View*. BEAM proposes a RGB composition built on the combination of several MERIS bands, called *MERIS L1b - Tristimulus*. Click *OK*.

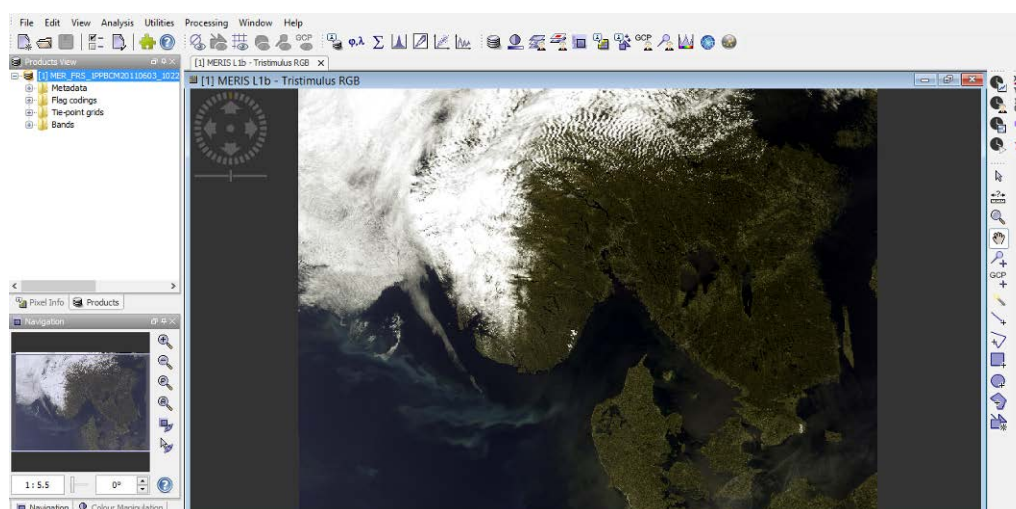


Figure 1. MERIS L1b – Tristimulus combination visualization of MERIS product acquired on June 3<sup>rd</sup> 2011.

The image includes southern Swedish territories, as well as the surrounding Baltic Sea, Skagerrak, Kattegat and North Sea.

- Zoom in on Swedish territories: as can be seen in the image, a lot of small lakes are visible in the map in addition to the two large lakes (Vänern and Vättern),.
- Open the subset FUB products of June 3<sup>rd</sup> 2011: *File>Open Product...* and choose 'MERIS\_FUB\_20110603\_SouthSweden.dim' file in 'Sample\_data' directory.
- In the Products tab, expand 'bands' folder: some FUB products are reported, including 'CHL' (Chl concentration) and reflectance in three MERIS bands. The last band, 'CALIB\_CHL' contains Chl concentration obtained from the calibration of FUB products over Swedish lakes. Right click on band name and choose *Properties* for more information on this band definition.
- Double click on 'CALIB\_CHL' band to open the visualization of Chl concentration: in



the *Colour Manipulation* tab the scale ramp with the colours legend is shown and you can manipulate or change it, changing colours, sliders positions, range values or assign single colours to fixed ranges.

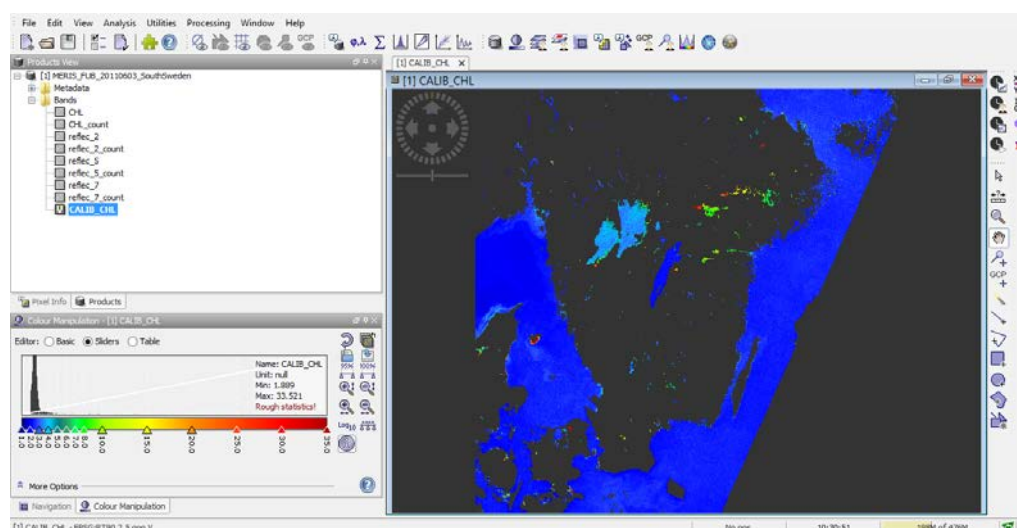


Figure 2. Chl concentration in southern Sweden Lakes and the surrounding seas in the FUB product of June 3<sup>rd</sup> 2011 shown in BEAM-VISAT and Colour Manipulation tab (bottom-left side).

- Looking at the range in the *Colour Manipulation* tab: Chl varies in a very large range. Lake Vättern (dark blue) has very low Chl concentration, while in Lake Vänern, Chl values vary significantly between different parts of the lake. The Chl concentration varies between and within the smaller lakes too.

## Part 2 Characterization of Swedish lakes status

To evaluate trophic status based on Chl concentration, two limits and thus three classes have been defined, which are different for each pre-defined Eco-region in Sweden. In addition, lakes are categorized as humic and non humic based on CDOM (Coloured Dissolved Organic Matter) concentration. Table 1 summarizes existing WFD limits and classes for the exemplified region.

Table 1 Humic levels for South Sweden for lake type definition and WFD Chl limits.

|                            | Eco region (NFS 2006:1) | Humic level    | WFD Chl limits | WFD classes               |
|----------------------------|-------------------------|----------------|----------------|---------------------------|
| South Sweden – Clear lakes | 4, 5, 6                 | ABS420/5 ≤0.06 | 0-≤5 µg/l      | <b>High</b>               |
|                            |                         |                | >5-≤8.5 µg/l   | <b>Good</b>               |
|                            |                         |                | >8.5 µg/l      | <b>Moderate/Poor/Bad*</b> |
| South Sweden – Humic lakes | 4, 5, 6                 | ABS420/5 >0.06 | 0-≤6 µg/l      | <b>High</b>               |
|                            |                         |                | >6-≤10 µg/l    | <b>Good</b>               |
|                            |                         |                | >10 µg/l       | <b>Moderate/Poor/Bad*</b> |

\* If insufficient (moderate-poor) quality is indicated by the Chl sample, supplementary phytoplankton analysis should be performed.

### Activities

- Import 'WFD\_sample\_lakes.shp' shapefile, containing some sample ROIs on three different lakes. BEAM asks whether you want to consider elements separately;



choose 'Yes' and set as *Attribute for mask/layer naming* the attribute 'Name': three geometry objects and three new masks are created.

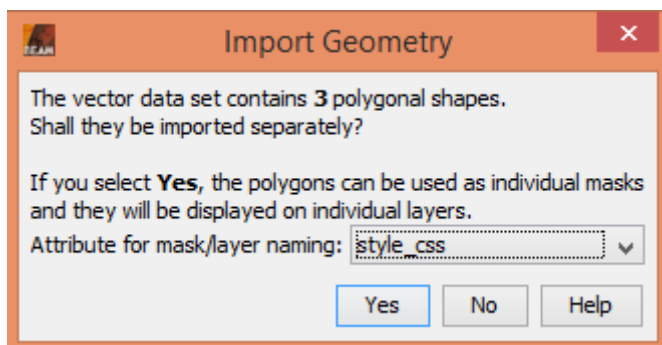



Figure 3. Import Geometry options window.

- Expand the 'Vector' directory in *Product View* tab: 'Station\_1', 'Station\_2' and 'Station\_3' geometries are shown. For each ROI, information on humic status is reported (Y=yes and N=not in 'humic' column) and can be assessed for each ROI clicking with the *Selection Tool* on each single geometry shown in the RGB image and clicking on . To easy find

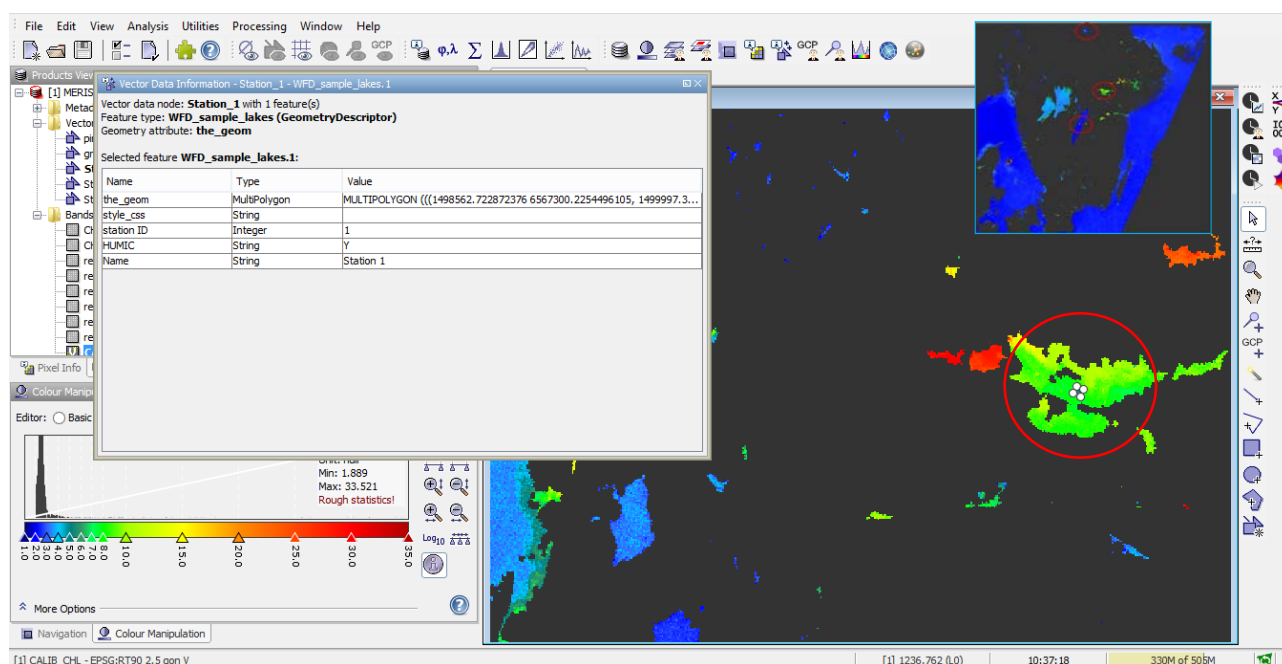




Figure 4. Vector data information for Station 1 selected in the RGB visualization (in the red circle). In the top right cyan box, red circles show where the three ROIs are located in the image for easier individuation.

- For each ROI, assess the class it belongs to, then open *Statistics* operator , enable the *Use ROI mask(s)* option in order to include only ROIs pixels for statistics computation, and select all the sample ROIs.
- Compute statistics with .
  - Which ROIs are classified as "High" according to WFD limits?

### Part 3 WFD analysis of Lake Vänern on MERIS time series

In this second part, WFD criteria will be applied to a series of monthly mean Chl maps of Lake Vänern, to evaluate its ecologic status and changes in time and space of trophic conditions. A time series of Chl concentration is extracted for the predefined ROIs from the monthly averaged Chl maps.

To accomplish this task the *PixEx* operator is used in batch-mode, exploiting the BEAM *Graph Processing Tool (gpt)*.

#### Activities

- Return to South Sweden Chl map.
- Import the shapefile containing points for WFD evaluation in sub-basins in Lake Vänern, 'WFD\_VÄNERN.shp'.
- Open 'Extract\_Ch1.xml' file with any text editor software. This script use *PixEx* operator, which allows to extract values from given time series from single pixels or averaging values from a window of given size around the pixel. In this case a three by three window is set for average value computation and extraction.
- Complete the path for products input (the directory containing Vänern products), the coordinates file and the output directory.
- Open the BEAM Command line ('BEAM Command Line', look for it in your browser).
- Type 'gpt  
...\GLaSS\_Training\_Lesson10\_WFD\GLaSS\_Training\_Lesson10\_DataAndTools\Tools\Extract\_Ch1.xml' (completing the line with the correct path, avoid blank character).
- Beam start collecting images from the input directory.
- In the output path you selected, two txt files are created:  
'match\_COLLOCATED\_measurements.txt' and 'match\_productIdMap.txt' containing respectively extracted values (mean and standard deviation) for each input product and the name of all products included in extraction operation.
  - *What's the worst year for each sub-basin? What's the WFD class for that year?*
  - *Calculate Chl average values on the whole period for each ROIs: where 'Good' sub-basin are located?*
- To build up an histogram showing the frequency of Chl concentration values, repeat the extraction of Chl values setting 'no aggregation' as aggregating method in 'Extract\_Ch1.xml'. Import the results in a spreadsheet to build up the histogram, dividing values on the basis of WFD limits.
  - *What class was the most frequent in humic and in non-humic stations?*
- Extract again Chl values this time from *in situ* stations (use 'coordinates\_insitu\_measurements.txt' as coordinates file).
- Open 'In\_situ.txt' and compare results of WFD classification retrieved for single *in situ* measurements and from EO averaged products.
  - *Are the classification results obtained through remote sensing techniques and in situ measurements comparable?*

## 4 More information and further reading

This lesson is based on the following report:

- GLaSS Deliverable D5.7, 2015. Global Lakes Sentinel Services, D5.7: WFD reporting case study results. SYKE, WI, EOMAP, BC, CNR, TO, BG. Available via: [www.glass-project.eu/downloads](http://www.glass-project.eu/downloads)

The report is suggested for further reading. It contains the directive monitoring and reporting activities of six EO member states:

- Finland
- Estonia
- Sweden
- Germany
- The Netherlands
- Italy

Examples of the use of EO data for the reporting are also included.

For more information on GLaSS, and to download all public reports: [www.glass-project.eu](http://www.glass-project.eu).

## References

- Bresciani M., Stroppiana D., Odermatt D., Morabito G., Giardino C. (2011). Assessing remotely sensed chlorophyll-a for the implementation of the Water Framework Directive in European perialpine lakes. *Science of the Total Environment*, 409: 3083-3091.
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- Schroeder Th., Schaale M., Fischer J. (2007). Retrieval of atmospheric and oceanic properties from MERIS measurements: A new Case-2 water processor for BEAM. *International Journal of Remote Sensing*, 28 (24): 5627-5632.

## Colophon

### Global Lakes Sentinel Services

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How remote sensing could support EC -Water  
Framework Directive implementation in lakes?

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