Lake depth measurements (oct/nov 2020)

Technical Report No. 1
Original project title (danish):
Automatiske klima- og vandmiljø stationer (AKVA-MS)
Projectnumber: NNF20OC0061808

Rybners
TEKNISKE GYMNASIUM

funded by:

novo nordisk fonden

Dato: (Tuesday 25$^{\text{th}}$ January, 2022)

Typesetted in: LaTeX

Author: Steffen Podlech, Ph.D., project- and scientific coordinator

Photography on titlepage: Taken by Steffen Podlech; Kvaglund lake outlet, view in easterly direction.

Contents

1. Introduction

This project "automatic climate and water environment monitoring stations" (Danish title: Automatiske klima- og vandmiljø stationer (AKVA-MS)) consists of numerous activities and tasks. The performed lake depth measure-

Figure 1.1: The figure shows a general overview image of town site Esbjerg including a red rectangle indicting the area of interest (A). The lower image is an enlargement of the area of interest indicating the location of Kvaglund lake relative to Spangsbjerg Mølle lake. Furthermore, the location of the technical high school (Rybners HTX) is indicated (B).

ment is one of the preliminary tasks needed, in order to design the climate and lake water monitoring stations according to the local environmental conditions.

The area of interest within Esbjerg municipality is shown in figure 1.1 (A). The area enlarged area in figure 1.1 (B) shows the particular location of Kvaglund lake and Spangsbjerg Mølle lake. Both lakes are connected with each other by Spangsbjerg Mølle creak. Finally, the location of the Technical High School (Rybners HTX) is marked, to indicate that both lakes are in the close vicinity of the school and hence easily reachable for frequent visits.

Identifying possible water catchment areas and determining the bathymetry of both lakes, is one of the tasks highly relevant for the success for the project. Both parameters have a strong impact on the station design as well as position of the individual station within each lake.

The water depth measurements were performed by the newly established science club, located at the technical high school in Esbjerg (Rybners HTX). This includes planning of field work, acquiring necessary equipment or design and construct equipment in the schools workshop and finally performing the actual measurement.

2. Lake bathymetry

Figure 2.1: Location of Kvaglund Lake (A) and Sp. Mølle Lake (B) shown on aerial image to the left and on schematic map to the right, respectively.

The lakes of interest in this study are Kvaglund Lake and Spangsbjerg Mølle Lake. Both lakes are located in Esbjerg municipality (see figure 2.1). Extensive depth measurements of both lakes where performed in order to establish detailed bathymetry maps as well as idenifying posssible water catchment areas. This information is necessary to determine the optimal location for each lake to position the automatic climate and water environmental monitoring station. Additionally, the lake depth information will be essential with respect to the specific station design.

2.1 Material and method

The depth measurement of both lakes were performed in the following way, using a rubber boat, a wired flexible tape measure and a gps-application (gps-app; from app-store; *My GPS Coordinates*) for mobile devices.

When necessary, the rubber boat was steadily positioned relative to the lake floor, using wooden poles (see figure 2.2, example from Sp. Mølle Lake).

Figure 2.2: Fixing position with wooden pole, recording GPS-coordinates and water depth.

Figure 2.3: Measuring water depth using a metal plate attached to a wired tape-measure.

Figure 2.4: Recording GPS-coordinates (Latitude and Longitude) and water depth in field book.

Having fixed the rubber boats position, the manual depth measurement was carried out (see figure 2.3). The metal plate attached to the end of

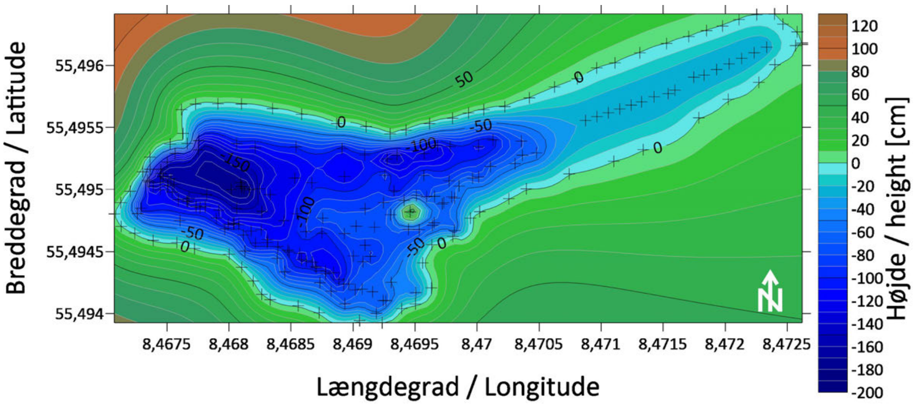


Figure 2.5: Positions of measure points for Kvaglund Lake indicated by a cross.

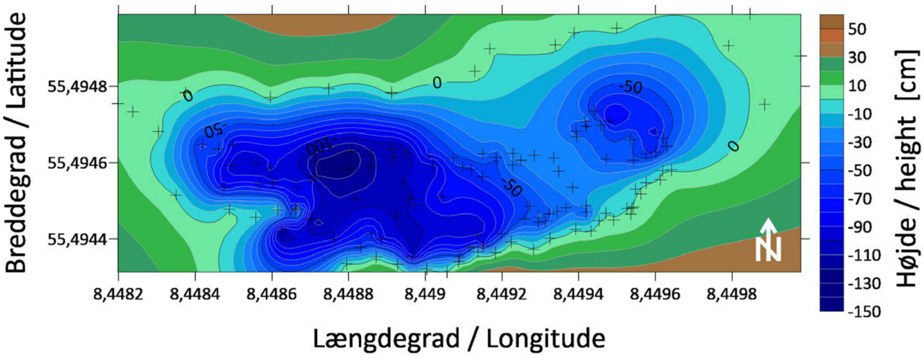


Figure 2.6: Positions of measure points for Sp. Mølle Lake indicated by a cross.

the wired tape measure was lowered to the lake floor and the depth was recorded. Simultaneously, corresponding GPS - coordinates of the sample location was recorded, using the GPS-app. According to the GPS-app, the accuracy of the position measurement is between 1 - 2 meter. The GPS-coordinates are recorded in decimal degrees Latitude (Lat) and Longitude (Long) and are referenced to the World Geodetic System 1984 (WGS84). If necessary the coordinates can be easily converted to the degree, minute

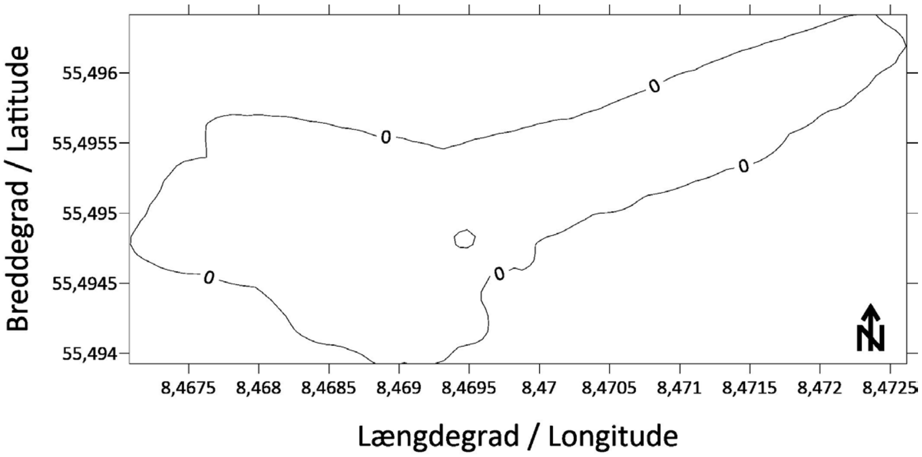


Figure 2.7: Determined lake -shore contour line of Kvaglund lake.

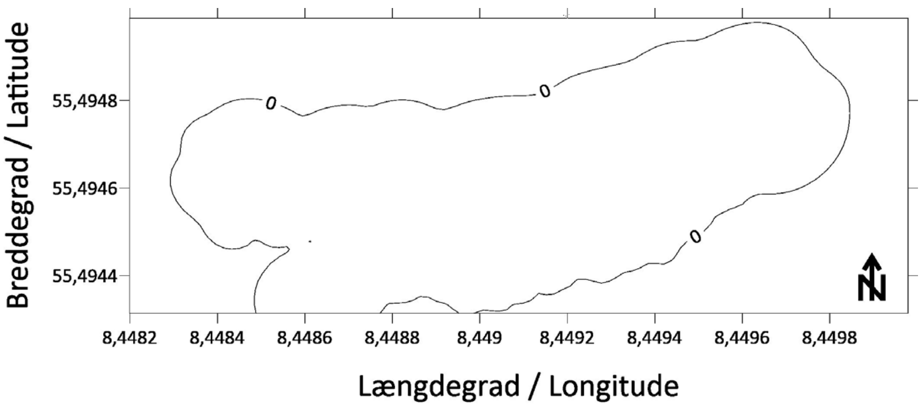


Figure 2.8: Determined lake -shore contour line of Spangsbjerg Mølle lake.

and seconds (DMS) format. The GPS-coordinates together with the depth measurements are systematically recorded in a field-book (see figure 2.4).

Following the above procedure, 140 individual depth measurements, distributed over Kvaglund Lake area are basis for the lake bathymetry (see figure 2.5). Analogue, 80 individual depth measurements distributed over Sp. Mølle Lake are fundament for the lake bathymetry (see figure 2.6).

In order to know the approximate geographic extend of both lakes, each lake-shore contour line was determined. In case of Kvaglund lake, the lake-shore contour line was traced by obtaining the gps-coordinates along the footpath around the lake (see figure 2.7). For Sp. Mølle lake, the lake-shore contour line was traced along the footpath at the western, northern and eastern lake shore line. The southern lake-shore contour was traced using the rubber boat, as there is no accessibility by land. The entire contour line of Spangsbjerg Mølle lake is presented in figure 2.8.

2.2 Results

The results from the lake depth measurements are presented in the following subsections.

2.2.1 Kvaglund Lake

The depth measurement of Kvaglund lake was carried out on Saturday, the 31^{st} of October 2020. In relation to depth measurement of Kvaglund lake it is important to note, the measurements are taken right after a week of extensive rain. This means that the recorded water depth presented, are at

(a) Water level 22. Sept. 2020

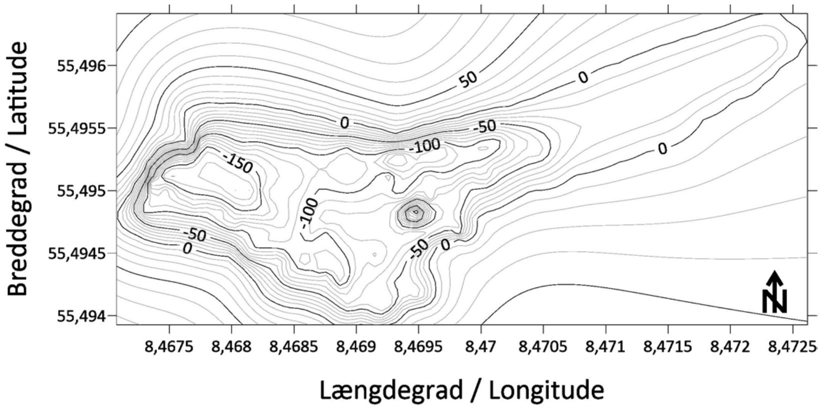
(b) Water level 31. Oct. 2020.

Figure 2.9: Water level of Kvaglund lake outlet measured the 22^{nd} of September 2020, water level 20 cm below upper edge of outlet barrier. (a); Water level of Kvaglund lake outlet measured the 31^{nst} of October 2020, water level at upper edge of outlet barrier. (b)

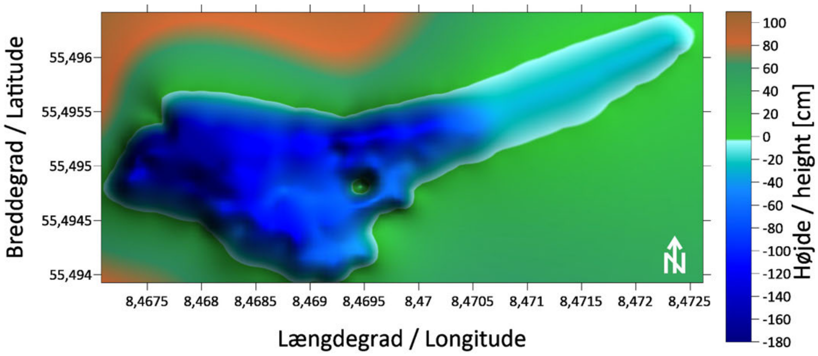
maximum level for Kvaglund lake. The maximum water level is indicated in figure 2.9 (b). Consequently, after a dry period (22^{nd} of September 2020), the water level of Kvaglund lake are expected about 20 cm lower (see figure 2.9 (a)).

Figure 2.10 (a) shows the modelled 2D lake depth based on the performed depth measurements. The depth is indicated by the individual contour lines. The difference between each contour line is set to 10 cm.

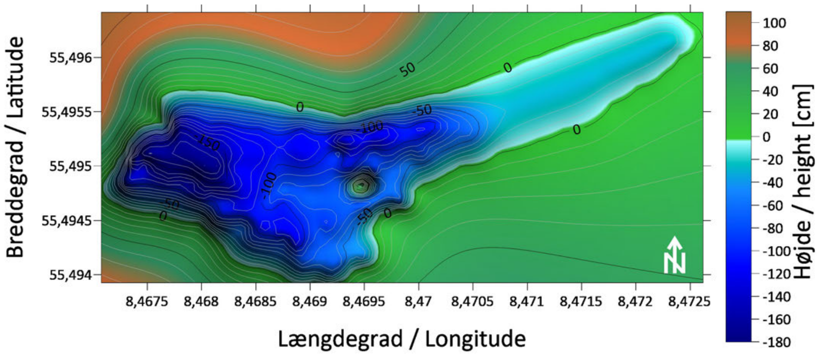
To visualise the lakes depth more graphically, a depth colour profile was created from the depth data. The result is shown in figure 2.10 (b). The



(a) Contour lines.



(b) Colour map.



(c) Coloured contour map.

Figure 2.10: Depth distribution of Kvaglund lake in [cm]. Contour line interval is set to 10 cm. (a); Colour map of Kvaglund lake representing lake depth (see colour bar). (b); The combination of (a) and (b) provides a colour contour map of Kvaglund lake. (c.)

colours indicate the depth, where deep blue indicates the deepest regions of the lake and light blue the shallow regions. Combining figure 2.10 (a) and 2.10 (b) provides a coloured contour map of Kvaglund lake, indicating the individual depth levels by both contour lines and colours (see figure 2.10 (c)).

The coloured contour map from figure 2.10 (c) and the gridded depth data from Kvaglund lake are now used as basis for calculating a 3D representation of the lakes floor topography (bathymetry). The result of the 3D bathymetry model of Kvaglund lake is shown in figure 2.11. One should be

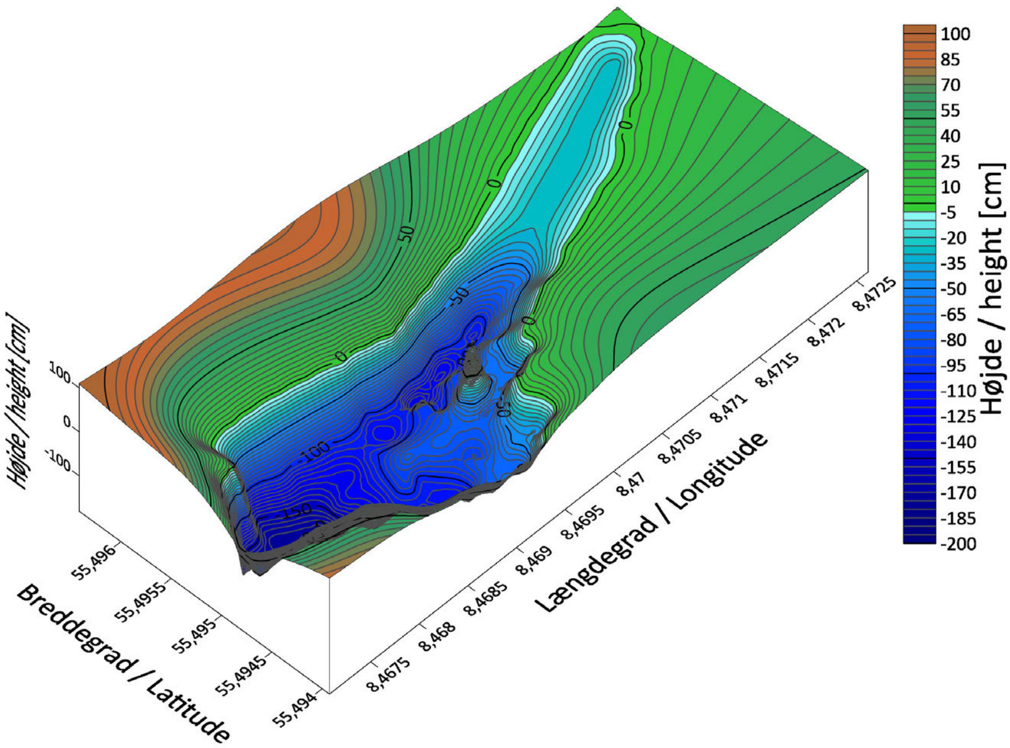
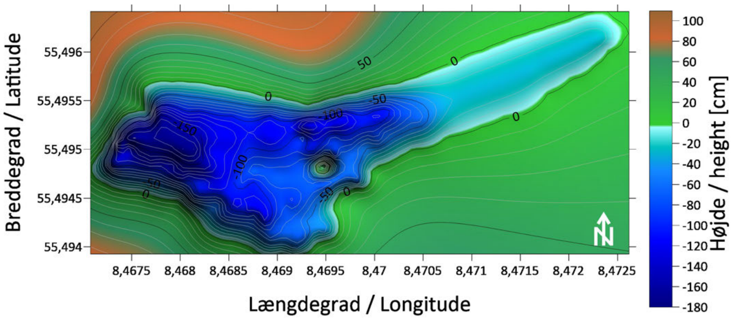


Figure 2.11: 3D bathymetry model of Kvaglund lake.

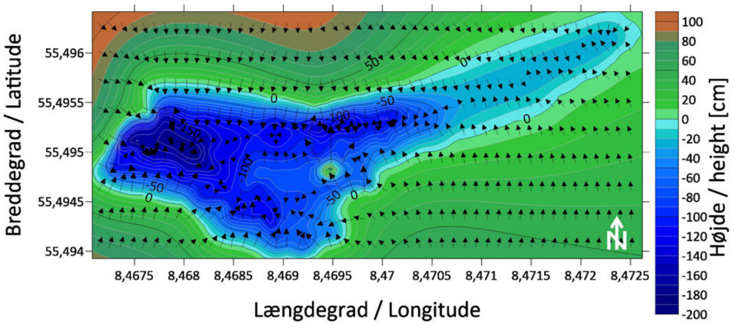
aware that, when using the 3D bathymetry model presented in figure 2.11, only depth data below the zero contour line are representative. All topography above the zero contour line is only approximated and not based on real elevation measurements.

Figure 2.10 (c) is basis for the subsequent analysis og the Kvaglund Lake water catchment basin. Therefore, the coloured contour map of Kavglund lake is once more shown in figure 2.12 (a) as reference map. Figure 2.12 (b) illustrates the Kvaglund lake surface water catchment as vector map.

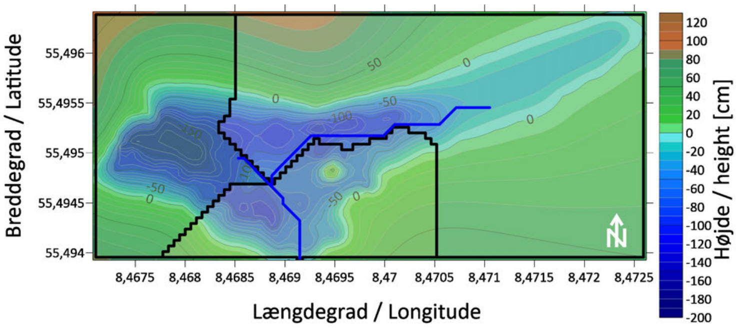
Each vector indicates the flow direction of surface water (downhill), based on the surface topography. One should keep in mind that the topography



(a) Coloured contour map.



(b) Vector map.



(c) Watershed map.

Figure 2.12: Colour contour map of Kvaglund lake. (c.) (a); Vector map of Kvaglund lake topography. Vectors pointing downhill indicating surface water flow. (b); Watershed map of Kvaglund lake indicating the lowest points of the bathymetry (blue line) and the water catchment area (black lines). (c.)

above the zero contour line is not a representation of the actual topography. Therefore, the vectors presented in this particular area can be very different with respect to both length and direction. The vectors below the zero contour line (in the blue area of the map), give a good prediction of the water flow pattern in the lake, solely based on the lake bathymetry.

Figure 2.12 (c) represents a watershed map of Kvaglund lake. The calculated watershed map is based on both the contour map (figure 2.12 (a)) and the vector map (figure 2.12 (b)). In order to interpret the map, it is necessary to have some background information. The basic definition of the calculated watershed reads as follows: *A watershed is defined as the region draining into a stream, stream system, or body of water. A watershed map reads the data from a grid file and splits the grid up into basin, or catchment areas (black lines). Basin areas are areas that drain water to the stream (blue line). Stream paths are calculated based on the amount of flow into the grid node from all surrounding grid nodes. This shows the path water will take across the grid. Stream lines mark the low points on the map.*

Following the definition of a watershed, one can identify three distinct water catchments related to Kvaglund lake. The catchments provides information about, where surface water entering Kvaglund lake originates from. Nevertheless, the main water input into the lake originates from the two inlets, located at the north-eastern arm and at the south- eastern side of the lake.

2.2.1.1 Georeferencing results

The presented results from the water depth measurements of Kvaglund lake in the previous section, are now used to superimpose the colour contour map onto a georeferenced satellite image. This provides a better understanding

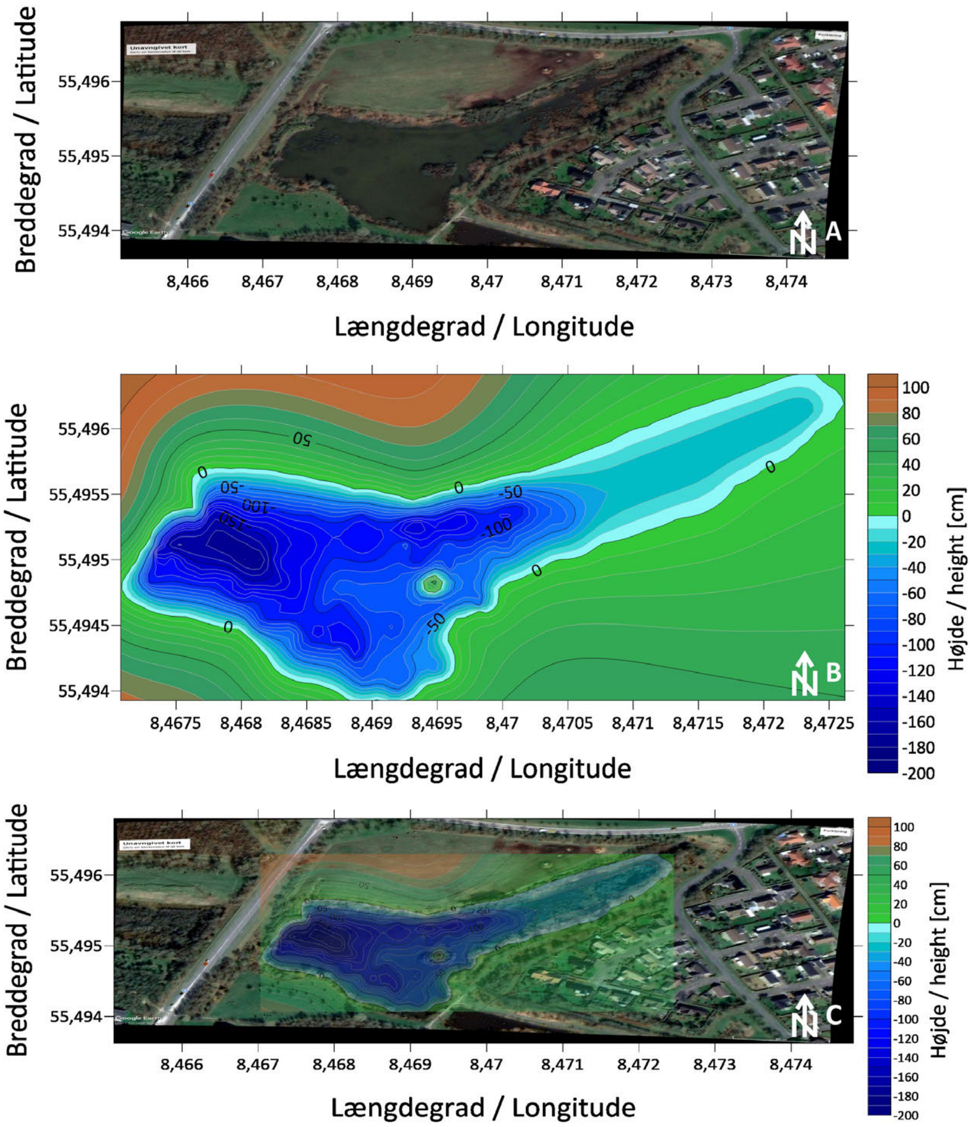


Figure 2.13: Georeferenced satellite image of Kvaglund Lake taken from Google Earth. (A); Colour contour map of bathymetry from lake depth measurements of Kvaglund lake. (B); Superimposed image containing satellite image and colour contour map of bathymetry. (C)

of the calculated bathymetry and the actual geographic location of the lake.

For this purpose, a satellite image of 20^{th} of March 2020 was exported from Google Earth. In order to use the image for our purpose, a reference coordinate system needed to be applied. Here the satellite image was georeferenced according to the World Geodetic System 1984 (WGS84) ellipsoid, to match the image coordinates for each pixel to the pixel coordinates of the coloured contour map[1]. The final georeferenced satellite image is shown in figure 2.13 (A). One may notice that the image is distorted i relation to the bounding box, which is a result of the georeferencing process. However, each image pixel matches the longitudinal and latitudinal coordinates presented on the horizontal and vertical axis, respectively. Furthermore, the georeferenced image is geographically placed in such a way that the north-south direction follows the papers vertical orientation indicated by the North arrow in the lower right of the image.

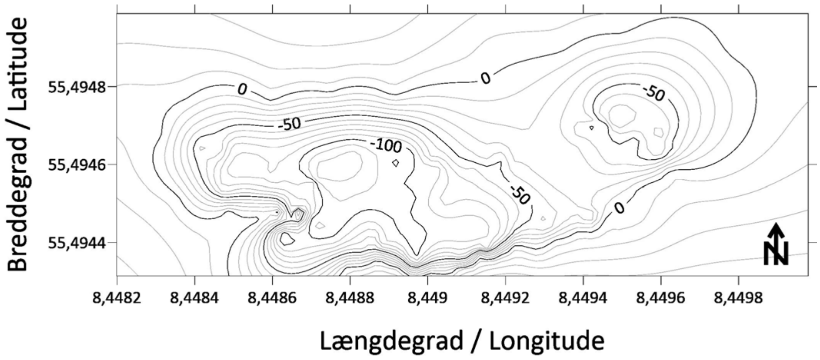
Figure 2.13 (B) presents the colour contour map of Kvaglund lake bathymetry in relation to the longitudinal and latitudinal coordinates from the previous section. Superimposing figure 2.13 (A) and 2.13 (B) results in figure 2.13 (C). The superimposed map provides a much better understanding of Kvaglund lake bathymetry in relation to the actual surroundings. Furthermore, figure 2.13 (C) is the final result of this preliminary study. It will be basis for where to place the monitoring station in Kvaglund lake and how the station should be designed according to the lake depth at this particular position.

The superimposed image is also useful with respect to determine both surface area of Kvaglund lake as well as the mean depth of the lake. The surface area of Kvaglund lake is determined to be ca. 24560 m^2 and the mean lake depth based on the 3D bathymetry model (see figure 2.11, of (31^{st} of October 2020) is ca. 98 cm. This leads to a total water volume of approximately 24050 m^3. This value corresponds to the maximum volume og Kvaglund lake. During a dry period, as mentioned earlier, the water level in Kvaglund lake can decreases by ca. 20 cm in relation to the presented measurement results, leading to change in water volume by ca. 4610 m^3 or a total volume of ca. 19440 m^3. It is important to notice, that a change in water level not only changes the depth and hence the lake volume, but also the surface area of the lake, which is closely related to the topography.

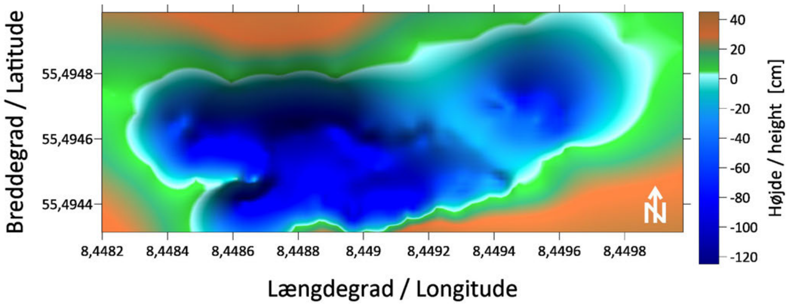
[1]GIS software used for georeferencing: QGIS 3.16 (freeware)

2.2.2 Spangsbjerg Mølle Lake

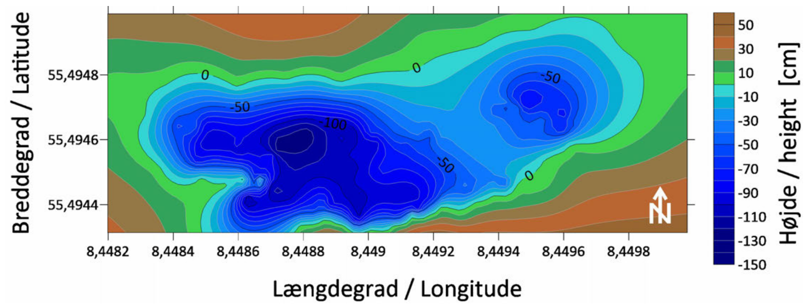
The lake depth measurement of Spangsbjerg Mølle lake and the resulting data are carried out in a similar manner to the previously presented data of Kvaglund Lake. However, water level changes of Spangsbjerg Mølle lake



(a) Contour lines.



(b) Colour map.



(c) Coloured contour map.

Figure 2.14: Depth distribution of Spangsbjerg Mølle lake in [cm]. Contour line interval is set to 10 cm. (a); Colour map of Spangsbjerg Mølle lake representing lake depth (see colour bar). (b); The combination of (a) and (b) provides a colour contour map of Spangsbjerg Mølle lake. (c.)

could not be conclusive identified. The stone wall placed at the outlet of the lake suggests, that the water level could rise with *ca.* maximal 30 cm above the values presented subsequently. Figure 2.14 (a) shows the modelled 2D lake depth based on the performed depth measurements. The depth is indicated by the individual contour lines. The difference between each contour line is set to 10 cm.

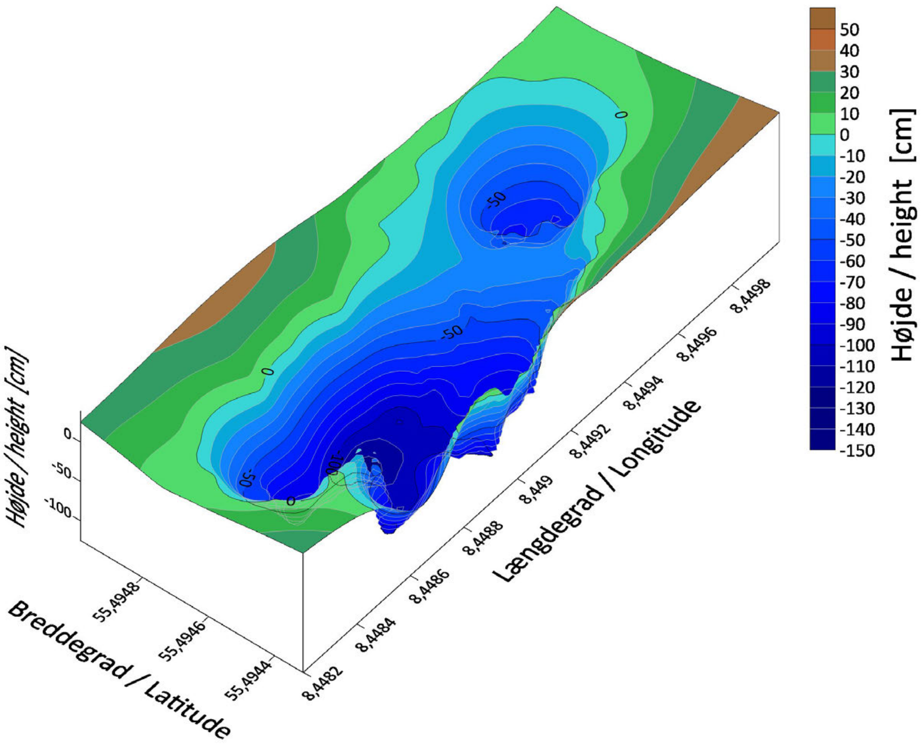
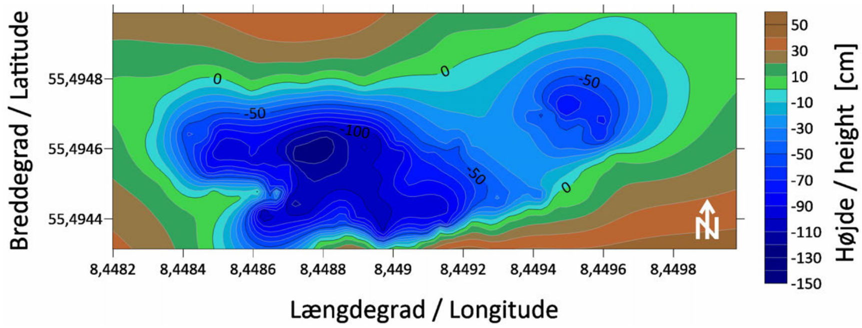


Figure 2.15: 3D bathymetry model of Spangsbjerg Mølle lake.

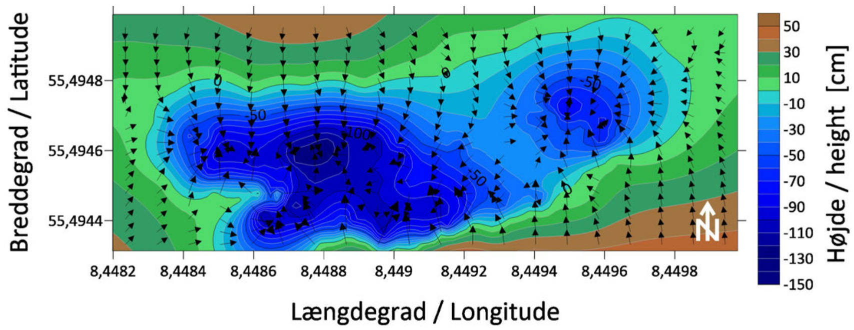
To visualise the lake depth more graphically, a depth colour profile was created from the depth data. The result is shown in figure 2.14 (b). The colours indicate the depth, where deep blue indicates the deepest regions of the lake and light blue the shallow regions. Combining figure 2.14 (a) and 2.14 (b) provides a coloured contour map of Spangsbjerg Mølle lake, indicating individual depth levels of the lake by both contour lines and colours (see figure 2.14 (c)).

The coloured contour map from figure 2.14 (c) and the gridded depth data from Spangsbjerg Mølle lake are now basis for the calculation of a 3D representation of the lake floor topography (bathymetry). The result of the 3D bathymetry model of Spangsbjerg Mølle lake is shown in figure 2.15.

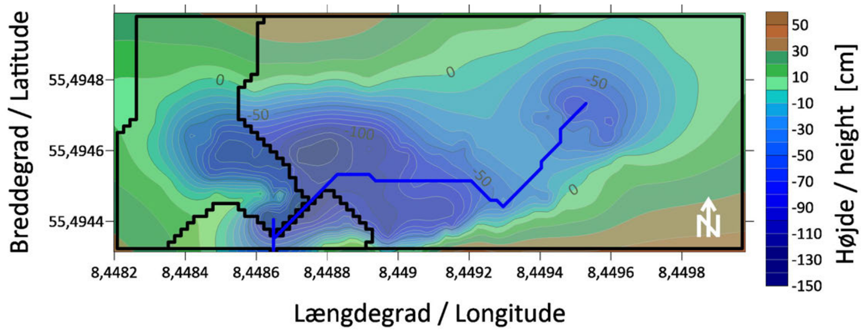
One should be aware of when using the 3D bathymetry model presented in figure 2.15, that only depth data below the zero contour line are representative. All topography above the zero contour line is only approximated, not based on real topographic measurements. Figure 2.14 (c) is basis for the



(a) Coloured contour map.



(b) Vector map.



(c) Watershed map.

Figure 2.16: Colour contour map of Spangsbjerg Mølle lake. (c.) (a); Vector map of Spangsbjerg Mølle lake topography. Vectors pointing downhill indicating surface water flow. (b); Watershed map of Spangsbjerg Mølle lake indicating the lowest points of the bathymetry (blue line) and the water catchment area (black lines). (c.)

subsequent analysis of the Spangsbjerg Mølle Lake water catchment basin. Therefore, the coloured contour map of Spangsbjerg Mølle lake is once more shown in figure 2.16 (a) as reference map. Figure 2.16 (b) illustrates the surface water catchment as vector map of Spangsbjerg Mølle lake. Each vector indicates the flow direction of surface water (downhill), based on the surface topography.

One should keep in mind, that the topography above the zero contour line is not a representation of the actual topography. Therefore, the vectors presented in this particular area can be very different with respect to both length and direction. The vectors below the zero contour line (in the blue area of the map), give a good prediction of the water flow pattern in the lake, solely based on the lake bathymetry.

Figure 2.16 (c) represents a watershed map of Spangsbjerg Mølle lake. The calculated watershed map is based on both the contour map (figure 2.16 (a)) and the vector map (figure 2.16 (b)). Following the definition of a watershed from section 2.2.1, one can identify three distinct water catchments related to Spangsbjerg Mølle lake. The catchments provides information about where the surface water entering Spangsbjerg Mølle lake originates. Nevertheless, the main water input into the lake comes from the inlet, located at the eastern side of the lake.

2.2.2.1 Georeferencing results

The results from the water depth measurements of Spangsbjerg Mølle lake presented in the previous section, are now used to superimpose the coloured contour map onto a georeferenced satellite image. This provides a better

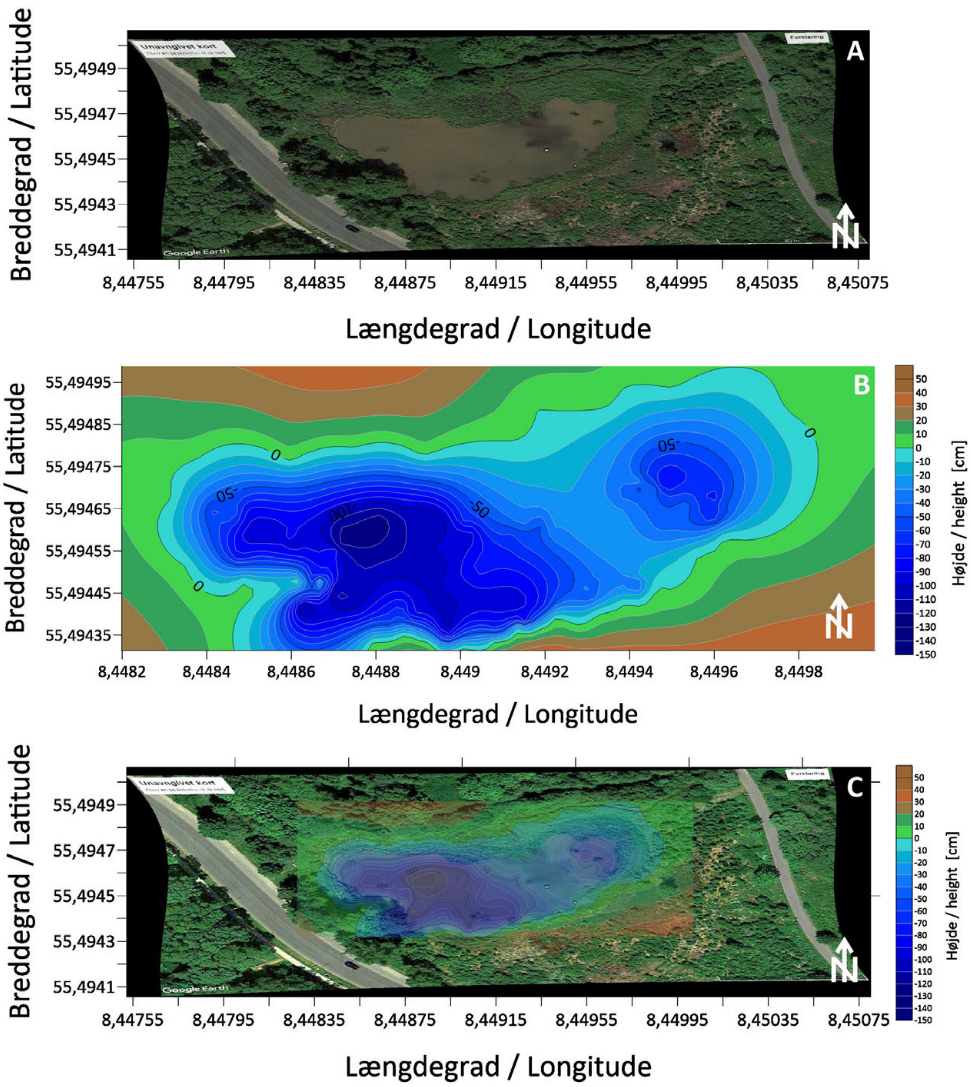


Figure 2.17: Georeferenced satellite image of Spangsbjerg Mølle Lake taken from Google Earth. (A); Colour contour map of bathymetry from lake depth measurements of Spangsbjerg Mølle lake. (B); Superimposed image containing satellite image and colour contour map of bathymetry. (C)

understanding of the calculated bathymetry in accordance to the actual geographic location of the lake. For this purpose, a satellite image of 2^{nd} of

June 2018 was exported from Google Earth. In order to use the image for our purpose, a reference coordinate system needed to be applied in analogy to the method applied to Kvaglund lake (see section 2.2.1.1).

Figure 2.17 (B) presents the colour contour map of Spangsbjerg Mølle lake bathymetry in relation to the longitudinal and latitudinal coordinates. Superimposing figure 2.17 (A) and 2.17 (B) results in figure 2.17 (C). The superimposed map provides a much better understanding of Spangsbjerg Mølle lake bathymetry in relation to the actual surroundings. Furthermore, figure 2.17 (C) is the final result for Spangsbjerg Mølle lake of this preliminary study. It will be basis for where to place the monitoring station in the lake and how the station should be designed according to the lake depth at this particular position.

In analogy to Kvaglund lake, the superimposed image is used to determine both the surface area of Spangsbjerg Mølle lake as well as the mean depth. The surface area of Spangsbjerg Mølle lake is calculated to ca. 3690 m^2 and the mean water depth based on the 3D bathymetry (see figure 2.15, of 22^{nd} of November 2020) is ca. 52 cm. The total water volume of Spangsbjerg Mølle lake is calculated to approximately 1920 m^3. This volume represents an intermediate value as the water level can be expected lower (than the presented data) after a dry period or higher considering cloudburst events og long lasting rain periods. During heavy cloudburst conditions, as mentioned earlier, the water level of Spangsbjerg Mølle lake can possibly increase by 30 cm, leading to change in water volume by ca. 950 m^3 or a total volume of ca. 2870 m^3. The topography model of Spangsbjerg Mølle lake suggests, that the surface area of the lake will increase considerably during periods og elevated water level. The increase in surface area will be most pronounced along the northern shore of Spangsbjerg Mølle lake.

3. Conclusive remarks

3.1 Lake depth measurements

In section 2, the presented depth measurements of Kvaglund lake and Spangsbjerg Mølle lake are basis for the monitoring station design. One can see that Kvaglund lake has a maximum depth of 1,8 m (ca. 1,6 m maximum water depth after dry period) and Spangsbjerg Mølle lake of 1,25 m (ca. 1,55 m after long period of rain). According to the watershed map for both lakes (see figure 2.12 (c) and 2.16 (c)), it is possible to determine the optimal location placing the monitoring station in each lake. For each lake the position will be chosen along the blue line at the deepest location of the lake. The final location of each station will have an impact on its design. Furthermore, using the depth data and the calculated 3D bathymetry,

Figure 3.1: Field work at Spangsbjerg Mølle lake 22^{nd} of November 2020.

allows an estimate of water volume and change in water volume of each lake. The water volume of Kvaglund lake is estimated to 24050 m^3 (after a long period of rain; maximum lake volume) and ca. 19440 m^3 after a long dry season. Therefore, the water volume of Kvaglund lake is expected to fluctuate between these values in relation to weather conditions. The volume of Spangsbjerg Mølle lake was estimated to 1920 m^3 (related to an intermediate volume). It is possible, that the volume of Spangsbjerg Mølle lake can increase to ca. 2870 m^3, considering long periods of rain or cloudburst events.

Designing the stations will not only include the lake depth and water catchment areas, it will also include weather conditions throughout a year (including cloudbursts, heavy wind, freezing, dry and warm periods). Furthermore, there will also be requirements to the station design set by Esbjerg municipality, which will be met.

Following the projects timeline, it is expected that the monitoring station design is completed in spring 2021 and will be send for approval to Esbjerg municipal authority for water environment.

Results of lake depth measurements:

Resultat	Kvaglund lake	Spangsbjerg Mølle lake
Surface area [m^2]	24560	3690
Mean water depth [m]	0,98[a]	0,52[b]
Estimated volume [m^3]	24050[c]	1920[d]
Deepest point (mean) [m]	1,70	1,35
Deepest point (max) [m]	1,80	1,55
Deepest point (min) [m]	1,60	1,15

[a]maximum mean water depth
[b]intermediate mean water depth
[c]maximum water volume
[d]intermediate water volume