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Digital elevation models of Forsmark

Site-descriptive modelling

SDM-Site Forsmark

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

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Abstract

A digital elevation model (DEM) describes the terrain relief. A proper DEM is an important data source for many of the different site descriptive models conducted in the Forsmark region. The existing DEM for Forsmark is classified due to national security reasons and hence not fully accessible to SKB. The aim of this project was to construct a non-classified DEM in lower resolution than the existing classified DEM, and to improve input data for the interpolation adding new elevation data. This new DEM describes land surface, sediment level/lake water surface at lake bottoms, and sea bottom.

The software ArcGis 9 Geostatistical Analysis and its extension Spatial Analyst were used for the interpolation among data points. The interpolation method used was Ordinary Kriging. This method allows both a cross validation and a validation before the interpolation is conducted. Cross validation with different Kriging parameters were performed and the model with the most reasonable statistics was chosen. Finally, a validation with the most appropriate Kriging parameters was performed in order to verify that the model fit unmeasured localities. The map projection used in the elevation model is RT 90 2.5 Gon W and the height system is RH 70. The DEM has a cell size of 20×20 metres.

In cases where the different sources of data were not in point form, they were converted to point values using GIS software. Because data from different sources often overlap, several tests were conducted to determine which sources of data that should be included in the dataset used for the interpolation procedure. Based on the test results, the source judged to be of highest quality for most areas with overlapping data sources were used. All data were combined into a database of approximately 1.9 million points unevenly spread over an area of about 900 km^2.

An analysis of the elevation model confirms existing knowledge of the area that it is extremely flat, with a range in the model of +51.1 to –58.8 metres, where the highest point is in the model's southwest section and the lowest point is in the northern part of the Gräsörännan.

Sammanfattning

En digital höjdmodell (DEM) är en modell som beskriver reliefen i terrängen. Den är en viktig del av indatat till olika modeller som tas fram över Forsmarksområdet i samband med platsbeskrivningarna. En DEM över Forsmarksområdet har tagits fram tidigare med hjälp av punktdata för nivåer över både land och hav från ett stort antal olika datakällor. Denna DEM är idag säkerhetsklassad och därför inte fullt tillgänglig för SKB. I denna rapport presenteras en ny DEM över Forsmark som har en lägre upplösning och därför inte är säkerhetsklassad. Den är baserad på data som beskriver landyta, sedimentytan alt. vattenyta för sjöar och havsbotten.

Interpolering mellan olika datapunkter utfördes i programmet ArcGis 9 och dess extension Spatial Analyst. Som interpoleringsmetod valdes Ordinary Kriging. Metoden tillåter både en korsvalidering och en validering av höjdmodellen innan interpolering genomförs. Korsvalideringar med olika Krigingparametrar utfördes och modellen med den mest rimliga statistiken valdes. Slutligen utfördes en validering med de mest passande parametrarna för att verifiera att modellen passar även där det inte finns några mätpunkter. Höjdmodellen har koordinatsystemet RT 90 2.5 Gon W och höjdsystemet RH 70 och har en cellstorlek om 20×20 meter.

I de fall där de olika datakällorna inte var i punktform, t ex befintliga höjdmodeller över land eller djuplinjer i det digitala sjökortet, har de konverterats till punktform i ArcGis 9. Flera av datakällorna överlappar med varandra, varför tester utfördes för att avgöra om båda källorna eller bara den ena bör ingå i det dataset som utgör ingångsdata till interpoleringsproceduren. Resultaten av testerna medförde att för de flesta områden med överlappande data användes endast den datakälla som bedömdes vara av högre kvalitet. All data slogs ihop till en databas med sammanlagt cirka 1,9 miljoner punkter ojämnt spridda över ett cirka 900 km^2 stort område.

En analys av denna nya höjdmodell visar på stora likheter med tidigare höjdmodell och bekräftar vetskapen om att området är mycket flackt. Värdeomfånget i modellen är 51,1 till –58,8 meter där den högsta höjden återfinns i modellens sydvästra del och den lägsta punkten ligger i Gräsörännans norra del.

Contents

1 Introduction 9

2 Method 11

2.1 Data collection from land areas 11

2.2 Data collection from sea areas in Forsmark 13

2.2.1 Complementary field work 15

2.3 Handling overlapping data from different data sources 19

2.4 Interpolation of the digital elevation model 21

3 Results and conclusion 23

3.1 The digital elevation modell (DEM) 23

4 References 25

Appendix 1 27

1 Introduction

For siting of the repository of spent nuclear fuel, SKB has undertaken site characterisation at two different locations, Forsmark and Laxemar-Simpevarp. The surface system part of the site descriptive model includes, e.g. hydrology, Quaternary deposits, chemistry, vegetation, animals, human population and land use. Access to a proper digital elevation model (DEM), describing the terrain relief, is important for many of the different models constructed for the Forsmark region. The existing DEM for Forsmark /Brydsten and Strömgren 2004a/ is classified due to national security reasons and hence not fully accessible to SKB. The aim of this project was to construct a non-classified DEM in lower resolution than the existing classified DEM, and to improve input data for the interpolation adding new elevation data.

DEM resolution is the size of DEM cells. DEM interpolates irregular spaced elevation data. In this model, Kriging interpolation was used. Kriging is a geostatistical interpolation method based on statistical models that include autocorrelation (the statistical relationship among the measured points). Kriging weights the surrounding measured values to predict an unmeasured location. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement among the measured points.

Normally, a DEM has a constant value for sea surface and constant values for lake surfaces. For the Forsmark area, the DEMs has negative values in the sea to represent water depth, but constant positive values for lake surfaces represent the lake elevations or varying values represent lake bottom elevations.

Input data for the interpolation have many different sources, such as existing DEMs, elevation lines from digital topographical maps, paper nautical charts, digital nautical charts, and depth soundings in both lakes and the sea. All data are converted to point values using different techniques. The Kriging interpolation was performed in ArcGis 9 Geostatistical Analysis extension.

2 Method

2.1 Data collection from land areas

Five sources were used to collect elevation point data for land areas: 1) the existing DEM from the Swedish national land survey (LMV) with a resolution of 50 metres, 2) the SKB DEM with a resolution of 10 metres /Wiklund 2002/ (Figure 2-1), 3) measured values from lakes /Brunberg et al. 2004/, 4) fixed points from the Property map, and 5) brook measurements /Brydsten and Strömgren 2005/.

The existing DEMs were converted to point layers in shape-format using ArcToolbox in ArcGis 9.

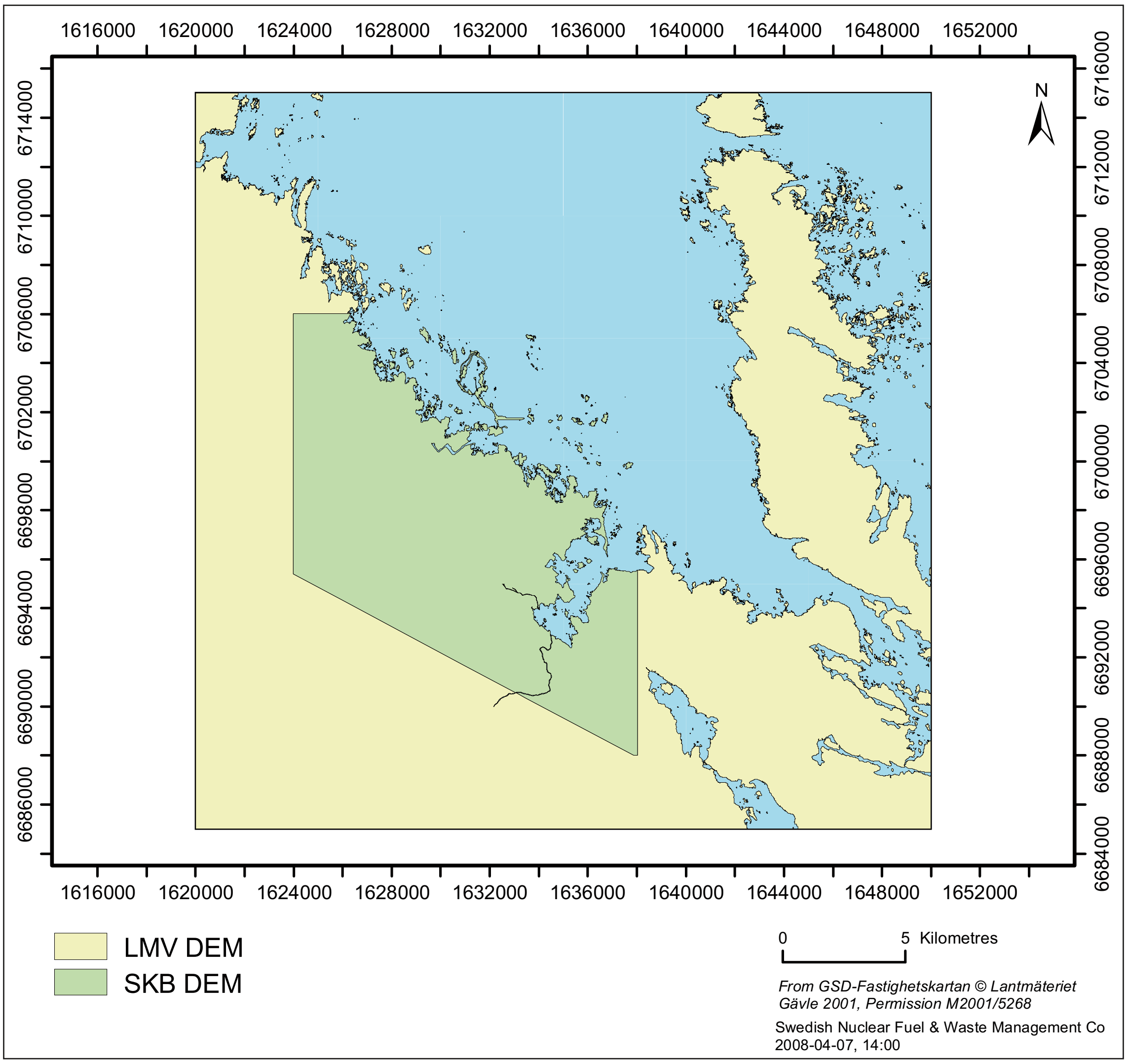

Figure 2-1. *Extensions of the LMV DEM and SKB DEM in Forsmark, respectively.*

All points from the 10-metre DEM, placed within the lakes shown in Figure 2-2 were deleted from the dataset and replaced by measured depth values /Brunberg et al. 2004/ converted to RH 70. For most of these lakes, the lake surface levels at the depth-measuring occasions were used (measured with levelling instrument). However, continuous measurements of the lake surface levels are performed in six lakes /Juston and Johansson 2005/. The mean lake surface levels were calculated only for these six lakes (Table 2-1). For three other very closely lying lakes, an approximate mean lake level was estimated based on the mean lake surface level of the six lakes. The points from the 10-metre DEM and the depth values from the 25 lakes were merged into one single point layer. The map projection used for this layer is RT 90 2.5 g W and the height system is RH 70.

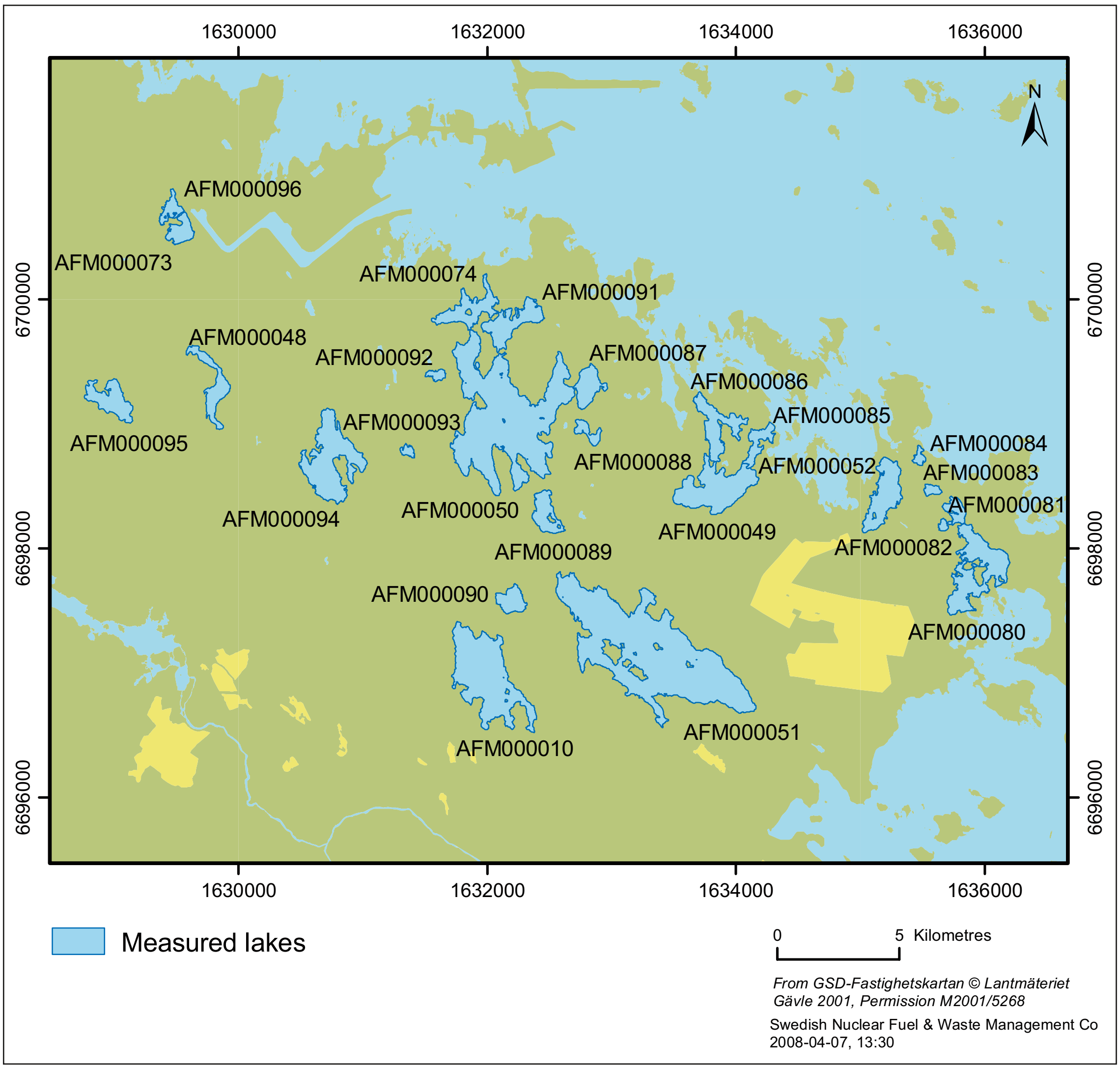

Figure 2-2. *Lakes where the 10-metre DEM points were replaced by measured values.*

Table 2-1. Lake surface elevations for the 25 lakes in Forsmark shown in Figure 2-2. The unit is metre above RH70. The mean lake surface elevations are calculated for the six lakes referred to [1)]. The lake surface elevation for the three lakes referred to [2)] is adjusted to an approximate mean lake surface elevation from closely lying, measured lakes. For the other lakes, surface elevation measurements were performed.

Lake	Ma RH 70 (m)	Period for mean lake surface calculation
AFM000010[1)]	5.32	040112–050111
AFM000049[1)]	0.17	040506–050505
AFM000050[1)]	0.42	030516–050515
AFM000051[1)]	0.56	040205–050204
AFM000074[1)]	0.40	030430–050429
AFM000094[1)]	2.82	040421–050420
Lake	**Ma RH 70 (m)**	**Lake used for adjustment**
AFM000085[2)]	0.365	AFM000049
AFM000087[2)]	0.675	AFM000050
AFM000091[2)]	0.730	AFM000050
Lake	**Ma RH 70 (m)**	**Date**
AFM000048	3.660	020226
AFM000052	0.413	020207
AFM000073	1.625	020226
AFM000080	0.06	030115
AFM000081	0.374	020206
AFM000082	0.305	020206
AFM000083	0.489	020206
AFM000084	0.413	020207
AFM000086	0.389	020209
AFM000088	1.352	020208
AFM000089	1.190	020207
AFM000090	3.015	020225
AFM000092	1.860	020205
AFM000093	2.745	020207
AFM000095	5.820	020830
AFM000096	1.725	020226

2.2 Data collection from sea areas in Forsmark

Figure 2-3 shows the extensions of elevation data for the sea area. The elevations have been obtained from the following 10 sources:

1. the digital nautical chart (the Swedish Maritime Administration), area A in Figure 2-3,
2. the base map to the nautical chart, area C in Figure 2-3,
3. the paper nautical chart (number 535 Öregrund – Grundkallen – Björn), area A in Figure 2-3,
4. SGU /Elhammer and Sandkvist 2005/, area B in Figure 2-3,
5. interpreted depth data performed by the Geological Survey of Sweden, SGU /Elhammer and Sandkvist 2004/, area B in Figure 2-3,
6. depth soundings of shallow bays /Brydsten and Strömgren 2004b/, area D in Figure 2-3,
7. with DGPS measured shoreline points,

8. digitized shoreline points from IR orthophotos,
9. the sea shoreline from the Property map from Lantmäteriet,
10. constructional drawings for the inlet channel to the nuclear power plant /Vattenfall 1977/, area F in Figure 2-3.

The digital nautical chart has depth lines for 3, 6, 10, 15, 25, and 50 metres. These line objects have been transformed into point objects in ArcView using the Avenue script LineToPoints.avx. The maximum distances between adjacent points were set to 50 metres.

Because the digital nautical chart lacks the point depths that are present in the paper nautical chart, these points were manually digitized from the paper nautical chart. The paper nautical chart was scanned and rectified to WGS-84 with ArcGis, and the point depths were manually digitized on screen. The point depths (single water depth values) and symbols for "Stone in water surface" (a plus sign with dots in each corner) and "Stone beneath water surface" (a plus sign) were digitized as points. The water depth for "Stone in water surface" was set to +0.1 metre and for "Stone beneath water surface" to –0.5 metre.

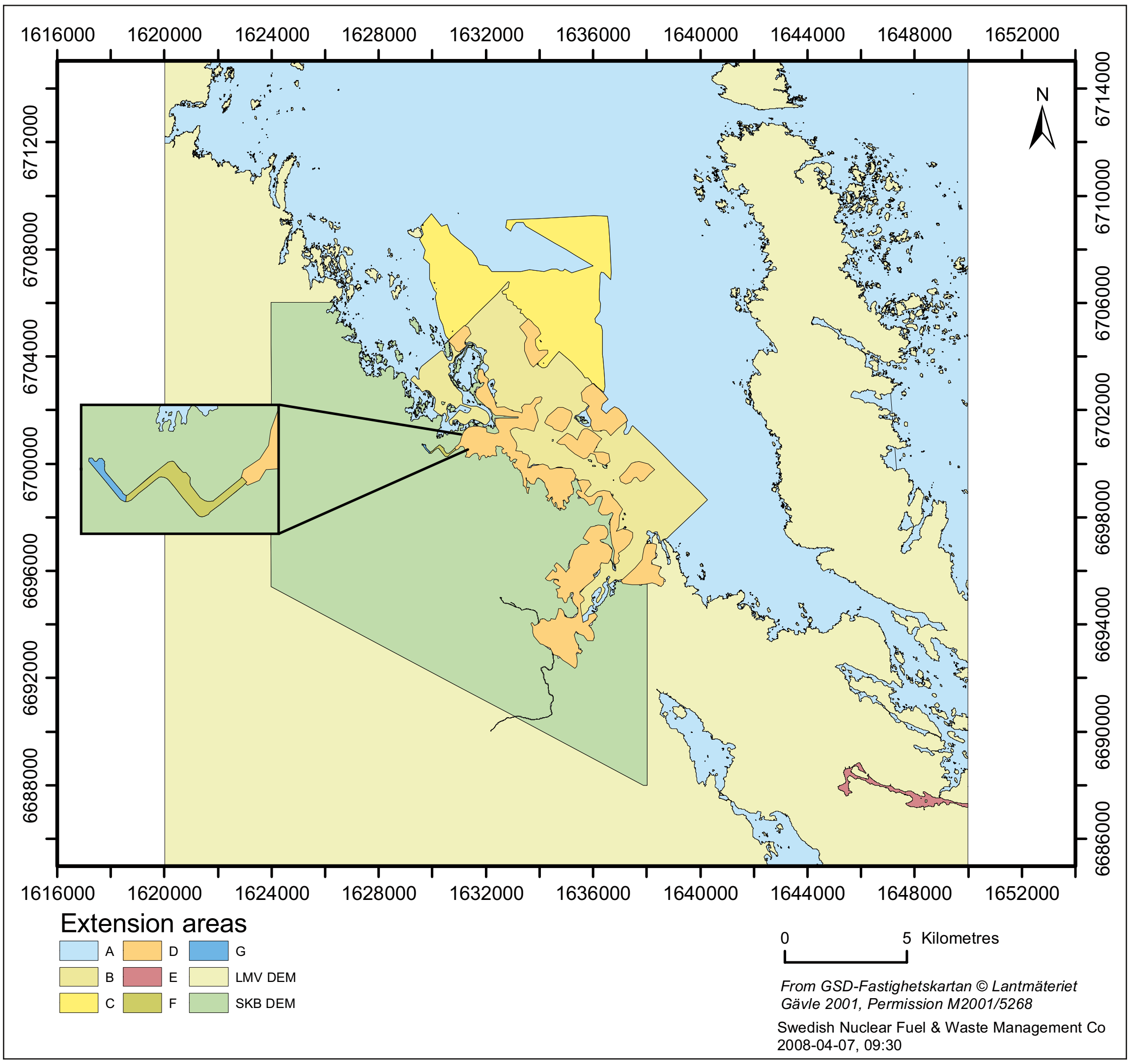

Figure 2-3. *Extensions of different data sources for the sea area in Forsmark. A = the digital nautical chart and the nautical chart, B = depth soundings and interpreted depth data performed by the Geological Survey of Sweden, C = the base map to the nautical chart, D = depth soundings of shallow bays, E and G (enlarged area) = "false depth values", and F = constructional drawings for the inlet channel to the nuclear power plant (enlarged area).*

For the area C in Figure 2-3, the base map for the nautical chart was used to digitize point depths. Because these depth soundings were performed as early as 1898, it was necessary to convert these values from foot to metre and at the same time adjust the values for shore displacement since 1898. The adjustment for shore displacement (1898–1970) was calculated to +0.45 metre using equations presented in /Påsse 1997/ with the following parameters:

As = 300, Bs = 7,250, Af = 95 and Bf = 1,000.

The base map was scanned and rectified to WGS-84 using the point depths from the paper nautical chart. The point depths on the base map were then manually digitized on screen.

The depth values in both the digital nautical chart and the paper nautical chart refer to mean sea level 1970, so no adjustment is needed for mixing soundings and land elevation data in RH 70.

The SGU depth soundings were delivered to SKB as 201 files in ascii-format, generally one file for each transect in the survey /Elhammer and Sandkvist 2005/. The columns in the files consist of X-coordinates and Y-coordinates with a resolution of 4 digits (1/10 of a mm) and a Z-value with a resolution of two digits. The coordinate system is RT 90 and the Z-values are corrected to RH 70. The ascii-files were imported to Excel and exported in dBase4-format to be able to import these files to ArcGis 9. All 201 files were merged into one single point layer in ArcGis 9.

The SGU interpreted depth data /Elhammer and Sandkvist 2005/ has depth lines for 1, 3, 5, 8, 10, 13, 15, 18, and 20 metres. These line objects were transformed into point objects in ArcGis 9. The distance between adjacent points was set to 10 metres.

2.2.1 Complementary field work

The SGU depth soundings were not performed in the shallow bays due to size of the vessel. Therefore, a complementary depth sounding using a small boat was performed /Brydsten and Strömgren 2004b/. To map water depths a digital echo sounder was used (Simrad EQ32 Mk 11) as well as a DGPS (Trimble Pro XR) connected to a field computer (Itronix GoBook) using ESRI ArcPad real time GIS software. For each update of the GPS position (every second), the X and Y coordinates were recorded from the GPS. The Z values (water depth) were recorded from the digital echo sounder. Approximately 2,000 depth values per hour were recorded. The coordinates were measured in RT 90 coordinate system with an accuracy of one centimetre.

An orthophoto (1 metre resolution) was used as background imaging in the field computer. Each recorded depth point was displayed on top of the orthophoto. It was possible to observe which parts of the area had already been mapped, and this was used as a navigational aid. The depth values were adjusted because of different water levels in the sea over time. Using sea level records from Forsmark with hourly accuracy, the water depth values were adjusted to zero sea level in the RH 70 height system.

During depth soundings of shallow bays, the depths of the inlet channel of the nuclear power plant were also measured. However, we were only permitted to survey from the bay up to the inlet channel bridge. The depths of the rest of the channel were digitized from a scanned and rectified construction drawing /Vattenfall 1977/. In the innermost 400 metres of the channel, no depth data is available.

In some small areas within the DEM extension, no elevation data are available, e.g. inner parts of the inlet channel mentioned above (area G in Figure 2-3), in smaller areas between the depth soundings of shallow bays and the sea shoreline (the inner part of area D in Figure 2-3), and two shallow bays in the southeast part of the model area (area E in Figure 2-3). For these areas, we have manually placed “false depth values”, between –2 and –11.7 metre in the channel and between –0.3 and –2.0 metre in the bays. This keeps these areas from being classified as land in the final DEM.

Although a small boat was used in the shallow bay depth soundings, depth values are absent between the shoreline and approximately 0.7 m water depth. When using the final DEM in modelling of the modern hydro-geological properties, the DEM of the sea shoreline must be very accurate due to its influence on groundwater pressure gradients. A measurement of elevation points close to the present shoreline was therefore performed.

There are four opportunities to catch elevation points close to the sea shoreline by: (i) using the sea shoreline from the Property maps, (ii) using the 0-line from the digital nautical chart, (iii) manually digitizing the shoreline with the IR orthophoto as background, and (iv) measuring the sea shoreline by walking the line with a DGPS.

The accuracy of the sea shoreline from the Property maps and the 0-line from the digital chart was tested using GIS and the IR orthophoto. Figure 2-4 shows the result from this test.

The selected test area has a fairly steep shore. The sea water level at the time for photographing was –0.01 metres, so the distance between the digitized shoreline and the shoreline in RH 70 height system is small. The test shows that both the shorelines in the localities map and the nautical chart have low accuracies, but some localities have higher accuracy for the localities map. The test also showed that it is difficult to digitize the shoreline from IR orthophotos if the shoreline has a low gradient, because low gradient shorelines are often covered with reeds.

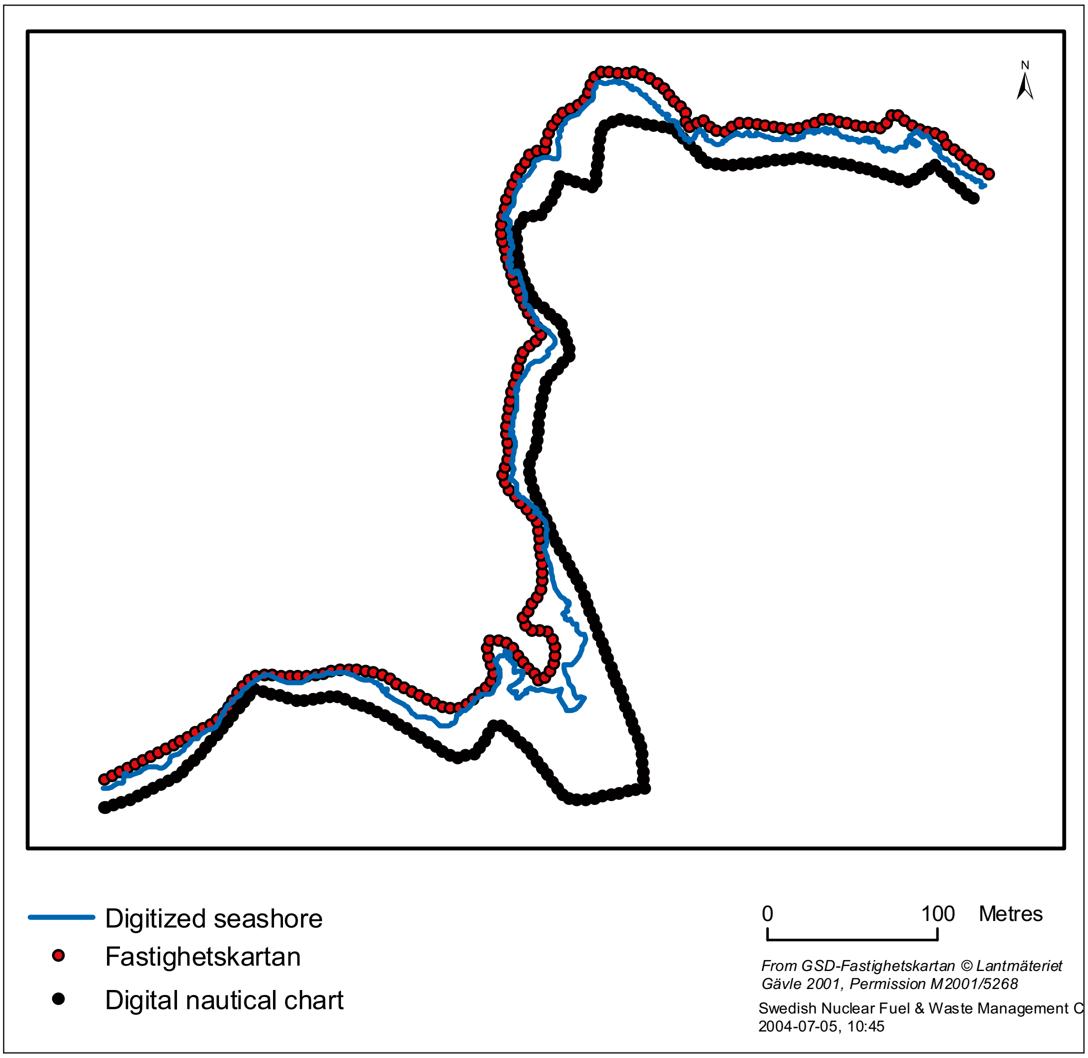

***Figure 2-4.** Comparison between shorelines in Forsmark from the Property map (Fastighetskartan), the digital nautical chart, and manually digitizing the shoreline with the IR orthophoto as background.*

The most appropriate method for catching elevation data close to the zero level is therefore by measuring the sea shoreline by walking along the shoreline with a DGPS. This approach is too expensive to use for the whole area, so this was only performed for vegetated shores within the local model area that are difficult to observe using the IR orthophoto. The rest of the shorelines within the local model area were manually digitized with the IR orthophoto as background, and the sea shoreline from the Property maps was used for the rest of the DEM (Figure 2-5).

The accuracy of the DGPS measurements was tested by measuring the coordinates of two fixed points for approximately 3 minutes.

One of the fixed points was measured at two occasions to detect different errors at different times of the day. The DGPS filter was set to a PDOP < 6, SNR > 6 (Signal to Noise Ratio) and a elevation mask < 15 degrees (only satellites situated higher than 15 degrees over the horizon are used in the calculation). These are the same settings as for the usual measurements. PDOP (Positional Dilution Of Precision) is a measure of overall uncertainty in a GPS position. The best PDOP (lowest value) would occur with one satellite directly overhead and three others evenly spaced above the horizon. The results of the tests are shown in Figure 2-6 and Table 2-2. The mean errors for the three tests were 0.28, 0.72, and 0.46 metres, respectively. The maximum error among the approximately 300 measurements is 1.50 metres. Of the approximately 300 measurements, 95% have errors lower than one metre.

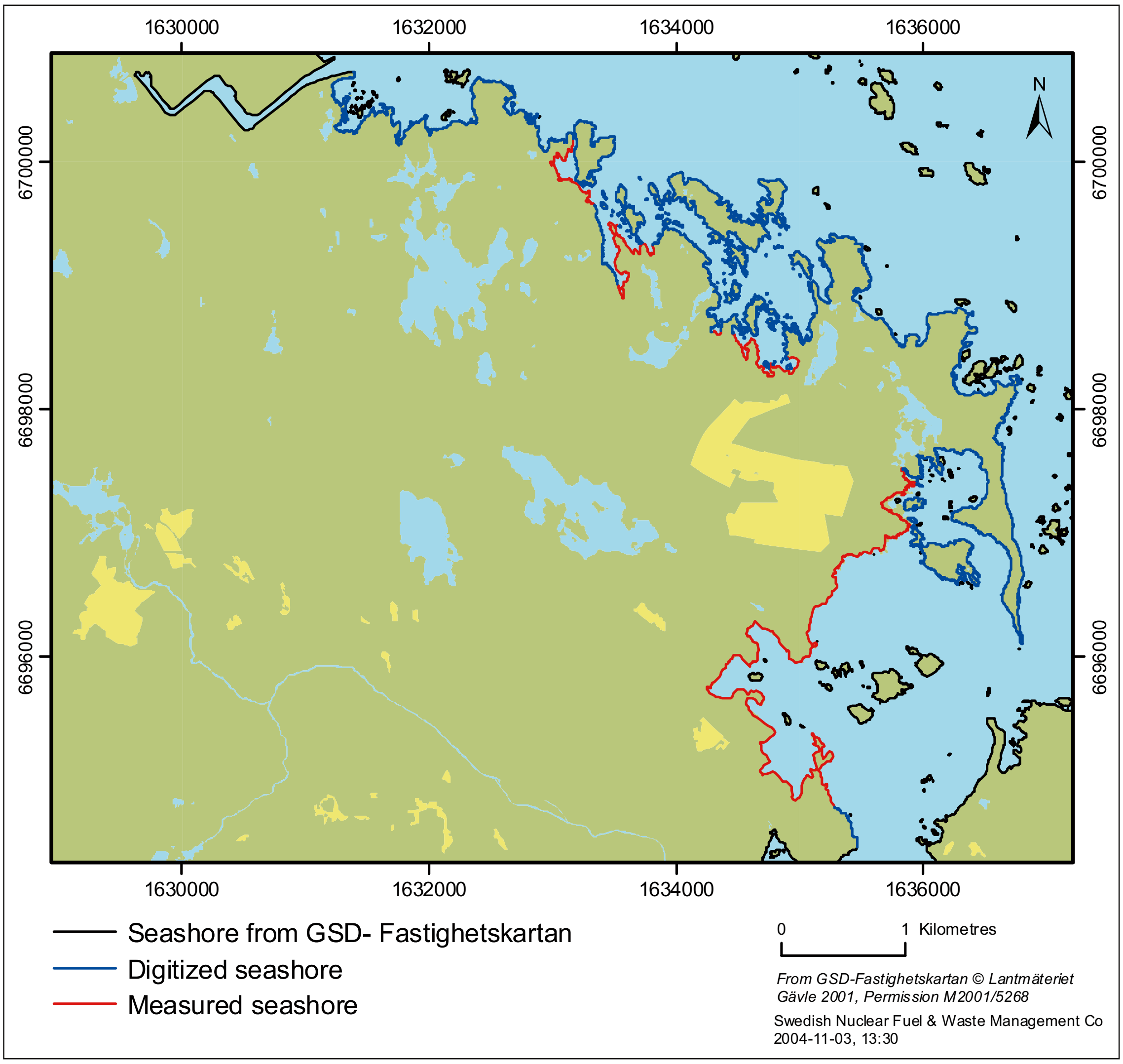

Figure 2-5. *Extensions of different data sources for the sea shoreline in Forsmark.*

Figure 2-6. *The spread in positions recorded in Forsmark area for repeated GPS measurements of the fixed point 1009 during the date 2004-06-17.*

Table 2-2. Results from tests of DGPS accuracy.

Date	Time	Fix Nr.	X	Y	Z	Count	Mean error	Max. error	SD
20040617	081721–082027	1009	1633467.781	6698933.04	7.903	100	0.279	0.618	0.131
20040616	160330–160726	1003	1630743.981	6699758.29	5.943	94	0.722	1.502	0.323
20040617	113149–113459	1003	1630743.981	6699758.29	5.943	96	0.464	0.687	0.082

During a post-processing procedure, each x/y-record was given a z-value using sea level data from a water level gauge situated close to SFR. The time resolution of the gauge was one hour. The DGPS measurements were carried out during the third week of August 2004, and during this period the sea water level varied between –0.046 and 0.091 metres in the RH 70 height system. The water level gauge in Kallrigafjärden, managed by SKB, was not working during this period, so only the gauge close to SFR was used.

2.3 Handling overlapping data from different data sources

Because some of the extensions of different point elevation data overlap (Figure 2-7), different tests were performed to determine whether all datasets in the overlapping area should be used or only one of the datasets. The SGU depth soundings are estimated to be the most accurate data source for sea areas followed by the depth soundings of shallow bays. The SKB 10-metre DEM are estimated to be the most accurate data source for land areas. The five tests are as follows:

(i) the 10-metre DEM against the 50-metre DEM,

(ii) he digital nautical chart and the nautical chart against SGU depth soundings,

(iii) the base map and the nautical chart against SGU depth soundings,

(iv) the depth soundings of shallow bays against SGU depth soundings,

(v) the digital nautical chart and the nautical chart against the base map.

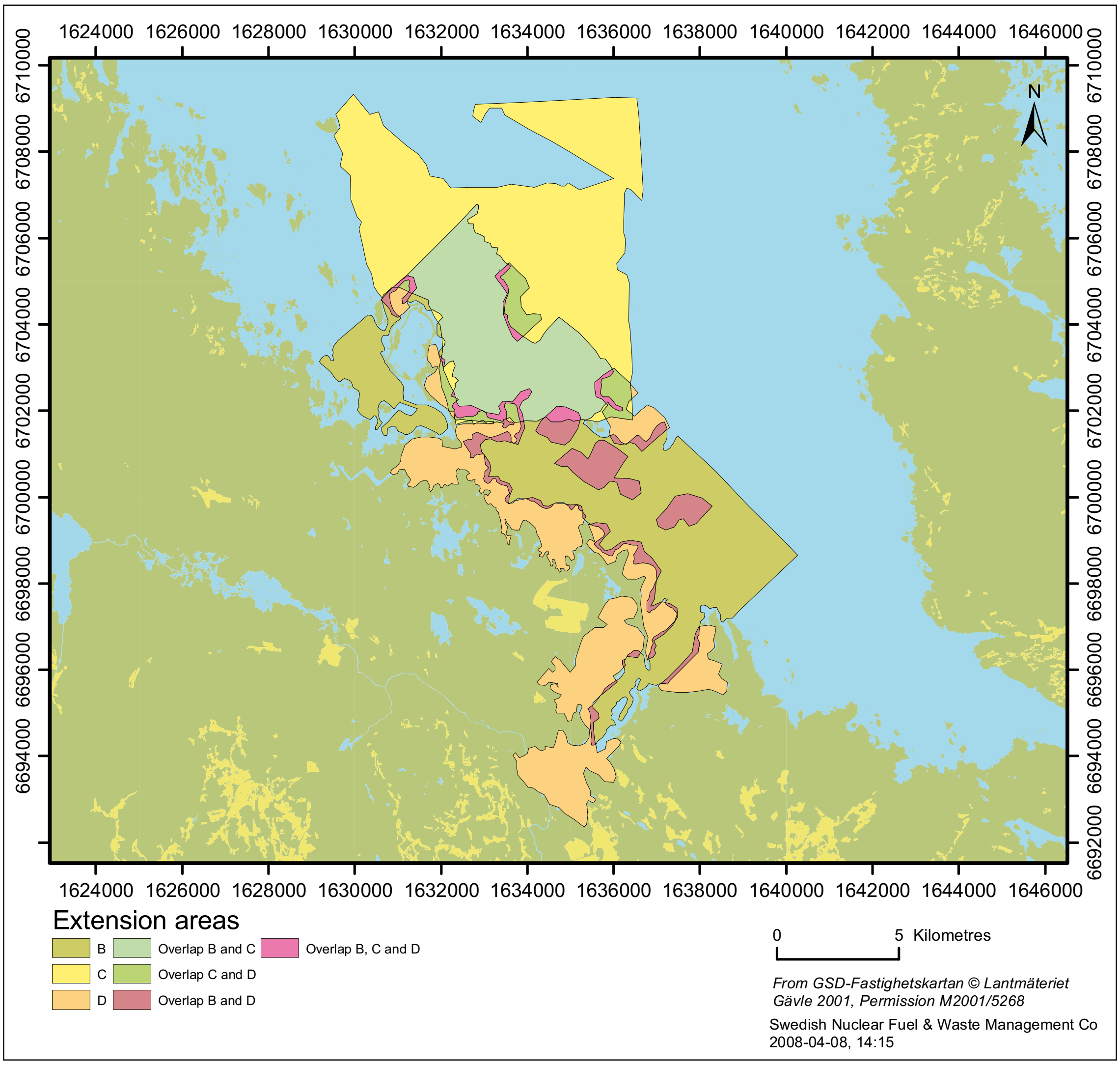

Figure 2-7. *Extensions of overlapping data sets in the sea area. B = depth soundings and interpreted depth data performed by the Geological Survey of Sweden, C = the base map to the nautical chart, and D = depth soundings of shallow bays.*

The point elevation data sets were joined against the SGU or SKB 10-metre DEM datasets. This GIS function (point to point join) gives a new attribute with the distance to the closest point in the join to dataset. Points in actual dataset with a distance shorter than 1 metre were selected and the difference in z-value was calculated. Only in an exceptional case, the differences in Z-values larger than one metre are aloud for the dataset to be classified as accurate as the join to dataset (one metre difference in XY-plane and one metre in Z-value means at least a 45 degree slope). A summary of the test results is shown in Table 2-3.

The two existing DEMs are overlapping within the 10-metre DEM extension with approximately 51,000 height values with exactly the same coordinates. If duplicate points are incorporated in the final elevation point data set, the ArcGis program will use the mean value. If there are great differences in Z-values among the duplicates, there is a risk for errors in the final DEM. Therefore, a statistical analysis was carried out for the duplicates. All datasets were not tested against each other as all sets do not contain all data points, hence only the ones with overlapping points were compared.

The difference in Z-values for the duplicate points was calculated. The results of the comparison are presented in Table 2-3. Only about 38% of the duplicate points have a difference in z-value lower than one metre. That means that it is not appropriate to use the mean values of duplicate points. The 50-metre DEM is evaluated from air photos from 4,600 metre level while photos from 2,300 metre level were used for evaluation of the 10-metre DEM /Wiklund 2002/. Therefore, the 10-metre DEM will probably be of higher quality. Another reason for using only the 10-metre DEM points is the abnormal differences in z-values between adjacent points could occur, i.e. a point from the 50-metre DEM surrounded by 8 points from the 10-metre DEM. All duplicate points from the 50-metre DEM were deleted and not used in the final interpolation.

The tests for the sea depth datasets show that only the depth soundings of shallow bays and the SGU depths soundings have low differences in depth values between points situated within a metres distance. All other comparisons produce significant differences.

Based on the test results, the following datasets were used in the final interpolation procedure:

- when the 50-metre DEM overlapped the 10-metre DEM, only values from the 10-metre DEM were used,
- when the digital nautical chart and the nautical chart overlapped the SGU depth soundings, only the SGU dataset were used,
- when the base map overlapped the SGU depth soundings, only the SGU dataset were used,
- when the depth soundings of shallow bays overlapped the SGU depth soundings both datasets were used and,
- when the digital nautical chart and the nautical chart overlapped the base map, only data from the base map were used.

The fixed points and brook measurements are small datasets (less than 100 points and a little more than 600 points) and were therefore not used in the statistical test presented in Table 2-3. However, these datasets are more accurate than the 10-metre DEM and the 50-metre DEM. Therefore points from the 10-metre DEM and 50-metre DEM, in the nearest surrounding from the fixed points, were not used in the interpolation procedure. The measured brooks are only situated within the extension of the 10-metre DEM. The brook furrows are only a few metres wide and the range in altitude between the brook furrow and the surrounding is sometime high in only a short distance. Because of that, no removals of surrounding points from the 10-metre DEM were made in order for the interpolation to result in a more representative 20-metre DEM.

The SGU interpreted depth data were also excluded from the statistical test in Table 2-3. Only SGU interpreted depth data within the area for the SGU depth soundings were used in the interpolation procedure. In case the SGU interpreted depth data were close to point elevation data from other sources, the SGU interpreted depth data were removed.

Table 2-3. Summary results from tests for deciding if one or both datasets should be used in the final interpolation when these datasets are overlapping. Total Nb. = total number of points in the "join from" dataset, Nb. < 1 m = number of points within a distance lower than one metre from a point in the "join to" dataset, Nb. Diff. > 1 m = number of points with a difference in elevation value in the "Nb. < 1 m" dataset that are higher than one metre, Max. diff. (m) = the maximum difference in elevation value between two points in "join from" and "join to" datasets that is situated closer than one metre from each other and Mean diff. (m) = the average difference in elevation value between all points in "join from" and "join to" datasets that is situated closer than one metre from each other.

Join from	Join to	Total nb.	Nb. < 1 m	Nb. Diff. > 1 m	% error	Max. diff. (m)	Mean diff. (m)
DEM 50 m	DEM 10 m	50,693	50,693	31,459	62	11.0	1.7
Dig. chart	SGU	32,881	41	29	71	6.4	1.9
Base map	SGU	4,335	8	2	25	2.1	0.7
Shall. bays	SGU	84,122	202	10	5	1.9	0.5
Dig. chart	Base map	4,335	55	55	100	11.0	2.6

2.4 Interpolation of the digital elevation model

All elevation point values were merged to a database with approximately 1,920,000 points. With this database a digital elevation model representing land surface, lake bottoms, and sea bottom was interpolated. The RT 90 2.5 Gon W map projection and the height system RH 70 is used in this elevation model.

The interpolation from irregularly spaced point values to a regularly spaced DEM was done using the software ArcGis 9 Geostatistical Analysis extension. Kriging was chosen as the interpolation method /Davis 1986, Isaaks and Srivastava 1989/. The choosing of theoretical semivariogram model and the parameters scale, length, and nugget effect were done with the extension. The resolution was chosen to 20-metre.

Before the interpolations start, the model is validated both with cross-validation (one data point is removed and the rest of the data is used to predict the removed data point) and ordinary validation (part of the data is removed and the rest of the data is used to predict the removed data). Both the cross-validation and ordinary validation goals produce a standardised mean prediction error near 0, small root-mean-square prediction errors, average standard error near root-mean-square prediction errors, and standardised root-mean-square prediction errors near 1.

Cross validations with different combinations of Kriging parameters were performed until the standardised mean prediction errors were close to zero, but not necessarily the lowest value was always chosen. Because the aim was to determine the most valid model for both measured and unmeasured locations, a model that produced low values for the root-mean-square prediction errors and minimise the difference between the root-mean square prediction errors and the average standard errors is to prefer. Different models were compared and the ones with the most reasonable statistics were chosen.

Finally, a validation was performed with the most appropriate Kriging parameters in order to verify that the models fit unmeasured locations. The final choice of parameters is presented in Appendix 1.

Another DEM was constructed from the interpolated DEM. In this DEM, the cells representing lake bottoms, inside the 25 lakes shown in Figure 2-2, were replaced by cells representing lake water surface elevation (Table 2-1). This was done using the Spatial Analyst extension in ArcGis 9.

3 Results and conclusion

3.1 The digital elevation modell (DEM)

The digital elevation model describing land surface, sediment level at lake bottoms, and sea bottom is illustrated in Figure 3-1.

An analysis of the elevation model confirms existing knowledge of the area that it is extremely flat. The range in elevation is only approximately 109 metres with the highest point at 51.1 metres above sea level at the south-west part of the DEM, and the deepest sea point at –58.8 metres in the northern part of the so called Gräsörännan. The final digital elevation model had a size of approximately 30×30 kilometres, a cell size of 20-metres, 1,501 rows, and 1,501 columns: a total number of DEM cells of 2,253,001 and a file size of approximately 8.8 MB (ESRI Grid format). The extension is 1619990 West, 1650010 East, 6715010 North, and 6684990 South in the RT 90 coordinate system. As mentioned earlier, the height system is RH 70.

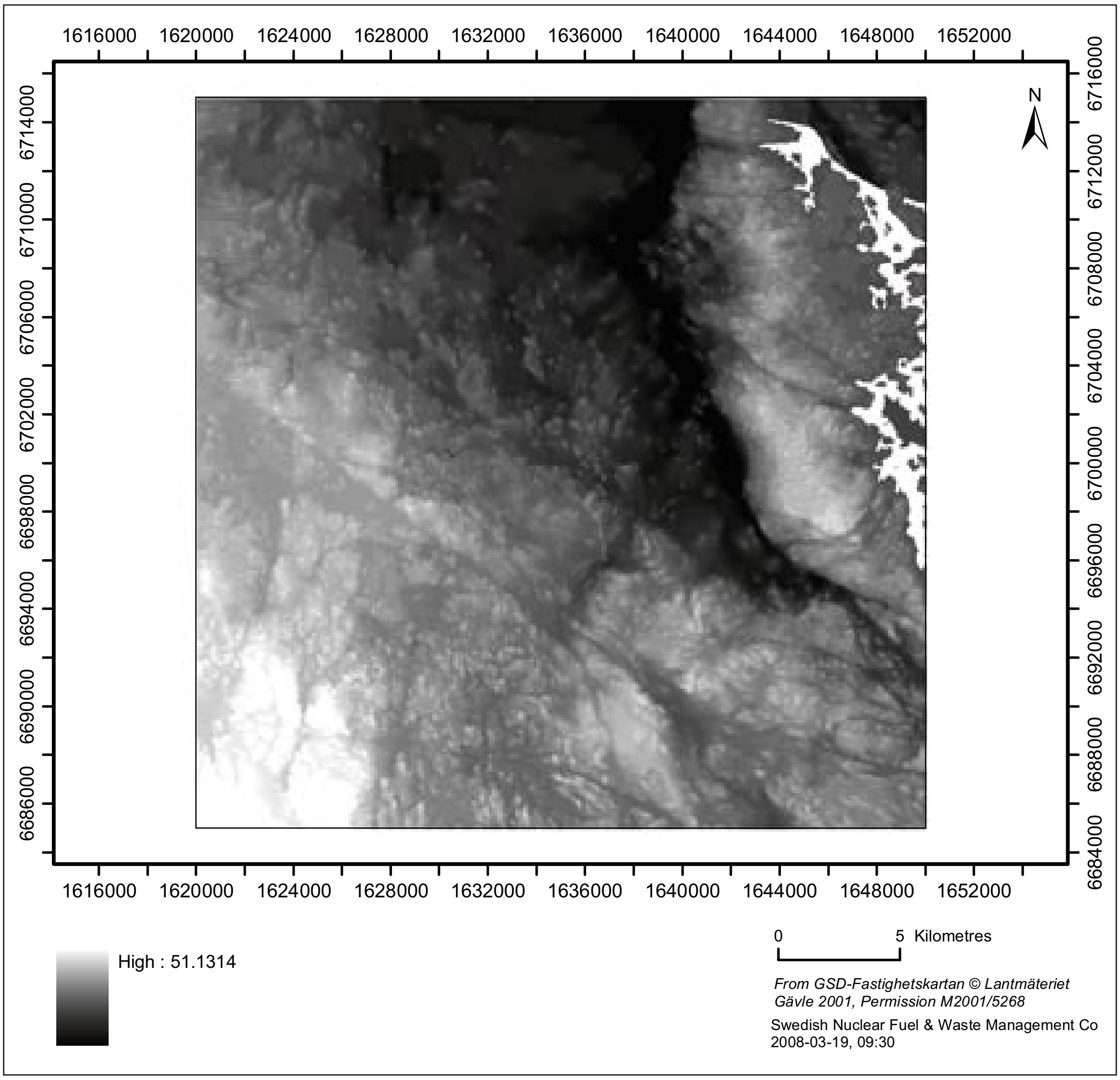

Figure 3-1. *The 20-metre digital elevation model describing land surface, lake bottoms, and lake sediment surfaces.*

The mean elevation in the DEM is only 2 metres. The model area is covered by 58% land and 42% sea. The flat landscape is also shown in the statistics of the slope where the mean slope is 1.47 degrees, and 97.3% of the cells have slopes lower than 5 degrees and 2.6% have slopes between 5 and 10 degrees. Almost all of the cells with slopes steeper than 10 degrees (0.1%) are man-made such as the inlet channel to the nuclear power plant or piers and wharfs close to SFR. Mathematical and statistical analyses of the digital elevation model will be presented in a later report /Strömgren and Brydsten in prep/.

In order to use this DEM in many types of models like hydrological, terrestrial and DOS models in the Forsmark region, the following data files were delivered to SKB data base.

- Forsm_DEM_bot ESRI Grid format, land surface, lake bottoms, and sea bottoms.
- Forsm_DEM_yta ESRI Grid format, land surface, lake surface, and sea bottom.

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Appendix 1

Cross validation of model

Lag size	Number of Lags	Regression function	Mean	RMS	Average SE	Mean stand	RMS stand	Samples
55	12	0.999 * x + 0.006	–0.0005701	0.3348	0.4478	–0.0009128	0.6507	1,920,427

Validation of model

Lag size	Number of Lags	Regression function	Mean	RMS	Average SE	Mean stand	RMS stand	Samples
55	12	0.999 * x + 0.007	0.001016	0.4083	0.5086	–	–	960,213

Model parameters

The model equation should be read as follows:

Partial sill * Theoretical Semiovariogram (Major Range, Minor Range, Anisotropy Direction) + (Nugget value * Nugget)

Points	Modell	MS[1)]	Me[1)]	N[1)]	A[1)]
1,920,427	8.3222*Spherical(651.93,579.75,319.7)+0.00087267*Nugget	0.00087267 (100%)	0 (0%)	5/2	4

[1)] MS = Microstructure, Me = Measurement error, N = Searching Neighbourhood and A = Angular Sectors.