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# Analysis of water quality parameters on lakes by in situ and remote sensing methods

DOI: 10.54598/000310

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**2020**

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## Background and objectives

Water is one of the most important, as well as the most vulnerable, natural resources. Therefore, the chemical, physical and biological properties of water are of very high importance (DÉVAI et al., 1992). The influence of water quality parameters between each other is also an important question. One of the major points is the detection of changes among the different water quality parameters. Water quality is a complex concept, that refers to the hydrological, chemical, physical and biological characteristics of water (ZSENI and BULLA, 2002).

The protection of surface and subsurface water resources is a top priority in most countries. The European Union's Water Framework Directive states that the Member States of the European Union should aim to achieve at least good water quality status of their water resources or, where good water quality status already exists, it should be maintained. For this reason, it is inevitable to monitor the relevant parameters of water bodies (European Community, 2000).

Changes in water quality parameters cause remote sensing reflectance deviations (DEKKER et al., 2001). Applying remote sensing techniques, we can detect these reflectance changes. With the help of remote sensing, it is possible to measure and monitor the temporal changes in many different water quality parameters, such as water temperature, a-chlorophyll concentration, oil spills, concentration of suspended matters.

Joint application of *in situ* and remotes sensing techniques is a useful method to examine aquatic ecosystems in a detailed way. a-chlorophyll concentration of water bodies is one of the highlighted points in biological water quality assessment (PADISÁK, 2005). Accumulation of specific nutrients leads to phytoplankton overgrowth throughout the aquatic system. The described process negatively influences water quality and affects the economic, social and ecological uses of water resources (KISS KEVE, 1998). The vertical distribution of phytoplankton is not homogenous in the water column and influences the optical properties of the system (REYNOLDS, 2006). With reference to the vertical distribution of algae, we need to measure many physical, chemical, biological water quality parameters and the underwater light conditions to identify the most highlighted influencing factors (FELFÖLDY, 1974). The depth of the vertical maximum of a-chlorophyll concentration could influence remote sensing reflectance. It could affect the accuracy of satellite measurements through changes in the shape of the reflectance curve when the maximum a-chlorophyll concentration is close to the surface or it is staying in the deeper layers.

The main measured water quality parameters were the following: a-chlorophyll concentration, total suspended solids, dissolved oxygen concentration, total Fe, $NO_2^-$, $NO_3^-$, $NH_4^+$, $PO_4^{3-}$, $Na^+$ content, underwater light conditions, UV radiation and remote sensing reflectance. During the resource project we designated two study sites: Lake Naplás, located in Budapest; and Lake Vég, situated close to Ecséd.

The actuality and significance of the resource project are based on three main points. Firstly, the European Union's Water Framework Directive determined that the water resources must be in good water quality status in the EU. Secondly, developing remote sensing techniques gives a widely-used opportunity in the water quality monitoring. We need to ensure the complex measuring methods in hydrology. Thirdly, systematic physical, chemical and biological water quality monitoring promotes the understanding of the connections between the different water quality parameters.

The main objective of the study is to determine how the vertical distribution of phytoplankton influences remote sensing reflectance. To achieve this main objective, I took the following steps:

1. Creation of a complex measuring program (based on remote sensing, on-site and laboratory measurements). The system allows to simultaneously investigate the physical, chemical, biological, algological and spectral properties of water.
2. Determination of spatial and temporal distribution of phytoplankton based on the influencing factors.
3. Establishing correlations between the vertical distribution of the phytoplankton stock and underwater light conditions.
4. Determination of remote sensing reflectance with different vertical distribution of phytoplankton based on different observation angles.

## Materials and methods

### Data collection

The sampling period covered 2.5 years and contained two complete vegetation periods. There were 95 sampling campaigns (85 in Lake Naplás and 10 in Lake Vég) and we have collected more than 2500 samples. The sampling campaigns have been carried out by a self-made deep water sampler and diving equipment. Three sampling points have been designated in Lake Naplás and one in Lake Vég. Detailed description of the sampling campaigns can be seen in Figure 1 and Table1.

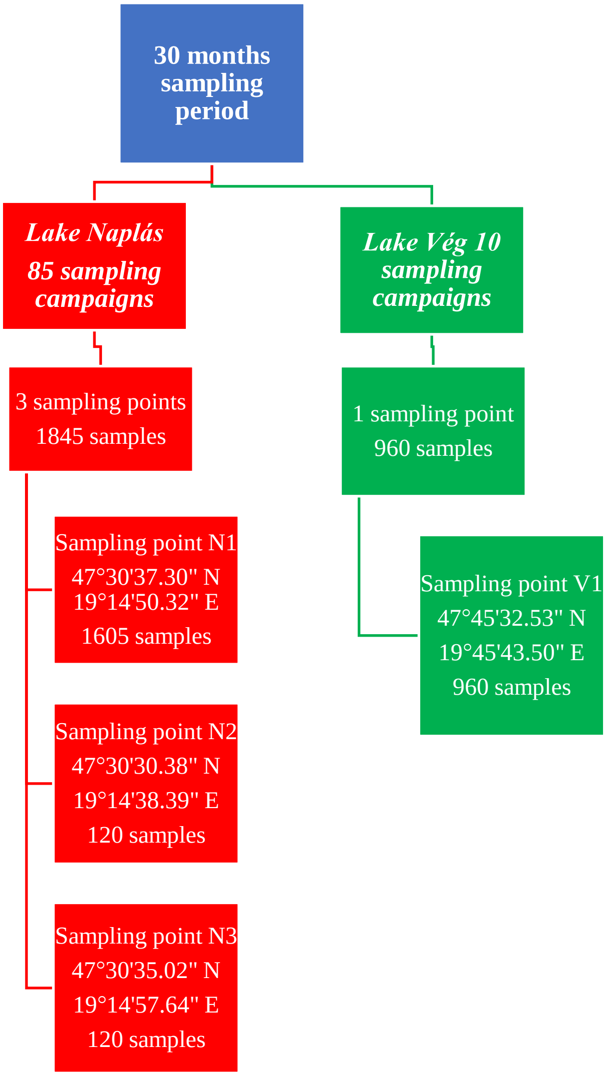


Figure 1. Detailed description of the sampling campaigns

Table 1: Vertical distribution of sampling points at the four observation locations

| Study area | Sampling point | Coordinates | Water depth | Sampling depth 0-1 m | Sampling depth 1-10 m | Sampling depth 10-15 m | Number of sampling | Sampling times |
|---|---|---|---|---|---|---|---|---|
| Lake Naplás | N1 | 47°30'36.17" N; 19°14'50.66" E | 1.8 m | By 0.1 m | By 0.2 m | n.a. | 15 | In spring, summer and fall, 14:00 h and 19:00 h |
| | N2 | 47°30'30.38" N; 19°14'38.14" E | 1.8 m | By 0.1 m | By 0.2 m | n.a. | 15 | In winter 14:00 h |
| | N3 | 47°30'34.23" N; 19°14'59.84" E | 0.7 m | By 0.1 m | n.a. | n.a. | 8 | During algal blooms, 15:00 h |
| Lake Vég | V1 | 47°45'31.55" N; 19°45'44.09" E | 15 m | By 0.1 m | By 0.2 m | By 1 m | 60 | In spring, summer and fall, 14:00 h |

## Measurements

The implemented research project had two sub-objectives. On one hand, to collect information about the influencing factor of the vertical distribution of phytoplankton. On the other hand, to examine the effect of the different vertical distribution of phytoplankton on the spectral properties of the water. Physical, chemical, biological water quality and spectral measurements have been carried out during the research. Detailed description of the different measurement types can be seen in Figure 2.

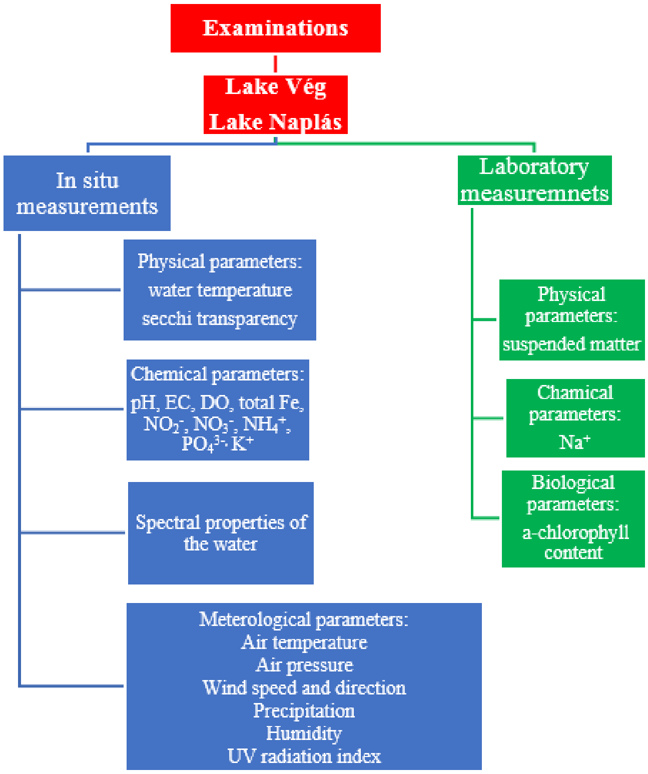


Figure 2. Detailed description of the examinations

Water temperature, secchi transparency and suspended matter were included among the physical water quality measurements. From these parameters, the water temperature and the secchi transparency surveys have been performed by *in situ* measurements. To measure the water temperature, Mares Icon HD diving computer was used. For secchi transparency, a standard secchi disk has been used during the measurement. The suspended matter concentration has been determined in the laboratory by calculating of the difference between the total dry matter content and total solute content.

Regarding the *in situ* chemical water quality parameters, Hanna Instruments HI 83399 Photometer was applied to measure the total Fe, $NO_2^-$, $NO_3^-$, $NH_4^+$, $PO_4^{3-}$, $K^+$, dissolved oxygen concertation, pH, and the electrical conductivity of the samples. For laboratory analysis, MOM Falmom-B Fame Photometer was used to determine the $Na^+$ concentration of the water samples.

Biological water quality measurements were a significant part of the research project. One of the most important biological parameters was the a-chlorophyll content. Jenway 6400 spectrometer was used to measure its concentration in the samples. FELFÖLDY's

(1981) method was used to determine the a-chlorophyll concentration in the laboratory. Taxonomic separation of phytoplankton was performed by BTC BIM312T microscope.

In case of spectral and the underwater light condition measurements, I examined the connection between the a-chlorophyll content and the spectras properties of the water.

In the study of the spectral properties of water, on one hand, I measured the energy and intensity of the light, as well as the remote sensing reflectance depending on wavelength. On the other hand, I examined the observation angle dependence of the optical sensor on the remote sensing reflectance. Ocean Optics STS-VIS modular spectrometer was applied in different sensor positions - 90° 60° 45° - during the measurements.

Several meteorological parameters, for example, wind, temperature, air pressure, UV radiation are affecting the vertical distribution of phytoplankton. From meteorological components, the air temperature, air pressure, wind speed and direction, precipitation, humidity and UV radiation were measured by Hyundai WSP 3080RWIND mobile weather station in the study areas.

## Study areas

Two test areas have been designated in Hungary. There were several aspects that we needed to take into account during the designation process. The main point was the following: the lakes need to be in different trophic level and lakebed characteristics. As for the lakebed characteristics, the vertical distribution of phytoplankton shows different vertical patterns in the shallow lakes or the deep lakes. Regarding the trophic level, the frequently occurring algae blooms highly effect the underwater light condition in the eutrophic lakes.

### Lake Naplás

Lake Naplás is the largest lake in Budapest. The lake and its surroundings (150 hectares) are the second largest nature reserve area in the capital city. Lake Naplás is an eutrophic water body. It has been a landscape protection area since 1997. Concerning the lakebed characteristics, it is a shallow lake with 1.5 meters average water depth. The deepest point is 3 meters. The water recharge is supplied by the Szilas Creek.

Lake Vég

Lake Vég is located close to Ecséd and it is an oligotrophic, mid-deep lake in Hungary. It is formed in a closing pit of a lignite mine after they have abandoned mining activities in 1970. Average depth of the lake is 15 meters and the deepest point is 30 meters. Lake Vég serves as a fishing and diving area. Water recharge is supplied from 9 subsurface – groundwater – sources that are passing through a coal wall.

## Results

### Dynamics of α-chlorophyll content in the studied areas

The fundamental task of my research was to examine the phytoplankton population of the test areas. Lake Naplás, based on the average and maximum a-chlorophyll content, is an eutrotrophic water body. Regarding the phytoplankton population, the class of *Bacillariophyceae* (within the *Heterocontophyta strain*) was the predominant one at the beginning of the vegetation period. In the first half of the summer period, the *Chlorophyta strain* then in late summer and in the early autumn period, the *Cyanobacteria strain* dominated. In terms of the trophic category, Lake Vég is an oligotrophic and mesotrophic body of water. With reference to Lake Vég, the *Bacillariophyceae class* was the dominant during the beginning of the vegetation period. Finally, the *Chlorophyta strain* was the predominant one in the summer period. The cyanobacteria did not appear in the lake because it is a nutrient-limited, oligotrophic water body.

### Investigation for the influencing factors of vertical distribution of phytoplankton

Based on statistical analyses (multivariate linear regression, cluster analysis, analysis of variance), the vertical distribution of phytoplankton was mostly influenced by water temperature, UV radiation, available light and nutrients.

**Nutrients**

Among the chemical water quality parameters, an inverse vertical distribution was observed for total Fe, $NO_2^-$, $NO_3^-$, $NH_4^+$, $PO_4^{3-}$ contents. This meant that at the depth where the a-chlorophyll content reached the maximum value, the nutrients reached the minimum value.

Based on the analysis of meteorological data, high amount of rainfall (daily precipitation above 10 mm) significantly increased the concentration of nutrients in the water body, especially the $Na^+$ content. Excess $Na^+$ content contributes to the formation of algal blooms. It is an essential element for cyanobacteria. Huge algae bloom usually occurred when the $Na^+$ concentration exceeded 200 mg $l^{-1}$. On one hand, the excess $Na^+$ content may have come from anthropogenic sources: cleaning and disinfecting chemical substances used in the food industry, agriculture and animal husbandry; waste water. On the other hand, the natural source: leaching processes in soil. A time series of UAV-based recording of algae bloom is shown in Figure 3.

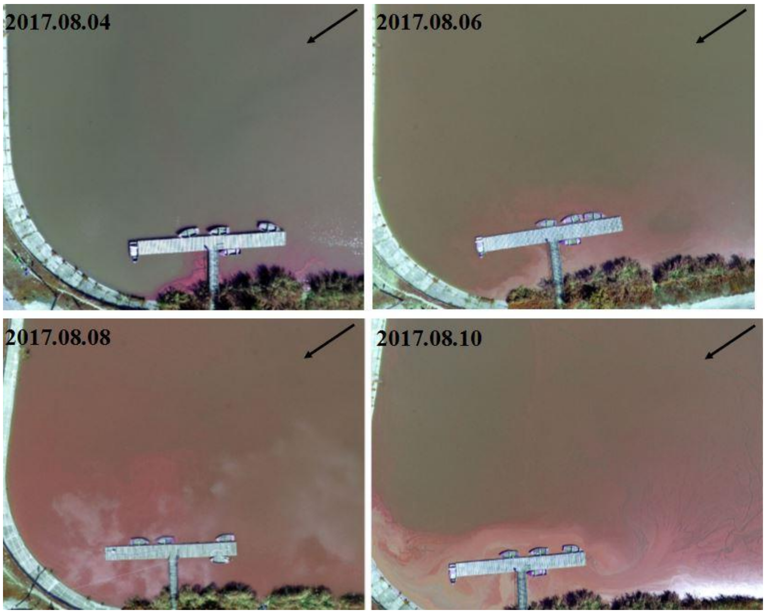

Figure 3. Algae bloom in Lake Naplás (drone image false color)

## Water temperature

The vertical maximum of a-chlorophyll content was often located in layers where the temperature range was between 20–27°C. Based on the measurements, the a-chlorophyll content reached the minimum value in the high-temperature surface layers during the summer period. Viscosity also played an important role in this phenomenon, because the viscosity of warm water is lower than cold water. Its biological role is significant, as floating organisms sink faster in warm water than in cold water. That kind of vertical distribution of phytoplankton was observed when the surface water temperature was not warmer than 29.5°C and under normal trophic conditions.

## UV radiation

During the research program, the UV radiation had a significant effect on the vertical distribution of the phytoplankton. The effect of UV radiation on the phytoplankton distribution can be observed in Figure 4. Based on the measurement results, I distinguished four significantly different main cases:

- Case 1
    - During low UV radiation circumstances (UV radiation index: 0-3), the maximum a-chlorophyll content was located in the near-surface (0-30 cm) water layers.
- Case 2
    - During high UV radiation circumstances (UV index: above 7), the maximum a-chlorophyll content was located in the deeper (deeper than 50 cm) water layers.
- Case 3
    - Water temperature also affected the distribution of phytoplankton.
    - Despite low UV radiation circumstances (UV radiation index: 0-3), the maximum a-chlorophyll content remained in the deeper layers (deeper than 50 cm). In these cases, the temperature of the near-surface (0-20 cm) water layers exceeded 29.5°C. Due to the high near-surface water temperature, the significant part of algae population remained in the deeper layers.
- Case 4
    - It was observed under special hydrobiological conditions (algal blooms).

- Despite the high surface water temperature, the maximum a-chlorophyll content was located on the water surface.

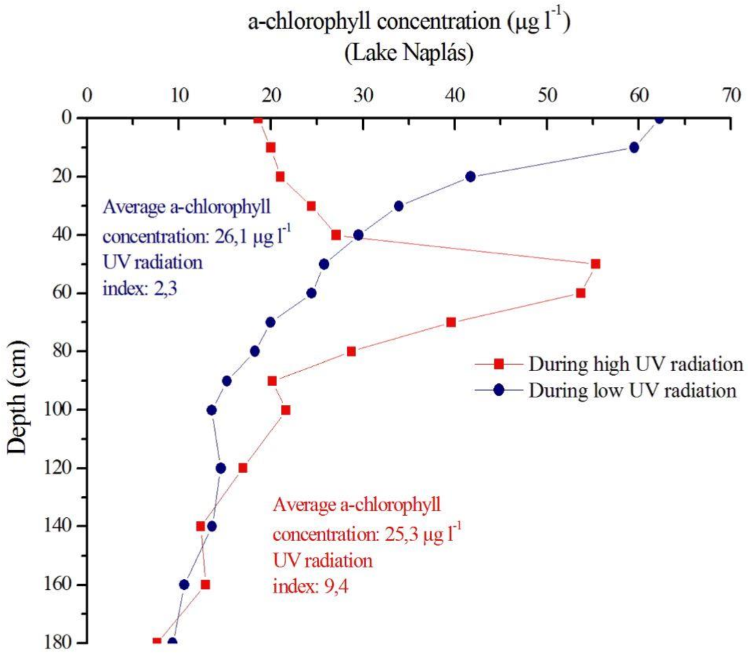


Figure 4. Vertical distribution of phytoplankton population under different UV radiation
(Lake Naplás, N1 sampling point)

## Available light source

In the course of the research, more than 85% of the suspended matters was made up by planktonic organisms. Underwater light conditions were significantly different in different trophic categories. Underwater light conditions in different trophic categories are shown in Figures 5 and 6. According to our measurements, the a-chlorophyll content decreased significantly at the depth where the maximum irradiance decreased below 0.4 W $m^{-2}$ $nm^{-1}$, in blue (420 - 490 nm) and red (650 - 750 nm) wavelength range. Therefore, at this depth, significant amount of phytoplankton had no longer sufficient usable light. The energy of the light, below the location depth of the maximum a-chlorophyll content, decreased greatly. The difference of maximum irradiance between the consecutive depth points was directly proportional to the increase in a-chlorophyll concentration.

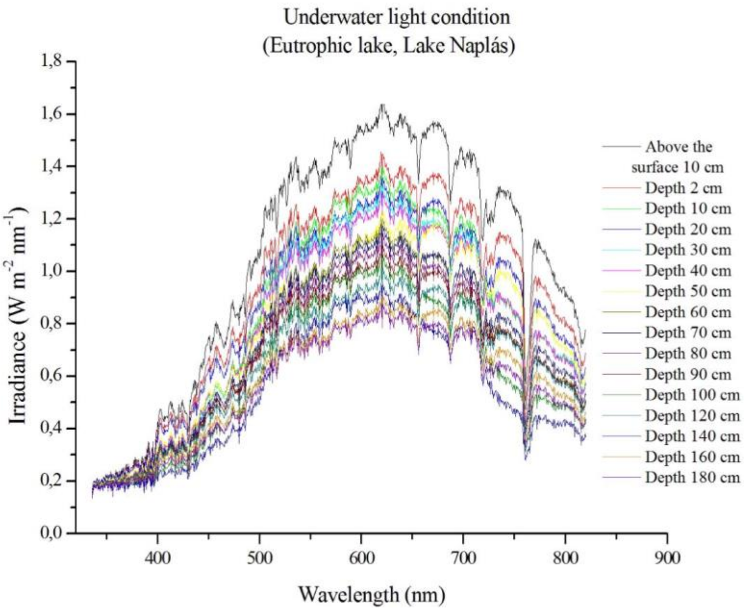


Figure 5. Underwater light conditions as a function of depth (Oligotroph lake, Lake Vég, sampling point V1)

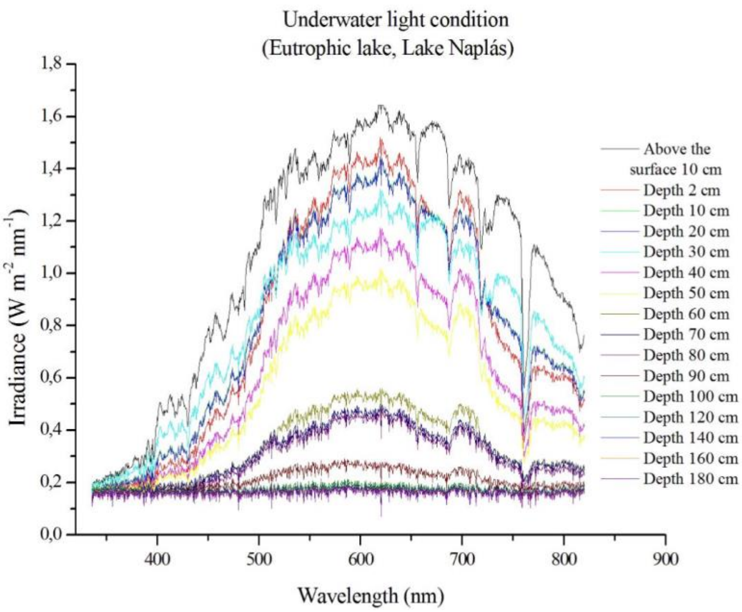


Figure 6. Underwater light conditions as a function of depth (Eutrophic Lake, Lake Naplás, sampling point N1)

## Analysis of remote sensing reflectance

The main task of my research was to investigate the effect of the depth of the vertical maximum of a-chlorophyll content on the remote sensing reflectance. According to the measurement results, I distinguished four significantly different cases, in depending on the depth of the vertical maximum of a-chlorophyll content:

- the maximum of a-chlorophyll content was located in the near surface layer (0–20 cm)
- the maximum a-chlorophyll content was located in the deeper layer (deeper than 50 cm)
- algal bloom (vertical maximum of a-chlorophyll content was on the surface)
- before algal bloom (high a-chlorophyll concentration in whole water column, maximum a-chlorophyll content was on the surface)

I examined the shape of the reflectance curves in six highlighted wavelength ranges for a-chlorophyll:

- 500-600 nm: Increasing reflectance values, due to decreasing light absorption of photosynthetic pigments and light reflection from suspended matters (CAMPBELL, 2006).
- 565 nm: Local minimum reflectance value associated with the absorption of phycoerythrin (SVÁB, 2008).
- 630 nm: Local minimum reflectance value associated with the absorption of phycocyanin (SVÁB, 2008).
- 650 nm: Local maximum reflectance, due to the reflectance properties of suspended matters (DEKKER et al. 1992).
- 670 nm: Minimum reflectance value associated with the absorption of a-chlorophyll (DEKKER et al. 1992).
- 685-730 nm: Local maximum value associated with the specific light emission phenomenon of the phytoplankton (CAMPBELL, 2006).

In cases where the maximum a-chlorophyll content was located in the near-surface layers, steeply rising, high reflectance values could be detected between 500 and 600 nm. This was followed by the minimum value appearing at 670 nm, which could be related to the light absorption of a-chlorophyll. According to the results, a maximum reflectance value was detected at 715 nm. That was related to the light emission of the phytoplankton.

In contrast, when the maximum a-chlorophyll content was in the deeper layers, an elongated, flat curve with lower reflectance values was recorded between 500 and 600 nm. The minimum value connecting to absorption of a-chlorophyll could also be detected in this case. The maximum reflectance value related to light emission phenomenon of the phytoplankton could be registered at 725 nm with peak shifting. Analyzing the results, 30% lower reflectance values could be measured in when the maximum a-chlorophyll content was in the deeper layers than in case when it was close to the surface. Different shapes of the reflectance curves can be seen in Figures 7 and 8.

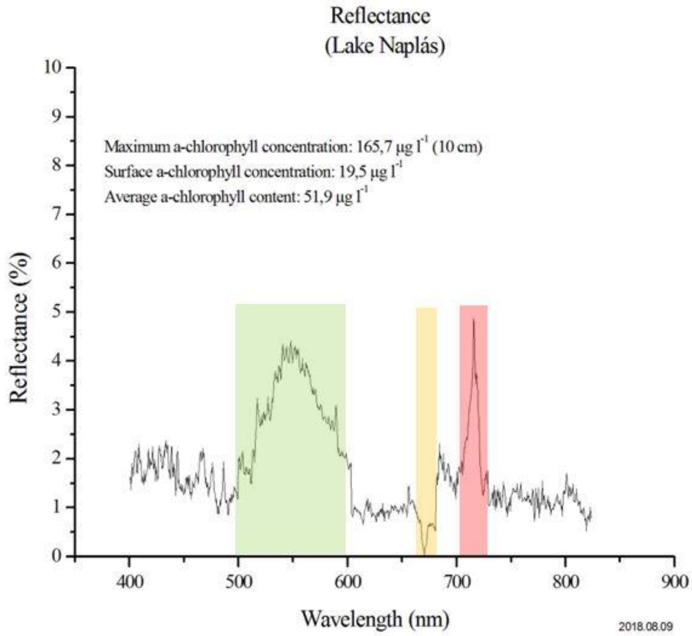


Figure 7. Shape of reflectance curve when the maximum a-chlorophyll content
was in the surface layer (0-20 cm)

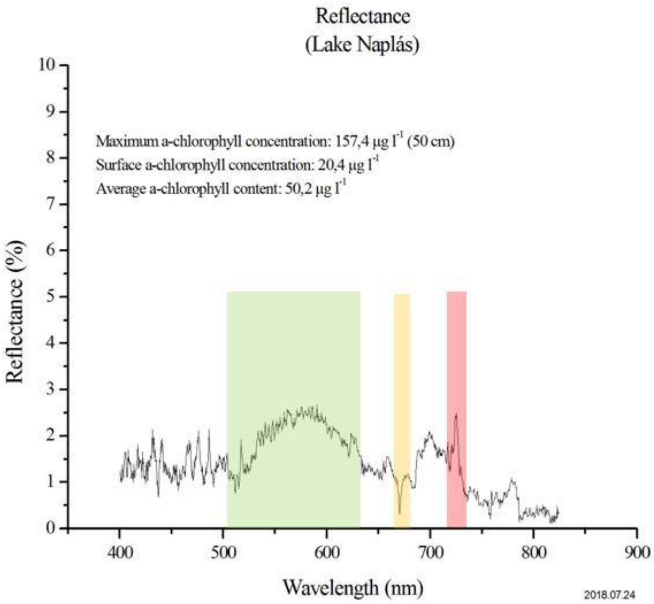


Figure 8. Shape of reflectance curve when the maximum a-chlorophyll content
was in the deeper layer (deeper than 50 cm)

During algae bloom, steeply rising, high reflectance values could be determined between 500-600 nm. That was broken off by the minimum value related to phycoerythrin at 565 nm. This was followed by a minimum value at 630 nm, which related to the absorption of phycocyanin. Both of these minimum values were related to the growth of cyanobacteria. Because of the increased suspended matter content, maximum value was detected at 650 nm. Differently from the previous cases, a steeply rising curve shape was observed from 685 nm. These high reflectance values persisted until the end of the detection range. This phenomenon was related to the light emission properties of phytoplankton that was accumulating in clumps on the surface. Similar curve characteristic could be detected before the algae bloom. In this case lower reflectance values and a flattening curve were measured. Evaluating the results, 35% lower reflectance values could be detected before algae bloom than during the total algae bloom. Different shape of the reflectance curves can be seen in Figures 9 and 10.

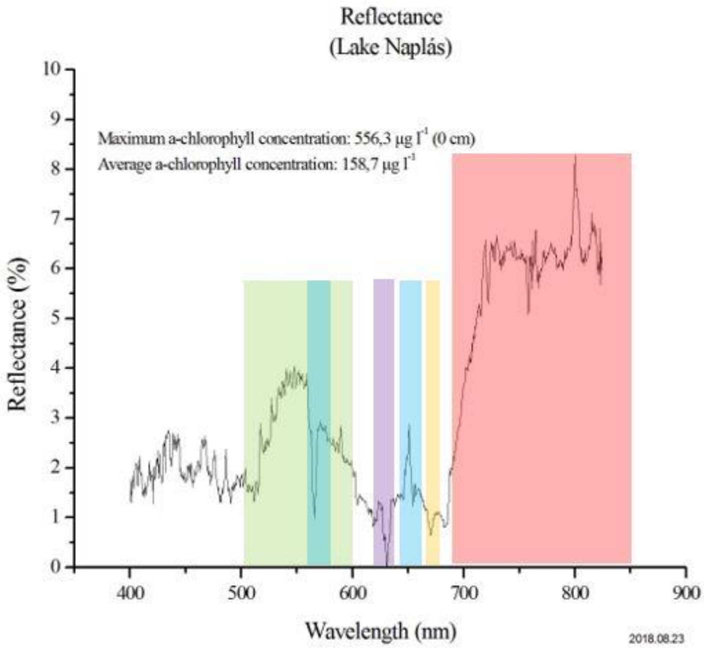


Figure 9. Shape of reflectance curve during algae bloom

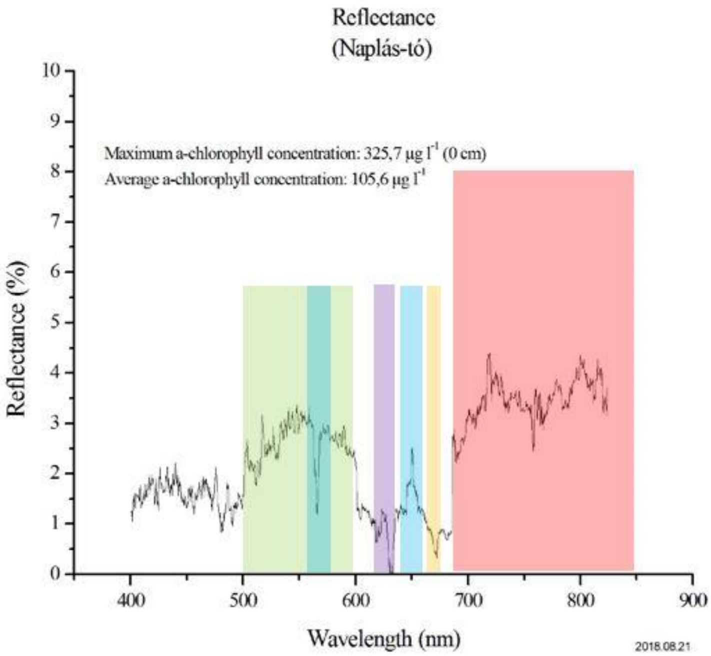


Figure 10. Shape of reflectance curve before algae bloom

## Dependence of remote sensing reflectance on observation angle

An important part of my research was to investigate the dependence of remote sensing reflectance on the observation angle. During the measurements, an observation angle of 60° and 45° was used to examine the remote sensing reflectance spectra. Based on my measurements, a significant shift of local minimum and maximum values towards the higher wavelength ranges and the flattening of the reflectance curves could be detected. This could be due to several reasons: changes in the length of the light path, changes in concentration, and scattering.

The dependence of the remote sensing reflectance on the observation angle, in terms of the placement depth of the maximum a-chlorophyll content was investigated in three cases:

- the maximum a-chlorophyll content was in the near-surface layer (0-20 cm)
- the maximum a-chlorophyll content was in the deeper layer (deeper than 50 cm)
- algae bloom (maximum a-chlorophyll content was on the surface)

According to the results, the shape of the reflectance curves at 60° and 45° observation angles differed significantly in case when the maximum of the a-chlorophyll content was in the near-surface water layer. At the 45° observation angle, elongated curves and significantly lower reflectance values were detected, compared to the 60° detector position. The shifts of the minimum and maximum values are shown in Table 2. The shape of reflectance curve is shown in Figure 11.

Table 2. Shift of minimum and maximum values when the vertical maximum of a-chlorophyll was in the near-surface layers

| **Observation angle** | **500-600 nm** | **670 nm** | **685-730 nm** |
|---|---|---|---|
| 90° | 550 nm | 670 nm | 715 nm |
| 60° | 580 nm | 684 nm | 730 nm |
| 45° | 585 nm | 691 nm | 750 nm |

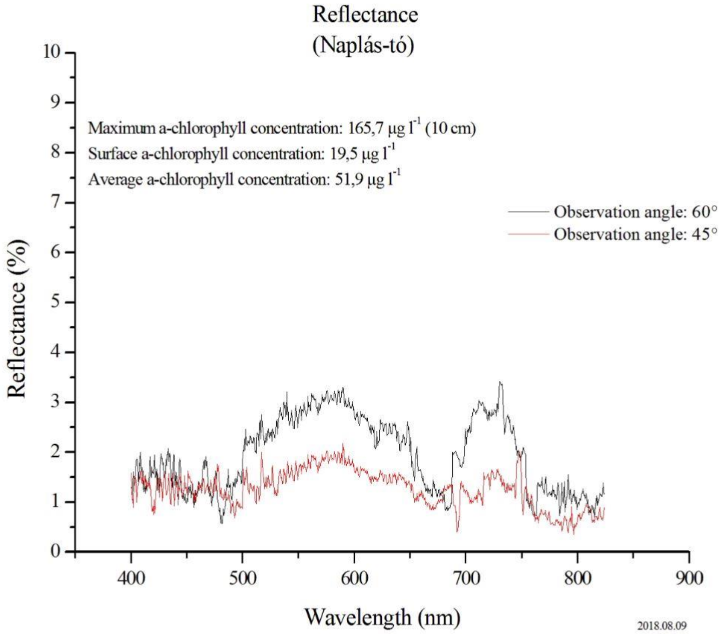


Figure 11. The shape of reflectance curves at different observation angle when the maximum of a-chlorophyll content was in near-surface layers

Shifting of peaks and flattening of reflectance curves could be observed in all cases. In case where the a-chlorophyll maximum was in the deeper layers, a completely flattened, elongated curve could be detected at both observation angles. This flattened curve made the evaluation difficult because the detection of minimum and maximum peaks was problematic. In case of algae bloom, the largest difference between the reflectance at the two observation angles occurred from 685 nm. Significantly lower values could be detected at the 45° detector position, compared to the 60°.

## Conclusions and suggestions

In my doctoral research, I developed a complex (based on remote sensing, on-site and laboratory measurements) measuring methodology - for shallow, high trophic lakes and deep, low trophic lakes. This structural measuring method can form the basis of the complex measurement systems in the future. Using this complex method, we can achieve cost effectiveness and detailed examination in aquatic system.

Based on the results of microscopic examinations, I created a database for monitoring the phytoplankton population of Lake Naplás and Lake Vég with taxonomic isolation (family, genus). It could be later very useful for remote sensing techniques to taxonomically isolate the phytoplankton.

Among the examined physical, chemical, biological and spectral parameters, the UV radiation, water temperature and the available light had a significant effect on the vertical distribution of phytoplankton. The results could be used to parameterize and prepare explicit models to study the light properties in water and between the water and the sensor.

According to the results, the location depth of the vertical maximum of a-chlorophyll content had a significant effect on remote sensing reflectance. The results could be useful in the development of bio-optical models that take into account the vertical distribution of a-chlorophyll content within the water column. With that kinds of techniques, the accuracy of the a-chlorophyll measurement methods could be improved.

In the research project, I have determined that the remote sensing reflectance was affected by the applied observation angle (angular position of the spectrometer detector). This effect was the shifting of highlighted minimum and maximum values and a flattening of the reflectance curves. The results could be useful to develop remote sensing techniques that are suitable to examine the object at different observation angles. Using this method, the accuracy of the measurements could be improved.

## New scientific results

The new scientific results of the doctoral thesis can be summarized in the following points:

1. I developed a complex (based on remote sensing, on-site and laboratory measurements) measuring method - for shallow, high trophic lakes and deep, low trophic lakes. The monitoring program covers the analysis and evaluation of the physical, chemical, biological, algological and spectral properties of water. This structural measuring method can form the basis of the complex measurement systems in the future. Using this complex method, we can achieve cost effectiveness and detailed examination in aquatic system.

2. As for the statistical analyzes of physical, chemical, biological and spectral parameters, the UV radiation (0.79), available light (0.76), and water temperature (0.53) had a significant effect on the vertical distribution of phytoplankton.

3. By examining the depth-dependent spectral properties of water column, I found that the placement depth of maximum a-chlorophyll content direct proportionally affected the remote sensing reflectance. It affects the determination of a-chlorophyll content by remote sensing.
   - When the maximum a-chlorophyll concentration was in the deeper layers, the remote sensing reflectance was 30% lower than it was in the near-surface layer.
   - Before the algae bloom, reflectance values were 35% lower than during the total algae bloom.

4. According to the results, I determined that the applied observation angle (angular position of the spectrometer detector) had a significant effect on the remote sensing reflectance. This effect was the shifting of highlighted minimum and maximum peaks and a flattening of the reflectance curves. Based on the measurements, the 45° observation angle was not proper for reflectance determination, because in several the identification and evaluation of highlighted minimum and maximum values were not possible.

## List of publications

1. Peer-reviewed research articles
1.1. With impact factor, in English

**GRÓSZ, J.;** WALTNER, I.; VEKERDY, Z. (2019): First analysis results of in situ measurements for algae monitoring in Lake Naplás (Hungary). In: *Carpathian Journal of Earth and Environmental Sciences*, 14 (2) 385-398. pp.

1.2. Without impact factor
1.2.1. English publisher

**GRÓSZ, J.;** SEBŐK, A.; NAGY, N.; KOVÁCS, A.; WALTNER, I. (2019): Analysis results of in situ water and sediment quality of Újpest Backwater. In: *Tájökológiai Lapok,* 17 (2) 179-192. pp.

1.2.2. Hungarian publisher

**GRÓSZ, J.;** KRUPPINÉ FEKETE, I. (2016): Az Ecsédi Vég-tó vízminőségének és üledékének környezetanalitikai vizsgálata. In: *Tájökológiai Lapok,* 14 (1) 13-20. pp.

SAEIDI, S.; **GRÓSZ, J.;** SEBŐK, A.; DEGANUTTI DE BARROS, V.; WALTNER, I. (2019): Területhasználat-változás a Szilas-patak vízgyűjtő területén 1990-től. In: *Tájökológiai Lapok,* 17 (2) 265-275. pp.

SAEIDI, S.; **GRÓSZ, J.;** SEBŐK, A.; DEGANUTTI DE BARROS, V.; WALTNER, I. (2019): Területhasználat-változás a Rákos-patak vízgyűjtő területén 1990-től. In: *Tájökológiai Lapok,* 17 (2) 287-296. pp.

1.3. Other evaluable Hungarian language journal articles

**GRÓSZ, J. (2016):** Az Ecsédi Vég-tó vízminőségének és üledékének vizsgálata. In: *Hidrológiai Tájékoztató*, 2016. évi szám 19-21.pp.

2. Conference-proceedings

2.1. Full-length conference publications in Hungarian language

SEBŐK, A.; CZINKOTA, I.; FEKETE, GY.; DÁLNOKI, B.; **GRÓSZ, J. (2017):** Humuszoldat adszorpciós és deszorpciós kinetikájának meghatározása homokos talajon oszlopkísérlet segítségével. In: *Tájvédelem Különszám,* 2017. év 251-260. pp.

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