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Digital elevation models of Laxemar-Simpevarp

SDM-Site Laxemar

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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 Laxemar-Simpevarp area. The existing DEM for Laxemar-Simpevarp 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 almost 7.5 million points unevenly spread over an area of about 800 km^2.

The analysis of the elevation model confirms existing knowledge of the area. The range in elevation is approximately 151 metres, with the highest point at 106 metres above sea level at the southwest part of the model and the deepest sea point at –45 metres in the southeast part of the DEM.

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 Laxemar-Simpevarpsområdet i samband med platsbeskrivningarna. En DEM över Laxemar-Simpevarpsområdet 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 Laxemar-Simpevarp 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 interpoleringen. 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 nästan 7,5 miljoner punkter ojämnt spridda över ett cirka 800 km^2 stort område.

En analys av denna nya höjdmodell visar på stora likheter med tidigare höjdmodell. Värdeomfånget i höjdmodellen är 106 till –45 meter, där den högsta höjden återfinns i modellens sydvästra del och den lägsta punkten ligger i modellens sydöstra del.

Contents

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 Laxemar-Simpevarp area. The existing DEM for Laxemar-Simpevarp /Brydsten and Strömgren 2005/ 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 Laxemar-Simpevarp 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

Three sources (Figure 2-1) were used to collect elevation point data for land: the existing DEM from the Swedish national land survey (LMV) with a resolution of 50 metres, the SKB DEM with a resolution of 10 metres /Wiklund 2002/, and the high resolution DEM (0.25 m) produced from the laser scanning in the Laxemar-Simpevarp area /Nyborg 2005/. However, only points every second metre were used from the laser scanning DEM.

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

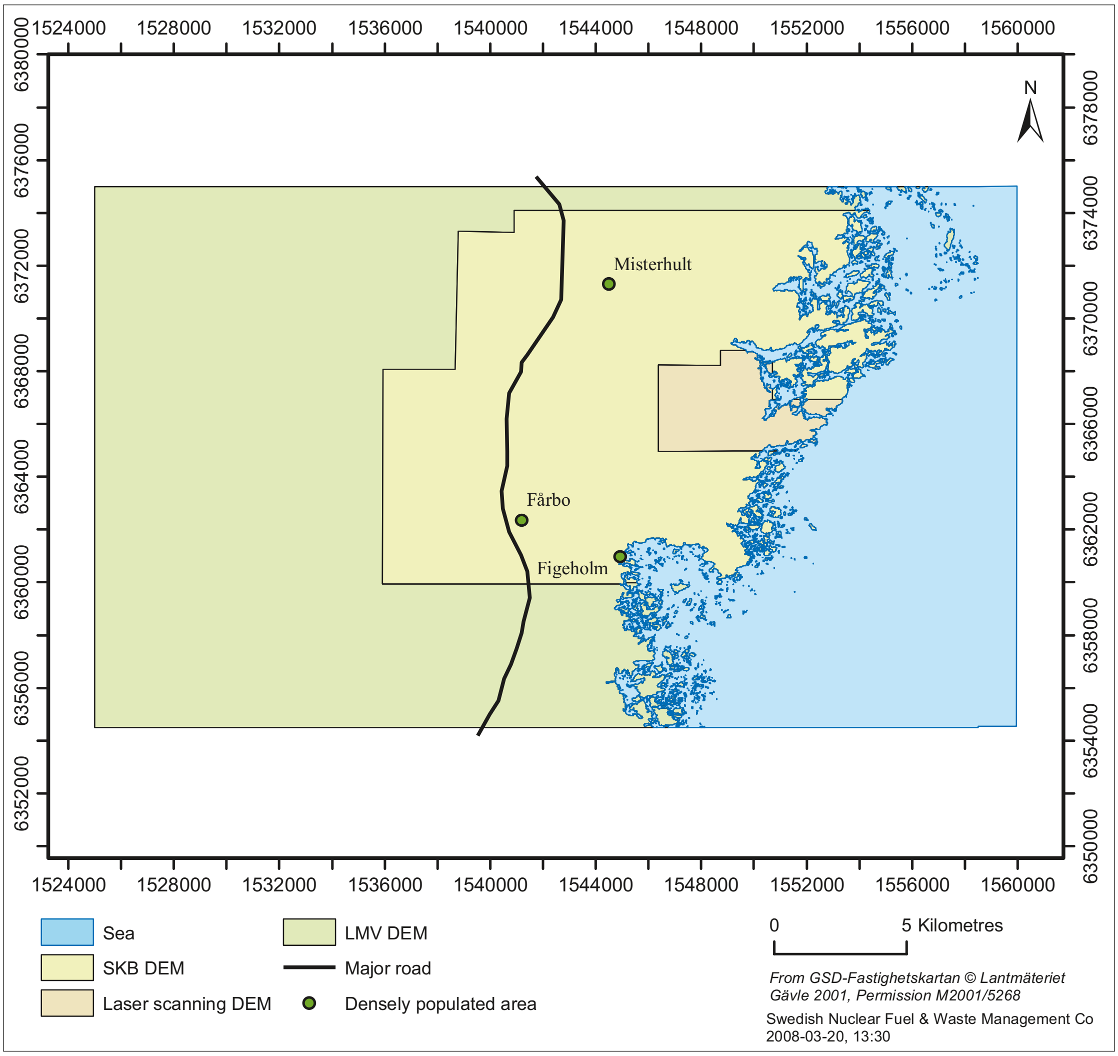

Figure 2-1. *Extensions of the LMV, SKB, and laser scanning DEM in Laxemar-Simpevarp region, respectively.*

All points from the 10-metre DEM and the laser scanning DEM placed within the lakes shown in Figure 2-2 (not within Lake Fjällgöl) were deleted from the dataset and replaced by measured depth values /Brunberg et al. 2004/. Because Lake Fjällgöl, in the centre of the map, has not been measured, the mean value for the elevation in the 10-metre model was used instead. Continuous lake surface level measurements have been performed in four lakes /Lärke et al. 2006, Sjögren et al. 2007/. The mean lake surface levels were calculated for these four lakes (Table 2-1) instead of using the lakes surface levels at the depth measurement occasions. The points from the 10-metre DEM and the depth values from Lake Plittorpsgöl and Lake Jämsen were merged into one single point layer. The depth values from Lake Frisksjön and Lake Söråmagasinet, and the points from the laser scanning DEM were also merged into a single point layer. The map projection used for these layers is RT 90 2.5 g W and the height system is RH 70.

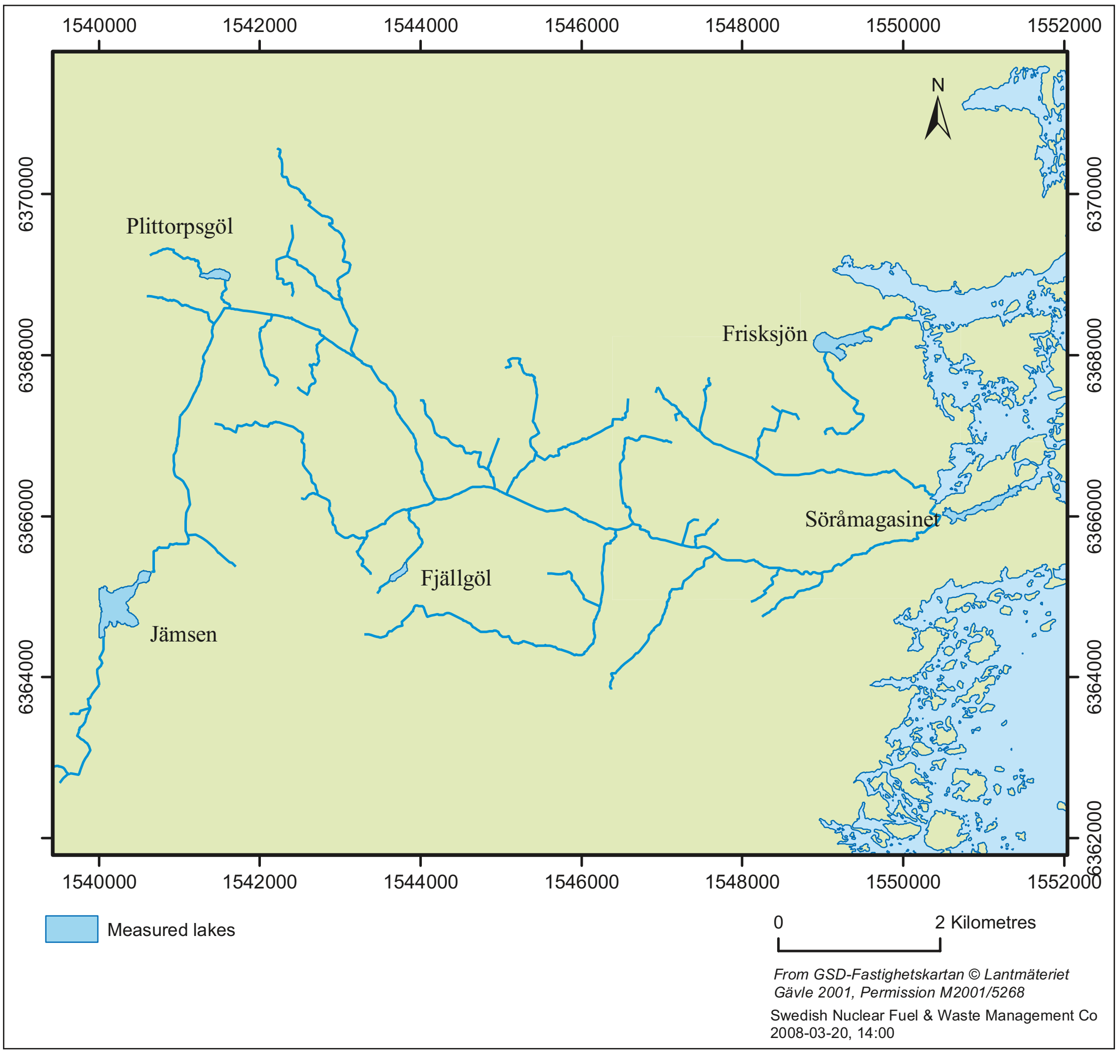

Figure 2-2. *Lakes in Laxemar-Simpevarp area where the SKB DEM points and laser scanning DEM points were replaced by measured points.*

Table 2-1. Lake surface elevations for the five lakes shown in Figure 2-2. The unit is metres above RH 70. The mean lake surface elevations are calculated for the four lakes referred to [1]. The lake surface elevation for the lake referred to [2] is calculated from the 10-metre DEM.

Lake	Elevation (ma RH 70)	Measurement period for mean lake surface calculation
Fjällgöl[2]	21.29	Calculated from the 10-metre DEM
Söråmagasinet[1]	1.81	28 May 2004 – 27 May 2006
Jämsen[1]	25.52	1 July 2005 – 30 June 2006
Plittorpsgöl[1]	25.04	1 July 2005 – 30 June 2006
Frisksjön[1]	1.51	1 July 2005 – 30 June 2006

2.2 Data collection from sea areas in Laxemar-Simpevarp

Figure 2-3 shows the extensions for elevation data for the sea area. The elevations have been obtained from the following 9 sources:

1. the digital nautical chart (the Swedish Maritime Administration, blue area in Figure 2-3),
2. detailed depth soundings performed by the Geological Survey of Sweden, SGU /Elhammer and Sandkvist 2003/ (yellow area in Figure 2-3),
3. regional depth soundings performed by the Geological Survey of Sweden, SGU /Elhammer and Sandkvist 2003/ (black dots in Figure 2-3),
4. interpreted depth data performed by the Geological Survey of Sweden, SGU /Elhammer and Sandkvist 2003/ (yellow area in Figure 2-3),
5. depth soundings of shallow bays performed by Marin Mätteknik AB (MMT) /Ingvarsson et al. 2004/ (red area in Figure 2-3),
6. shoreline points measured with DGPS,
7. digitized shoreline points from IR orthophotos,
8. the sea shoreline from the Property map from Lantmäteriet,
9. the sea shoreline from the digital nautical chart.

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 ArcGis 9. The maximum distance between adjacent points was set to 5 metres. 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 already stored as points. The water depth for “Stone in water surface” was set to +0.2 metre and for “Stone beneath water surface” to –0.5 metre.

The SGU depth soundings were delivered to SKB as 141 files in ASCII-format, generally one file for each transect in the survey /Elhammer and Sandkvist 2003/. 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 merged to one single comma separated ASCII-file using a small program written in Pascal.

The SGU interpreted depth data /Elhammer and Sandkvist 2003/ 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 5 metres. The SGU depth soundings were not performed in the shallow bays due to size of the vessel. Therefore, a completing depth sounding using a small boat was performed by the company Marin Mätteknik (MMT) /Ingvarson et al. 2004/. The z-values (water depth) were recorded both with single and multi beam techniques.

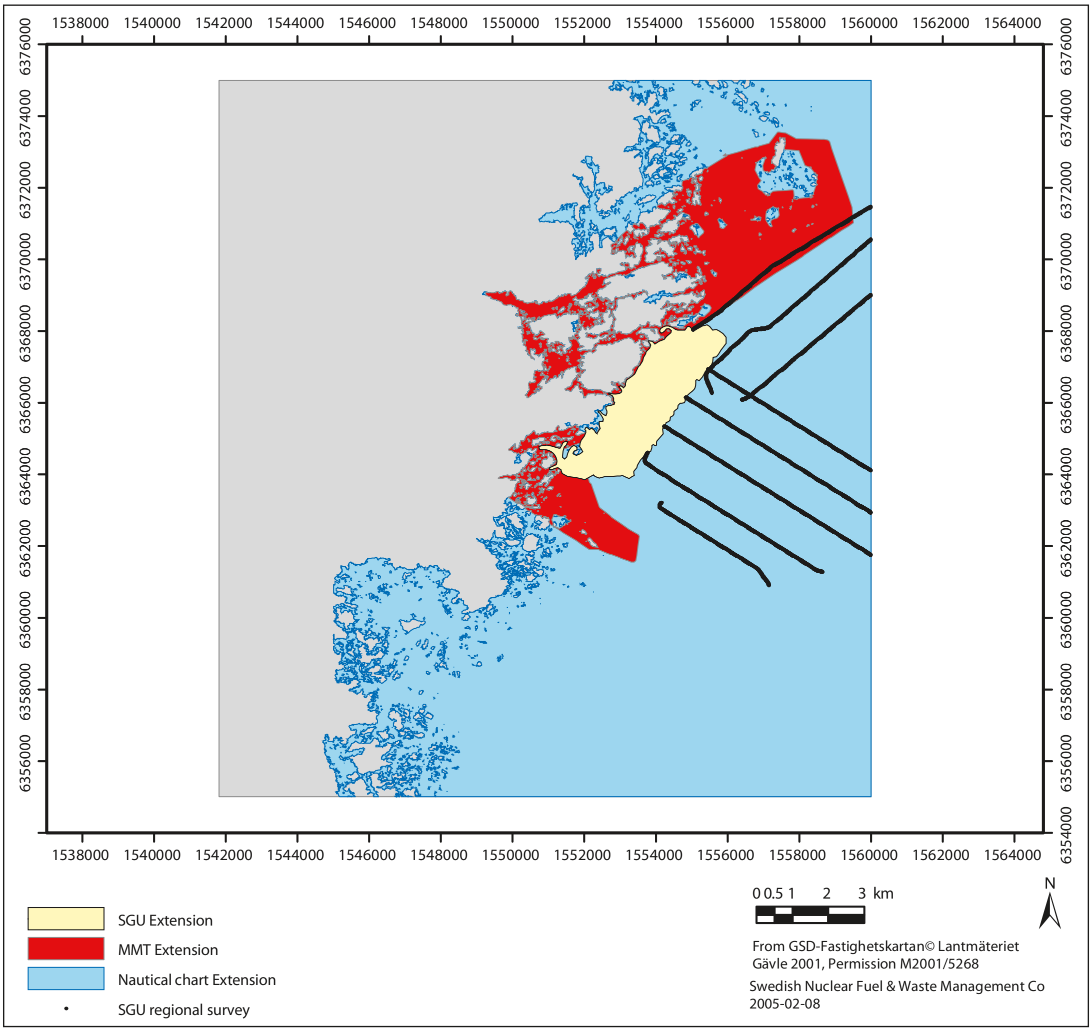

Figure 2-3. *Extensions of different data sources for the sea areas in Oskarhamn region.*

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 hydrogeological properties, the DEM of the sea shoreline must be very accurate. Therefore, a measurement of elevation points close to the present shoreline was performed. Elevation points close to the sea shoreline was obtained from four different data sources:

- the sea shoreline from the digital Property map (*Fastighetskartan*),
- the 0-line from the digital nautical chart,
- manually digitizing of the shoreline with the IR orthophotos as background, and
- measuring the location of the sea shoreline during walking the shore with a DGPS.

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

The sea water level at the time for photographing was 0.06 metres, so the distance between the digitized shoreline and the shoreline in RH 70 height system was small. The test shows that both the shorelines in the Property map and the nautical chart have low accuracies, but some localities have higher accuracy for the digital nautical chart. In addition, the test shows that low gradient shorelines are difficult to digitize using IR orthophotos if they are covered with reed.

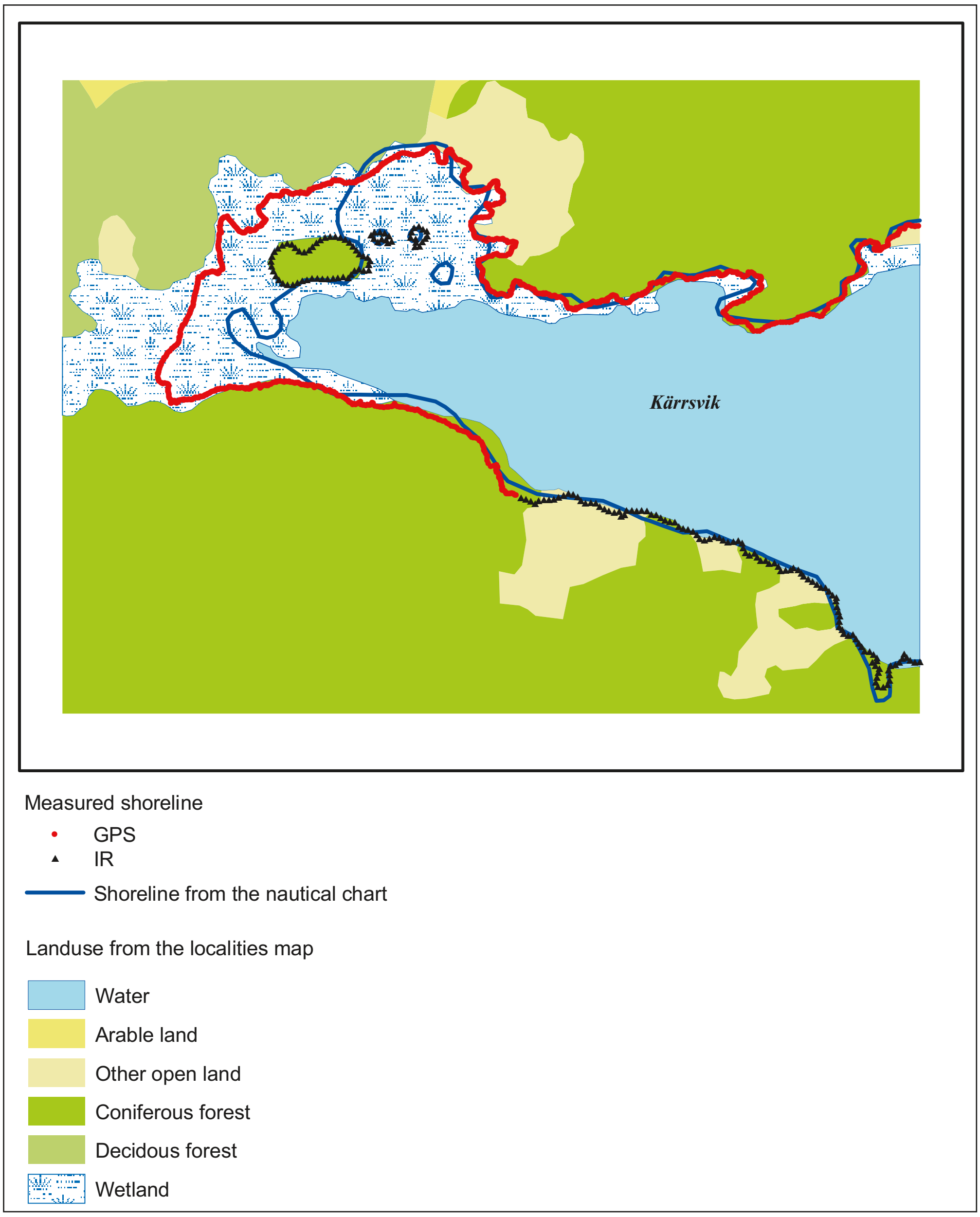

Figure 2-4. *Comparison between shorelines from the digital Property map (Fastighetskartan), the digital nautical chart, manually digitized shoreline with the IR orthophotos as background, and measurements done with DGPS by walking the shoreline.*

Therefore, the most appropriate method for catching elevation data close to the zero level is to measure the sea shoreline by walking the shore with a DGPS. This approach is too labour intensive 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 orthophotos.

During a post-processing procedure, each x/y-record was given a z-value using sea level data from a water level gauge in Laxemar-Simpevarp. The time resolution of the gauge was one hour. The DGPS measurements were carried out during week 50 of 2004, and during this period the sea water level varied between +0.186 and +0.284 metres in the RH 70 height system.

Another test was performed to find out whether the sea shoreline from the digital Property map has lower accuracy than the 0-line from the digital nautical chart in a larger area. The depth soundings of shallow bays performed by MMT were used in this test. The test shows that 1,755 points from MMT are situated "inside" the sea shoreline from the digital Property map, compared to 5,906 points situated "inside" the 0-line from the digital nautical chart. Based on this test, the sea shoreline from the digital nautical chart was used for the rest of model, except for areas in the southern and northern parts of the model which are not covered by the digital Property map. In these areas, the 0-line from the digital nautical chart was used instead. Figure 2-5 shows the different data sources used for the sea shoreline.

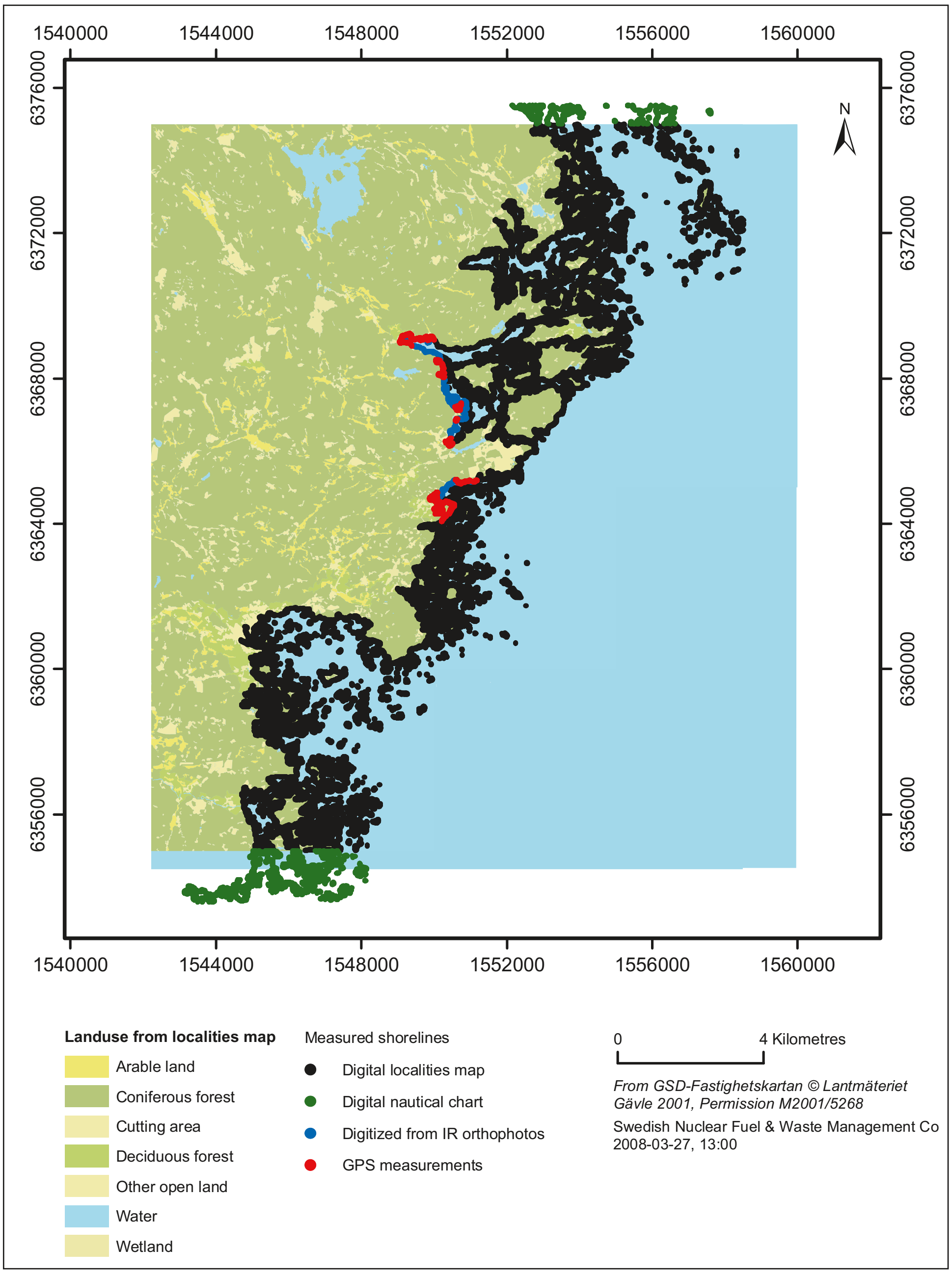

***Figure 2-5.** Extensions of different data sources for the sea shoreline in the Laxemar-Simpevarp area.*

2.3 Handling overlapping data from different data sources

Because some of the extensions of different point elevation data overlap (Figure 2-6), different tests were performed to determine whether both or only one of the datasets in the overlapping area should be used.

For land areas, measurements with a total station have been performed where points from the laser scanning DEM, the 10-metre DEM, and the 50-metre DEM have exactly the same coordinates (Strömgren and Brydsten, unpublished). The statistical analysis of the difference between points from the DEM:s and the total station measurement (Table 2-2) shows that the laser scanning DEM is the most accurate data source for land areas, followed by the 10-metre DEM and the 50-metre DEM.

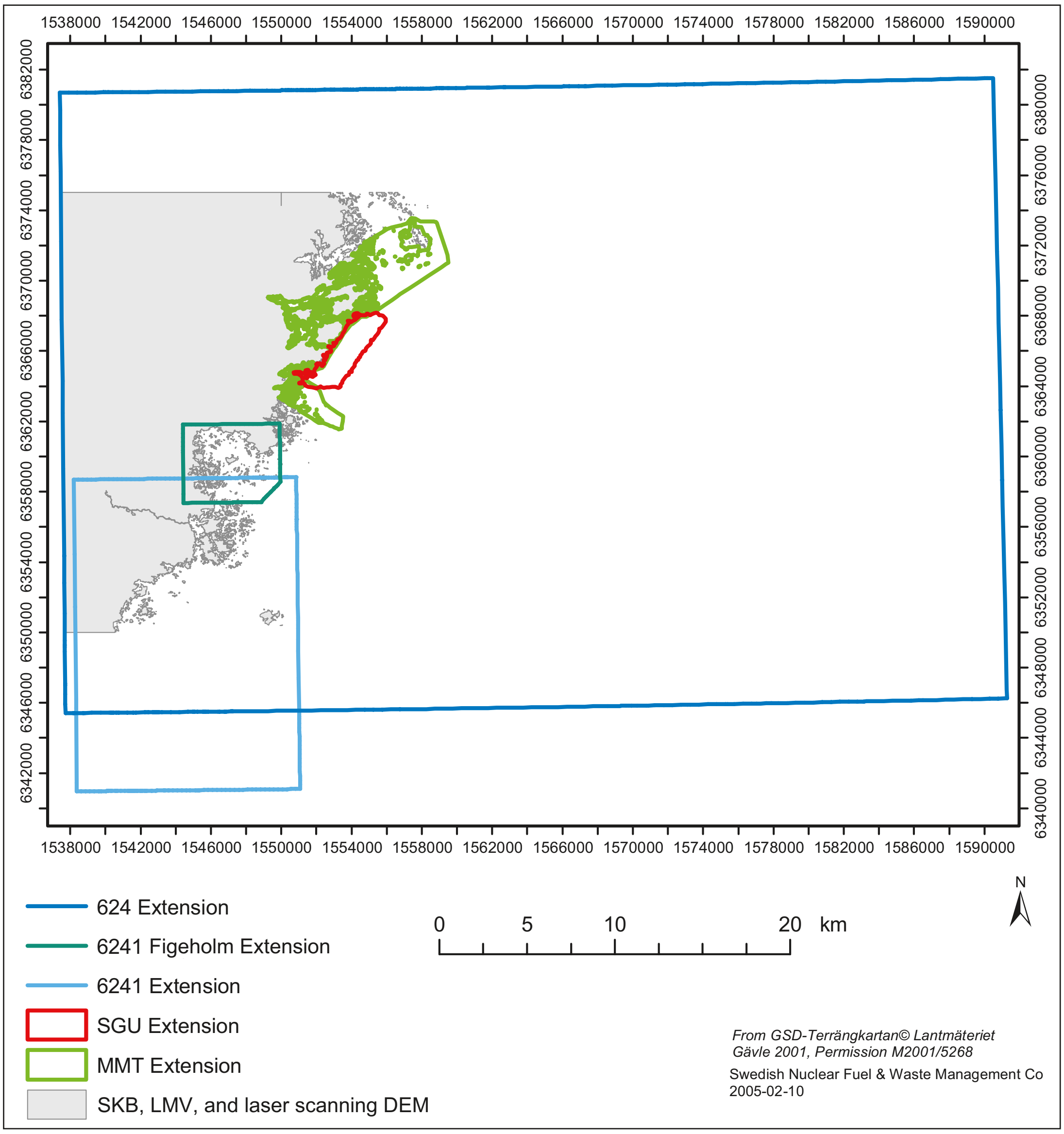

Figure 2-6. *Extensions of overlapping data sets for the sea area in Laxemar-Simpevarp area. The 624 extension, the 6241 Figeholm extension, and the 6241 extension refer to digital nautical charts.*

Table 2-2. Statistical analysis of total station measurements of points from the laser scanning DEM, the 10-metre DEM, and the 50-metre DEM in the Laxemar-Simpevarp regional model area. The statistics shows the difference between the DEM:s and the total station measurements. 493 total station measurements are performed where points from the laser scanning DEM and points from the 10-metre DEM have exactly the same coordinates (referred to [1)] in the table). 60 measurements are performed where points from the laser scanning DEM, the 10-metre DEM, and the 50-metre DEM have exactly the same coordinates (referred to [2)] in the table).

Data source	Nr of total station measurements	Mean	Median	Standard deviation
Laser scanning DEM	493[1)]	0.011	0.024	0.188
10-metre DEM	493[1)]	0.339	0.382	1.862
Laser scanning DEM	69[2)]	0.024	0.041	0.106
10-metre DEM	69[2)]	0.310	0.457	1.337
50-metre DEM	69[2)]	–0.181	–0.290	1.758

For sea areas, no validation measurements of the different data sources have been performed and therefore other kinds of tests had to be done for overlapping areas. The MMT depth soundings are estimated to be the most accurate data source for sea areas, followed by the SGU depth soundings. In order to determine which of the overlapping datasets should be used, the following three tests were performed:

- the digital nautical chart against MMT depth soundings,
- the digital nautical chart against SGU depth soundings, and
- the SGU depth soundings against MMT depth soundings.

The point elevation data sets were joined with the MMT, or SGU point 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 an actual data set with a distance shorter than 1 metre were selected and the difference in z-value was calculated. If the dataset is 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), then the differences in Z-values are larger than one metre, which is rare. A summary of the test results is shown in Table 2-3.

Table 2-3. Summary results from the overlapping tests for deciding if one or both datasets should be used for the final interpolation. 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 are 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 are closer than one metre from each other.

Join from	Join to	Nb. < 1 m	Nb. Diff. > 1 m	% error	Max. diff. (m)	Mean diff. (m)
Dig. chart	MMT	318	152	48	6.0	1.4
Dig. chart	SGU	80	60	75	12.1	2.5
SGU	MMT	616	47	8	2.3	0.5

The tests for the sea depth datasets show that only the depth soundings of shallow bays (MMT) 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 total station measurements and test results, the following datasets were used in the final interpolation procedure:

- when the 10-metre model and 50-metre model overlapped the laser scanning model, only values from the laser scanning model were used,
- when the 50-metre model overlapped the 10-metre model, only values from the 10-metre model were used,
- when the digital nautical chart overlapped the SGU depth soundings, only the SGU dataset was used,
- when the digital nautical chart overlapped the MMT depth measurements, only the MMT depth measurements were used,
- when the depth soundings of shallow bays overlapped the SGU depth soundings, both datasets were used.

There are also overlapping areas among different nautical charts. Three different charts were used in the data collection:

- Nautical chart number 624, an archipelago chart with scale 1:50,000.
- Nautical chart number 6241, a special chart with scale 1:25,000.
- Nautical chart number 6241_Figeholm, a harbour chart with scale 1:5,000.

A comparison between the three charts shows that the degree of generalization increases from the harbour chart to the special chart, and even more from the special chart to the archipelago chart. Therefore, when the harbour chart overlaps the special chart, only data from the harbour chart is used. When the special chart overlaps the archipelago chart, only data from the special chart is used.

The SGU interpreted data were excluded from the statistical test in Table 2-3. Instead only following SGU interpreted data were used in the interpolation procedure:

(i) within 100 metres from the SGU depth soundings but more than 10 metres from the SGU depth soundings,

(ii) more than 10 metres from the digital nautical chart data,

(iii) more than 10 metres from the base map data,

(iv) more than 100 metres from the depth soundings of shallow bay,

(v) more than 50 metres from the sea shoreline from the digital Property map, and

(vi) more than 50 metres from the digitised sea shoreline.

2.4 Interpolation of the digital elevation model

After the deletion of some points from overlapping datasets, all other elevation point values were merged to a database with almost 7,460,000 points. With this database. a digital elevation model representing land surface, lake bottoms, and sea bottom was created in the Swedish national grid projection (RT 90 2.5 Gon W) and the Swedish national height system 1970 (RH 70).

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 semi-variogram model and the parameters scale, length, and nugget effect were done in this 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). Because of the large number of points in the database, it was only possible to use half of the points in the cross-validation and validation processes. 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 the lowest value was not necessarily always chosen. Because the aim was to determine the most valid model for both measured and unmeasured locations, special effort was taken to produce 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. 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 5 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 discussion

3.1 The digital elevation model (DEM)

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

The final model had a size of approximately 35 × 20 kilometres, a cell size of 20-metres, 1,001 rows, and 1,751 columns: a total number of DEM cells of 7,005,501 and a file size of approximately 8.9 MB (ESRI Grid format). The extension is 1524990 west, 1560010 east, 6375010 north, and 6354990 south in the RT 90 coordinate system and the elevation of the model is expressed in the RH 70 height system. The area is undulating with narrow valleys situated at bedrock-weakened zones.

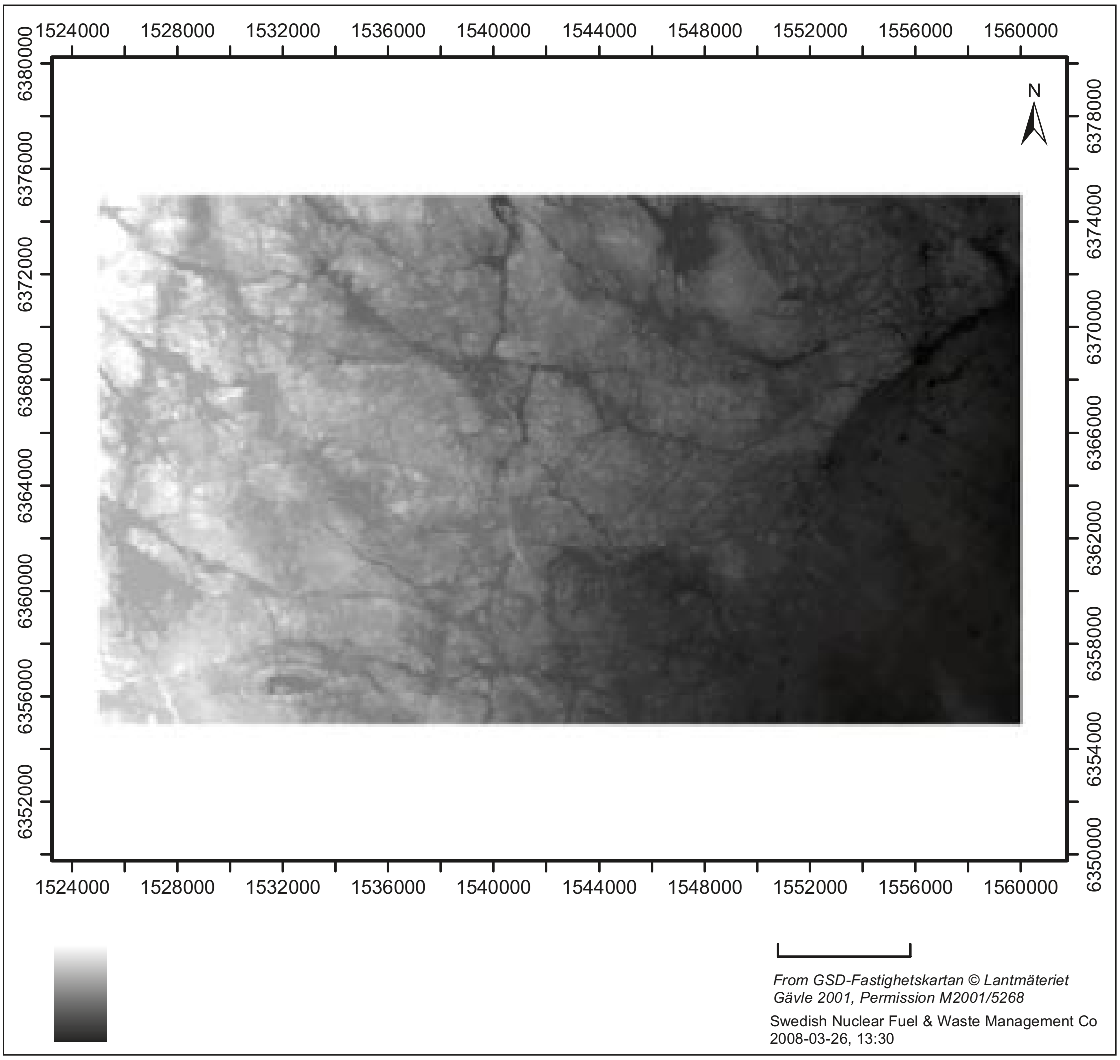

Figure 3-1. *The 20-metre digital elevation model (Simp_DEM_5) describing land surface, sea bottom, and lake sediment surfaces.*

The range in elevation is approximately 151 metres with the highest point at 106 metres above sea level at the southwest part of the model and the deepest sea point at –45 metres in the south-east part of the DEM. The mean elevation in the model is 24 metres. The model area is covered by 73% land and 27% sea. The flat landscape is also shown in the statistics of the slope, where the mean slope is 2.52 degrees. 87.0% of the cells have a slope lower than 5 degrees and 11.7% have a slope between 5 and 10 degrees. As expected, almost all of the cells with slope steeper than 10 degrees (2.5%) are situated along the earlier mentioned narrow valleys or lake shores.

In order to use this DEM in other types of models, like hydrological, terrestrial and dose models in the Laxemar-Simpevarp, the following data files were delivered to SKB data base.

Simp_DEM_5 ESRI Grid format, land surface, lake bottoms, and sea bottom

Simp_DEM_6 ESRI Grid format, land surface, lake surface, and sea bottom

Simp_points_5 ESRI Shape format, points for Simp_DEM_5

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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
20	12	1.000 * x + 0.007	–0.0006944	0.3509	0.6288	–0.000368	0.493	3728887

Validation of model

Lag size	Number of Lags	Regression function	Mean	RMS	Average SE	Mean stand	RMS stand	Samples
20	12	0.999 * x + 0.021	–0.0006407	0.5811	0.8588	–0.0005693	0.5512	960213

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)]
3728887	10.883*Spherical(237.07,207.95,267.7)+0*Nugget	0 (100%)	0 (0%)	5/2	4

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