Final Report for A GIS Project

The New Slussen in Västmanland

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1. Introduction

1.1. Problem Description

Climate change is a big threat for the whole world and for each country in particular. In the IPCC Climate Change report 2007 several scenarios and probable consequences were developed. Each country tries to look at the most vulnerable areas to climate change and determine how much people, environment, culture and infrastructure are likely to be affected. The biggest threat caused by the climate change for the countries, which lie next to the sea is the rise of the sea level and for Sweden it is number one problem, since the capital Stockholm lies on the Baltic Sea, Lake Mälaren – biggest lake in Sweden and in between plenty of natural and artificial water arteries. The rise of the sea level could lead to flooding of the big part of the shoreline, which means flooding of natural and cultural heritage, as well as plenty of important infrastructure facilities (buildings, roads, railways).

Another problem for Stockholm, which actually could worsen the affect of the flood due to the sea level rise, is Slussen area. Slussen was built as a lock between the Baltic Sea and Lake Mälaran in 1935. It is a hub of public transport and it also connects different parts of the city through road network. The infrastructure has aged and wore, therefore now some parts are being in a very poor condition. In addition the lock will not be able to keep the water pressure due to the sea level rise and possible flood events; as a result the water level in the lake Mälaran can get much higher point.

Recently the discussions and analyses of this problem have taken place. The conclusion was made that Slussen requires rebuilding and it was decided that the lock will be able to control the amount of water, which comes from the Baltic to Mälaren better and therefore the flood impact will not as tremendous as in case of old Slussen.

If no modifications in Slussen area is made (current Slussen) the flood levels were forecasted as follows: 157 cm for flood expected in 30-year period and 196 cm for flood expected in 100-year period. If Slussen area is rebuilt (new Slussen) 134 cm water level rise is expected due to flood event in 30-year period and 138 cm - in 100-year period (SMHI).

1.2. Goals

There are two main goals of this project. The first one is to determine the impact of flood events of the lake Mälaren due to extreme weather conditions and climate change with regard to current Slussen and new Slussen and the second one is to find appropriate areas for relocation of roads, railways and buildings, that will be flooded. The analyses was carried out using ArcGIS software, at first digital elevation model (DEM) was developed for our area of investigation, than relevant information data base was generated and then based on the result, the multi-criteria model (MCE) was developed, which was necessary for deciding available areas for relocation of roads, railways and buildings, that will be under water in case of flood event in 100-year period for current Slussen. This scenario was chosen for relocation analyses, firstly because life period of infrastructure facilities is usually longer than 30 years, so 100-year flood level consideration is more appropriate and secondly, this scenario is the most extreme situation with the highest flood level among the four cases. The analyses was carried out considering the impact of the flood event on people, properties, buildings, railways, roads, culture, nature and agriculture. The relocation analyses was carried out based on elevation level, existing land use, proximity to existing roads and railways, distance to buildings.

2. Study Area

The area assigned for analyses is Västmanland County, which has a stretch of shoreline by the lake Mälaren. It borders with Södermanland, Örebro, Gävleborg, Dalarna and Uppsala. It consists of 7 municipalities with the total area of 6 302 km2. The population is 252 819 citizens with density of 40 people per Km^2.

The data was downloaded from Länsstyrelseran and Ländmeterät websites. DEM was received from SWECO, with resolution of 2x2 meters, which provided reliable quality for evaluation of the flood events described above.

3. Methodology

There are two objectives for the research of this project. One is to find all of the possible flooding areas in region of Mälaren and to list all of the features spatially which will be flooded, such as buildings, roads, tourist attractions, etc. The second objective is to give out optional areas for these features by re-location analysis. Methodology for data preparation and two objectives will be illustrated in this part.

3.1. DEM

DEMs within the area of *Lake Mälaren* come from The *New National Elevation Model (NNH)* with 2m grid spatial resolution and 0.06 – 0.24m accuracy. According to the one .kml file displayed in Google Earth, specific DEMs covers the region of Västmanland will be selected. Based on this, all of the selected DEMs can be merged together by *Mosaic to New Raster Tool* in ArcGIS.

3.2. Shapefiles Data

Procedures for getting all of the features within the study area are described in Figure 1. Firstly, all of the features are in *Projected Coordinate System* of *SWEREFF99_Transverse_Mercator*. At the same time, boundary of DEM in format of shapefiles is created. By using *Clip* function with model of DEM boundary in ArcGIS, all of the features within the study area are created.

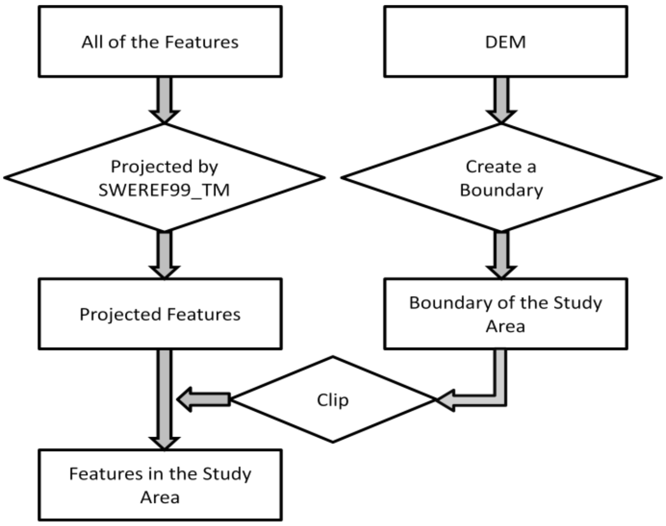


Figure 1. Procedures to Get Shapefiles Data

3.3. Flooding Area Definition

According to the flooding level (Table 1) of *Lake Mälaren* in different years provided by Sweco, four flooding levels will be created.

Table 1. Flooding Level in Different Years

Years	Current Slussen	New Slussen
In 30 Years	157cm	134cm
In 100 Years	196cm	138cm

To create the flooding layer, absolute water level of *2011 Year Current Slussen* is give with figure of 80cm. But because the accuracy of DEM is 0.06 – 0.24m, which is not qualified to do raster calculation to get correct areas which is higher than 80cm, alternative method is proposed. Current lake boundary polygon feature is taken into use to replace the figure of 80cm.

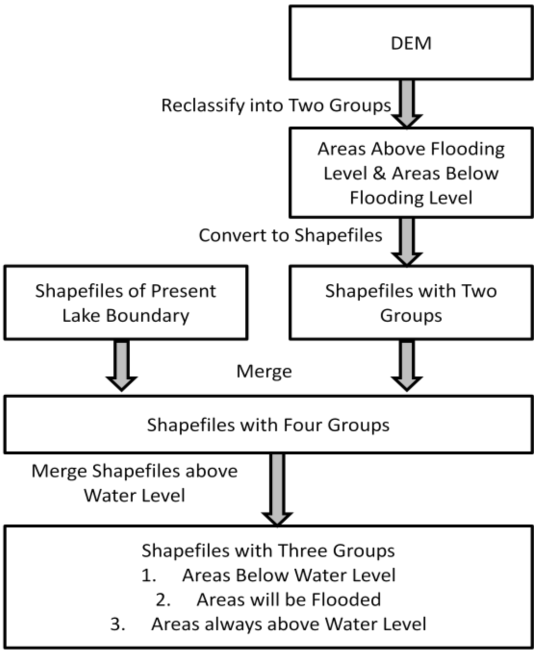


Figure 2. Procedures to Get Flooding Area

Producers to get the flooding areas are shown in Figure 2. Firstly, DEM is reclassified into two groups, one is areas above flooding level and the other is below flooding level. Then this raster data will be converted into shapefiles to merge the present lake boundary layer. Till now four groups will be created in one layer. Specifically, one group within this layer is meaningless, because polygons of this data group represent that they are above water leveling while at the same time, they are below water level. According to map algebra algorithm, polygons in this group will replaced into the group which are above water level, for the reason that all of these polygons are within the areas above the water level.

3.4. Relocation

For the work of relocation features will be flooded, only 196cm flooding level is taken into consideration, because this water level is the highest among the four, which is the most beneficial for a long period of time. Important features such as roads, highways, railways and buildings of historical attractions are going to relocate if they may be flooded, and all of the rest layers will be selected to be constraint maps and factor maps. After discussing, four constraint layers are created with the name of *Flooding Level of 196 cm*, *Water Line*, *Conservation Program* and

Historic Monument Program, respectively. And at the same time, four factor layers are created with the name of *Slope of DEM*, *Aspect of DEM*, *Agriculture* and *Land Use*, respectively. The original layer of *Road* is also taken into consider to calculate buffer proximity for relocating buildings. Then we start data preparation as all vector data were converted to raster data in order to use ArcGIS tools of *Reclassify* and *Raster Calculator* later.

The basic idea of flooded features relocations (Figure 3) comes from the theory of multicriteria evaluation (MCE). Firstly, constrain maps are reclassified with two values of 0 and 1, where 0 represents non-suitable areas while 1 represents suitable areas. At the same time, Potential areas with different suitable weights are created based on factor maps with different weights (Formula 1). Then suitable areas can be defined by considering previous constrain maps. Lastly, optional locations can be fixed for the flooding features.

Different values are given for different features (Table 2). Typically, slope of DEM are classified into four classes for locating suitable roads and buildings. Aspect of DEM is also taken into consideration, since the sun shine to be absorbed is quite different with various directions of building location. Similarly, different weights are also given for layers of agriculture and land use.

$$Potential\,Areas = \sum_1^i factorMap(i) * weight(i) \qquad \text{(Formula 1)}$$

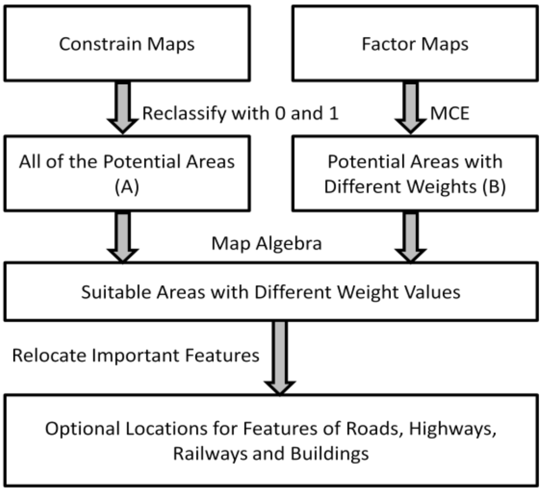


Figure 3. Procedures for Flooded Features Relocation

Table 2. Different Feature Weights

NO.	Features	Weights
1	196cm Flooding Level	within 200 meters buffer away from flooded areas cells are assigned weight 0, and the others are given weight 1
2	Water Line	within 200 meters buffer away from water line cells is classified to weight 0, and No data is of weight 1
3	Conservation Program	within conservation program areas cells are be assigned weight 0 and No-data is assigned weight 1
4	Historic Monument Program	within historic monument program areas cells is assigned weight 0 and No-data assigned weight 1

5	Slope of DEM	slope <= 20 degrees is given weight 1; slope <= 40 degrees & slope > 20 degrees is given weight 0.6; slope <= 60 degrees & slope > 40 degrees is given weight 0.2; slope > 60 degrees is given weight 0
6	Aspect of DEM	(aspect >= 70 & aspect <= 110) or (aspect >= 250 & aspect <= 290) is of weight 1; (aspect >= 50 & aspect < 70) or (aspect >= 230 & aspect < 250) or (aspect >= 110 & aspect < 130) or (aspect > 290 & aspect < 310)is of value 0.8; (aspect >= 0 & aspect < 50) or (aspect >= 130 & aspect < 230) or (aspect >= 310 & aspect < 360)is of value 0.6;
7	Agriculture	within agriculture areas we assigned value 1, No-data we assigned value 0.5
8	Land Use	within urban areas, camping and creational areas, Coniferous forest on lichen-covered soil and so on we assigned value 0.5. Within Low density built-up areas, Gravel and sand pits, field, pasture and so on we gave value 1 which are most suitable for relocation and the others as mixed forest on marshland, harbor areas or airfields which are not suitable for relocation are given value 0

All of the constraint maps and factor maps are projected to the same spatial reference with the same extent and cell-size of DEM. Then all maps are overplayed by using raster calculator. In the final result, cells are with value of 0 means that these areas cannot be used for relocation. Values with different values but 0 indicates areas where are suitable for relocations.

In order to find suitable areas for new roads, highways and railroads, firstly the longest flooded roads, highway and railroads are fixed by using *Geometry Calculator* by ArcGIS for attribute table. Then the longest road, highway and railroad are highlighted by selecting the attribution tables of the final layer, which enables to find suitable areas for relocation. Moreover, when to relocate new buildings, proximity buffer for roads with ranges of 100, 150, 200 and 250 meters are also considered.

3.5. Visualization

Result visualization is another important part for our project. We consider six important sample layers with flood level 196 cm. These six layers are building, road, railroad, highway, night population and day population. And for relocation visualization, we consider the most affected building with maximum number of population. As it shows in Figure 4, firstly we used GeoServer which allows share geospatial data and is very popular open source server. Then we used Styler which enables us to edit our layer styles. And, lastly we overlay our layers on Google map to visualize our layers on map and recognize the affected area and suitable area for relocation.

Figure 4. Structures for the Visualization

4. Results

4.1. DEM

As it shows in Figure 5, 191 DEMs (grids in white color) are selected and merged together with the total size of 1.78GB.

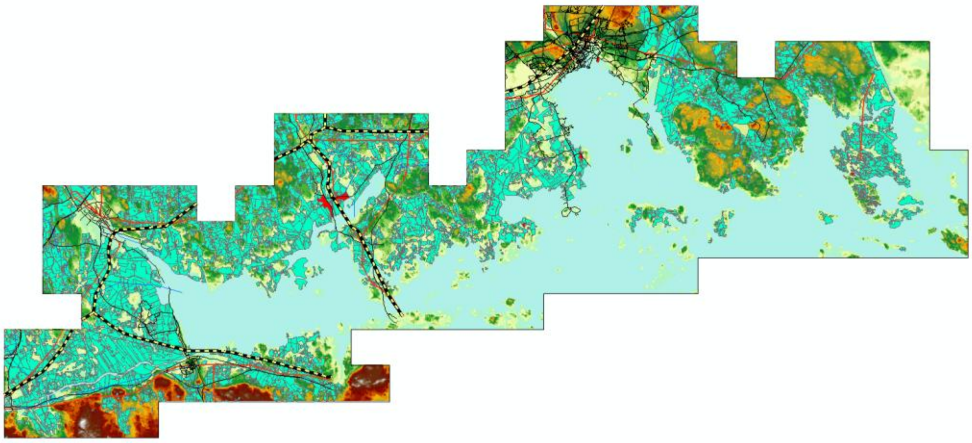
Figure 5. Region Covered by DEMs

4.2. Shapefiles Data

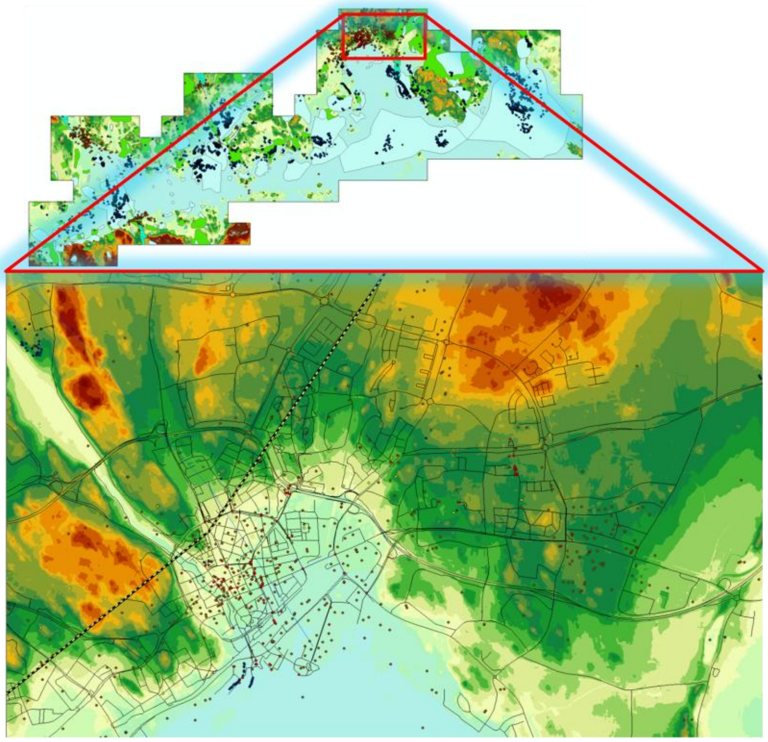
All of the necessary clipped features which may be analyzed are listed in the Table 3. And the performance of these features is presented in Figure 6 below.

Table 3. Clipped Features in Different Data Format

Types	Features
Point	places, points, pollutions damage, contaminated soil, security trad
Polyline	rails, roads, highways, shore protection, water lines,
Polygon	buildings, population, habitat mapped water, nation kind, nation nat, nation fun, landuse, boundary, historic monuments program, historic buildings, conservation programs, habitat, ancient house area, agriculture, water areas, state forest objects, nature seserve and conservation area



a. Clipped Features within the Study Area



b. DEM within the Study Area

Figure 6. Features to be Analyzed

4.3. Flooding Area

According to the producers, four layers in three different colors are created. For instance in 100 year of current Slussen (Figure 7), blue color with -1 represents the present water level; yellow color with 0 describes the flooding areas; while green color with 1 defines the areas where are still above water level.

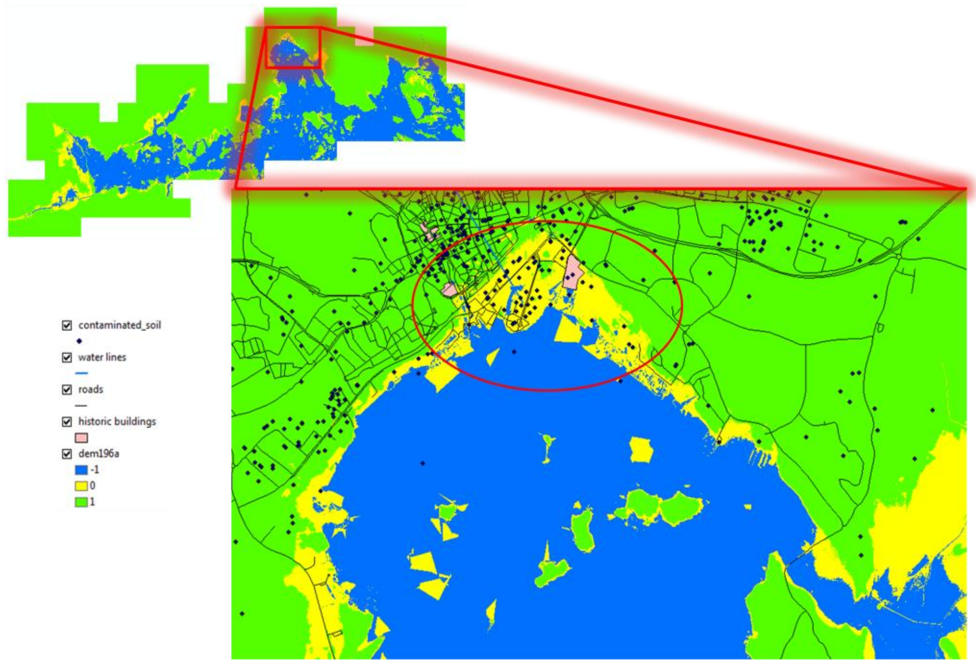


Figure 7. Flooding Area in the Yellow Color

Accordingly, all of the features will be flooded in different years and situations are defined for the convenience of the following spatial analysis (Figure 8).

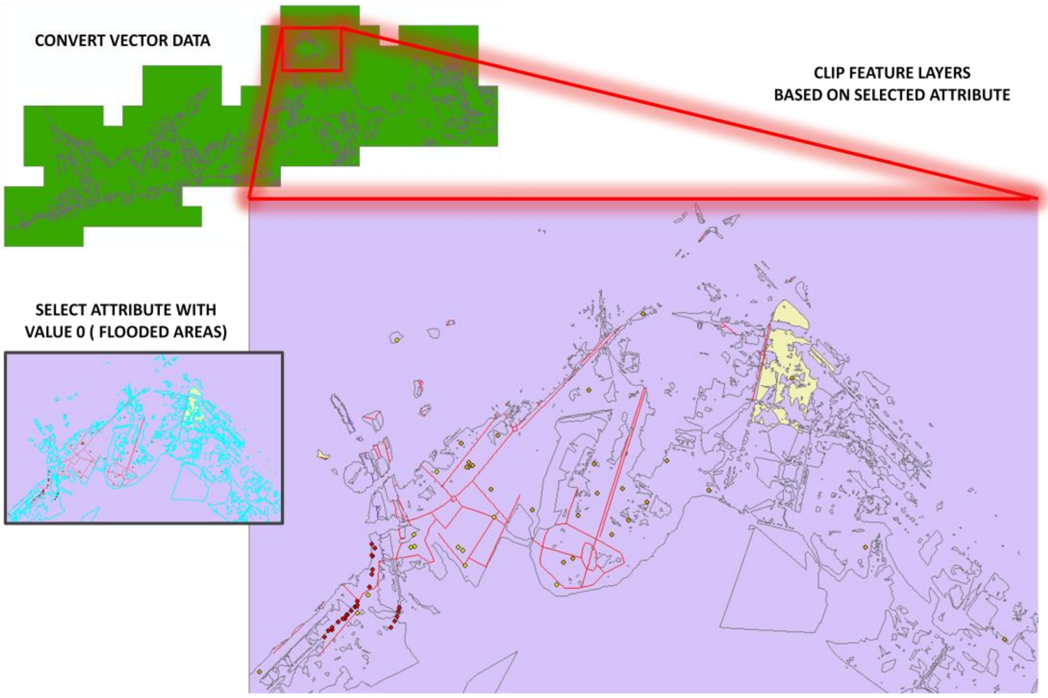


Figure 8. Features will be Flooded

Also, all of the flooded features in four different water levels are listed in *Appendix. Table 1-4*.

4.4. Relocation

After overlaying constraint maps and factor maps we achieved the result with red, white and blue color representing not, less and most suitable areas respectively (Figure 9).

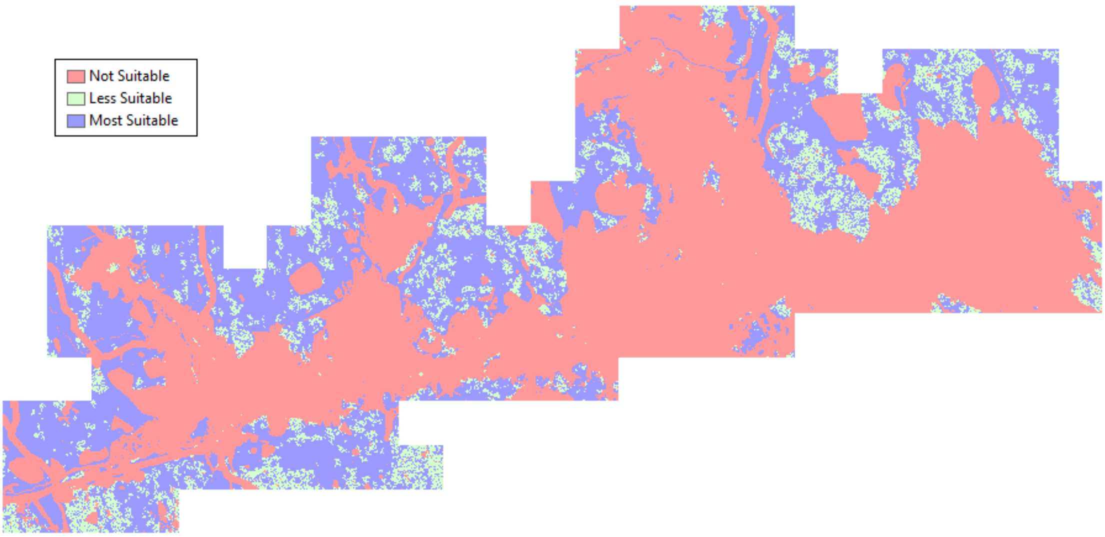


Figure 9. Overlaying Constraint and Factor Maps

As it can be seen from the figure (*Figure 1-Appendix*), blue area indicates most suitable area in order to rebuild the flooded road. The red line represents for original road, highlighted line represents for flooded road and pink line indicates for optional new road. Flooded road with the longest length is 1,495 meters and new road is 1,892 meters.

The figure (*Figure 2-Appendix*) shows that the red line represents for original highway, amethyst line represents for flooded highway and Tuscan red line indicates for optional new highway (flooded highway: 1,542 meters and new highway: 3,466 meters).

In this figure (*Figure 3-Appendix*) the highlighted line represents for flooded railroad and red line represents for new railroad (flooded railroad: 1,528 meters and new railroad: 2,298 meters).

The figure (*Figure 4-Appendix*) shows that the red polygon on the right corner represents new buildings. Flooded building is 1046 square meters and number of people affected is 296, night-time with 104 and day-time 192, respectively.

4.5. Visualization

Four flooded features, influenced population during day time and night time, Road Buffers, and new buildings are represented in details respectively in *Figure 5-11-Appendix*.

5. Analysis and Discussion

The project report covers methodology part, which describes spatial analyses methods used for developing DEM, MCE and database; a small section is devoted to methods, which were used for visualization of the results; results part, where final results of flooded areas are presented: number of people affected, buildings, summation of the lengths of roads and railways, number of world heritages, ancient monuments, areas of national interest and agriculture affected. Appropriate areas for relocation of important roads (motorways and national roads) and railways are presented as well as available areas for relocation of the biggest residential areas, which will be flooded.

From the summary tables of affected area, we can say that, the affect may differ depend on the different flood level of four different scenario 134 cm, 138 cm, 157 cm and 196 cm. For the road in 134 cm flood level total 2.29 km will be flooded but for 138 cm, 157 cm and 196 cm of flood level total 2.515 km, 3.736 km and 8.522 km will be affected, respectively. The longest affected roads are for four different flood levels around 800m, 900m, 1 km and 1.6 km, respectively.

Another important issue is population. We have two kinds of population, day time population and night time population. Total 4410 persons will be affected in night time and 6549 persons for the day time for the flood level 134. But, for the flood level of 196 cm the number of affected people are 5190 person for night and 9570 person for day period. Here we can see, the number increases based on the flood level. And this is very obvious. For all other results we also have got similar result. Depend on the flood level the numbers increased.

6. Reference

http://geoserver.org/display/GEOS/Welcome
http://opengeo.org/

7. Appendix

Table 1. Summary of Features in 134 cm Flooded Areas

Features Name	Values	Unit
Console Land	8	no
Polluted Land	8	no
Security	45	no
Habitat Water	19.5	Km
Highway	1.63	Km
Rail road	1.71	Km
Road	2.29	Km
Shore protection	91.52	Km
Water line	1.79	Km
Agriculture	16.998	sq Km
conservation program	18.538	sq Km
Habitat	0.022	sq Km
Historic Building	0.03	sq Km
Historic Monuments Program	9.043	sq Km
Nationwide fun	7.163	sq Km
Nation Interest (kind)	24.59	sq Km
National Nature (nat)	18.185	sq Km
Natural monument	0.009	sq Km
Natural reserve conservation area	13.024	sq Km
Protection of water rates	0.136	sq Km
Building	253	no
Night Population	4410	no
Day Population	6549	Total

Table 2. Summary of Features in 138 cm Flooded Areas

Features Name	Value	Unit
Polluted Land	9	no
Habitat water	11.741	Km
Highway	1.654	Km
Rail	1.8199	Km
Road	2.515	Km
conservation program	19.307	sq Km
Habitat	0.025	sq Km
Historic build	0.034	sq Km
Historic monument program	9.453	sq Km
National fun	7.444	sq Km
National Interest (Kind)	25.491	sq Km
Natural monument	0.01	sq Km
Natural reserve conservation area	13.518	sq Km

Building	294	no
Night Population	4481	no
Day Population	8023	no

Table 3. Summary of Features in 157 cm Flooded Areas

Features Name	Value	Unit
Polluted Land	12	no
Habitat water	13.18	km
Highway	1.74	km
Rail road	2.11	km
Road	3.736	km
Conservation program	21.7415	sq/km
Habitat	0.0289	sq km
Historic building	0.0439	sq km
Historic Monument program	10.77227	sq km
National fun	8.34954	sq km
National Interest (Kind)	28.154889	sq km
Natural monument	0.013	sq km
Natural reserve conservation area	14.97236	sq km
Building	468	no
Night Population	4664	Total
Day Population	8084	Total

Table 4. Summary of Features in 196 cm Flooded Areas

Features Name	Value	Unit
points_196_Clip	4	no
Polluted Land	27	no
Habitat water	14.28075	km
Highway	2.258	km
Rails road	2.987	km
Road	8.522	km
Conservation program	26.72456	sq km
Habitat	0.035847	sq km
Historic building	0.05997	sq km
Historic Monument program	13.44023	sq km
National Interest (Kind)	33.323199	sq km
National fun	10.2695	sq km
Natural monument	0.02028	sq km
Natural reserve conservation area	17.76565	sq km
Building	1008	no
Night Population	5190	Total
Day Population	9570	Total

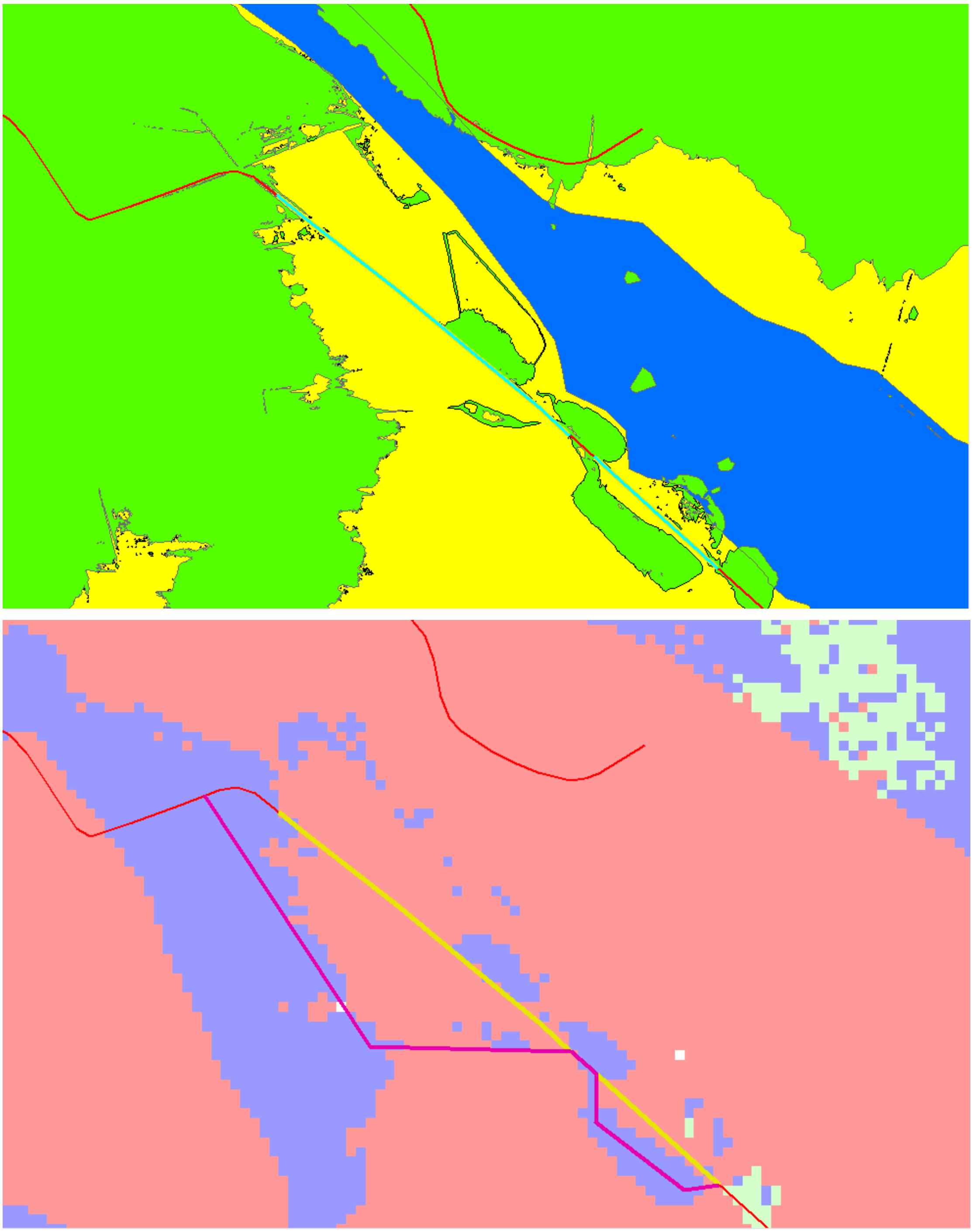


Figure 1. Suitable Area for Rebuild Flooded Roads

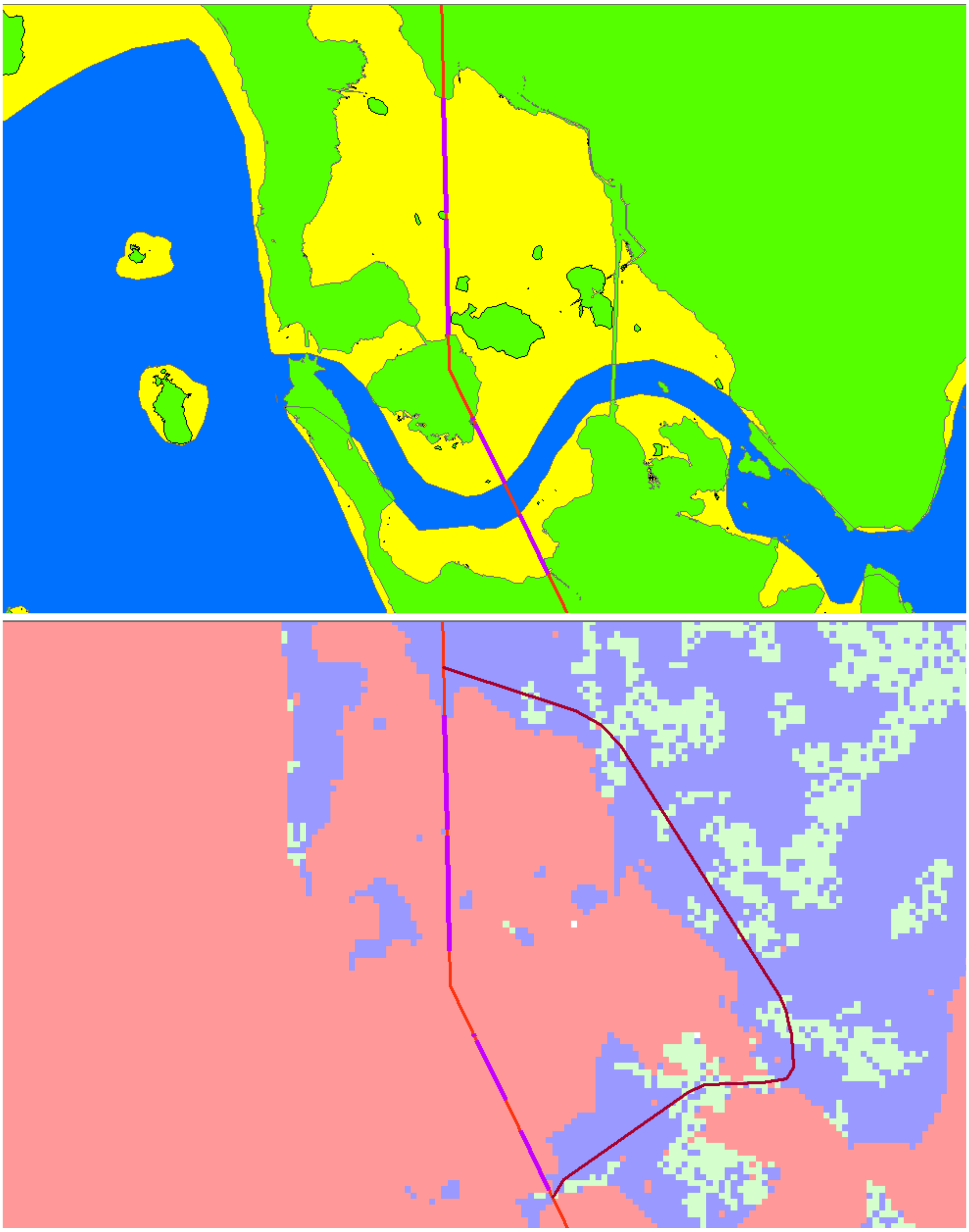


Figure 2. Suitable Area for Rebuild Flooded Highway

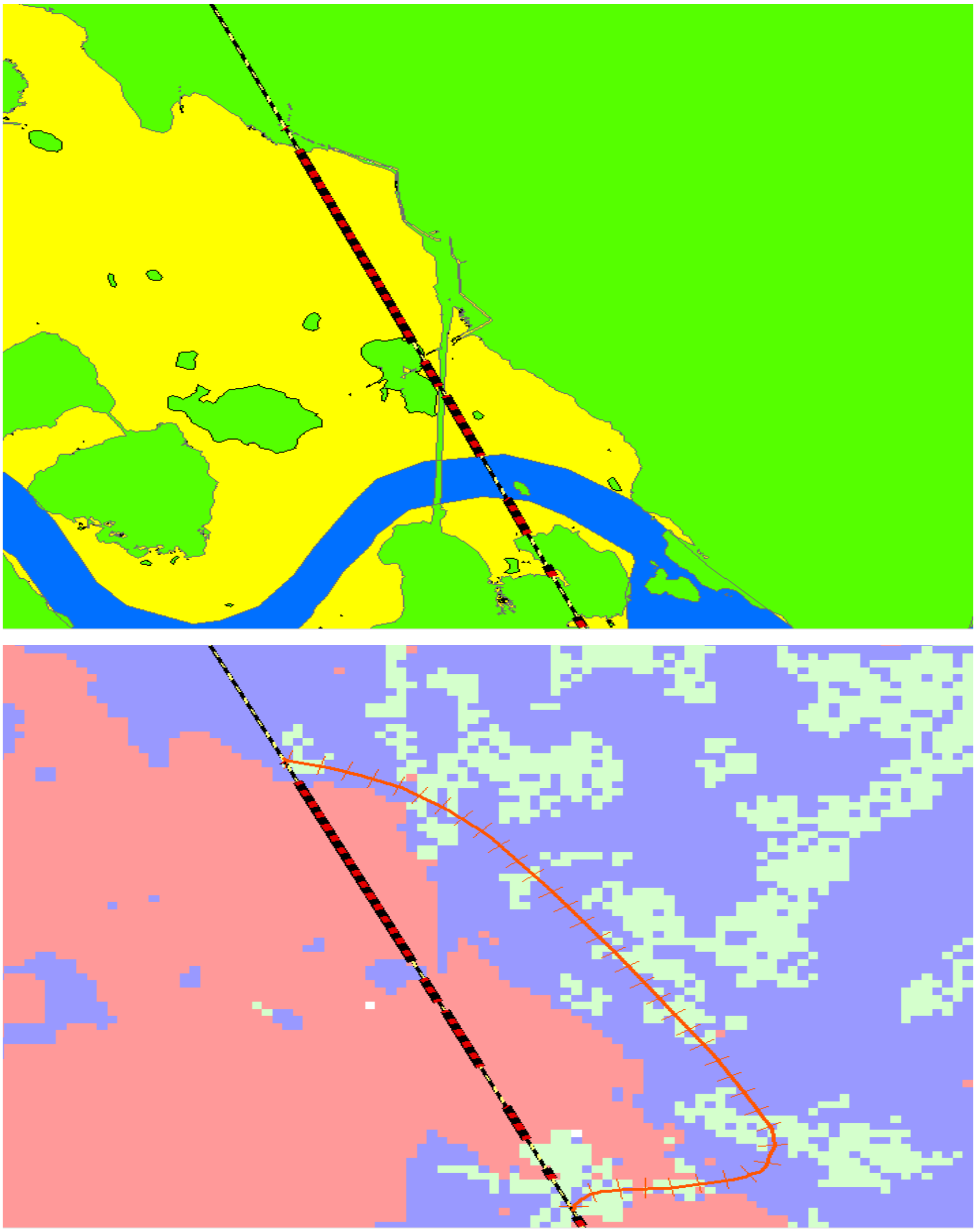


Figure 3. Suitable Area for Rebuild Flooded Railroads

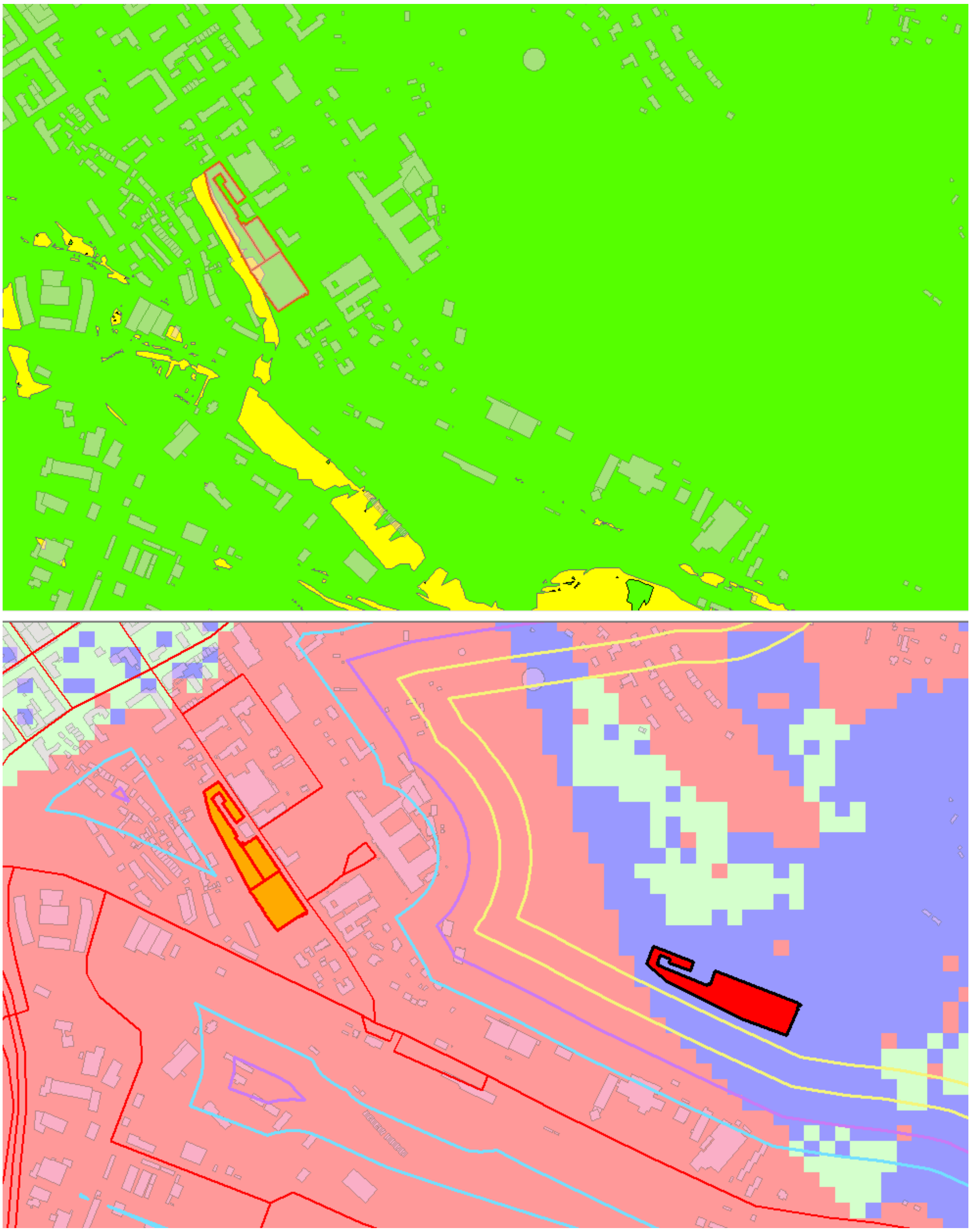


Figure 4. Suitable Area for Rebuild Flooded Buildings

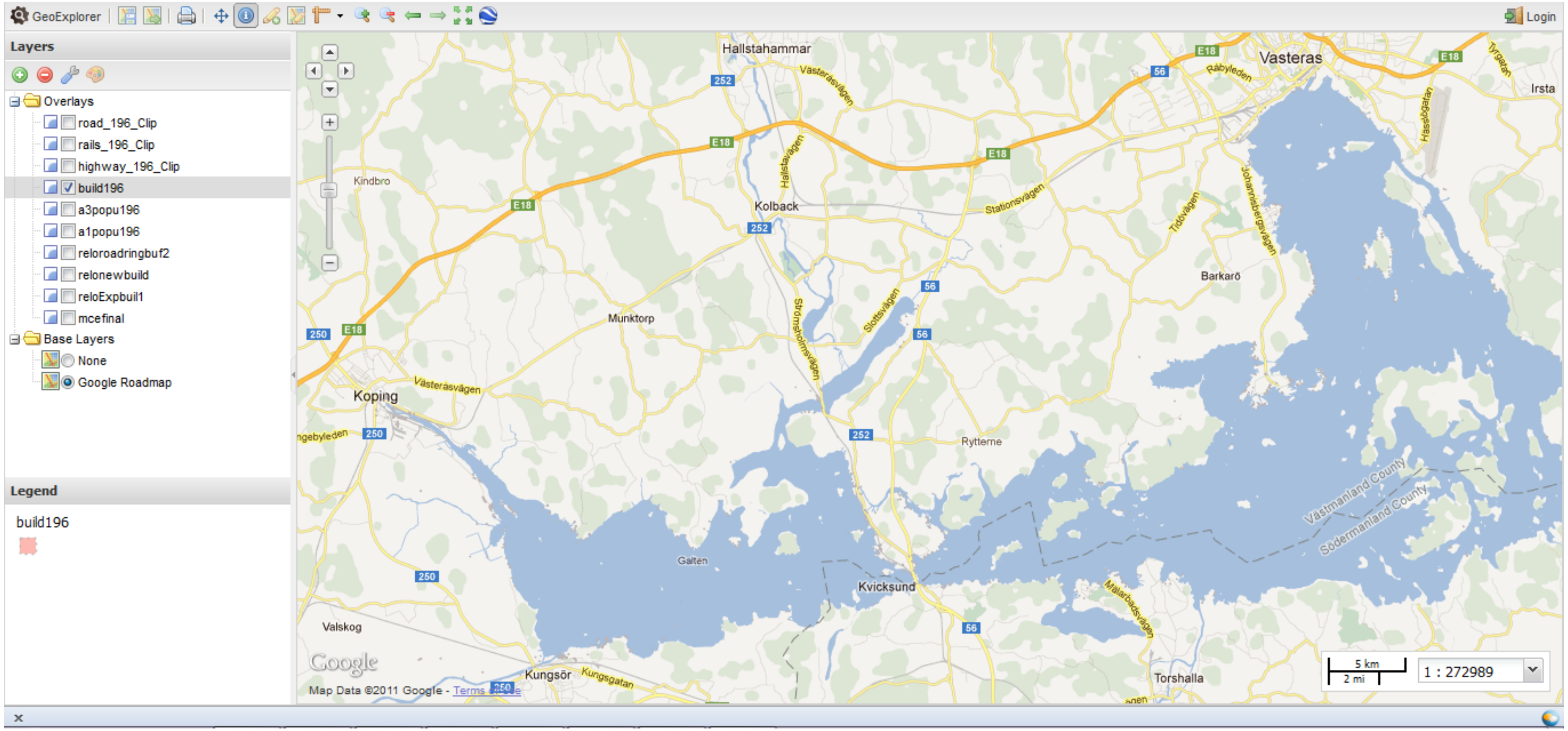


Figure 5. Flooded Buildings In 196 cm Water Level

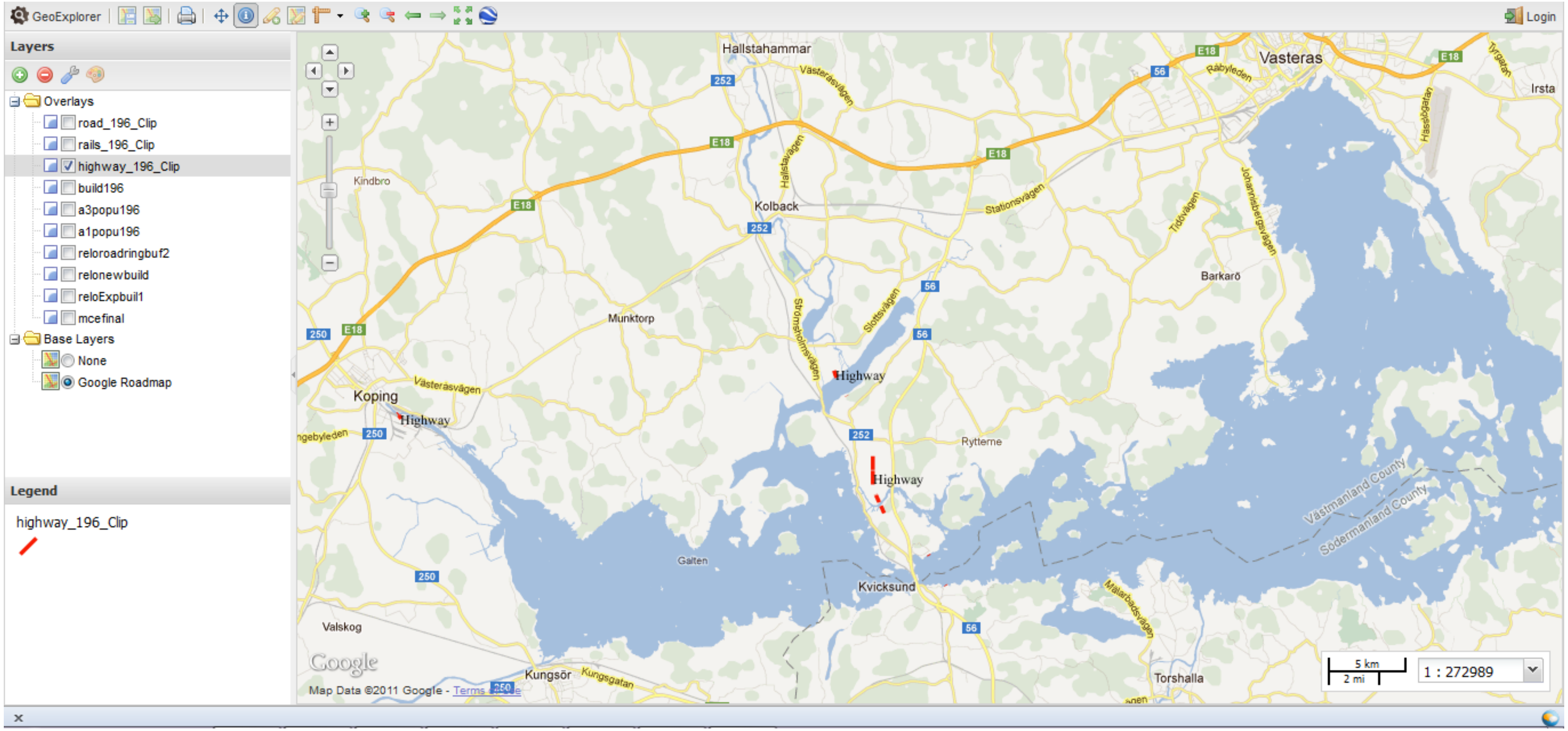


Figure 6. Flooded Highway In 196 cm Water Level

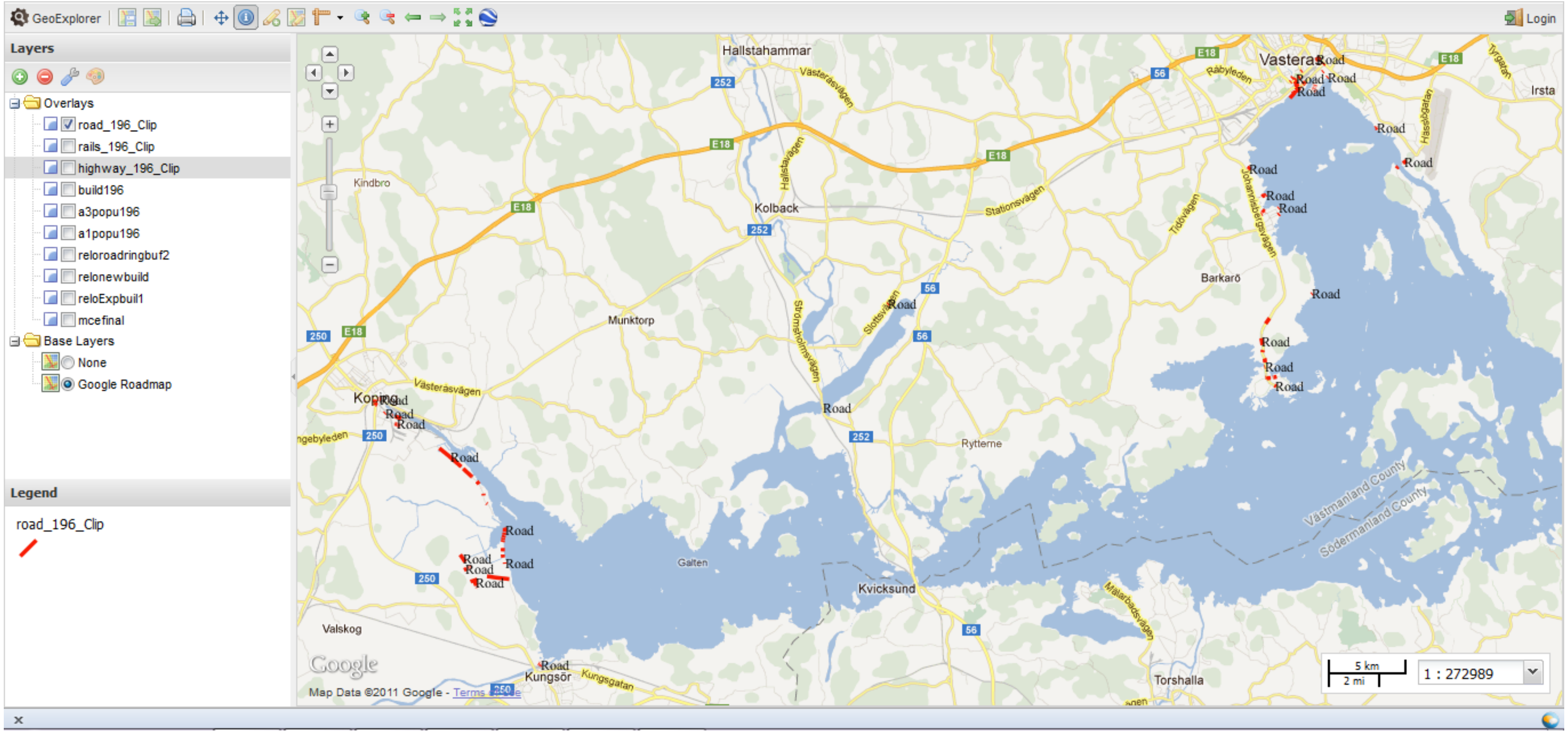


Figure 7. Flooded Roads In 196 cm Water Level

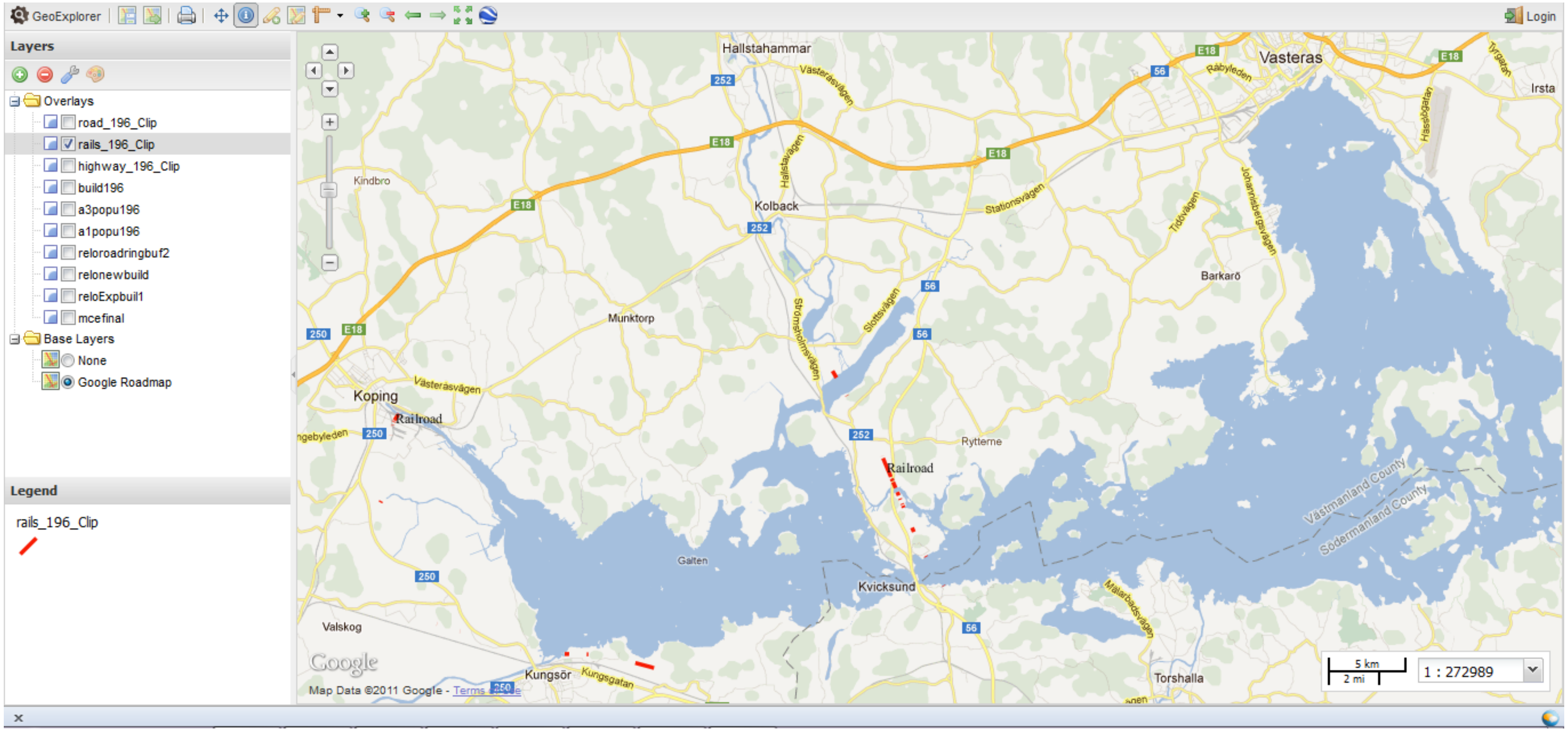


Figure 8. Flooded Railway In 196 cm Water Level

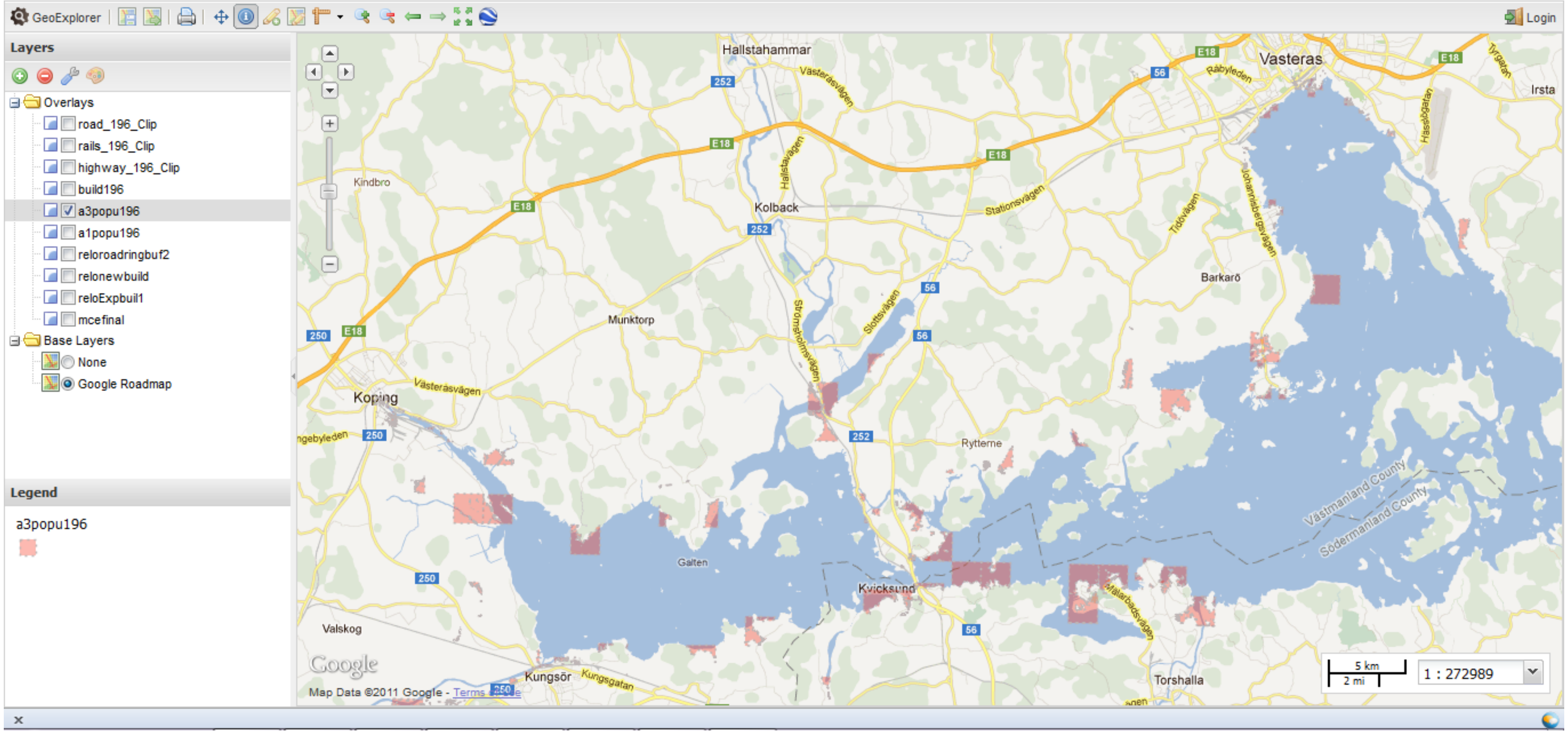


Figure 9. Day Time Influenced Population In 196 cm Water Level

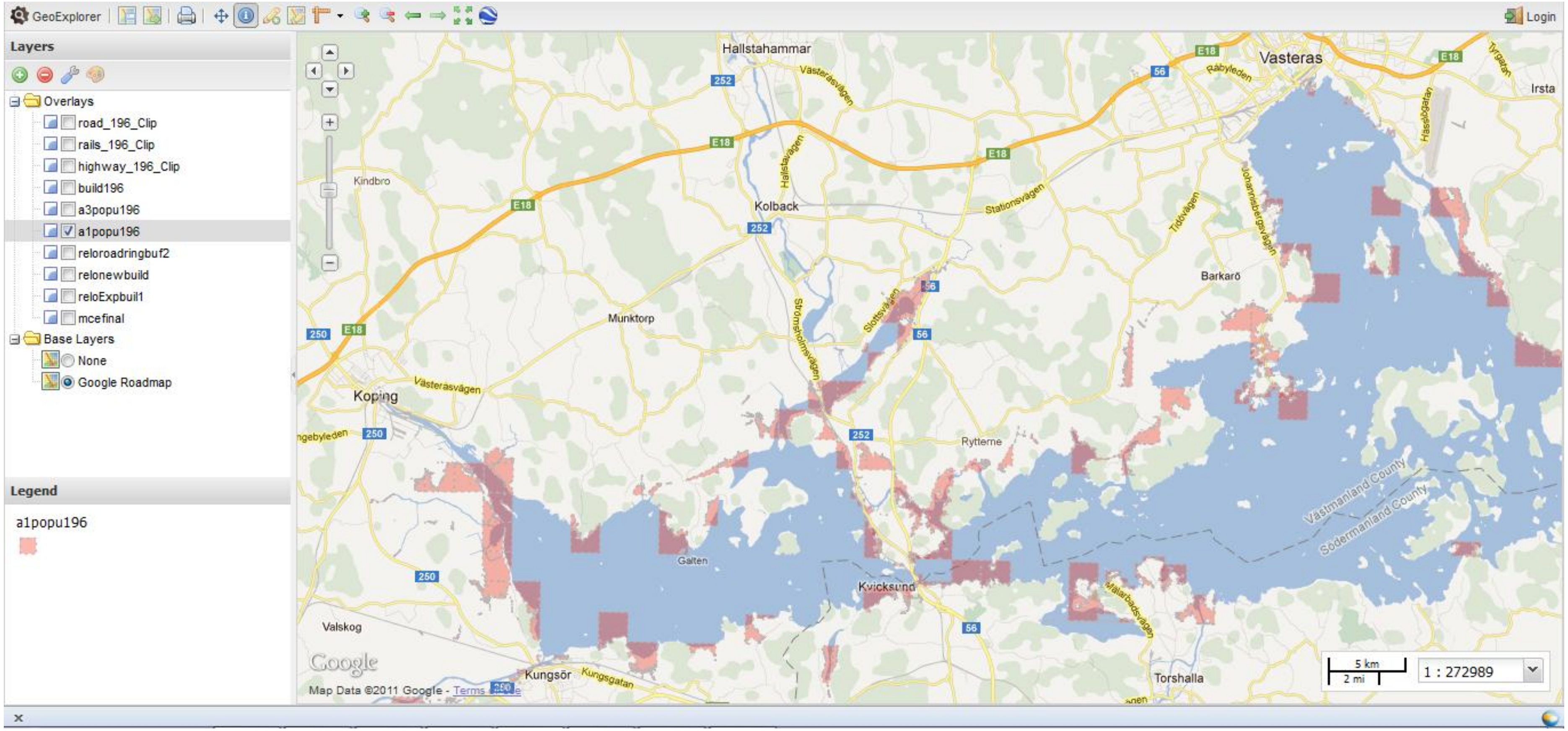


Figure 10. Night Time Influenced Population In 196 cm Water Level

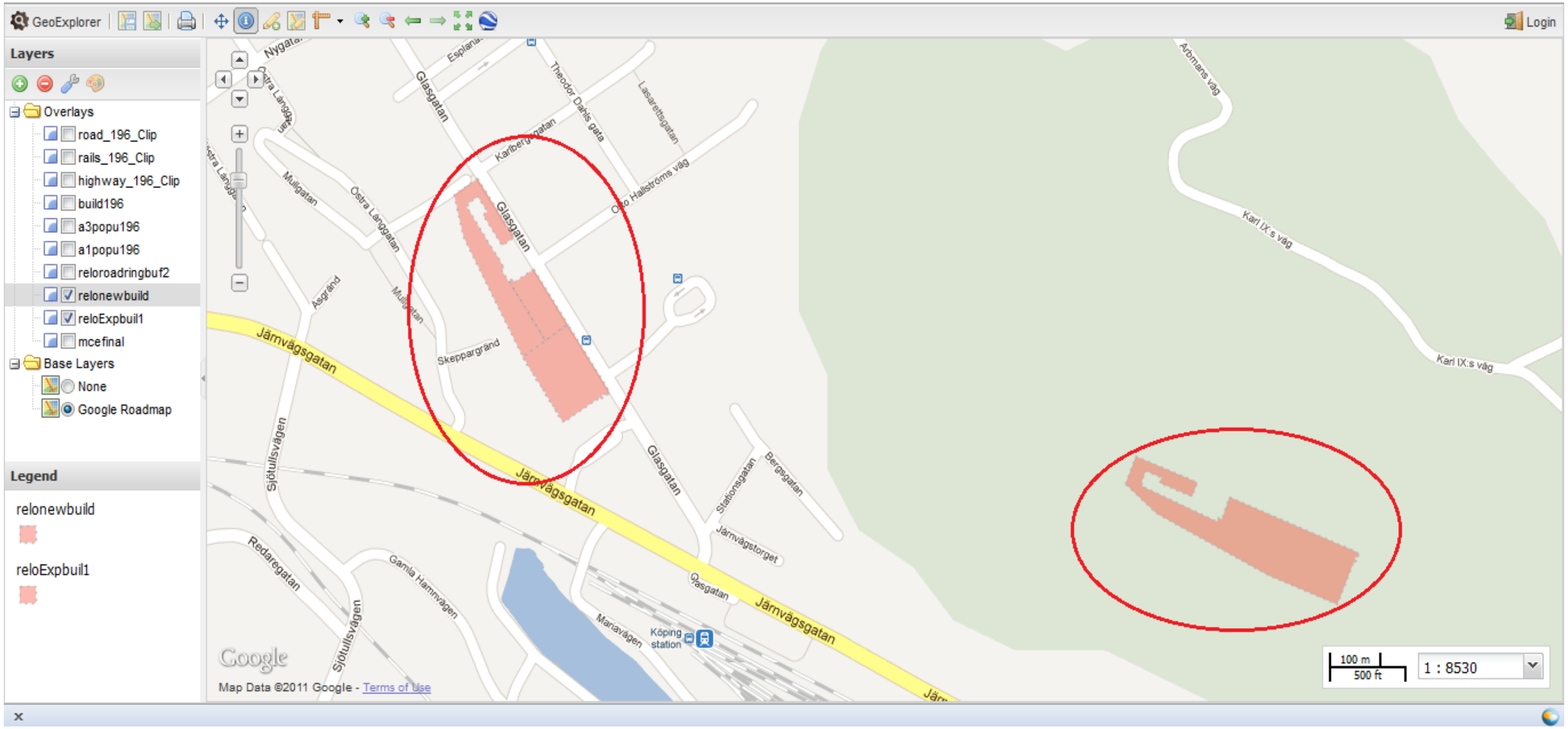


Figure 10. New Building to be Moved

Figure 10. Road Buffer