

SUSTAINABLE URBAN DRAIN- AGE SYSTEMS (SUDS) AREA DETECTION USING GIS

Guideline. Version 1.0

Dennis Patrick Kliever and
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Sustainable urban drainage systems (SUDS) area detection using GIS. Guideline. Version 1.0

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Preface

A generic Decision-Support Method (DSM) for Sustainable Urban Drainage Systems (SUDS) selection and where to locate these solutions has been developed. The method will help decision makers and city planners to make sound decisions based upon knowledge of where the water will accumulate and where to find the most optimal location for installing stormwater measures.

Klima 2050 - Risk reduction through climate adaptation of buildings and infrastructure is a Centre for Research-based Innovation (SFI) financed by the Research Council of Norway and the consortium partners. The SFI status enables long-term research in close collaboration with private and public sector, as well as other research partners aiming to strengthen Norway's innovation ability and competitiveness within climate adaptation. The composition of the consortium is vital in order to being able to reduce the societal risks associated with climate change.

The Centre will strengthen companies' innovation capacity through a focus on long-term research. It is also a clear objective to facilitate close cooperation between R&D-performing companies and prominent research groups. Emphasis will be placed on development of moisture-resilient buildings, storm water management, blue-green solutions, measures for prevention of water-triggered landslides, socio-economic incentives and decision-making processes. Both extreme weather and gradual changes in the climate will be addressed.

The host institution for SFI Klima 2050 is SINTEF, and the Centre is directed in cooperation with NTNU. The other research partners are BI Norwegian Business School, Norwegian Geotechnical Institute (NGI), and Norwegian Meteorological Institute (MET Norway).

The business partners represent important parts of Norwegian building industry; consultants, entrepreneurs and producers of construction materials: Skanska Norway, Multiconsult AS, Mesterhus/Unikus, Norgeshus AS, Leca AS, Isola AS, Skjæveland Gruppen AS and Powel AS. The Centre also includes important public builders and property developers: Statsbygg, Statens vegvesen, Jernbanedirektoratet and Avinor AS. Key actors are also Trondheim kommune, The Norwegian Water Resources and Energy Directorate (NVE) and Finance Norway.

Trondheim, August 2019

Berit Time
Centre Director
SINTEF Community

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List of Abbreviations

CRS	Coordination Reference System
DSM	Decision Support Method
dsm	Digital Surface Model
dtm	Digital Terrain Model
ETRS89	European Terrestrial Reference System 1989
GDAL	Geospatial Data Abstraction Library (http://www.gdal.org)
GIS	Geographic Information System
OSM	Open Street Map
OTF	On the fly coordinate transformation
SUDS	Sustainable Urban Drainage Systems
tmp	temporal
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WMS	Web Map Service

1 Introduction

A generic Decision-Support Method (DSM) for Sustainable Urban Drainage Systems (SUDS) selection and where to locate these solutions has been developed. The method will help decision makers and city planners to make sound decisions based upon knowledge of where the water will accumulate and where to find the most optimal location for installing stormwater measures. Giving reliable decision-support, knowledge about topological, geological and technical conditions is required (Woods Ballard, Wilson et al. 2015), and the objective of the DSM has been to obtain, organise and use this knowledge in a structured way.

This guideline gives in Chapter 2 an introduction to the DSM, with focus on the GIS analysis and the detection of potential SUDS areas. The remaining chapters presents in more detail the GIS analysis and the different steps needed; that is Chapter 3 presents the settings and nomenclature used to describe the GIS operations, Chapter 4 presents the data acquisition and data pre-processing steps, Chapter 5 presents the SUDS area detection steps, whereas Chapter 6 presents the pre-defined models that has been developed combining different steps from Chapter 5 into complete models.

As an example of application of the developed DSM, please refer to Muthanna et al. (2018). In this paper the Gløshaugen Campus in Trondheim, Norway, has been used as a case.

2 Decision-Support Method for SUDS implementation

2.1 6 stages in the Decision-Support Method

The developed Decision-Support Method (DSM) is structured in six stages as illustrated in Figure 1 as well as Table 1. Table 1 also shows the type of action each stage represents, i.e. GIS analysis, Field measurements, Design or Expert planning.

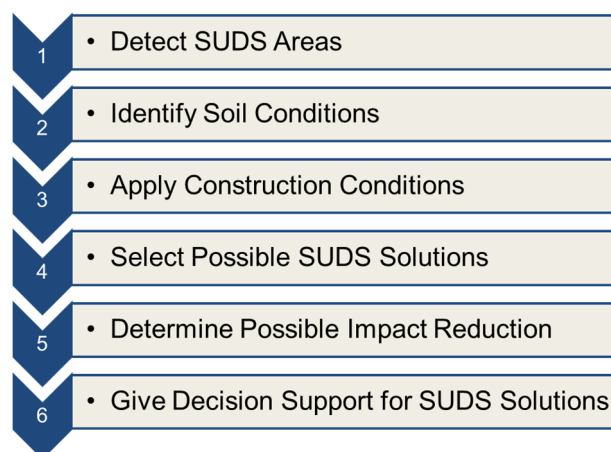


Figure 1: Stages of the Decision-Support Method (DSM) for a Sustainable Urban Drainage Systems (SUDS) planning process.

In stage 1 possible SUDS areas are detected by analysing the topological properties using a geographic information system (GIS), followed by a ranking of the areas as either potential or high-potential areas for SUDS implementation. After detecting potential and high-potential areas for SUDS implementation, the soil properties of these areas will be determined in Stage 2. Field measurements to determine the infiltration rate, the groundwater level and the soil characteristics may be necessary at this stage.

In Stage 3 it is recommended to assess the national and local guidelines to determine the technical and dimensioning requirements that apply for the area of interest. In addition, the performance for different SUDS measures needs to be assessed, and if necessary, modified to local climatic conditions.

Stage 4 combines the information gathered in the three first stages, *i.e.* *i)* possible SUDS areas from Stage 1, *ii)* infiltration capacity from Stage 2, and, *iii)* technical requirements and design criteria from Stage 3. This information will enable the expert planners to determine where on the site and which SUDS measures that are realizable for the area of interest. The information about where to and which SUDS to implement, is used in Stage 5 to simulate the impact on the storm water runoff for different scenarios. The result from the simulations are then used in Stage 6 to select the most efficient combination of SUDS measure for the area of interest. The final selection in Stage 6 may also depend on other factors, such as environmental, economic and social, but details about these factors are not considered here.

Table 1: Stages in the Decision-Support Method.

Stage	Action	Type of action
1	Detect possible SUDS areas (see Figure 2)	GIS analysis
2	Determine soil properties	Field measurements
3	Apply construction conditions	Design/ Dimensioning
4	Select possible SUDS solutions	Expert planning
5	Determine possible impact reduction	Expert planning
6	Give decision support for SUDS solutions	Expert planning

2.2 GIS analysis

The GIS analysis in Stage 1 determines the areas within the catchment that are available for SUDS implementation and evaluate these areas by their potential for SUDS implementation. The overall approach taken is given in Figure 2 and is split into three main steps: 1. Potential SUDS Area Detection which focus on surface and infrastructure analysis; 2. Main Flow Path Determination to show surface runoff paths within the area of interests; 3. High Potential SUDS Area Detection which select SUDS areas close to surface runoff. This stepwise approach is selected to provide an easy to follow and simple procedure to reproduce catchment analysis. As shown in Figure 2, the approach depends only on basic information, which for most regions have the advantage to be open source. Inputs are digital elevation model raster and vector data for land use and infrastructure. The three main steps of the approach are described in more detail in the following subsections.

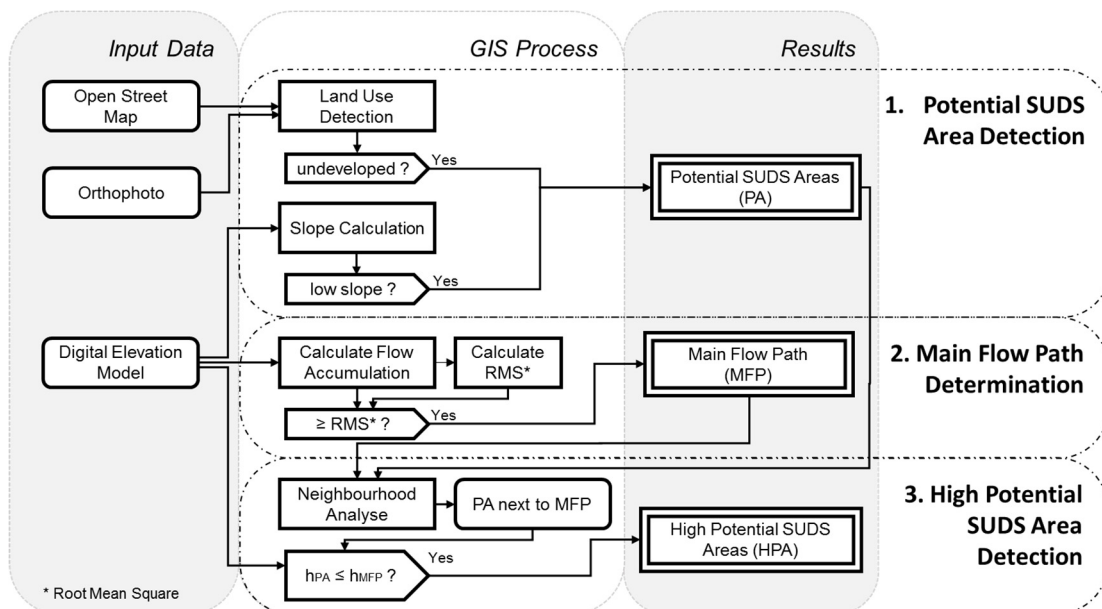


Figure 2: Main steps in the Decision Support Method - Stage 1 Detect Possible SUDS Area: 1. Potential SUDS Area Detection; 2. Main Flow Path Determination; 3. High Potential SUDS Area Detection.

2.2.1 Potential SUDS Area Detection

The first factor needed to identify possible locations for SUDS measure is the availability of undeveloped area. Undeveloped area in this case could be unused green areas, inactive courtyards or storage areas. Also, areas like parking place, where a reduction of the pervious area is planned, could be "undeveloped" in the broad sense of this method. The area must be available as vector data in a GIS and can be extracted from existing available urban vector e.g. from Open Street Map, or manually added using orthophotos or similar map services.

Next, based on a digital elevation model (DEM), the slope of the surface is calculated using elevation values from the raster data and the 9 parameters 2nd order polynomic method (Zevenberg & Thorne, 1987). The slope of the surface comprises the second main factor to determine potential SUDS areas and are divided into two categories, low surface slope areas and high surface slope areas. The categorisation is based on technical recommendations typical for infiltration measures, where a recommend maximum surface slope for surface infiltration measure like swales is 10 % (Woods Ballard, et al., 2015). The low slope areas will ensure lower investment costs for surface modification, higher natural storage capacities and longer infiltration times due to low flow velocities compared to the high slope areas.

Areas fulfilling these two factors are defined as Potential SUDS Areas and will have the potential for positive impacts on the urban water balance, due to the ability to hold and handle storm water.

2.2.2 Main Flow Path Determination

It is possible to create a general view of the surface runoff situation by using spatial flow tracing and resulting flow accumulation methods in GIS. The GIS calculation uses elevation data from the DEM to determine the flow direction of a flow line. To ensure uninterrupted flow lines, local surface depressions in the DEM are filled, using a sink filling algorithm (Wang & Liu, 2006). Flow accumulation shows for each cell in a DEM raster the number of cells which flow lines pass through that grid cell (López-Vicente, Pérez-Bielsa, López-Montero, Lambán, & Navas, 2014). This means that the number of flowlines from the entire map which have segment endpoints within that cell will be shown for each DEM raster cell. The flow direction is calculated using the Rho8 algorithm (Fairfield & Leymarie, 1991) and a single flow direction calculation to the steepest downslope neighbour. The Rho8 algorithm gives the advantage of fast calculation time and catches good the Norwegian topographical and metrological conditions, representing steep areas under high precipitation volume influence (López-Vicente, Pérez-Bielsa, López-Montero, Lambán, & Navas, 2014).

To separate the high flow concentrations from the flow accumulation results, a threshold for the main flow paths is calculated. The root mean square flow accumulation is calculated according to Equation 1, considering all flow accumulation values:

$$x_{RMS} = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + \dots + x_n^2)} \quad (1)$$

where x_n is the flow accumulation value in grid cell n and x_{RMS} is the root mean square used as flow accumulation threshold. Higher values are given larger weight by the RMS, due to the squaring of each value. This is necessary since there is many low values which are slightly higher than 1 (which is not of interest for the calculation) and only a few high values (of interests for the calculation). All cells with a higher flow

accumulation than the root mean square is defined as the Main Flow Paths. These paths represent a large connection of many flow paths, so in case of an overland flow, most of the runoff will follow these paths. This method gives a good overview of the runoff situation in a catchment to the accuracy necessary for the Decision-Support Method.

2.2.3 High Potential SUDS Area Detection

Potential SUDS Areas close to high surface runoff provide the opportunity to treat storm water effectively without the need of large drainage systems and/or intake infrastructure. Furthermore, if the elevation of the Potential SUDS Areas is equal or lower than the nearby runoff areas, it enables natural drainage and avoids costly modification of nearby terrain. Areas that fulfil these requirements are highly recommended for SUDS implementation and are therefore defined as High Potential SUDS Areas.

2.3 Software

The GIS analysis is performed by the open source program QGIS ® v. 2.18.13 with implementations from the open source program SAGA © GIS v. 2.3.2. The most used tools are the SAGA © GIS Modules "Slope, Aspect, Curvature" for terrain analysis and "Catchment Area (Flow Tracing)" for surface runoff detection. The output of the GIS analysis are several maps, that show urban planners *Potential* - and *High Potential SUDS Areas*, but also *Main Flow Paths* for surface runoff. Complete reference guidelines, including files of the developed tools to perform the described GIS analysis, can be downloaded from www.klima2050.no.

3 General Guideline Settings

This GIS method was tested and works with the geo-information system program QGIS 2.18.13 64bit version for Windows. You can download it from:

<https://www.qgis.org/en/site/forusers/download.html>

Follow the installation instructions from QGIS User Guide » Chapter 6 Getting Started » 6.1 Installation (Athanasios, Blazek et al. 2018)

The main objectives in this Guideline are using GIS tools which are included into the QGIS version 2.18.13. So, at the beginning of most of the working steps the used GIS tool is called, with its tool library, the tool name and the way to start the tool (see the example below).

[Tool Library – Tool Name]

(way » to » start)

[QGIS – Merge Raster]

(Menu bar » Raster » Miscellaneous » Merge)

Another distinctive feature in this guideline are repeating steps. These instructions are given for steps which must be performed more than once, but with mainly the same settings. Repeating steps are shown by lists with **small roman numbers** in the settings (see example below). Repeat the step as often as there are orders (number of small roman numbers) in the list.

- I. Input Layer:
 - i. **"Raster 1 – digital terrain model (dtm)"**
 - ii. **"Raster 2 – digital surface model (dsm)"**
- II. Target CRS: Project CRS
- III. Uncheck rest settings
- IV. Output file:
 - i. **"Raster 3 – converted dtm raster"**
 - ii. **"Raster 4 – converted dsm raster"**

In this example you have to repeat each step twice. First i.) with **"Raster 1" as Input Layer and "Raster 3" as Output file** and then ii.) with **"Raster 2" as Input Layer and "Raster 4" as Output file**.

4 Data Acquisition and Pre-processing

Step 1 Define Coordination Reference System (CRS)

- 1.1 Defining the Coordination Reference System for the GIS process at the beginning of the whole process, will prohibit transformation and editing errors. Selected Project CRS should be used for every data in the GIS process.

[QGIS – Project Properties | CRS]

(Menu Bar » Project » Project Properties » CRS)

- I. Open the Project Properties and enable 'on the fly' CRS transformation (OTF)

This allows you to load data with different CRS into your GIS project without layout conflicts. Displays data in the project CRS, but just transforms the coordinates temporary. The original data coordinates will not be changed. This option is activated for easier display.

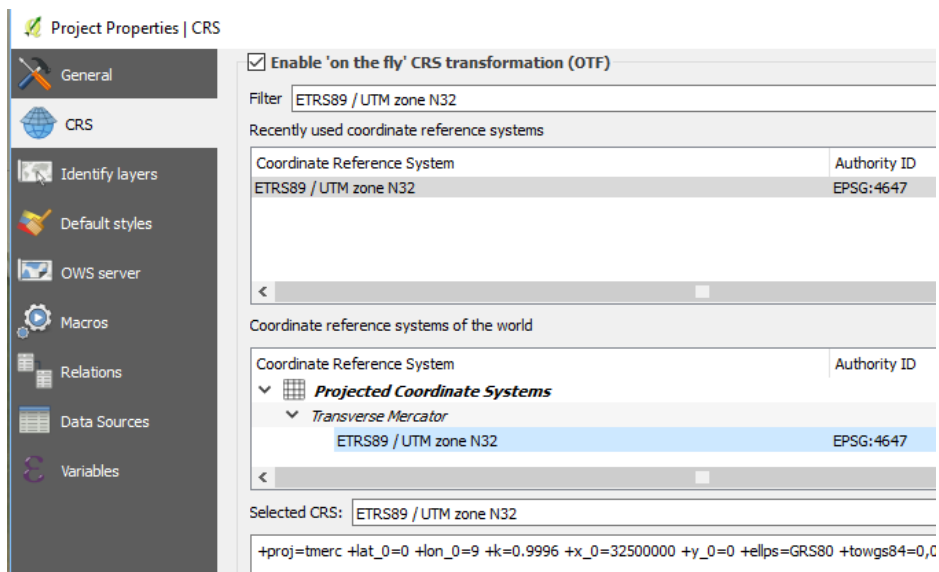


Figure 3: Example working sheet for CRS selection in [QGIS – Project Properties | CRS].

- II. Set the "Selected CRS" for the project. Search a CRS with the Filter and select the fitting one from the list (see Figure 3).

Recommendation: use the relevant **UTM zone** at your project side. i.e.: ETRS89 / UTM zone N32 for Trondheim, Norway. For Norway, you can see a common zonal classification shown in Figure 4.

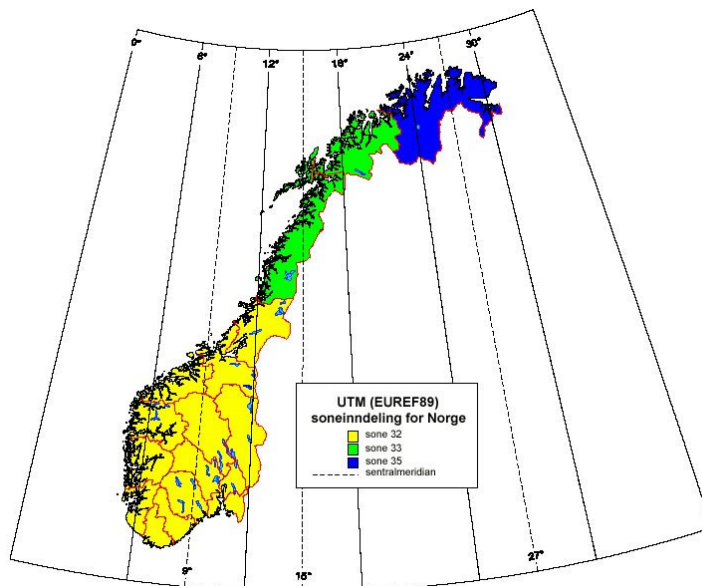


Figure 4: UTM zonal classification in Norway.

Step 2 Determine project extension and coordinates

- 2.1 Get the minimum North and East Coordinate and the maximum North and East Coordinate.

The minimum North and East and the maximum North and East coordinates of the project area will give the project extension (see Figure 5b). For following process, you will need the coordinates in the following Coordination Reference Systems:

WGS84: A global standard used coordinate system for mapping and navigation, i.e. used by Google Maps and Open Street Map. The map service hoydedata.no will also give you these coordinates.

Project CRS, this should be the CRS you set in Step 1. Define Coordination Reference System (CRS), i.e.: ETRS89 – UTM 32N

Recommendation: An easy way to obtain the coordinates in Norway is given by the map service www.hoydedata.no from the Norwegian Mapping Authority.

- I. Select the used CRS from your project (Step 1. Define Coordination Reference System (CRS)) in the menu bar on the website (see Figure 5a)
- II. Search for your project area via the search bar (see Figure 5a)
- III. You get the needed coordinates, by Left-Click on the relevant location at the map (see Figure 5b) in **WGS84 CRS** and in **UTM coordinates** selected in the website menu bar

The **UTM coordinates** should be the same as the Project CRS from Step 1

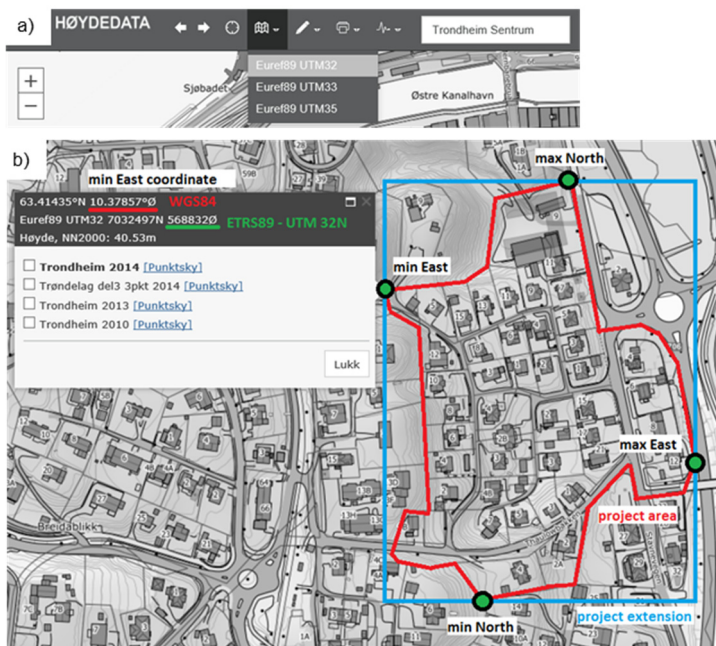


Figure 5: Example coordinate determination by the map service www.hoydedata.no, a) Menu bar of the website, b) map canvas of the website with highlighted extension points (right) and popped up coordinate window(left)

Step 3 Get input elevation data

- 3.1 The digital terrain model (dtm) and digital surface model (dsm) of your project area are the most important input data for the GIS DSM. It is highly recommended to use raster size 1m x 1m.

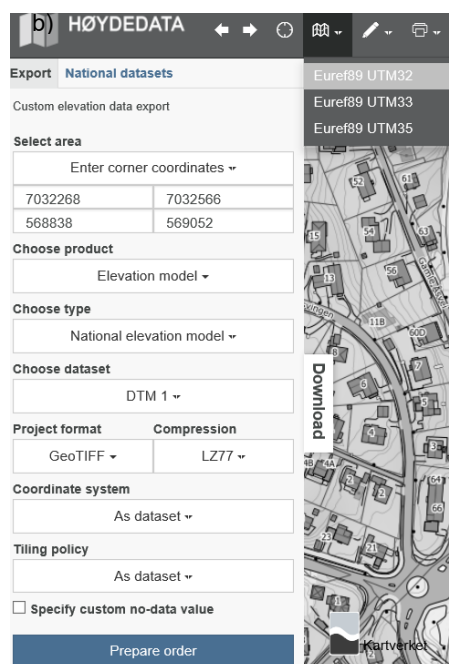
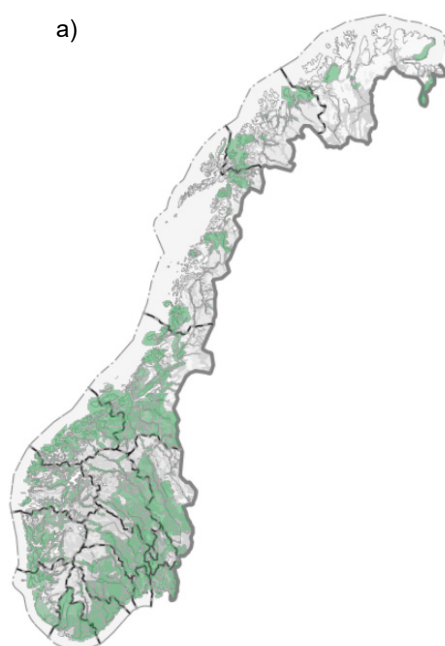
Recommendation: For most of Norway you can obtain this data by the map service www.hoydedata.no from the Norwegian Mapping Authority (green areas in Figure 6). Use the following procedure to obtain data from this site:

- I. Select **UTM CRS** in the menu bar
- II. Open Download tab
- III. Select area by "Enter corner coordinates"
- IV. Enter **UTM coordinates** from Step 2 (you will see the resulting map in the canvas)
- V. Choose product "Elevation model"
- VI. Choose type "National elevation model"
- VII. Choose data set:
 - i. "DTM 1" for digital terrain model in raster size 1x1m
 - ii. "DSM 1" for digital surface model in raster size 1x1m
- VIII. Project format "GeoTIFF" and Compression "LZ77"
- IX. Coordinate system and Compression "As dataset"
- X. Uncheck "Specify custom no-data value"
- XI. Prepare the order

Give your email and a short description. You will get the data probably in the next few hours.

- i. "Raster 1 – digital terrain model (dtm)"
- ii. "Raster 2 – digital surface model (dsm)"

You will get a much bigger raster file than your project area, because the map service will not cut their files to your project coordinates, but will send you the original dtm or dsm files (normally 15 km x 15 km raster squares). Also, you may get more than one raster file for the dtm or dsm, if your project area is on the border of these original dtm or dsm files. If you don't get more than one file, pass to next GIS tool.



a) Figure 6: Elevation data availability in Norway for the green areas, by the map service www.hoydedata.no

b) Figure 7: Example pop-up window for elevation data export from by the map service www.hoydedata.no

3.2 Sometimes you get more than one raster files for your project area. Merge these separated raster files, so you can use one raster layer, which will simplify the coming processes. To do so, use [QGIS – Merge Raster] as following:

[QGIS – Merge Raster]

(Menu bar » Raster » Miscellaneous » Merge)

- I. Input files:
 - i. All dtm raster files (.tif)
 - ii. All dsm raster files (.tif)
- II. Uncheck all remaining settings
- III. Output file:
 - i. New "Raster 1 – digital terrain model (dtm)"
 - ii. New "Raster 2 – digital surface model (dsm)"

- 3.3 If you choose another CRS in Step 1 than the CRS which is used for your raster data (i.e. the elevation raster from www.hoydedata.no), you must convert your input raster data CRS to the project one. Also, if you choose the same CRS, it is recommended to translate the CRS anyway, because often the CRS is customised for such map services.

Doing this for each Input Data will prohibit transformation and editing errors in the following process by using for all input data the same source code for the CRS. Use [GDAL – Translate (Convert format)] as following:

[GDAL – Translate (Convert format)]

(Menu bar » Raster » Conversion » Translate (Convert format))

- I. Input Layer:
 - i. "Raster 1 – digital terrain model (dtm)"
 - ii. "Raster 2 – digital surface model (dsm)"
- II. Output file:
 - i. "Raster 3 – converted dtm"
 - ii. "Raster 4 – converted dsm"
- III. Target CRS: Project CRS
- IV. Uncheck rest settings

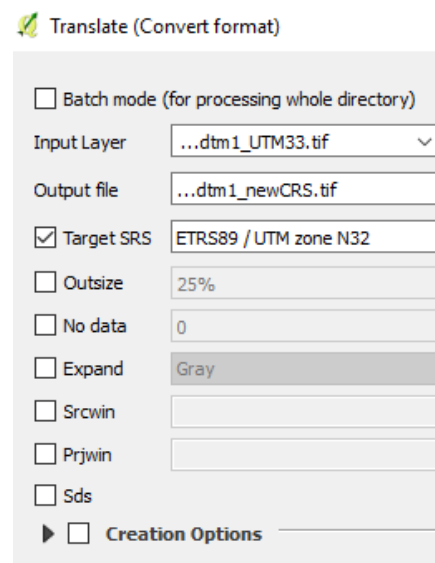


Figure 8: Exemplary working sheet for [GDAL – Translate (Convert format)]

Step 4 Get input buildings and infrastructure data

- 4.1 Recommendation: Open Street Map gives good basic vector data for buildings and infrastructure. You can download this data directly from QGIS by using [QGIS – Download Open Street Map Data].

[QGIS – Download Open Street Map Data]

(Menu bar » Vector » OpenStreetMap » Download Data...)

- I. Select "Manual" for extent definition
- II. Enter your **WGS84** coordinates for the project extension (minimum North and East and maximum North and East coordinates) from Step 2, as seen in Figure 9
- III. Choose Output file direction
- IV. By pressing OK, the tool will download the data

If no data has been downloaded this could mean a) the coordinates are wrong or b) no data for this area is available. In both cases make sure that your coordinates are right, i.e. via www.hoydedata.no.

- V. Output file: "OSM 1 – open street map data"

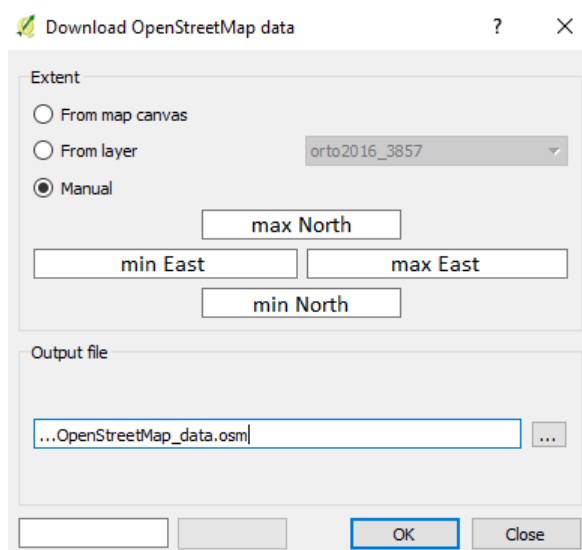


Figure 9: Example working sheet for [QGIS – Download Open Street Map Data].

- 4.2 Add the vector data for buildings and infrastructure to the GIS project. Here the Open Street Map data is used for explanation, but this could be as well vector data from different sources. Use [QGIS – Add vector layer] as follow:

[QGIS – Add vector layer]

(Menu bar » Layer » Add vector layer...)

- I. Source type: File
- II. Encoding: System
- III. Press Browse » select "OSM 1 – open street map data" » press Open
- IV. Press Open » select "lines" and "multipolygons" » press OK
- V. Output files: "Vector 1 – OSM lines" and "Vector 2 – OSM multipolygons"

The output files for OSM vector data is quite rough, like shown in Figure 10b, and will be edited in Step 6



Figure 10: Example Open Street Map output, showing a) the project Layer Panel with "Vector 1 – OSM lines" and "Vector 2 – OSM multipolygons" and b) the appropriated map canvas.

- 4.3 As for the raster data, the vector data must be in the Project CRS as well. Doing this for each Input Data will prohibit transformation and editing errors in the following process by using for all input data the same source code for the CRS. Here the Open Street Map data is used for explanation, but this could be vector data from different sources. Use [GDAL – Translate (Convert format)] as following:

[QGIS – Define current projection]

(Menu bar » Vector » Data Management Tools » Define current projection)

- I. Input Layer:
 - i. "Vector 1 – OSM lines"
 - ii. "Vector 2 – OSM multipolygons"
- II. Output CRS: Project CRS

This tool will not create a new file, but just overwrite the old one.

Step 5 Get orthophotos and background maps

- 5.1 Orthophotos or background maps will be needed in a following step, to verify and complete the building and infrastructure data. Therefore, WMS server layers provide good opportunities, because these are often freely available.

Recommendation: For most of Norway you can obtain WMS server layers by the map service <http://kartkatalog.geonorge.no> from the Norwegian Mapping Authority. To get WMS server layers, proceed as follow:

- I. Set Filter search on: » Distribution form » WMS-Service
- II. Search for a suitable Map data, i.e. by the community name

Test several WMS Servers to find the needed maps (guidance, how to load into your GIS will following). Sometimes it is not clear from the description, what is given by the WMS-Server. I.e.: For Trondheim, the best suitable WMS-Server is the "DTM, DOM over Trondheim kommune" service. It is not clear from the title and the description, but this service also provides a background map and several orthophotos over Trondheim.

- III. Copy the "Get Capabilities URL" (see Figure 11)

DTM, DOM over Trondheim kommune

Tjeneste

Vis i kart Last ned Vis dekningskart Hjelp Kontakt dataer

Vis produktark Vis produktspesifikasjon Vis tegnelegger Nettside Vis produktside

Digital terrengmodell (DTM) og overflatemodell (DOM) av laserdatta 2014. I tillegg finnes det en fargesatt sommerutgave og vinterutgave av overflatemodellen

Bruksområde

Visning

Distribusjoner

TITTEL	TYPE	DATAEIER	ÅPNE DATA	KART	LAST NED	FORMAT
DTM, DOM over Trondheim kommune	WMS-tjeneste	Trondheim kommune				png
...						
1 m skyggeomodell av DTM	WMS-tjenestelag	Trondheim kommune				png

Kontaktinformasjon

Metadatakontakt:
Kartavdelingen_kart_postmottak@trondheim.kommune.no - Trondheim kommune

Distribusjon

Format:
- png 1.3

Distribusjonstype: WMS-tjeneste

Get Capabilities Uri:
http://kart.trondheim.kommune.no/geoserver/Raster/wms?_f

Figure 11: Website layout of by the map service <http://kartkatalog.geonorge.no> and highlighted Capabilities URL.

- 5.2 To add the layers from the WMS Server to your GIS project, use [QGIS – Add Layer(s) from a WM(T)S Server].

[QGIS – Add Layer(s) from a WM(T)S Server]

(Menu bar » Layer » Add WMS/WMTS Layer...)

- I. Press "New", open new window as seen in Figure 12b
- II. Paste the copied URL into the URL bar, name the WMS connection and press OK
- III. Leave the rest of the settings in the start window as Default
- IV. Select the new WMS connection in the pick list
- V. Press "Connect"
- VI. Select the wanted layer in the new layer pick list as seen in Figure 12a, you can select more than one layer
- VII. Leave the rest of the settings as Default
- VIII. Press "Add"
- IX. Output Layer: "WMS Layer Map"

You get one or more layers, which give a good overview about the project area, with buildings, streets, courtyards, etc.

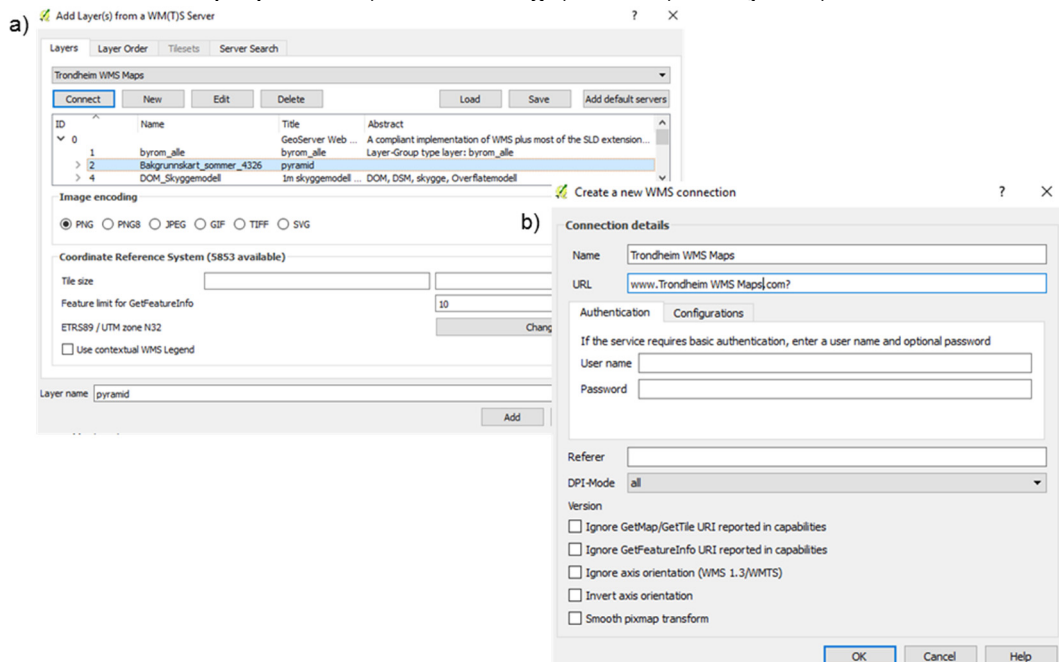
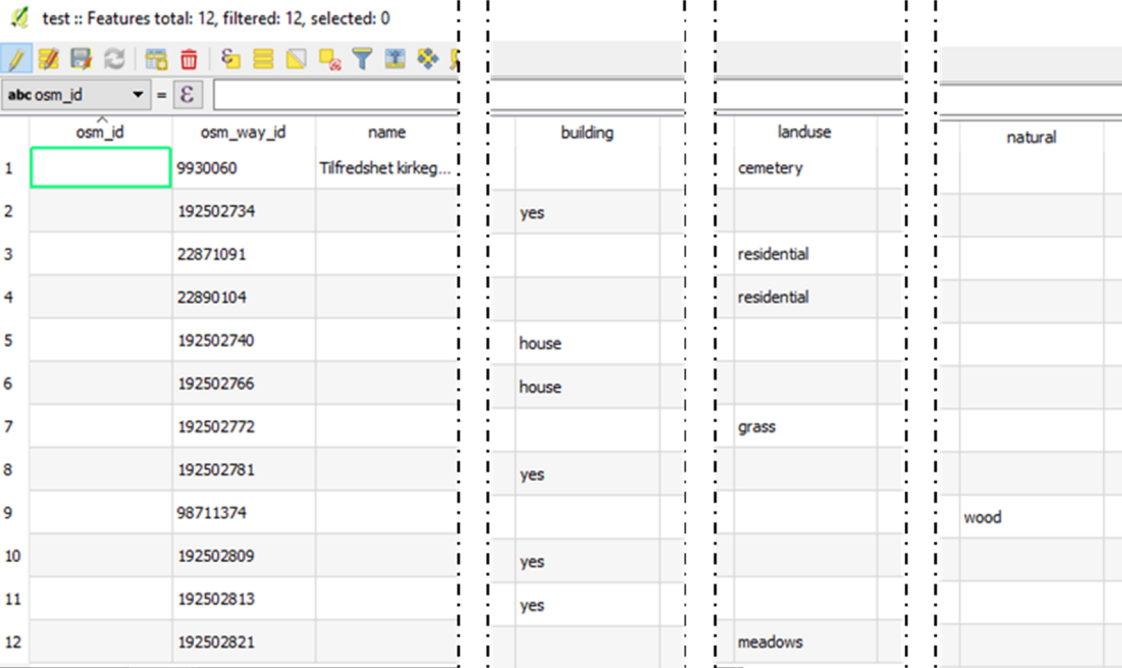


Figure 12: Example working sheet for [QGIS – Add Layer(s) from a WM(T)S Server], a) start working sheet , b) working sheet to create new WMS connection.

Step 6 Add rough Open Street Map vector data

- 6.1 The Open Street Map data is normally merged to just polygons or lines. In the following process you should filter the necessary vectors out of the data pool. Depending on the OSM input data, the used orders can be random. To get criteria to filter the vectors, analyse the attribute table of the vector data carefully (Right-Click "Vector 1 – OSM lines" or "Vector 2 – OSM polygons" in the Layer Panel (see Figure 10a) » Attribute Table) Check the Attribute Table for fitting attributes which could classify possible buildings, land use or streets (see example attribute table in Figure 13).

In the following GIS process are typical expressions called to extract data out. Depending on the OSM data there could be more and/or different selections.



	osm_id	osm_way_id	name	building	landuse	natural
1		9930060	Tilfredshet kirkeg...		cemetery	
2		192502734		yes		
3		22871091			residential	
4		22890104			residential	
5		192502740		house		
6		192502766		house		
7		192502772			grass	
8		192502781		yes		
9		98711374				wood
10		192502809		yes		
11		192502813		yes		
12		192502821			meadows	

Figure 13: Example Attribute Table for Open Street Map vector data.

- 6.2 The following shows an example to extract suitable vector data from OSM data, for:

- i. building vector
- ii. land use vector
- iii. (optional) street vector

A street vector layer is for the GIS DSM not needed, but due to following data correction processes in Step 8 and afterwards to the DSM usage GIS post-processing, it is recommended to have knowledge about streets, too.

Use [QGIS – Extract by expression]. The used expressions are examples. In this guideline there will be always an explanation to the meaning of the expression. For a general explanation to the QGIS expression string building process and format rules, see QGIS Training Manual » 3 Module: Creating a Basic Map » Working with vector data » Expressions (Thiede, Sutton et al. 2018).

[QGIS – Extract by expression]

(Processing Toolbox » search for: Extract by expression)

I. Input Layer:

- i. "Vector 2 – OSM polygons"
- ii. "Vector 2 – OSM polygons"
- iii. (optional) "Vector 1 – OSM lines"

II. Expression:

i. **"building" IS NOT NULL**

i.e.: in the attribute table the column "building" indicates buildings by a simple "YES" or type indicator (see the attribute table in Figure 13). Any polygon which is not a building, gives no value in this field. The expression ' **"building" IS NOT NULL** ' indicates all fields with content in the column "building". See the results in Figure 14.

ii. (**"landuse" = 'grass' OR "landuse" = 'meadows' OR "landuse" = 'residential') AND "natural" IS NOT 'wood'**

i.e.: in the attribute table the column "landuse" shows if polygons have specific land use (see the attribute table in Figure 13). For areas with land use which enable SUDS application, we select "meadows" and "grass", but also in a wider view "residential" where in a following step we must remove the streets and private areas. Deal breaker for SUDS usage are mainly natural areas, where no constructions are allowed, like shown in the column "natural" with the indicator "wood". See the results in Figure 15.

iii. (optional) **"highway" IS NOT NULL**

i.e.: in the attribute table the column "highway" indicates streets by a type value (see Figure 23). Any line which is not a street, gives no value in this field. The expression ' **"highway" IS NOT NULL** ' indicates all fields with content in the column "highway". See the results in Figure 16.

III. Extracted Output Layer:

- i. "Vector 3 – OSM buildings"
- ii. "Vector 4 – OSM landuse"

iii. (optional) "Vector 5 – OSM street lines"



Figure 14: Example Open Street Map output, showing "Vector 1 – OSM lines", "Vector 2 – OSM multipolygons" and extracted "Vector 3 – OSM buildings" highlighted in red and b) appropriate working sheet for building extraction by [QGIS – Extract by expression].



Figure 15: Example Open Street Map output, showing "Vector 1 – OSM lines", "Vector 2 – OSM multipolygons" and extracted "Vector 4 – OSM landuse" highlighted in green and b) appropriate working sheet for landuse extraction by [QGIS – Extract by expression].



Figure 16: Example Open Street Map output, showing a) "Vector 1 – OSM lines", "Vector 2 – OSM multipolygons" and extracted " Vector 5 –street lines" highlighted via dotted lines and b) appropriate working sheet for street extraction by [QGIS – Extract by expression].

Step 7 Validate and correct Open Street Map vector data for buildings

- 7.1 Because the Input data is based on the rough open source data from OSM, it could be possible that the data is not complete and accurate enough for the purpose of the decision support method. For "Vector 3 – OSM buildings" this could be inaccurate or not complete polygons (see Figure 17a) or total missing polygons (see Figure 17b).

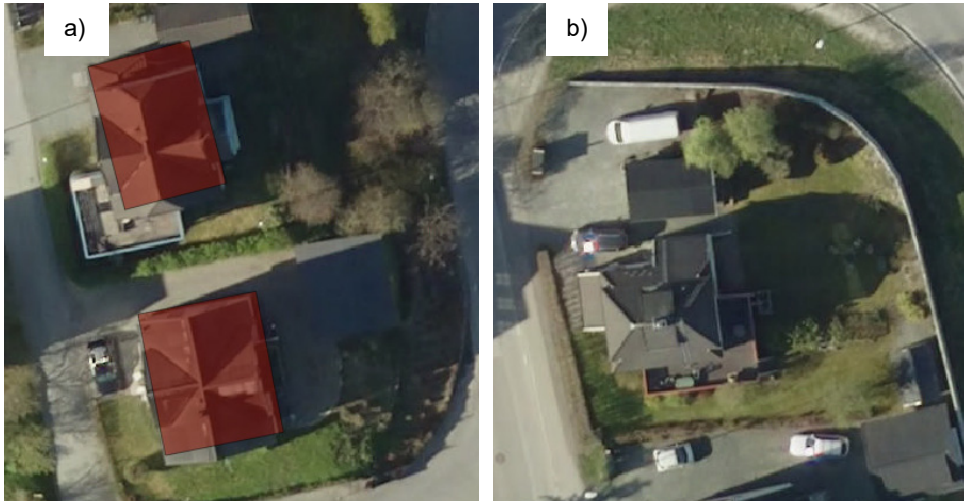


Figure 17: Example of errors in the OSM building vector, showing red building polygon and a WMS orthophoto layer map in background, a) not complete drawn polygon, b) missing polygons.

Recommendation: To find errors, it is recommended to use "WMS Layer Map" as background. In the Layer Panel, arrange "Vector 3 – OSM buildings" above the "WMS Layer Map" and make it transparency (Right-Click "Vector 3 – OSM buildings" » Properties » Style » Transparency \approx 50%).

- 7.2 You can easily fix errors of the existing data by editing the polygons. To do so, active the Editing Mode for "Vector 3 – OSM buildings " and adjust the polygons. i.) Drag and drop nodes of a polygon to their right position, ii.) add new nodes to change the polygon form or iii.) delete existing nodes. You can do so, by:

- I. Enable "Vector 3 – OSM buildings" in the Layer Panel
- II. Digitizing Toolbar » Toggle Editing » Node Tool » Left-Click on the to edit polygon outline

The outline and nodes of the polygon will be highlighted, like in Figure 18

The Digitize Toolbar may not be visible, to enable it click Menu bar » View » Toolbars

- III. Correct "Vector 3 – OSM buildings"
 - i. Move nodes: Left-Click on node » Drag and Drop to right position
 - ii. Add node: Double-Left-Click on the outline
 - iii. Remove node: Left-Click on the node » Press "Delete" key on keyboard

Recommendation: A useful tool to fit polygons together is to enable the snapping option of QGIS (Menu bar » Settings » Snapping option). This will help to snap the edges of the different polygons together and prevent gaps or overlapping between the polygons. There are more useful tips for editing GIS features in the QGIS – Training Manual » 6. Module: creating Vector Data » 6. Lesson: Feature Topology (Thiede, Sutton et al. 2018).

The results of the editing could look like the output in Figure 18a.

- IV. Save your edits (Digitizing Toolbar » Save layer edits) and disable the Editing Mode (Digitizing Toolbar » Toggle Editing)

- 7.3 Add missing polygons as follow:

- I. Enable "Vector 3 – OSM buildings" in the Layer Panel
- II. Digitizing Toolbar » Toggle Editing » Add feature

Add missing polygons by trace the streets from the "WMS Layer Map" in your map canvas like in Figure 18b

- III. Save your edits (Digitizing Toolbar » Save layer edits) and disable the Editing Mode (Digitizing Toolbar » Toggle Editing)



Figure 18 Example error correction for the OSM building vector, showing red building polygon and a WMS orthophoto layer map in background, a) correction for not complete drawn polygon, b) add missing polygons.

-
- 7.4 After validation, editing and correction we get the final vector for buildings. Rename "Vector 3 – OSM buildings" to "Vector 7 – buildings".

Step 8 **Validate and correct Open Street Map vector data for land use**

- 8.1 Because the Input data is based on the rough open source data from OSM, it could be possible that the data is not complete and accurate enough for the purpose of this project. "Vector 4 – OSM landuse" is mainly consisted of large, single polygons which do not consider buildings, courtyards or streets like seen in Figure 19.

Recommendation: To find errors, it is recommended to use "WMS Layer Map" as background. In the Layer Panel, arrange "Vector 4 – OSM landuse" above the "WMS Layer Map" and make it transparency (Right-Click "Vector 4 – OSM landuse" » Properties » Style » Transparency ≈ 50%).

To fix errors we remove the already known polygons from "Vector 4 – OSM landuse" for SUDS application. Depending if you pass the street vectors or not, the following process will change a bit.



Figure 19: Example errors in the OSM building vector, showing green landuse polygon and a WMS orthophoto layer map in the background, showing not the correct outlines and overlapping streets, buildings and courtyards.

If you did not create "Vector 5 – OSM street lines" in Step 6, continue with Step 8.2, otherwise go to Step 8.7 (p. 38)!

- 8.2 Due to the original OSM data and the manual editing, there could be overlapping building polygons (see Figure 19). For a first correction, these areas can be removed via [QGIS – Difference].

[QGIS – Difference]

(Menu bar » Vector » Geoprocessing tools » Difference)

- I. Input layer: "Vector 4 – OSM landuse"
- II. Difference layer: "Vector 7 – buildings"
- III. Output Difference Layer: "Vector 4_2 – tmp OSM landuse"

If you get a process error due to invalid features, check the layers for topology errors like described in Step 11 (p. 45).

The results could look something like Figure 22a.

-
- 8.3 The remaining polygons in "Vector 4_2 – tmp OSM landuse" must now be edited manually. Depending on which areas you selected to be suitable for SUDS application, you must remove not suitable areas from "Vector 4_2 – tmp OSM landuse". This should be streets and could be courtyards and private garden areas (see in Figure 22b).

Fix errors by editing the existing data. To do so, active the Editing Mode "Vector 4_2 – tmp OSM landuse" and cut off not suitable values. You can do so, by:

- I. Enable "Vector 4_2 – tmp OSM landuse" in the Layer Panel
- II. Digitizing Toolbar » Toggle Editing
- III. If the to cut off area don't touch a polygon outline, use:

- i. 'Advanced Digitizing Toolbar » Add Ring'

Trace the not suitable area, like in Figure 20

If the to cut off area touch a polygon outline, use:

- ii. 'Advanced Digitizing Toolbar » Split Feature' and 'Advanced Digitizing Toolbar » Delete Part'

Trace the not suitable area with a cutting line, begin and end at the outline of "Vector 4_2 – tmp OSM landuse". Also, you must cut a polygon completely, so no connections between the two

parts are existing (see Figure 21). Delete the resulting cut off part with "Delete Part".

Tip: At trace ending, do not end exactly on the border line, but cross the border line with the cutting line (see trace ending in Figure 21). This avoids execution errors.

If the Advanced Digitize Toolbar is not visible, enable it by clicking Menu bar » View » Toolbars



Figure 20 Example cut off via "Add ring" for the landuse vector correction, showing green landuse polygon, a WMS orthophoto layer map in background and the trace line in red, available if the cutting line doesn't touch the outline.



Figure 21 Example cut off via "Split feature" for the landuse vector correction, showing green landuse polygon, a WMS orthophoto layer map in background and the trace line in red, a) wrong tracing, the cutting line must cut off the polygon part completely, b) right tracing, if necessary follow an outline to cut off a complete part

- 8.4 Remaining errors can be fixed by editing the data. To do so, activate the Editing Mode for "Vector 4_2 – tmp OSM landuse" and adjust the polygons. i) Drag and drop nodes of a polygon to their right position, ii) add new nodes to change the polygon form or iii) delete existing nodes. You can do so, by repeating the Step 7.2 with "Vector 4_2 – tmp OSM landuse".

The results of the editing could look something like Figure 22b.

- 8.5 In the same way you find errors, you probably will find missing suitable landuse vectors for SUDS application, which are not implement into the OSM data. You can find these missing polygons in your "Vector 4_2 – tmp OSM landuse" also by using the "WMS Layer Map" as background. Add missing polygons by repeating the Step 7.3 with "Vector 4_2 – tmp OSM landuse".
-

- 8.6 After validation, editing and correction you get the final vector for SUDS suitable landuses. Rename "Vector 4_2 – tmp OSM landuse" to "Vector 8 – landuse".

If you did create "Vector 5 – OSM street lines" in Step 6, first go on with Step 9 to Step 10 (p. 45) and continue with Step 8.7!

- 8.7 Due to the original OSM data and the manual editing, there could be overlapping building and street polygons. For a first correction, overlapping areas from all vector layers can be removed via [QGIS – Difference].

[QGIS – Difference]

(Menu bar » Vector » Geoprocessing tools » Difference)

- I. Input layer:
 - i. "Vector 6_2 – tmp OSM streets"
 - ii. "Vector 4 – OSM landuse"
 - iii. "Vector 4_2 – tmp OSM landuse"
- II. Difference layer:
 - i. "Vector 7 – buildings"
 - ii. "Vector 7 – buildings"
 - iii. "Vector 9 – streets"
- III. Output Difference Layer:
 - i. "Vector 9 – streets"
 - ii. "Vector 4_2 – tmp OSM landuse"
 - iii. "Vector 4_3 – tmp OSM landuse"

If you get a process error due to invalid features, check the layers for topology errors like described in Step 11 (p. 47).

The results could look something like Figure 22a.

- 8.8 The remaining polygons in "Vector 4_3 – tmp OSM landuse" must now be edited manually. Depending on which areas you selected to be suitable for SUDS application, you must remove not suitable areas from "Vector 4_3 – tmp OSM landuse". This should be streets and could be courtyards and private garden areas (see Figure 22b).

Fix errors by editing the existing data. To do so, activate the Editing Mode "Vector 4_3 – tmp OSM landuse" and cut off not suitable values. You can do so, by:

- I. Enable "Vector 4_3 – tmp OSM landuse" in the Layer Panel
- II. Digitizing Toolbar » Toggle Editing
- III. If the to cut off area don't touch a polygon outline, use:
 - i. 'Advanced Digitizing Toolbar » Add Ring'

Trace the not suitable area, like in Figure 20

If the cut off area touch a polygon outline, use:

- ii. 'Advanced Digitizing Toolbar » Split Feature' and 'Advanced Digitizing Toolbar » Delete Part'

Trace the not suitable area, begin and end at the outline of "Vector 4_3 – tmp OSM landuse". Also, you must cut a polygon completely, so no connections between the two parts are existing (see in Figure 21). Delete the resulting cut off part with "Delete Part".

Tip: At trace ending, don't end exactly on the border line, but cross the border line with the cutting line (see trace ending in Figure 21). This provides execution errors.

If the Advanced Digitize Toolbar is not visible, enable it by clicking Menu bar » View » Toolbars.

- 8.9 Remaining errors can be fixed by editing the data. To do so, active the Editing Mode for "Vector 4_3 – tmp OSM landuse" and adjust the polygons. i) Drag and drop nodes of a polygon to their right position, ii) add new nodes to change the polygon form or iii) delete existing nodes. You can do so, by repeating the Step 7.2 (p. 31) with "Vector 4_3 – tmp OSM landuse".

The results of the editing could look something like Figure 22b.

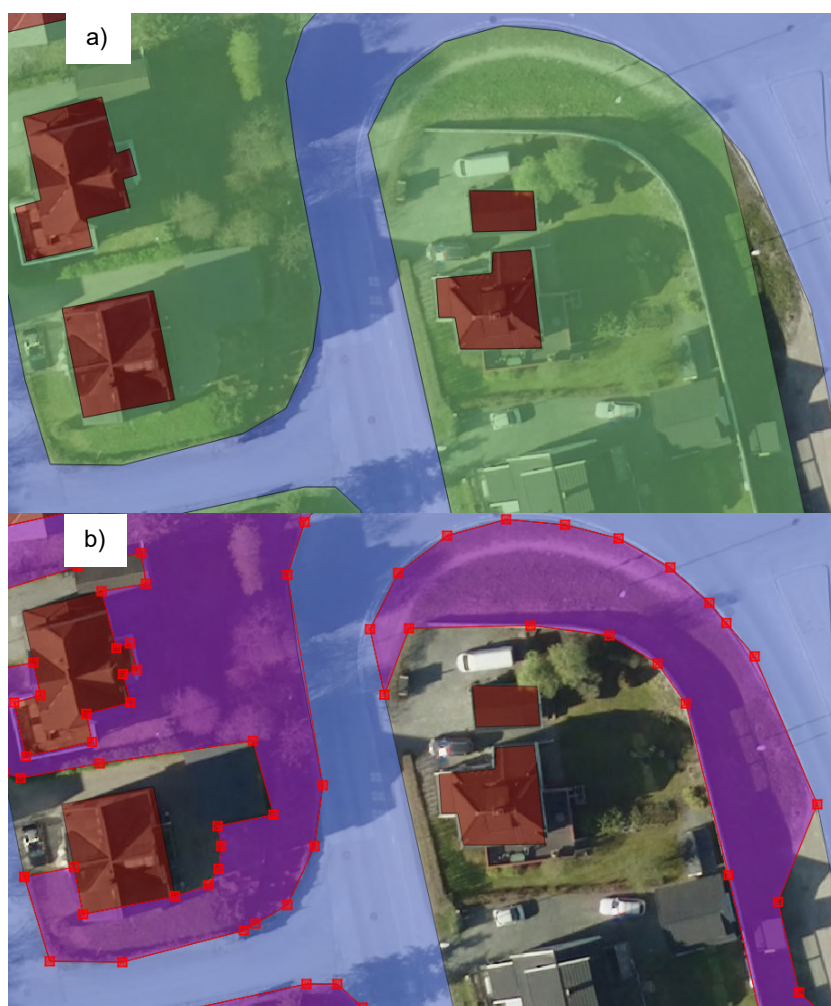


Figure 22 *Example error correction for the OSM street vector, showing the dotted OSM street lines, selected buffer polygon and adapting nodes in lilac and a WMS orthophoto layer map in background, a) correction for off-centre OSM street line, b) correction for validation errors due to the buffer creation in a crossing section.*

8.10 In the same way you find errors, you probably will find missing suitable landuse vectors for SUDS application, which are not implement into the OSM data. You can find these missing polygons in your "Vector 4_3 – tmp OSM landuse" also by using the "WMS Layer Map" as background. Add missing polygons by repeating the Step 7.3 (p. 31) with "Vector 4_3 – tmp OSM landuse".

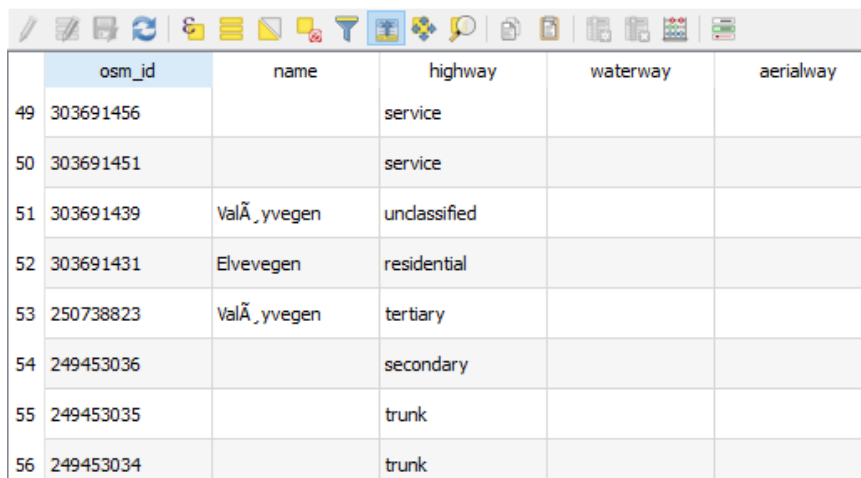
8.11 After validation, editing and correction we get the final vector for SUDS suitable landuses. Rename "Vector 4_3 – tmp OSM landuse" to "Vector 8 – landuse".

Step 9 (optional) Modify Open Street Map vector data for streets

- 9.1 The streets in OSM are just given by lines, but for further GIS work, polygons are more useful. Assuming that the lines are mainly in the middle of the streets and that the special street classes, see Figure 23, have mainly the same width, you can create buffer polygons around the lines to create simple street polygons. To do so, identify all "highway" classes and get representing street widths for them. Street widths can be detected by measure several widths with the help of the "WMS Layer Map" (Step 5) and the QGIS measure tool (Menu bar » View » Measure » Measure Line). Do this for all "highway" classes.

In this example, we do the whole procedure to determine the street width for the "highway" class "residential". Repeat the following for all "highway" classes.

OSM Lines :: Features total: 99, filtered: 99, selected: 0



	osm_id	name	highway	waterway	aerialway
49	303691456		service		
50	303691451		service		
51	303691439	ValÅ_yvegen	unclassified		
52	303691431	Elvevegen	residential		
53	250738823	ValÅ_yvegen	tertiary		
54	249453036		secondary		
55	249453035		trunk		
56	249453034		trunk		

Figure 23: Example Attribute Table for "Vector 5 – OSM street lines".

- 9.2 Add "Width" field to attribute table.

[QGIS – Add Field]

- I. Right-Click "Vector 5 – OSM street lines" » Toggle Editing
- II. Right-Click "Vector 5 – OSM street lines" » Attribute table » Add field
- III. Name: Width
- IV. Field Type: Decimal number (real)
- V. Field length: 10
- VI. Field precision: 2

- 9.3 Select all "residential" streets out of the data, see results in Figure 24.

[QGIS – Select by expression]

- I. Right-Click "Vector 5 – OSM street lines" » Attribute table » Select feature using an expression
- II. Expression: **"highway" = 'residential'**

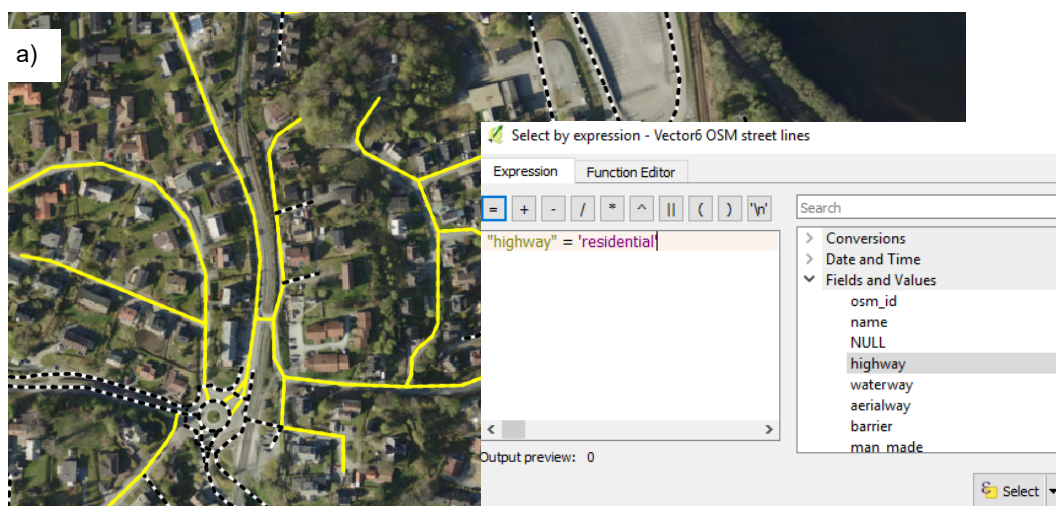


Figure 24: a) "residential highway" selection highlighted in yellow with WMS orthophoto layer map as background and b) appropriate working sheet for "residential" selection by expression.

- 9.4 Add "Width" Attribute Values to "residential" selection from "Vector 5 – OSM street lines".

[QGIS – Field calculator]

- I. Right-Click "Vector 5 – OSM street lines" » Attribute table » Open field calculator
- II. Check "Only update selected features"
- III. Check "Update existing field"
- IV. Select the field "Width"
- V. Expression: your determined width value in meter, i.e. 4

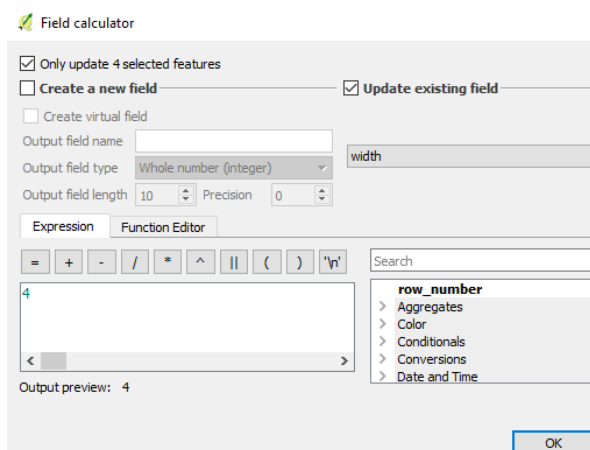


Figure 25: Exemplary work sheet for Attribute table » Field calculator to add "Width" value

- VI. By pressing "OK", all selected features will get the Width Attribute = 4

9.5 Save you results by ' Right-Click "Vector 5 – OSM street lines" » Toggle Editing » Save changes ' and repeat this procedure for all available "highway" classes.

9.6 To create the Buffer Polygon around the street lines, we need the Buffer Distance. This value is used as a radius value to create the buffer polygon around a line, with the line in the centre. Therefore, we must adjust the width value to the Buffer calculation, by dividing it in 2 via the Field calculator.

[QGIS – Field calculator]

- I. Right-Click "Vector 5 – OSM street lines" » Attribute table » Open field calculator
- II. Uncheck "Only update selected features"
- III. Check "Create a new field"
- IV. Output field name: Buffer
- V. Field Type:
Decimal number (real)
- VI. Field length: 10
- VII. Field precision: 2
- VIII. Expression:
"Width" / 2

this will divide all your "width" values with 2.
- IX. By pressing "OK", a new field will be created with Buffer Distance values

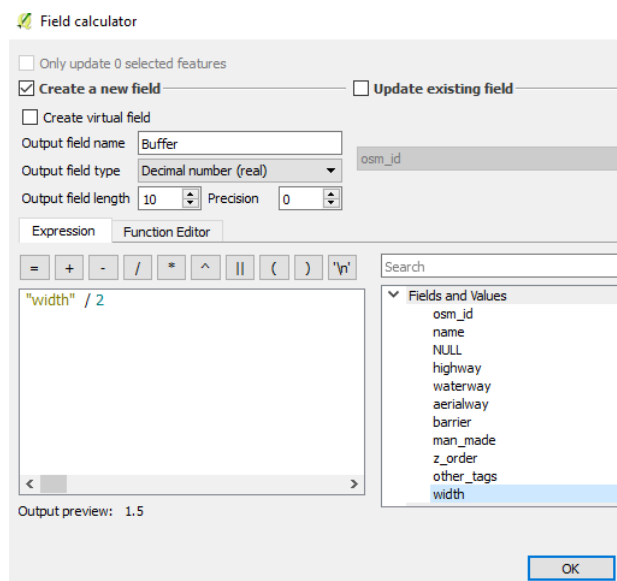


Figure 26: Exemplary work sheet for Attribute table » Field calculator to calculate "Buffer" value

9.7 Create a Street Polygon Vector, via [QGIS – Variable distance buffer].

[QGIS – Variable distance buffer]

(Menu bar » Vector » Geoprocessing tools » Variable distance buffer)

- I. Input layer: "Vector 5 – OSM street lines"
- II. Distance field: Buffer
- III. Segments: 5 (default)
- IV. Check "Dissolve result"

This will give one polygon for connected street lines and prevent overlapping. Eventual you want to cut the street polygons to separate parts later. Therefore use "Split feature" in the Editing Mode.

See QGIS Training Manual » 3 Module: Creating a Basic Map » Working with vector data » Expressions (Thiede, Sutton et al. 2018) and QGIS – Training Manual » 6. Module: creating Vector Data » 6. Lesson: Feature Topology (Thiede, Sutton et al. 2018) for a detailed editing description.

- V. Output Buffer Layer: "Vector 6 – OSM street polygons"

Step 10 (optional) Validate and correct Open Street Map vector data for streets

- 10.1 Because the Input data is based on the rough open source data from OSM, it could be possible that the data is not complete and accurate enough for the purpose of this project. For "Vector 6 – OSM street polygons" this could be off-centre OSM street lines (see Figure 27a) or validation errors due to the buffer creation, like in crossing sections (see Figure 27b).

a)



Figure 27: Example errors in the OSM street vector, showing the dotted OSM street lines, blue buffer polygon and a WMS orthophoto layer map in background, a) off-centre OSM street line, b) validation errors due to the buffer creation in a crossing section.

Recommendation: To find errors, it is recommended to use "WMS Layer Map" as background. In the Layer Panel, arrange "Vector 5 – OSM street lines" and "Vector 6 – OSM street polygons" above the "WMS Layer Map" and make "Vector 6 – OSM street polygons" transparency (Right-Click "Vector 6 – OSM street polygons" » Properties » Style » Transparency ≈ 50%)

-
- 10.2 You can easily fix errors by editing the existing data. To do so, active the Editing Mode for "Vector 6 – OSM street polygons " and adjust the polygons. i) Drag and drop nodes of a polygon to their right position, ii) add new nodes to change the polygon form or iii) delete existing nodes. You can do so, by repeating the Step 7.2 (p. 31) for "Vector 6 – OSM street polygons ".

The results of the editing could look something like Figure 28.



Figure 28 Example error correction for the OSM street vector, showing the dotted OSM street lines, selected buffer polygon and adapting nodes in lilac and a WMS orthophoto layer map in background, a) correction for off-centre OSM street line, b) correction for validation errors due to the buffer creation in a crossing section.

-
- 10.3 In the same way you find errors, you probably will find missing streets, which are not implemented into the OSM data. You can find these missing polygons in your "Vector 6 – OSM street polygons " also by using the "WMS Layer Map" as background. Add missing polygons by repeating the Step 7.3 (p. 31) for "Vector 6 – OSM street polygons ".

-
- 10.4 After validation, editing and correction we get a temporarily used vector for streets. Rename "Vector 6 – OSM street polygons" to "Vector 6_2 – tmp OSM streets".

The final adjustment to "Vector 9 – streets" will be done in Step 8.7.

Continue with Step 8.7 (p. 38)

Step 11 Check features for topology errors

- 11.1 Due to the complex adjustment process for all final Vectors: "Vector 7 – buildings", "Vector 8 – landuse" and (optional) "Vector 9 – streets", there is the possibility for topological errors. With the [QGIS – Topology Checker] you can localise most of the errors in your data.

[QGIS – Topology Checker]
(install manually)

- I. Menu bar » Plugins » Manage and Install Plugins...
- II. Search for "Topology Checker"
- III. Check Plugin
- IV. Menu bar » Vector » Topology Checker

This will open a new Topology Checker Panel, looking something like Figure 29a.

- V. Open the "Topology Rule Settings" (see Figure 29a)
- VI. Add rules like ' "Vector 8 – landuse" must not overlap with "Vector 7 – buildings" ' or ' "Vector 8 – landuse" must not have invalid geometries ' and alike, which could show errors in all of your final Vectors: "Vector 7 – buildings", "Vector 8 – landuse" and (optional) "Vector 9 – streets".

Resulting settings could look something like Figure 29b.

- VII. Validate all

By validate the layer, you will see areas with errors, like the one you defined before.

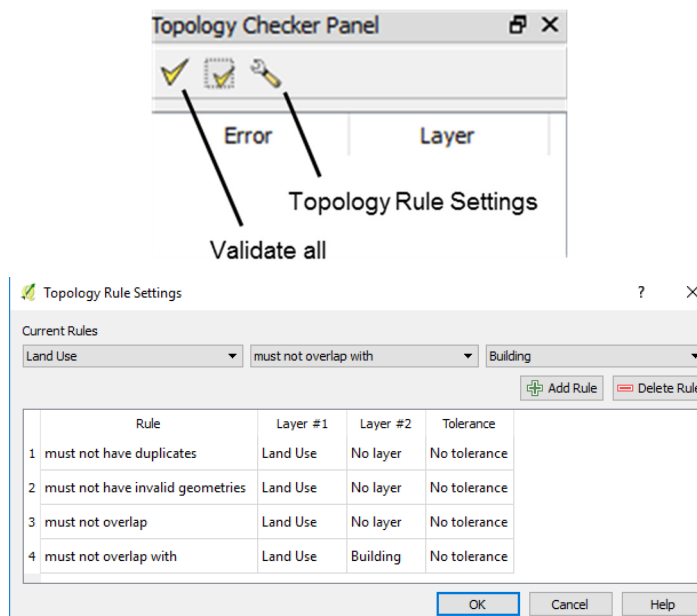


Figure 29: a) The Topology Checker Panel with button explanation and b) example working sheet for the Topology Rule Settings.

-
- 11.2 Adjust the errors. Use the same methods as described in step 7.2 (p. 31) for error correction.

If you have invalid geometries, this could often be caused by:

The outlines of a polygon cross each other

- I. Re-adjust the nodes, so the outlines do not cross each other

Or two nodes have the same coordinates

- I. Delete one of the nodes

Step 12 Create catchment area vector

- 12.1 Create a new catchment area vector shapefile. This vector will summarize the whole catchment area, including all final vector data. Create the new file with [QGIS – Create shapefile layer].

[QGIS – Create shapefile layer]

(Menu bar » Layer » Create Layer » Create shapefile layer)

- I. Type: Polygon
- II. CRS: Project CRS
- III. The other settings as Default
- IV. Output: "Vector 10 – catchment area"

-
- 12.2 The catchment area will be one polygon and should include all runoff areas inside the project area. Also, all possible areas for SUDS construction within the project area must be inside the catchment area. This file should have the same extensions as defined in Step 2. An example how this could look like can be found in Figure 5. You can use the "WMS Layer Map" as background. Draw the catchment area polygon for your project in Editing mode.

- I. Enable "Vector 10 – catchment area" in the Layer Panel
- II. Digitizing Toolbar » Toggle Editing » Add feature
- III. Draw the catchment area polygon for your project in the map canvas.
- IV. Save your edits (Digitizing Toolbar » Save layer edits) and disable the Editing Mode (Digitizing Toolbar » Toggle Editing)

5 SUDS Area Detection Algorithm – Step by step

The following steps give a stepwise in-depth description of all used QGIS tools to create the Potential SUDS Areas, Main Flow Paths and High Potential SUDS Areas. As in the chapter before it is **required** to use the **same coordination reference system (CRS) for all input data**. See Chapter 2 how to set the CRS.

Step 1 Adjust Raster Input

- 1.1 Modify the original raster to the necessary catchment area, to save storage volume and calculation time, by [GDAL – Clip raster by mask layer].

[GDAL – Clip raster by mask layer]

(Processing Toolbox » search for: Clip raster by mask layer)

- I. Input layer:
 - i. "Raster 3 – converted dtm"
 - ii. "Raster 4 – converted dsm"
- II. Mask layer: "Vector 10 – catchment area"
- III. Check "Crop the extent of the target dataset to the extent of the outline"
- IV. Check "Keep resolution of output raster"
- V. Rest setting as Default
- VI. Output – Clipped (mask):
 - i. "Raster 5 – dtm clipped"
 - ii. "Raster 6 – dsm clipped"

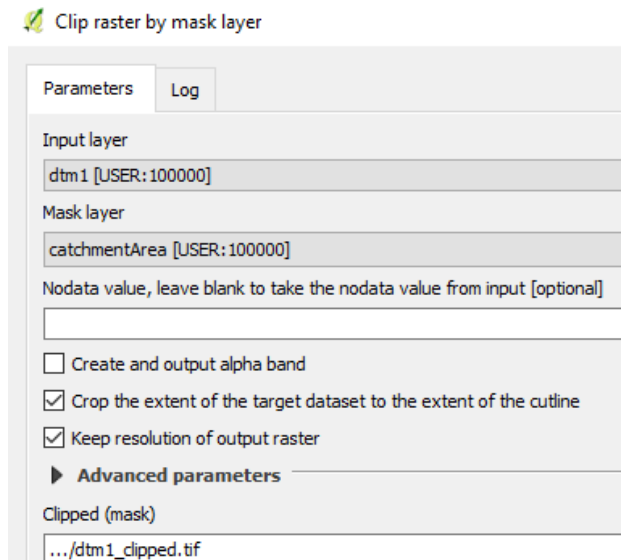


Figure 30: Example working sheet for [GDAL – Clip raster by mask layer].

Step 2 Determine Land Use Raster

- 2.1 Create template raster with the same size and resolution as the clipped Catchment Raster with i.) all cell values = 0 and ii.) all cell values = 1. These rasters are necessary for following GIS processes.

[SAGA – Reclassify values]

(Processing Toolbox » search for: Reclassify values)

- I. Input – Grid: "Raster 5 – dtm clipped"
- II. Method: Single
- III. Old value (for single value change): -32767 ("no data" value in QGIS)
- IV. New value (for single value change):
 - i. 0
 - ii. 1
- V. Operator (for single value change): >=
- VI. Uncheck "replace no data values"
- VII. Uncheck "replace other values"
- VIII. Rest settings as Default
- IX. Output – Reclassified Grid:
 - i. "Raster 7 – template zero"
 - ii. "Raster 8 – template one"

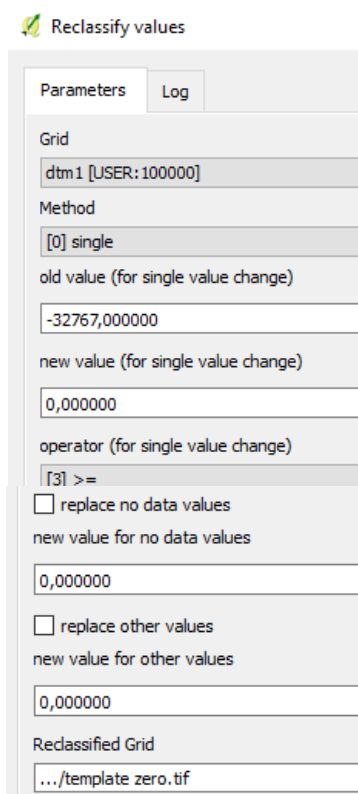


Figure 31: Example working sheet for [SAGA – Reclassify values].

- 2.2 Add new attributes to the Vector Data imported in the pre-processing part that will be used to create new raster files to represent buildings, terrain and landuse suitable for SUDS application. Use therefore the [QGIS – Field calculator].

[QGIS – Field calculator]

- I. Right-Click:
 - i. "Vector 7 – buildings" » Attribute table » Open field calculator
 - ii. "Vector 7 – buildings" » Attribute table » Open field calculator
 - iii. "Vector 8 – landuse" » Attribute table » Open field calculator
- II. Check "Create a new field"
- III. Output field name:
 - i. One
 - ii. Zero
 - iii. One
- IV. Output field type: Decimal number (real)
- V. Field length: 10
- VI. Field precision: 3
- VII. Expression:
 - i. 1
 - ii. 0
 - iii. 1
- VIII. By pressing "OK", a new field will be created with the "Expression" value
- IX. Save the edits (Digitizing Toolbar » Save layer edits) and disable the Editing Mode (Digitizing Toolbar » Toggle Editing)

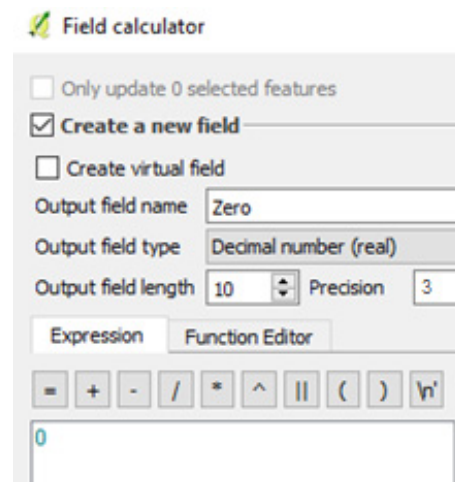


Figure 32: Example working sheet for [QGIS – Field calculator].

-
- 2.3 Write the added attributes from the vector data from Step 2.2 over the raster templates from Step 0. This will give raster for following purposes:
- i. A raster which shows the building roof area by a cell value = 1, rest of the cell values = 0.
 - ii. A raster which shows terrain by a cell value = 1, rest of the cells are all building roofs and have a cell value = 0. We use this raster to create an elevation raster with different values for terrain cells and building cells in Step 3 (p. 56). The flow accumulation in Step 6 (p. 62) also will be calculated only for the terrain.
 - iii. A raster which shows the landuse for SUDS applications by a cell value = 1, rest cell values = 0. This is used in the Potential SUDS Area Detection in Step 5 (p. 60).

Use therefore [GDAL – Rasterize (vector to raster)].

[GDAL – Rasterize (vector to raster)]

(Menu bar » Raster » Rasterize (Vector to raster))

II. Input file (shapefile):

- i. "Vector 7 – buildings"
- ii. "Vector 7 – buildings"
- iii. "Vector 8 – landuse"

III. Attribute field:

- i. One
- ii. Zero
- iii. One

IV. Output file for rasterized vectors (raster):

This will override any existing raster. Copy the template raster before, rename them and choose these copies as output. Do as followed:

- i. copy "Raster 7 – template zero" » rename Copy "Raster 7 – template zero" to "Raster 9 – pointing out building area" » select "Raster 9 – pointing out building" as output file
- ii. copy "Raster 8 – template one" » rename Copy "Raster 8 – template one " to "Raster 10 – pointing out terrain" » select "Raster 10 – pointing out terrain" as output file

iii. copy "Raster 7 – template zero" » rename Copy "Raster 7 – template zero" to "Raster 11 – pointing out land use" » select "Raster 11 – pointing out landuse" as output file

V. Check "Keep existing raster size and resolution"

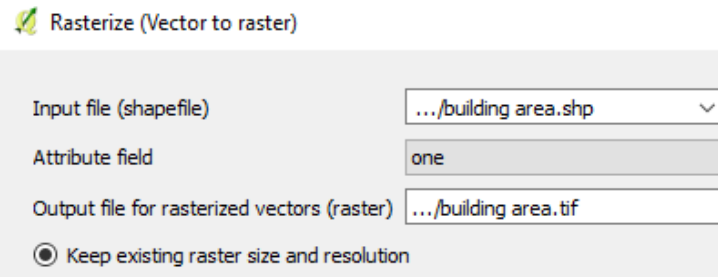


Figure 33: Example working sheet for [GDAL – Rasterize (vector to raster)]

Step 3 Create Combined Elevation Model

- 3.1 Fill local depressions in terrain to ensure uninterrupted flow lines in the flow accumulation calculation.

[SAGA – Fill sinks xxl (Wang & Liu)]

(Processing Toolbox » search for: Fill sinks xxl)

- I. Input – DEM: "Raster 5 – dtm clipped"
- II. Minimum Slope [Degree]: 0,010
- III. Output – Filled DEM: "Raster 12 – dtm filled"

-
- 3.2 Create the combined elevation model by merging information from different raster data. For the ground surface we use the filled dtm raster and buildings get elevation values from the dsm. By doing this we get an elevation model, as close to the reality as needed for our purpose. In Step 6 (p. 62) the flow accumulation will be calculated just for the ground surface. The runoff is not allowed to cross buildings. We use the real elevation values for buildings as a flow blockade, like it would be in reality.

Use the [QGIS – Raster Calculator] with data from "Raster 6 – dsm clipped", "Raster 12 – dtm filled" and "Raster 10 – pointing out terrain".

[QGIS – Raster Calculator]

(Menu bar » Raster » Raster Calculator)

- I. Raster calculator expression:

$$(("Raster\ 10\ -\ pointing\ out\ terrain" = 0) * "Raster\ 6\ -\ dsm\ clipped") + (("Raster\ 10\ -\ pointing\ out\ terrain" = 1) * "Raster\ 12\ -\ dtm\ filled")$$

By this expression there will be a new raster with the values for buildings from the dsm and for the rest of the values from the filled dtm.

- II. Set layer extent to catchment layer extent by selecting "Raster 6 – dsm clipped" and pressing "Current layer extent" button
- III. Output CRS: Project CRS
- IV. Output layer: "Raster 13 – combined elevation model"

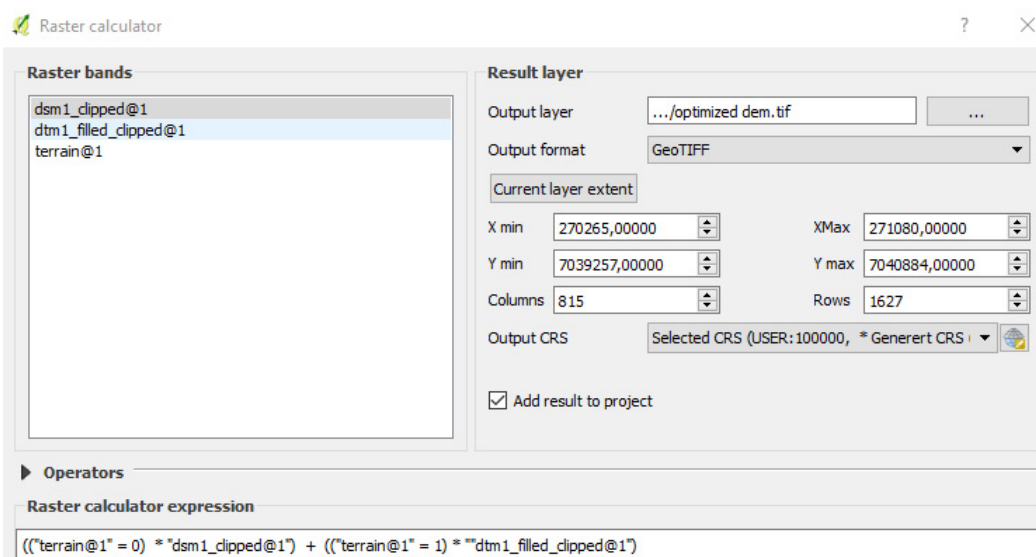


Figure 34: Example working sheet for [QGIS – Raster calculator].

- 3.3 Modify the original raster to the necessary catchment area, to save storage volume and calculation time.

[GDAL – Clip raster by mask layer]

(Processing Toolbox » search for: Clip raster by mask layer)

- I. Input layer: "Raster 13 – combined elevation model"
- II. Mask layer: "Vector 10 – catchment area"
- III. Check "Crop the extent of the target dataset to the extent of the outline"
- IV. Check "Keep resolution of output raster"
- V. Rest setting as Default
- VI. Output – Clipped (mask): "Raster 14 – combined elevation model clipped"

Step 4 Calculate Surface Slope

- 4.1 Calculate the slope for just the terrain with [SAGA – Slope, aspect, curvature], based on the dtm raster. Slopes for building roofs are not needed. Ignore the rest of the calculation possibilities in this tool.

[SAGA – Slope, aspect, curvature]

(Processing Toolbox » search for: Slope, aspect, curvature)

- I. Input – Elevation: "Raster 5 – dtm clipped"
- II. Method: 9 parameter 2nd order polynom (Zevenbergen & Thorne 1987)
- III. Slope Units: percent
- IV. Output – Slope: "Raster 15 – slope"

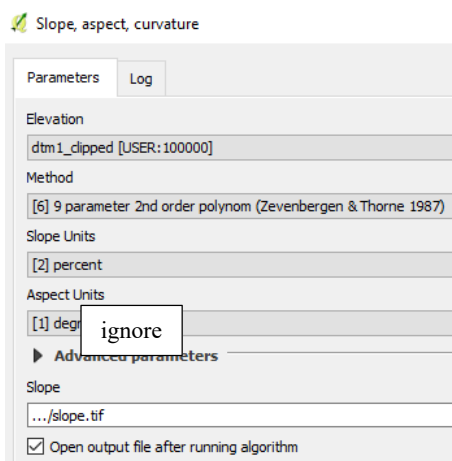


Figure 35: Example working sheet for [SAGA – Slope, aspect, curvature].

4.2 Modify the slope raster to the necessary catchment area.

[GDAL – Clip raster by mask layer]

(Processing Toolbox » search for: Clip raster by mask layer)

- I. Input layer: "Raster 15 – slope"
- II. Mask layer: "Vector 10 – catchment area"
- III. Check "Crop the extent of the target dataset to the extent of the outline"
- IV. Check "Keep resolution of output raster"
- V. Rest setting as Default
- VI. Output – Clipped (mask): "Raster 16 – slope clipped"

4.3 Create raster which shows areas with low slope (<10%) by the cell value 1.

[SAGA – Reclassify values]

(Processing Toolbox » search for: Reclassify values)

- I. Input – Grid: "Raster 16 – slope clipped"
- II. Method: Single
- III. Old value (for single value change): 10
- IV. New value (for single value change): 1
- V. Operator (for single value change): <=
- VI. Uncheck "replace no data values"
- VII. Check "replace other values"
- VIII. New value for other values: 0
- IX. Rest settings as Default
- X. Output – Reclassified Grid: "Raster 17 – low slope area"

Step 5 Determine Potential SUDS Areas

- 5.1 Create the Result Raster for Potential SUDS Areas by merging information from different raster data using calculation expression [QGIS – Raster Calculator] with data from "Raster 11 – pointing out landuse" and "Raster 17 – low slope area".

[QGIS – Raster Calculator]

(Menu bar » Raster » Raster Calculator)

- I. Raster calculator expression:

"Raster 11 – pointing out landuse" * "Raster 17 – low slope area"

By this expression there will be created a new raster which shows landuse suitable to SUDS applications with low slope, because:

in Raster 11 value for landuse = 1 and for rest = 0,

in Raster 17 value for areas with low slope = 1 and for rest = 0

and in new "Result Raster 1", landuse suitable to SUDS applications with low slope will have value = 1 ($1*1=1$), rest = 0

- II. Set layer extent to catchment layer extent by selecting "Raster 11 – pointing out landuse" and pressing "Current layer extent" button
- III. Output CRS: Project CRS
- IV. Output layer: "Result Raster 1 – Potential SUDS Area"

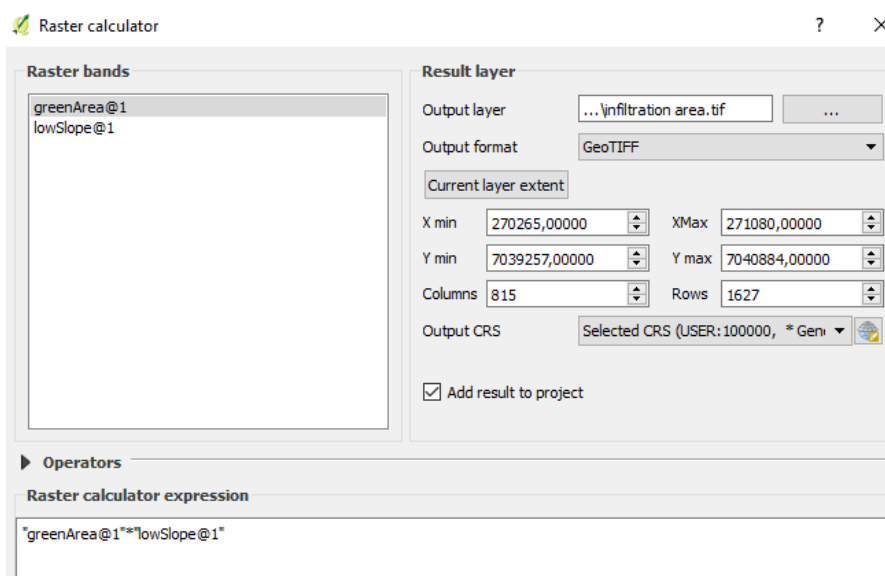


Figure 36: Example working sheet for [QGIS – Raster Calculator].

- 5.2 Convert the raster to separated polygons, which can be used in an post-processing GIS analyse.

[QGIS – Polygonize (Raster to vector)]

(Menu bar » Raster » Conversion » Polygonize (Raster to vector))

- I. Input file: "Result Raster 1 – Potential SUDS Area"
- II. Output file for polygons (shapefile): "Result Vector 1 – Potential SUDS Area"
- III. Field name: DN

-
- 5.3 The created polygons may have a few topology errors, which could cause calculation errors. Step 9 (p. 74) describes some methods to check and correct the polygons.

Step 6 Calculate Flow Accumulation

- 6.1 Calculate the flow accumulation on the ground surface, based on a flow tracing algorithm. Runoff from buildings is not considered in this calculation.

[SAGA – Catchment area (flow tracing)]

(Processing Toolbox » search for: Catchment area (flow tracing))

- I. Input – Elevation: "Raster 14 – combined elevation model clipped"

By using the combined elevation model, we can calculate the flow accumulation on the ground with the elevation values from the dtm and block flow across buildings due to elevation values for building from the dsm.

- II. Input – Weights:
"Raster 10 – pointing out terrain"

The weight in this tool show which cell gives which amount of runoff. Because we just want to calculate ground surface runoff, just terrain cells give runoff. In the pointing out terrain raster, all terrain cells have the value 1 and buildings have the value 0, which result in no runoff from building roofs.

- III. Flow Accumulation Units:
Cell Area

- IV. Step: 1

- V. Method: Rho 8

The Rho8 algorithm has the advantage of a fast calculation time. Other methods could also be used if it fits better to the project. Due to the Norwegian topographical and metrological conditions, the Rho8 algorithm gives good results to steep areas under high precipitation volume influence (López-Vicente, Pérez-Bielsa et al. 2014).

The screenshot shows the 'Catchment area (flow tracing)' tool parameters dialog box. It has two tabs: 'Parameters' and 'Log'. The 'Parameters' tab is active. The parameters are as follows:

- Elevation:** dem1 [USER:100000]
- Flow Accumulation Units:** [1] Cell Area
- Sink Routes [optional]:** [Not selected]
- Weights [optional]:** terrain [USER:100000]
- Material for Accumulation [optional]:** [Not selected]
- Input for Mean over Catchment [optional]:** [Not selected]
- Accumulation Target [optional]:** [Not selected]
- Step:** 1
- Method:** [0] Rho 8
- DEMON - Min. DQV:** 0,000000
- Flow Correction
- Advanced parameters** (expanded)
- Flow Accumulation:** .../flow accumulation.tif

Figure 37: Example working sheet for [SAGA – Catchment area (flow tracing)].

- VI. Output – Flow Accumulation:
"Raster 18 – flow accumulation"
- VII. Uncheck rest settings

6.2 Transform the raster values from flow accumulation raster to points. We use this method to create a link layer between raster and vector data. Also, it is much easier to calculate using vector points instead of raster cells, including the possibility to just edit a few points and ignore the rest. The points reside in the cell-centre and get the cell value (flow accumulation) as an attribute named "VALUE".

[SAGA – Raster values to points (randomly)]

(Processing Toolbox » search for: Raster values to points)

- I. Input – Grid: "Raster 18 – flow accumulation"
- II. Frequency: 1 (*create a point in each cell*)
- III. Output – Points: "Vector 11 – flow accumulation points"

6.3 Extract point vectors out of the flow accumulation points, which have a value greater 0. Cells with no data or 0 would falsify the Root Mean Square calculation of all flow accumulation values in the next Step.

[QGIS – Extract by expression]

(Processing Toolbox » search for: Extract by expression)

- I. Input Layer: "Vector 11 – flow accumulation points"
- II. Expression: "**Value**" >= 0
- III. Extracted Output Layer: "Vector 12 – flow accumulation points selected"

Step 7 Determine Main Flow Paths

- 7.1 Extract point vectors out of the flow accumulation points, which have a value greater than the Root Mean Square (RMS). The remaining points show the Main Flow Paths. We choose the RMS as separator, because in the data there are expected to be many low values which are slightly higher than 1 and only a few high values. The RMS grade higher values stronger, due to the squaring of each value and gives so a mean value for high flow accumulation.

[QGIS – Extract by expression]

(Processing Toolbox » search for: Extract by expression)

- I. Input Layer: "Vector 12 – flow accumulation points selected"
- II. Expression: **"VALUE"** **>=**
sqrt(sum(("VALUE"^2))/count("VALUE">0))
- III. Extracted Output Layer: "Vector 13 – Main Flow Path points"

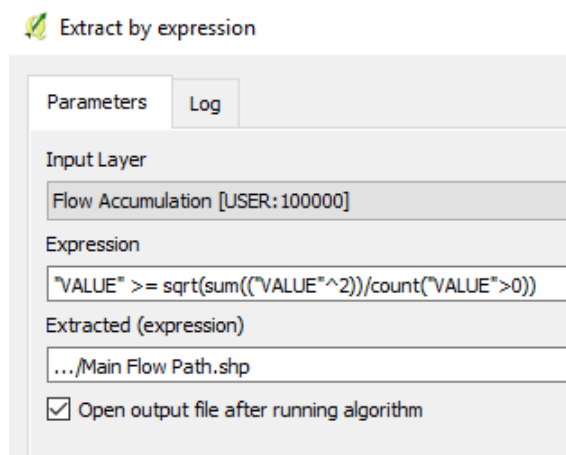


Figure 38: Example working sheet for [QGIS – Extract by expression].

-
- 7.2 Add new attribute = 1 to the Main Flow Path points which will be used to create the Result Raster files to represent the Main Flow Path.

[QGIS – Field calculator]

- I. Right-Click: "Vector 13 – Main Flow Path points"
- II. Check "Create a new field"
- III. Output field name: One
- IV. Output field type: Decimal number (real)
- V. Field length: 10
- VI. Field precision: 3
- VII. Expression: 1
- VIII. By pressing "OK", a new field will be created with the "Expression" value
- IX. Save the edits (Digitizing Toolbar » Save layer edits) and disable the Editing Mode (Digitizing Toolbar » Toggle Editing)

- 7.3 Create the "Result Raster 2 – Main Flow Path" out of the Main Flow Path points. Therefore, the attribute "One" (which is for every point 1) from Main Flow Path points will be written over a raster template with cell values = 0.

[GDAL – Rasterize (vector to raster)]

(Menu bar » Raster » Conversion » Rasterize (vector to raster))

- I. Input file (shapefile): "Vector 13 – Main Flow Path points"
- II. Attribute field: "One"
- III. Output file for rasterized vectors (raster):

This will override an existing raster. Copy the template raster before, rename them and choose these copies as output. Do as followed:

Copy "Raster 7 – template zero" » rename Copy "Raster 7 – template zero" to "Result Raster 2 – Main Flow Path" » select "Result Raster 2 – Main Flow Path" as output file

- IV. Check "Keep existing raster size and resolution"

To see the resulting Main Flow Paths in the map canvas, you must change the style by give a display min value = 0 and max value = 1.

(Right-Click: "Result Raster 2 – Main Flow Path" » Properties » Style)

More useful tips to modify the raster style can be found in QGIS Training Manual » 8. Module: Raster » 8.2. Lesson: Changing Raster Symbiology(Thiede, Sutton et al. 2018).

Step 8 Determine High Potential SUDS Area

- 8.1 To determine the High Potential SUDS Areas, we will work with the created point vectors. These points need additional attribute values from further raster. To get these attributes, the [Point Sampling Tool] plugin by Borys Jurgiel is highly recommended (see Figure 39 for plugin description).

[Point Sampling Tool] by Borys Jurgiel (install manually)

- I. Menu bar » Plugins » Manage and Install Plugins...
- II. Search for "Point Sampling Tool"
- III. Install plugin

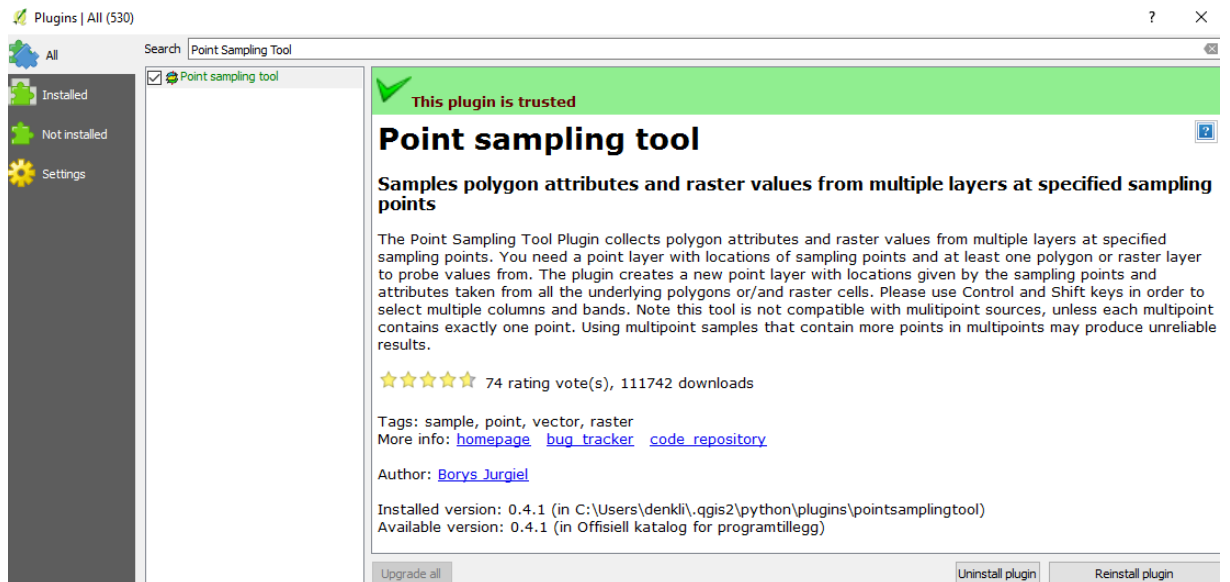


Figure 39: Working sheet to install the [Point Sampling Tool] plugin by Borys Jurgiel.

- 8.2 Get additional elevation and Potential SUDS Area attributes to point vectors from "Raster 5 – dtm clipped" and "Result Raster 1 – Potential SUDS Area". Use [Plugin Sampling Tool] by Borys Jurgiel.

[Plugin Sampling Tool] by Borys Jurgiel
(Menu bar » Plugins » Analyses » Point Sampling Tool)

- I. Layer containing sampling points:
 - i. "Vector 12 – flow accumulation points selected"
 - ii. " Vector 13 – Main Flow Path points"
- II. Layers with field/bands to get values from:

More than one selection possible

 - i. "Raster 5 – dtm clipped" and "Result Raster 1 – Potential SUDS Area"
 - ii. "Raster 5 – dtm clipped"
- III. Output point vector layer:
 - i. "Vector 14 – Potential SUDS Area points"
 - ii. "Vector 15 – Main Flow Path points with elevation"

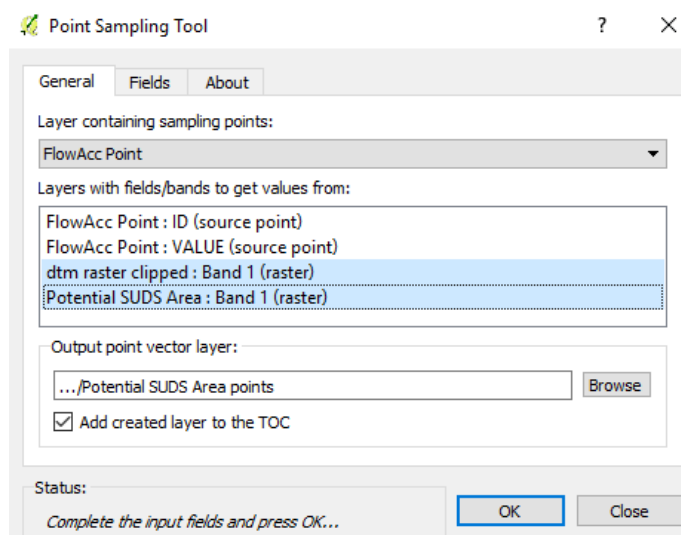


Figure 40: Example working sheet for the [Point Sampling Tool] plugin by Borys Jurgiel.

- 8.3 Extract point vectors out of the Potential SUDS Area points, which have the attribute "Potential SUDS Area VALUE" = 1. This attribute was added to the "Vector 14 – Potential SUDS Area points" in the previous step by the "Result Raster 1 – Potential SUDS Area" (A description what "VALUE" in the raster describe is given in Step 5.1 (p. 60)).

[QGIS – Extract by attribute]

(Processing Toolbox » search for: Extract by expression)

- I. Input Layer: "Vector 14 – Potential SUDS Area points"
- II. Selection attribute: Potential SUDS Area VALUE

[Plugin Sampling Tool] will cut the attribute name to 10 characters, so the real attribute name will be i.e. just "Potential " like in Figure 41
- III. Operator: =
- IV. Value: 1
- V. Extracted - Output Layer: "Vector 16 – selected Potential SUDS Area points"

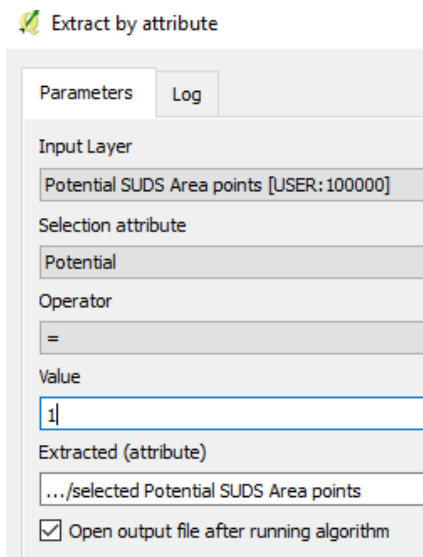


Figure 41: Example working sheet for [QGIS – Extract by attribute].

- 8.4 Calculate the distance between "Vector 16 – selected Potential SUDS Area points" and "Vector 15 – Main Flow Path points with elevation". Also [QGIS – Distance to nearest hub] adds attribute information from the nearest hub point to the related source point. The source point layer will be "Vector 16 – selected Potential SUDS Area points" and hub layer will be "Vector 15 – Main Flow Path points with elevation". By selecting elevation information as the add hub layer attribute, the Potential SUDS Area points will get the elevation of the nearest Main Flow Path point.

[QGIS – Distance to nearest hub]

(Processing Toolbox » search for: Distance to nearest hub)

- I. Input – Source point layer: "Vector 16 – selected Potential SUDS Area points"
- II. Destination hubs layer: "Vector 15 – Main Flow Path points with elevation"
- III. Hub layer name attribute: dtm raster clipped VALUE

This is the elevation data from "Raster 5 – dtm clipped". This attribute was added to the "Vector 15 – Main Flow Path points with elevation" in the Step 8.2 (p. 68).

[Plugin Sampling Tool] will cut the attribute name to 10 characters, so the real attribute name will be i.e. just "dtm raster" like in Figure 42

- IV. Output shape type: Point
- V. Measurement unit: Meter
- VI. Output – Hub distance: "Vector 17 – Potential SUDS Area points with hub dist and elev"

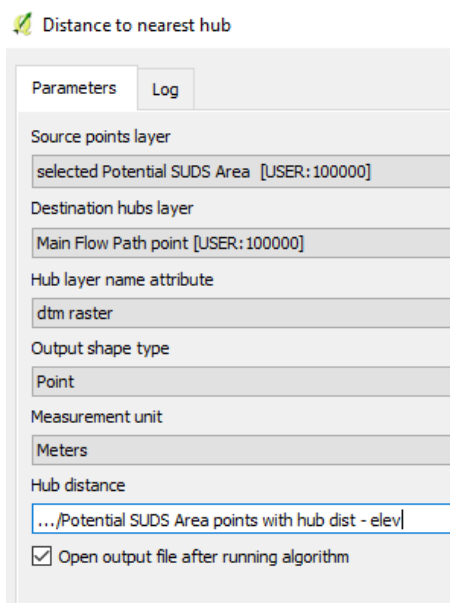


Figure 42: Example working sheet for [QGIS – Distance to nearest hub].

- 8.5 Extract point vectors out of the Potential SUDS Area points where the elevation of the Potential SUDS Area point is lower or equal than the elevation of the nearest Main Flow Path point, given to the vector as hub information in the previous step. This is the first step to get the High Potential SUDS Area points.

[QGIS – Extract by expression]

(Processing Toolbox » search for: Extract by expression)

- I. Input Layer: "Vector 17 – Potential SUDS Area points with hub dist and elev"

- II. Expression: **"dtm raster clipped VALUE" <= "HubName"**

"dtm raster clipped VALUE": own Elevation data of the Potential SUDS Area points. [Plugin Sampling Tool] in previous Step 8.2 will cut the attribute name to 10 characters, so the real attribute name will be i.e. just "dtm raster".

"HubName": Hub attribute, the elevation of the nearest Main Flow Path point. The attribute name "HubName" will be generated automatically.

Check the real attribute names in the attribute table of "Vector 18 – Potential SUDS Area points with hub dist and elev", before you give the expression.

- III. Extracted Output Layer: "Vector 18 – lower Potential SUDS Area points"

- 8.6 Extract point vectors out of the lower Potential SUDS Area points which are close to the nearest Main Flow Path point. The distance attribute is given to the Potential SUDS Area points in Step 8.4. This is the final step to get the High Potential SUDS Area points.

[QGIS – Extract by attribute]

(Processing Toolbox » search for: Extract by expression)

- I. Define a threshold for the distance to the next Main Flow Path. A recommended value is 100 m.
- II. Input Layer: "Vector 18 – lower Potential SUDS Area points "
- III. Selection attribute: HubDist

"HubDist": Hub distance, the distance to the nearest Main Flow Path point. The attribute name "HubDist" will be generated automatically.
- IV. Operator: <=
- V. Value: defined threshold, i.e.: 100
- VI. Extracted - Output Layer: "Vector 19 – High Potential SUDS Area points"

- 8.7 Create the "Result Raster 3 – High Potential SUDS Area" out of the High Potential SUDS Area points. Therefore, the attribute "Potential SUDS Area VALUE" (which for every point is 1) from High Potential SUDS Area points will be written over a raster template with cell values = 0.

[GDAL – Rasterize (vector to raster)]

(Menu bar » Raster » Conversion » Rasterize (vector to raster))

- I. Input file (shapefile): "Vector 19 – High Potential SUDS Area points"
- II. Attribute field: "Potential SUDS Area VALUE"

[Plugin Sampling Tool] in previous Step 8.2 will cut the attribute name to 10 characters, so the real attribute name will be i.e. just "Potential "

- III. Output file for rasterized vectors (raster):

This will override an existing raster. Copy the template raster before, rename them and choose these copies as output. Do so as followed:

copy "Raster 7 – template zero" » rename Copy "Raster 7 – template zero" to "Result Raster 3 – High Potential SUDS Area" » select "Result Raster 3 – High Potential SUDS Area" as output file

- IV. Check "Keep existing raster size and resolution"

-
- 8.8 Convert the "Result Raster 3 – High Potential SUDS Area" to separated polygons, which can be used in a post-processing GIS analyse.

[QGIS – Polygonize (Raster to vector)]

(Menu bar » Raster » Conversion » Polygonize (Raster to vector))

- I. Input file: "Result Raster 3 – High Potential SUDS Area"
- II. Output file for polygons (shapefile): "Result Vector 2 – High Potential SUDS Area"
- III. Field name: DN

-
- 8.9 The created polygons may have a few topology errors, which could cause calculation errors. Step 9 (p. 74) describes some methods to check and correct the polygons.

Step 9 Check features for topology errors

- 9.1 Because the "Result Vector 1 – Potential SUDS Area" and "Result Vector 2 – High Potential SUDS Area" are created out of raster, there is the high chance for topological errors. With the [QGIS – Topology Checker] you can localise most of the errors in your data.

[QGIS – Topology Checker]

(install manually, if not already done)

- I. Menu bar » Plugins » Manage and Install Plugins...
- II. Search for "Topology Checker"
- III. Check Plugin
- IV. Menu bar » Vector » Topology Checker

This will open a new Topology Checker Panel, looking something like Figure 29a.

- V. Open the "Topology Rule Settings" (see Figure 29a)
- VI. Add the rule ' "Result Vector 1 – Potential SUDS Area" must not have invalid geometries ' and "Result Vector 2 – High Potential SUDS Area" must not have invalid geometries '. This could look something like Figure 29b).
- VII. Validate all

By validate the layer, you should see all areas with errors (If not continue with Step 9.2)

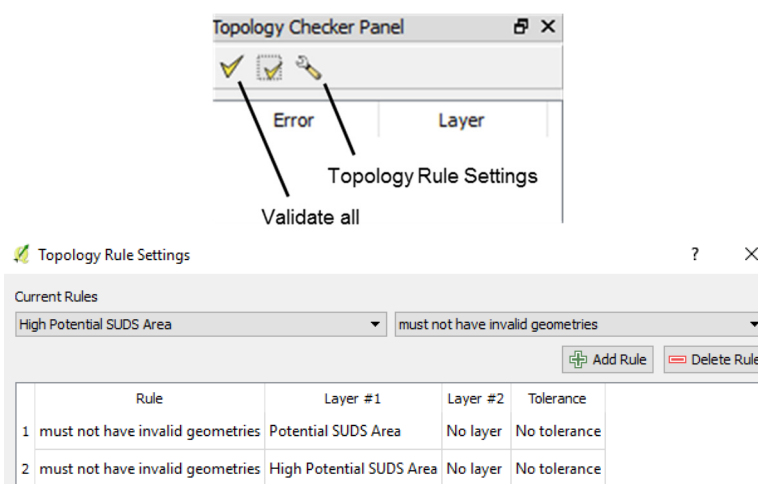


Figure 43: a) The Topology Checker Panel with button explanation and b) example working sheet for the Topology Rule Settings.

9.2 Sometimes the [QGIS – Topology Checker] does not show invalid geometries. If this is the case, you should check the polygons manually. The most likely reason for invalid geometries are two nodes with same coordinates (see Figure 44a for typical errors).

9.3 Adjust the errors by:

- I. Delete one of the nodes
- II. Move one node

In Figure 44b you can see the result of such adjustments.

How to edit and delete nodes is described in Chapter 2 step 7.2.

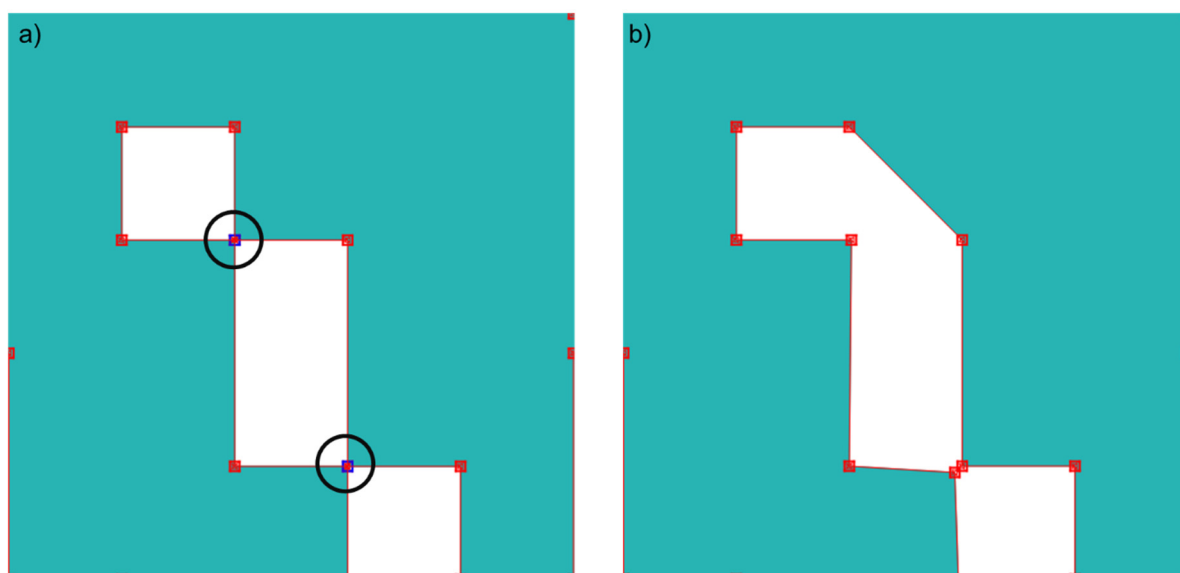


Figure 44: Example of polygonised raster, a) show the typical errors by two nodes with the same coordinates and b) possible error corrections by deleting one of the nodes for the upper error and just moving one of the nodes for the lower error.

6 SUDS Area Detection Algorithm – Combined models

To simplify the GIS process for getting the Potential SUDS Areas, Main Flow Paths and High Potential SUDS Areas, we have summarized all used GIS-tools into three QGIS models. You can download these models at www.klima2050.no and install them by just copy and paste the model data;

"Potential SUDS Area Detection.model"
"Main Flow Path Determination.model"
"High Potential SUDS Area Detection.model"

into the following QGIS user data installation folder:

C:\Users\\.qgis2\processing\models

This chapter will give you a stepwise description of the usage of these QGIS models to create the Potential SUDS Areas, Main Flow Paths and High Potential SUDS Areas. A detailed description of all used GIS tools will then be given in the next chapter "SUDS Area Detection Algorithm – ". The numbering of the Input and Output Raster and Vector data follow the numbering in the chapter "SUDS Area Detection Algorithm – ".

It is **required** to use the **same coordination reference system (CRS) for all input data**. See Chapter 2 about how to set the CRS.

Model 1 Potential SUDS Area Detection

- 1.1 The first model of the algorithm creates raster and vector data to show Potential SUDS Areas used in the Decision Support Method. These areas show locations in the catchment, where SUDS applications are recommended due to the landuse and surface slope. Figure 45a shows an example of input data from the study case in Trondheim (Muthanna et al., 2018). Figure 45b shows an example of the output of the analysis.

(This model combines tools used in Chapter "SUDS Area Detection Algorithm – ", Step 1, Step 2, Step 4 and Step 5.)

[QGIS Model 1 - Potential SUDS Area Detection]

(Processing Toolbox » search for: 1 - Potential SUDS Area Detection)

- III. Input Raster – Digital Terrain Model (dtm): "Raster 3 – converted dtm"
 - IV. Input Vector – Catchment Area: "Vector 10 – catchment area"
 - V. Input Vector – Landuse for SUDS application: "Vector 8 – landuse"
 - VI. Minimum Surface Slope (%): 0% (default value)
 - VII. Maximum Surface Slope (%): 10% (default value for swales)
 - VIII. Output Raster – Digital Terrain Model Clipped: "Raster 5 – dtm clipped"
- Dtm raster clipped to the catchment area.
- IX. Output Raster – Potential SUDS Areas: "Result Raster 1 – Potential SUDS Area"
- A raster showing all Potential SUDS Areas with the cell value 1.
- X. Output Raster – Slope: "Raster 15 – Slope"
- A raster giving slope values, calculated by the 9 parameter 2nd order method(Zevenberg and Thorne 1987).
- XI. Output Vector – Potential SUDS Areas: "Result Vector 1 – Potential SUDS Area"

Polygons showing all Potential SUDS Areas

- 1.2 The created polygons in "Result Vector 1 – Potential SUDS Area" will have a few topology errors, which could cause calculation errors. Chapter "SUDS Area Detection Algorithm – ", Step 9 (p. 74) describes some methods to check and correct these polygons.



Figure 45: a) Example Input Vectors showing building polygons in black, landuse polygons which enable SUDS applicates in green and elevation lines (not needed in the model). b) Example Output Vector for "Potential SUDS Areas", highlighted in blue and a WMS background map.

Model 2 Main Flow Path Determination

- 2.1 The second model of the algorithm creates raster and vector data to show Main Flow Paths used in the Decision Support Method. Main Flow Paths are regions with high surface runoff collection and are calculated by the flow accumulation in the catchment area. Therefore, it needs input data prepared in Chapter 2 and for "Model 1 - Potential SUDS Area Detection".

Model 2 needs two separated model-parts to run. In the first model-part we will calculate the flow accumulation using elevation data. It combines the tools used in Chapter "SUDS Area Detection Algorithm – ", Step 3 and Step 6.

[QGIS Model 2-1 – Main Flow Path Determination]

(Processing Toolbox » search for: 2-1 – Main Flow Path Determination)

- I. Input Raster – Digital Terrain Model (dtm): "Raster 3 – converted dtm"
- II. Input Raster – Digital Surface Model (dsm): "Raster 4 – converted dsm"
- III. Input Vector – Catchment Area: "Vector 10 – catchment area"
- IV. Input Vector – Buildings: "Vector 7 – buildings"
- V. Output Raster – Combined Elevation Model: "Raster 13 – combined elevation model"

A raster showing an elevation model which combine DSM elevation data for buildings and DTM elevation data for the terrain. Local depressions in the DTM are filled using "Fill sinks xxi (Wang & Liu)" from the SAGA GIS toolbox. You can see an example raster in Figure 46a.

- VI. Output Raster – Flow Accumulation: "Raster 18 – flow accumulation"

A raster showing the flow accumulation, calculated by "Catchment area (flow tracing)" from the SAGA GIS toolbox. You can see an example raster in Figure 46b.

- VII. Output Vector – Flow Accumulation Points: "Vector 11 – flow accumulation points"

Vector points showing all cells from the Flow Accumulation raster.



Figure 46: a) Example Input Raster "Combined Elevation Model" with data from the dtm for terrain and from dsm for buildings, also a WMS background map. b) Example Output Raster for flow accumulation, from low (blue) to high (red) accumulation and a WMS background map.

2.2 Next, we use model-part 2-2. This model-part combines the tools used in Chapter "GIS Decision Method – Single Tool Usage", Step 7. As a result we get the final vector data for the Main Flow Paths (see Figure 47).

[QGIS Model 2-2 – Main Flow Path Determination]

(Processing Toolbox » search for: 2-2 – Main Flow Path Determination)

- I. Input Vector – Flow Accumulation Points: "Vector 11 – flow accumulation points"
- II. Output Vector – Main Flow Path Points: "Vector 13 – Main Flow Path points"

Selected Flow Accumulation Points from the Input Vector, which show the Main Flow Path. Main Flow Path Points are all points with a flow accumulation value greater than the root mean square of all flow accumulation values.



Figure 47: Example Output Vector "Main Flow Path Points" in red and a WMS background map.

Model 3 High Potential SUDS Area Detection

- 3.1 The third and last model of the algorithm creates raster and vector data to show High Potential SUDS Areas used in the Decision Support Method. These areas show locations in the catchment, where SUDS applications are highly recommended due to the landuse and surface slope from the Potential SUDS Area Detection, and the close distance to lower Main Flow Paths. For this we use input data created in Chapter 2, in "Model 1 - Potential SUDS Area Detection" and in "Model 2 - Main Flow Path Determination". Figure 48a) shows example input data from the case study in Trondheim (Muthanna et al., 2018). Figure 48b) shows an example of output data.

This model combines the tools used in Chapter "SUDS Area Detection Algorithm – ", Step 8.

[QGIS Model 3 – High Potential SUDS Area Detection]

(Processing Toolbox » search for: 3 – High Potential SUDS Area Detection)

- I. Input Raster – Digital Terrain Model (DTM): "Raster 3 – converted dtm"
- II. Input Raster – Potential SUDS Areas: "Result Raster 1 – Potential SUDS Area"
- III. Input Vector – Catchment Area: "Vector 10 – catchment area"
- IV. Input Vector – Main Flow Path Points: "Vector 13 – Main Flow Path points"
- V. Maximum Distance to Main Flow Path (m): 100 (default)

The maximum distance between the Main Flow Paths and the nearest Potential SUDS Area, to create a High Potential SUDS Area.

- VI. Output Raster – High Potential SUDS Areas: "Result Raster 3 – High Potential SUDS Area"

A Raster showing all High Potential SUDS Areas with the cell value 1.

- VII. Output Vector – High Potential SUDS Areas: "Result Vector 2 – High Potential SUDS Area"

Polygons showing all High Potential SUDS Areas. In Figure 48b you can see example Vector Polygons.

-
- 3.2 The created polygons in "Result Vector 2 – High Potential SUDS Area" may have a few topology errors, which could cause calculation errors. Chapter "SUDS Area Detection Algorithm – ", Step 9 (p. 74) describes some methods to check and correct these polygons.

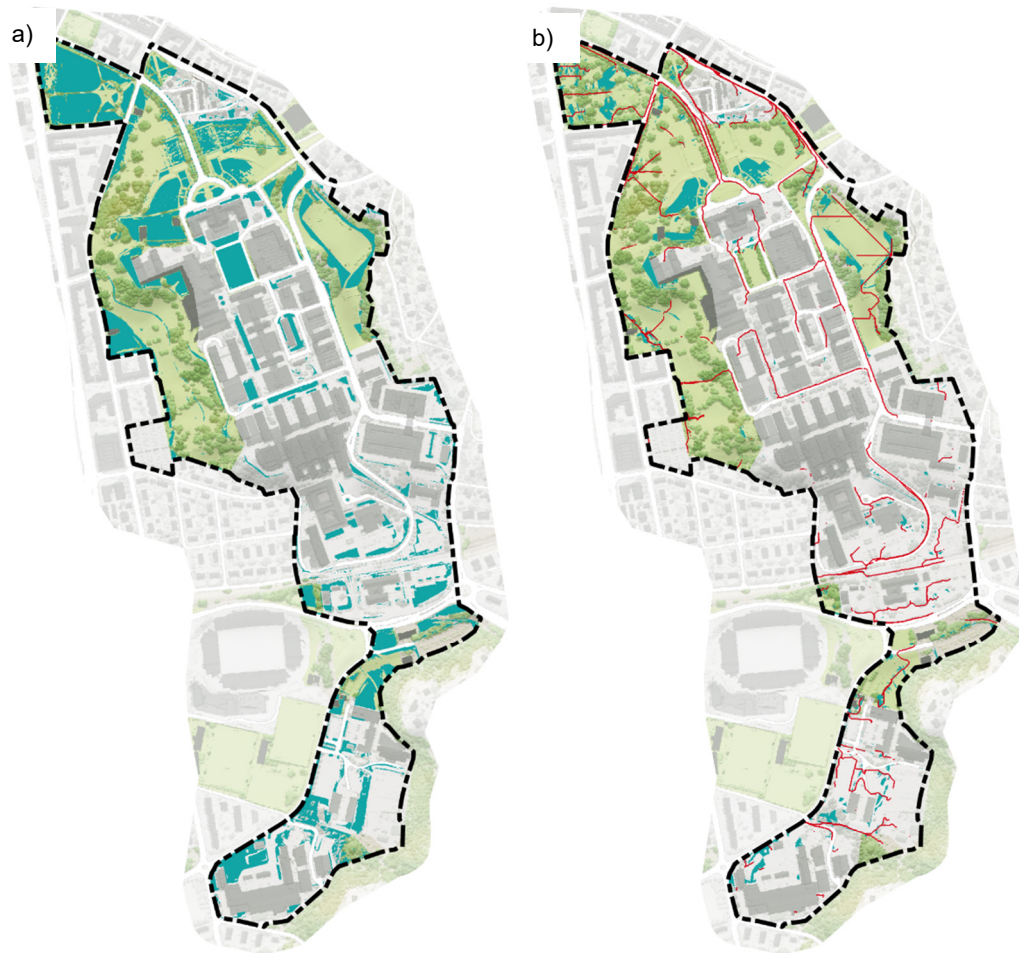


Figure 48: a) Example Input Vector "Potential SUDS Areas" in blue and a WMS background map. b) Example Input Vectors for "Main Flow Path points" in red and the resulting Output Vector "High Potential SUDS Area" in blue, also showing a WMS background map.

Literature

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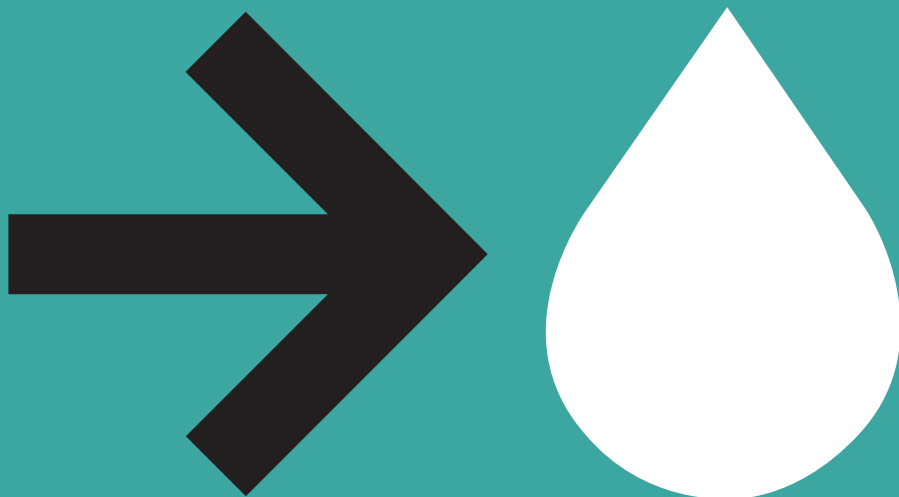
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