Deltares

WFlow manual

Model setup using QGIS and WTools

Version: April 29, 2015

© Deltares, 2015

© Deltares, 2015

Deltares

This manual is prepared by:

Daniel Tollenaar, Ifan Taufani, Maulina Indriyani, Ronald Vernimmen, Neeltje Goorden, Jaap Schellekens, Agnese Boccalon

Content: main document

1 Glossary **3**

2 Introduction: setup WFlow model(s) using QGIS and WTools **4**

3 Topographic layers **5**
3.1 Digital Elevation Model (DEM) 5
3.1.1 Description 5
3.1.2 (Free) sources 5
3.1.3 Preparation 6
3.2 Land use 6
3.2.1 Description 6
3.2.2 Free sources 6
3.2.3 Preparation 7
3.3 Soiltype 7
3.3.1 Description 7
3.3.2 Free sources 7
3.3.3 Preparation 8
3.4 River network and catchment 8
3.4.1 Description 8
3.4.2 Free sources 9
3.4.3 Preparation 10

4 WFlow model setup **11**
4.1 Maps: WFlow topographical description and forcing 11
4.1.1 PCRaster maps 11
4.1.2 WFlow grid 12
4.1.3 Static input 12
4.1.4 Dynamic input 13
4.2 Tables: WFlow parameterisation 16
4.2.1 Parameters and typical ranges 17
4.2.2 The structure of a tbl-file 18
4.2.3 The result 19

5 WFlow simulation **20**
5.1 Directory structure 20
5.2 Running WFlow 20
5.2.1 The ‘standard’ model run 21
5.2.2 The ‘FEWS’ model run 22
5.3 Run-directory 22

Appendices **23-54**

Content: appendices and exercises

A Software installation **23**

B QGIS **26**
B.1 Projections 26
B.1.3 **Exercise:** assigning a projection to a shapefile
B.1.4 **Exercise:** assigning a projection to a raster
B.2 WMS (OpenLayers plugin) 30
Exercise: Load Google Satellite as basemap
B.3 Vectors 31
B.3.1 **Exercise:** generate a new shapefile
B.3.2 **Exercise:** edit a shapefile
B.3.3 **Exercise:** change format (kml to ESRI shapefile)
B.3.4 **Exercise:** re-projecting a shapefile
B.3.5 **Exercise:** selecting attributes
B.4 Rasters 38
B.4.1 **Exercise:** convert raster format
B.4.2 **Exercise:** convert a shapefile to a raster
B.4.3 **Exercise:** clip a raster by a shapefile
B.4.4 **Exercise:** clip a raster to your window extent
B.4.5 **Exercise:** reclassify a raster
B.4.6 **Exercise:** merge existing rasters
B.4.7 **Exercise:** re-project a raster

C WTools **47**
C.1 WFlow and WTools 47
C.2 CatchRiver.exe 48
C.3 CreateGrid.exe 49
C.4 StaticMaps.exe 50

D PCRaster **51**
D.1 PCRaster 51
D.1 Aguila 52

E WFlow **53**
E.1 Command-line arguments 53
E.1 Ini-file 54

1 Glossary

CRS	Coordinate Reference System; a coordinate-based mapping system to map geospatial data.
Dynamic Input	PCRaster map-files (rasters) used in WFlow to describe forcing variables. It are 'dynamic' rasters, as cell-values change over time
FEWS	Flood Early Warning System, developed by Deltares. A system to store, visualize and process data, originally developed as support decision under flood conditions. In the context of this manual it is used as a desktop system to supply *Dynamic Input* for WFlow
GIS	Geographic Information System
LDD	Local Drainage Direction. The direction in which cell will discharge, based on its elevation relative to its neighbouring cells.
(ESRI) shapefile	Referring to ESRI shapefile (http://en.wikipedia.org/wiki/Shapefile), a popular format to store GIS vector data.
Static Input	PCRaster map-files (rasters) used in WFlow to describe topography. It are 'static' rasters as there is no change of data in time
(WFlow) tables	Tables describing the relation between a landuse-class, subcatchment, soiltype-class and a model parameter value

2 Introduction: setup WFlow model(s) using QGIS and WTools

This manual contains a procedure to setup WFlow models from topographic data and hydro-meteorological forcing using GIS techniques and WTools. GIS techniques will be explained using QGIS free and open source software. WTools is a set of tools developed to aid fast, consistent and simplified WFlow setup.

The procedure is shown in the schematic in Figure 2.1 and will be explained in the coming chapters in more detail:

Chapter 3: Generate a consistent set of topographic layers (chapter 3)

Chapter 4: Generate a WFlow model (*Model Input*) from the topographic data in (1) and a Hydro-meteorological database (chapter 4)

Chapter 5: Produce results (*Model output*) by running your model (chapter 5)

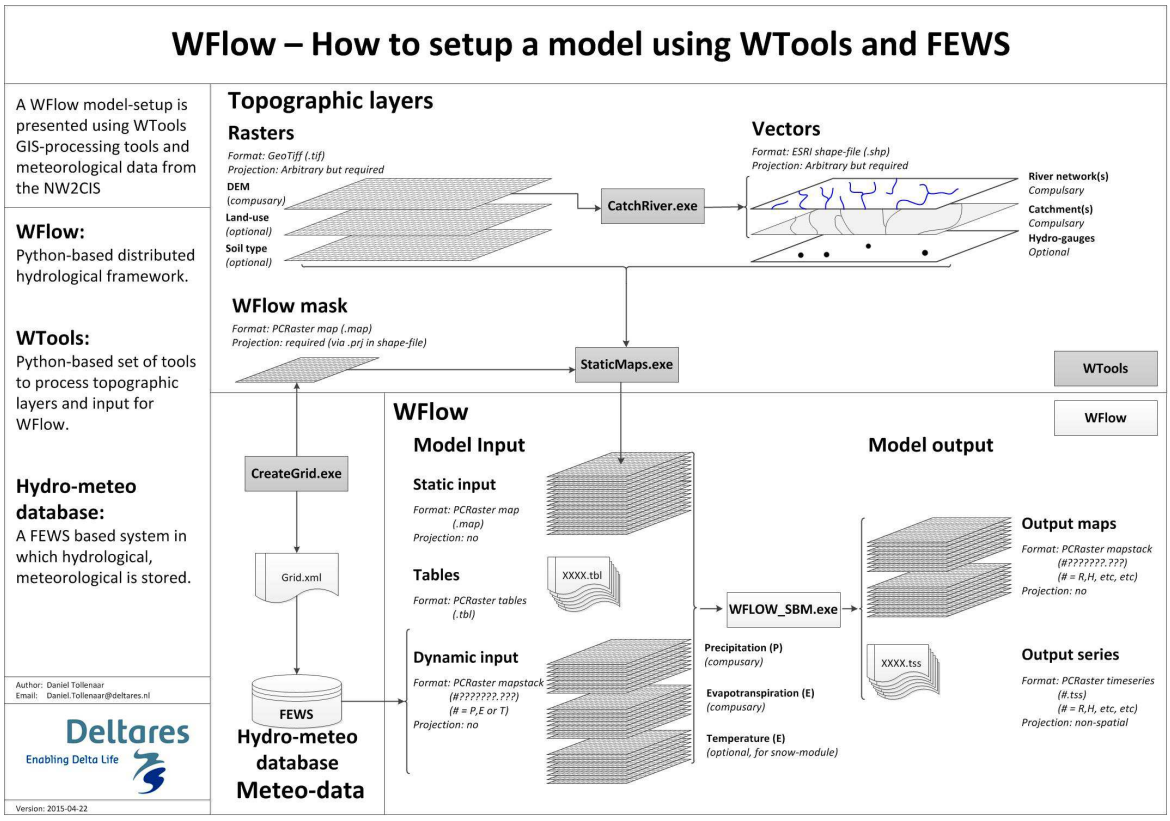


Figure 2.1 – Setup WFlow model using WTools

If you finish this manual, you will be able to derive and run WFlow models from topographic data. Depending on your needs, there is more to explore:

- To fully integrate your WFlow model in a FEWS configuration, please read the documentation at:
  - http://schj.home.xs4all.nl/html/wflow_adapt.html
  - http://ops-wflow.sourceforge.net/1.0RC7/wflow_adapt.html
- To calibrate a WFlow model by inter-comparison with observed discharges, please visit:
  - http://ops-wflow.sourceforge.net/1.0RC7/wflow_fit.html
  - http://ops-wflow.sourceforge.net/1.0RC7/calib_report.html

3 Topographic layers

A WFlow model can be derived with WTools from a supplied set of topographic layers. In this chapter, these layers will be described (see Figure 3.1):

- Digital Elevation Model (DEM): Compulsory data in raster-format
- landuse classes: Optional data in raster-format (GeoTiff)
- soiltype classes: Optional data in raster-format (GeoTiff)
- river network(s): Compusory data in polyline vector-format (ESRI-shapefile)
- catchment(s): Compulsory data in polygon vector-format (ESRI-shapefile)
- hydro-gauge(s): Optional data in point vector-format (ESRI-shapefile)

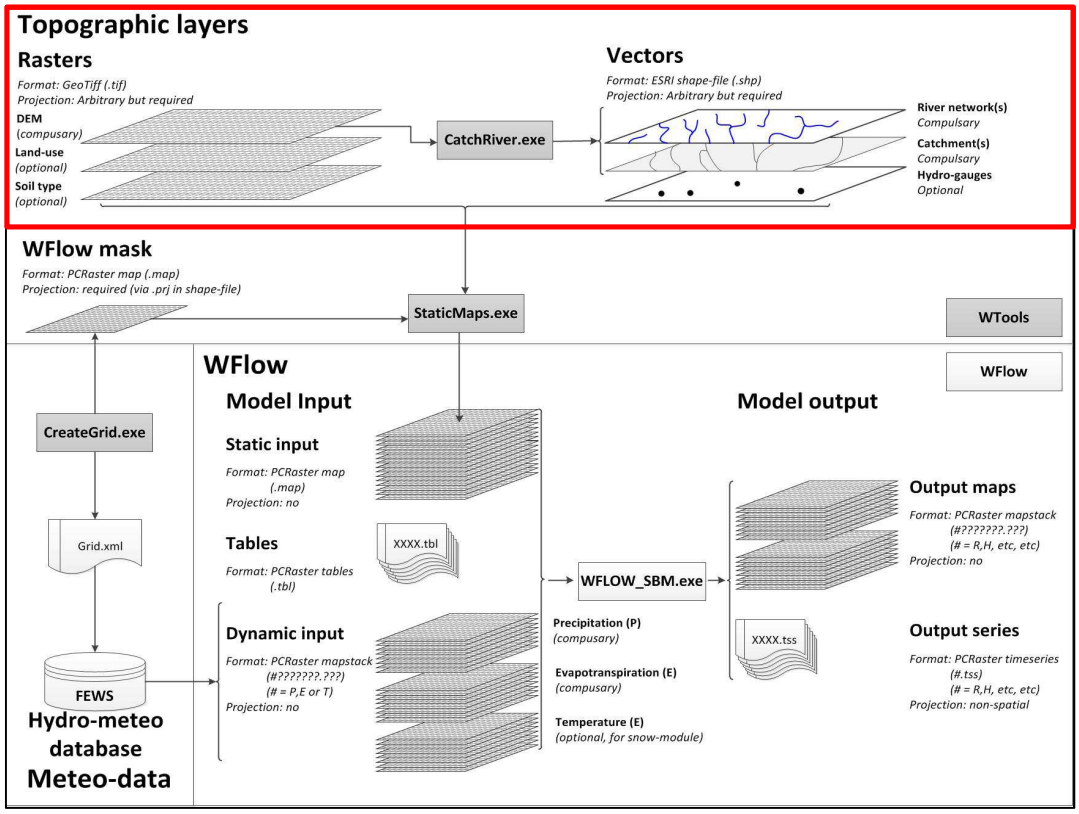


Figure 3.1 – Topgraphic layers section (red box) in the model setup procedure

3.1 Digital Elevation Model (DEM)

Geospatial properties of the DEM as input data for WFLOW:

Required format: GeoTiff (.tif)

CRS definition required: yes

3.1.1 Description

A Digital Elevation Model (DEM) describes the terrain elevation. A DEM is used as direct input for WFlow, as are derivatives, such as flow direction (Local Drainage Direction, LDD), stream-orders and sub-catchments.

3.1.2 (Free) sources

Continuous (raster) representations of elevation can be constructed by interpolation of ground surveys. Most commonly, DEMs are derived from earth observation.

SRTM
An elevation source which is often being referred to and used is SRTM (Shuttle Radar Topography Mission, 1999). SRTM resolution (30m or 90m) and accuracy is deemed acceptable as a DEM for WFlow. General information on SRTM data can be found at: http://www2.jpl.nasa.gov/srtm/.

To download SRTM 90m visit: http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp

To download SRTM30 m visit: http://earthexplorer.usgs.gov/

3.1.3 Preparation

The DEM should be prepared as input for WTools:

- The raster should be in GeoTiff format, including a projection definition and may need to be converted (see Exercise B.4.1 in the annexes).
- Some DEMs (e.g. SRTM) are supplied in tiles. Your area may be covered by more than one tile. These tiles need to be merged (see Exercise (0 in the annexes)
- NoData within the catchment boundary is not allowed, however cells covering sea should be set to NoData. For the latter, the raster can be clipped by a shapefile containing containing a land-mask (see Exercise B.4.3 in the annexes).

Note: SRTM 30m has NoData on land-surface. This should be filled first!

3.2 Land use

Geospatial properties of the land-use\land-cover input data for WFLOW:

Required format:	GeoTiff (.tif)
CRS definition required:	yes

3.2.1 Description

A landuse (or land use land cover: LULC) describes the use and/or cover of the land surface. In WFlow constants, used in the description of e.g. canopy-storage, infiltration and surface flow, can be related to a land use classification.

Note: only a sufficient amount of classes need to be defined to describe variability in constants. It is common to limit the amount off classes to 5-10. Typical classes are: water, paved, cropland, forest. From an original LULC map, classes with similar geo-hydrological characteristics need to be lumped using a reclassification.

3.2.2 Free sources

Nowadays there exist several online sources of land use data. Some of these sources are:

CRISP (Covering Indonesia, Malaysia and Singapore)
The Centre for Remote Imaging, Sensing and Processing (CRISP) of the National University of Singapore also provide a good alternative LULC data source to GlobCover. Data can be downloaded in GeoTiff on 250m resolution.

Data can be downloaded at: http://www.eorc.jaxa.jp/SAFE/LC_MAP/

ESAIoniaGlobCover
The European Space Agency (ESA) provides a Land Cover map at 300m resolution. GlobCover data have been collected by the Envisat environmental satellite.

Data can be downloaded at: http://maps.elie.ucl.ac.be/CCI/viewer/index.php

3.2.3 Preparation

The land cover maps should be prepared as input for WTools:

- The raster should be in GeoTiff format, including a projection definition and may need to be converted (see exercise B.4.1 in the annexes).
- A reclassification is usually required. Classes with similar geo-hydrological characteristics should be merged into one new class. In the GeoTiff, classes need to be numbered with subsequent integers starting at 1 (1,2,3,..). For this purpose, a reclassification is required (see exercise B.4.5 in the annexes)
- Some land-use of land-cover data is provided in shapefiles only. These need to be rasterized to a GeoTiff (see exercise 0 in the annexes)

3.3 Soiltype

Geospatial properties of the soil classification input data for WFLOW should be reclassified to:

Required format:	GeoTiff (.tif)
CRS definition required:	yes

3.3.1 Description

Soils have an important hydrological property of transporting and retaining water. In WFlow constants, used in the description of e.g. hydraulic conductivity and soil moisture storage, can be related to a soil type classification. Different values of constants can be assigned to different soil type classifications.

Soil classes vary in porosity (see Figure 3.2) and the depth of the hydrological base with respect to the surface elevation. These two properties mainly determine the hydraulic conductivity and storage capacity. As in the land-use classification, it is advised to limit the amount of soiltype classes to not more than 5-10.

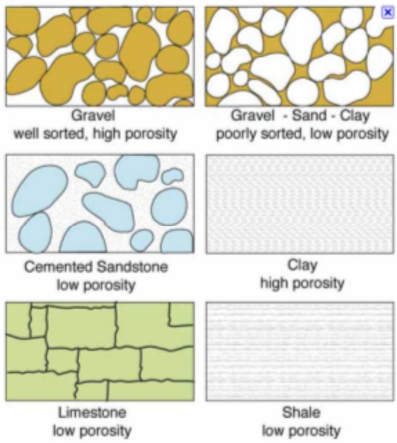


Figure 3.2 Porosity for different soil types (Source:http://www.amiadini.com/NewsletterArchive)

3.3.2 Free sources

FAO Digital Soil Map of the World (DSMW)

The Land and Water Division of the Food and Agriculture Organization of the United Nations (FAO) in collaboration with UNESCO has developed a digital world map of soils known as the *Digital Soil Map of the World (DSMW)*. This digital soil map is available in a vector format.

A more recent and refined source of information on soils mapping at the global scale is the FAO-IIASA (International Institute for Applied System Analysis) *Harmonized World Soil Database* (HWSD). The database was released in March 2009 and it uses the information

provided by the DSMW and integrates them with updated national and regional soil information collected from national institutes. This new database resulted from the recognized need to update the global agro-ecological zones study of FAO, and provides a more detailed information base for soil-related studies at a regional scale. The soil map was developed in 1:5.000.000 scale.

The soil map can be downloaded at:
http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116

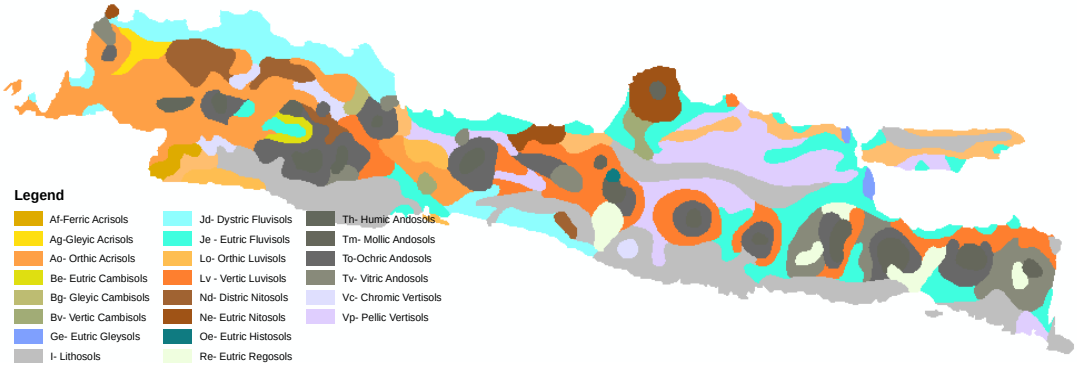


Figure 3.3 – Soil map of Java Island (DSMW FAO)

3.3.3 Preparation

The land cover maps should be prepared as input for WTools:

- The raster should be in GeoTiff format, including a projection definition and may need to be converted (see exercise B.4.1 in the annexes).
- A reclassification is usually required. Classes with similar geo-hydrological characteristics should be merged into one new class. In the GeoTiff, classes need to be numbered with subsequent integers starting at 1 (1,2,3,..). For this purpose, a reclassification is required (see exercise B.4.5 in the annexes)
- Some soil classification data (e.g. DSMW) is provided in shapefiles only. These need to be rasterized to a GeoTiff (see exercise 0 in the annexes)

3.4 River network and catchment

If not available from other sources, the river network and catchment delineation can be generated by CatchRiver.exe from the WTools package (see annex C.2). The following geospatial properties are required for the river network shapefile:

Data format:	ESRI shapefile (.shp)
Vector type:	Polyline
Attributes required:	None
CRS required:	yes

The following geospatial properties are required for the catchment shapefile:

Data format:	ESRI shapefile (.shp)
Vector type:	Polygon
Attributes required:	None
CRS required:	yes

3.4.1 Description

River networks and catchments are used to define the boundaries of the WFlow computation-grid and direction of flow. It is required for the generation of static input (see section 4.1.3).

For the Wflow model a river network needs to be supplied. This network should consist of polylines representing the river-axis. Every polylines represents a river segment between (1) two river confluences, (2) the river source and a confluence, (3) the river source and downstream boundary, or (4) the river source and first confluence. All polylines should be defined in downstream direction; the first point having the highest elevation. An example of an incorrect and correct river network is given in Figure 3.4. For every catchment used as input, only one river network, with one downstream boundary should be defined.

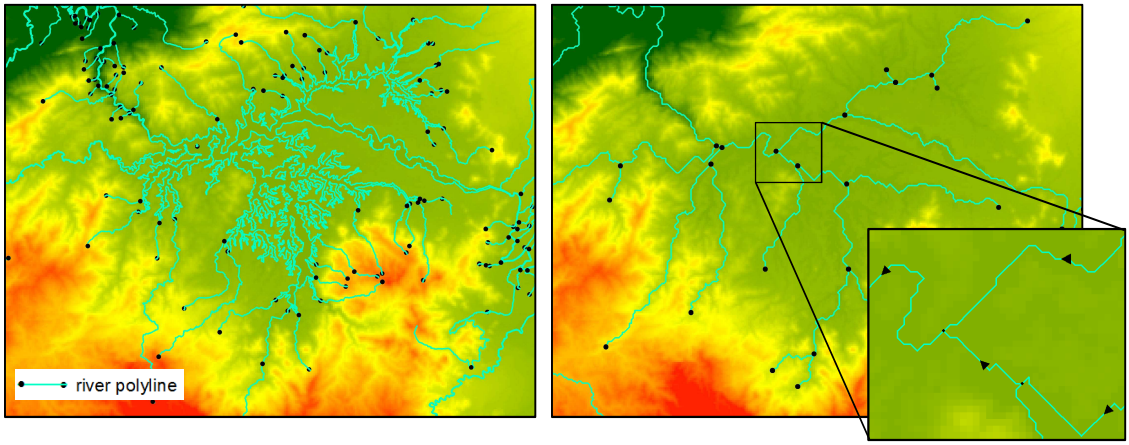


Figure 3.4 – Incorrect network layer (left) and correct network layer (right) around the Sangulin reservoir – Citarum - Indonesia

A catchment or drainage basin is an extent or an area of land where surface water from precipitation converges to a single point at a lower elevation. For Wflow this point is usually the river mouth where the river discharges to the sea. This point defines the downstream boundary condition of the hydrological model.

As input for the derivation of static input (see section 4.1.3), one shapefile with one or multiple polygons can be supplied in a catchments shapefile. For every polygon a river network should be supplied in the rivernetworks shapefile (see e.g. Figure 3.5).

3.4.2 Free sources

A ready available product comprising both valid river networks and catchments is provided by USGS. River networks and catchment delineations derived from a DEM of 15 arcsec ad 30 arcsed can be downloaded as ESRI shapefile:

Data can be downloaded via: http://hydrosheds.cr.usgs.gov/dataavail.php

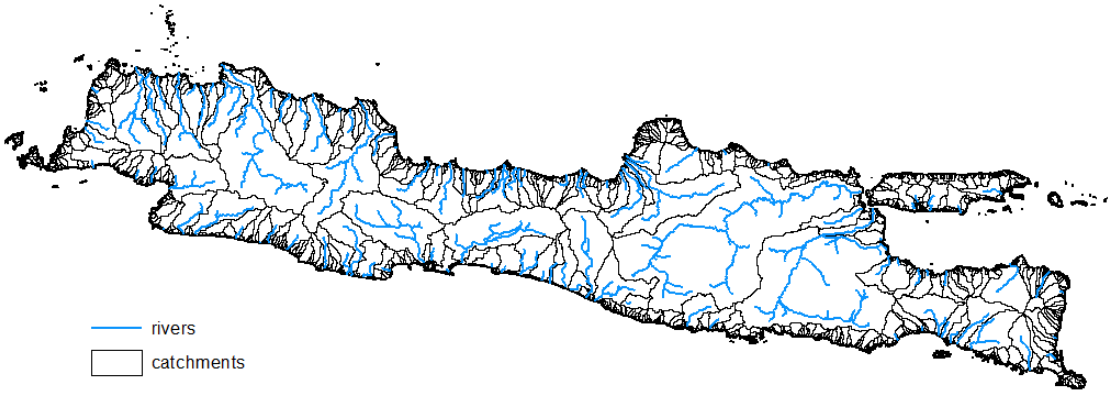


Figure 3.5 – HydroSheds rivernetworks and catchments layers of Java Island - Indonesia

3.4.3 Preparation

The catchment and rivers shapefile can be derived from the DEM only or (optional) with support of shapefiles, indicating the river course, river mouth and water bodies. For learning how to create and edit shapefiles, please view exercise B.3.1 and B.3.2.

CatchRiver.exe (see Annex C.2 for details) is the tool which will generate the river network and catchment(s) shapefiles from the command-line:

CatchRiver.exe [-d dem (raster)] [-l burn_line (shape)] [-p burn_point (shape)] [-a burn_area (shape)] [-R riverout (shape)] [-C catchmentout (shape)] [-O min strahler order (integer)] [-B burn value (integer)] –S

Defining the outlets and rivers are important to get a good result, especially in lowland areas. This is explained by the delineation of the Citarum catchment (see.Figure 3.6). First we just use an SRTM90 DEM:

CatchRiver.exe –d DEM_JAVA_CITARUM.tif –O 6

The result is shown in the left-hand side of Figure 3.6. As the SRTM is flat in the low-land area, it is not delineated correctly.

Then we try it with the help of a river shape (not a network yet!!) and outlets:

CatchRiver.exe –d DEM_JAVA_CITARUM.tif –l river_selection.shp –p outlets.shp –O 6

The generated river network now follows *river_selection.shp* and uses the point in *outlets.shp* as its downstream boundary.

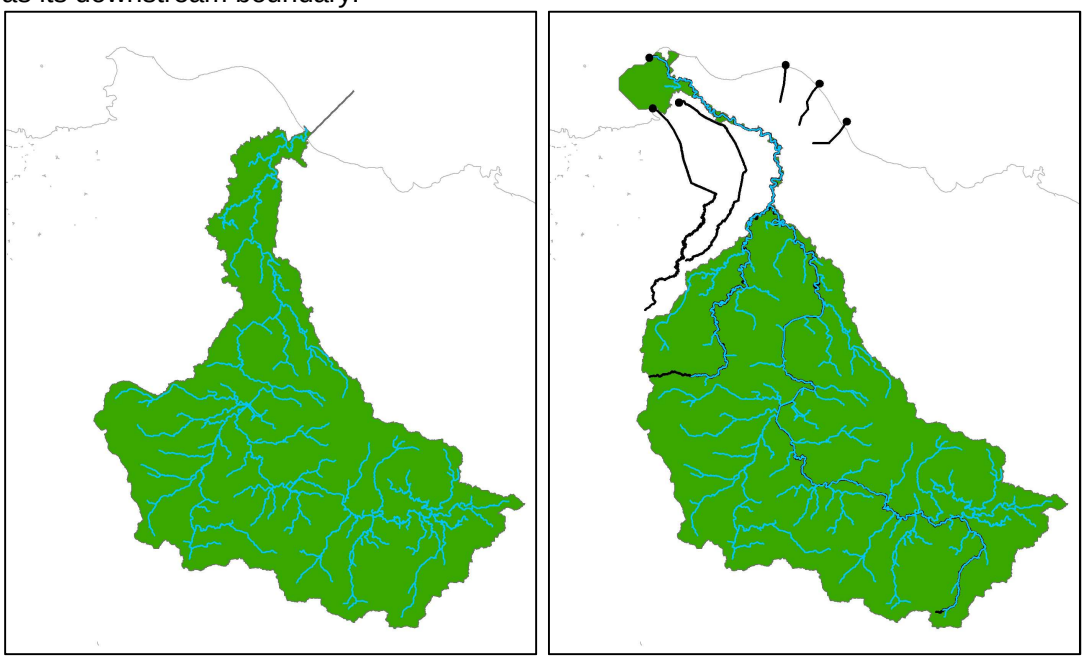


Figure 3.6 – Catchment (green) and river network (blue) without (left) and with (right) outlets (black dot) and main river (black line) defined.

4 WFlow model setup

From the topographic layers a WFlow model can be build, using the WTools StaticMaps.exe and CreateGrid.exe. Forcing for WFlow, precipitation, evapotranspiration and optionally temperature (required for the snow module), can be extracted from a FEWS-database.

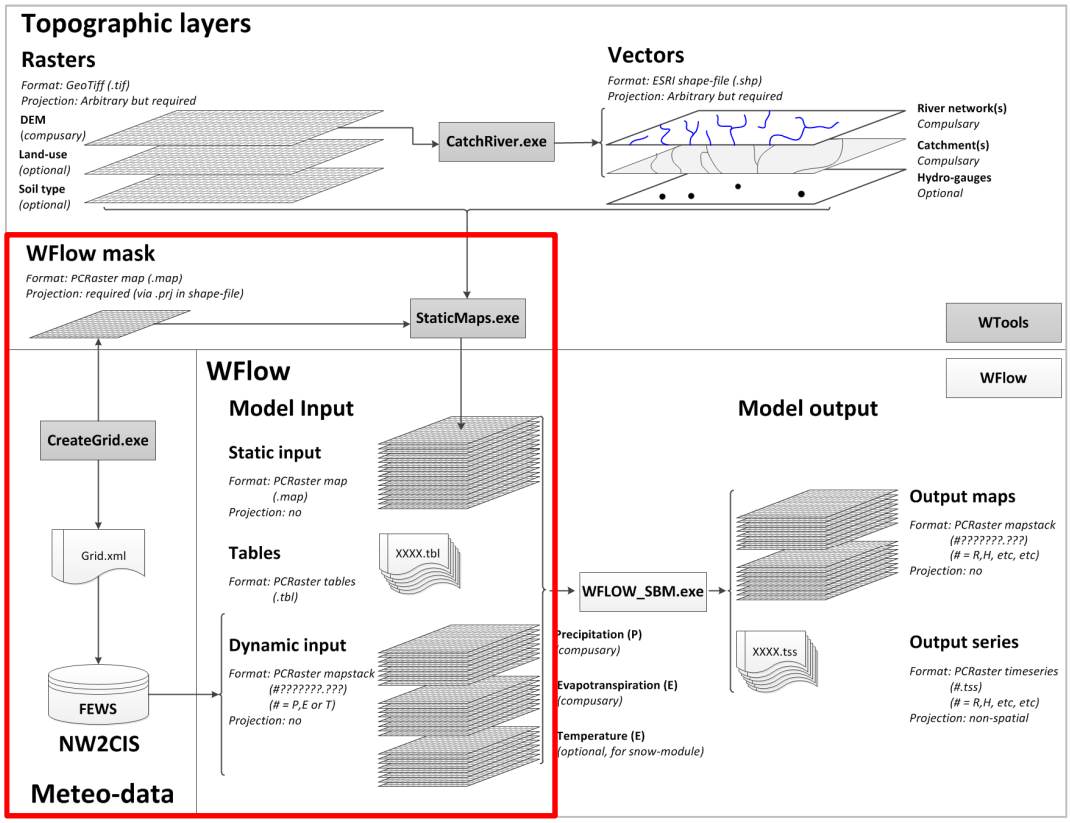


Figure 4.1 – WFlow input maps indicated in the model setup scheme with a red box

4.1 Maps: WFlow topographical description and forcing

4.1.1 PCRaster maps

For WFlow, topographic and forcing data are stored in PCRaster maps. PCRaster maps are rasters similar to GeoTiffs. In contrast to GeoTiffs, a CRS cannot be assigned to the map directly. For WFlow, all PCRaster maps, must have equal map projections. In other words, they should be in the same CRS, have the same cell size (cell length), same amount of columns and rows and the same origin (see Figure 4.2).

PCRaster maps come in with two extensions; (1) the extention .map for rasters fixed in time (static maps) or (2) the extentions .001, .002, .00# for rasters dynamic in time. For example, you can find PCRaster maps P0000000.001, P0000000.002, P0000000.003 in which data is stored for the parameter P (usually precipitation) for the first 3 timesteps.

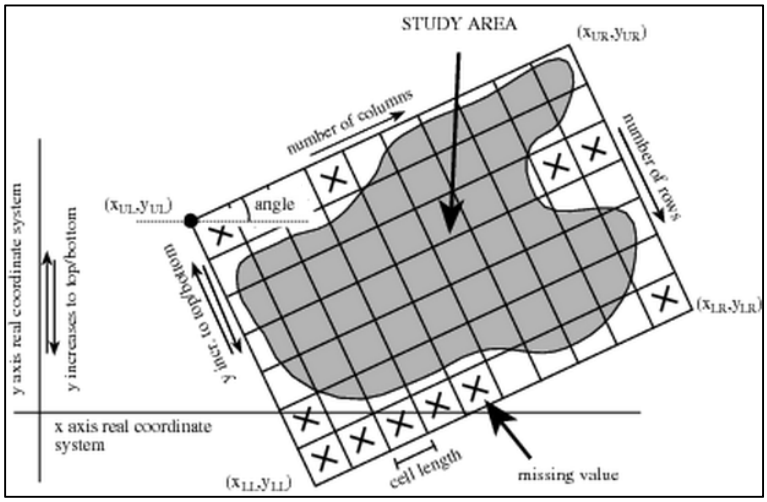


Figure 4.2 – PCRaster map projection

4.1.2 WFlow grid

The WFlow grid is the grid-definition for a WFlow model covering one or more catchment(s). It defines the extent and the resolution of the model. The WFlow grid can be generated by WTools using CreateGrid.exe (see annex C.3). All other data will be projected into this grid-definition

For CreateGrid.exe, a GIS-file from which the extent will be read and a cell-size is required. The GIS-file can be a shapefile or a GeoTiff. Most commonly, the catchment shapefile (see section 3.4) is used.

Choose your model-grid wisely. Fast models run with <100000 cells. Fast models have an advantage in calibration (requiring often many model runs), operational systems (requiring fast results) and or long model-runs. However, sometimes more cells are required when large areas are to be analysed in one model. Most common cell-size is 100-250m. Smaller cell sizes can be chosen in, for example in highly, heterogenic areas. Larger cell-sizes can be chosen when space and time resolutions are smaller. This could be the case in water resources studies.

4.1.3 Static input

Static input is the translation of topographic layers into WFlow PCRaster maps. PCRaster maps can be generated using StaticMaps.exe (see annex C.3), providing the topographic layers (see chapter 3) and WFlow grid (see previous section) as input.

These maps describe:

- Model boundaries: the upstream boundaries by the catchment mask and the downstream boundary by the identification of the outlet
- Elevation: an elevation map, elevation percentiles and a minimum and maximum. Percentiles, minimum and maximum maps are calculated
- Rivers and flow direction: indication of rivers, strahler orders, length of a river within a cell and local drainage direction (ldd)
- Result samplers: a sub-catchment map and sub-catchment outlets (gauges) map, to extract catchment averages and catchment outflows (discharges)
- Model parameterization: land-use (land cover) and soiltype maps to relate model parameters to.

A list of StaticMaps:

Model boundary maps:

- wflow_catchment.map (ordinal)
- wflow_outlet.map (scalar)

Elevation maps:

- wflow_dem.map (scalar)
- wflow_demmax.map (scalar)
- wflow_demmin.map (scalar)
- wflow-dem*percentile* - (10,25,33,50,66,75,90) (scalar)

River and flow direction maps:

- wflow_river.map (ordinal)
- wflow_streamorder.map (ordinal)
- wflow_riverlength_fact.map (scalar)
- wflow_ldd.map (ldd)

Result sample maps:

- wflow_gauges.map (ordinal)
- wflow_subcatch.map (ordinal)

Model parameterization maps

- wflow_landuse.map (nominal)
- wflow_soil.map (nominal)

4.1.4 Dynamic input

Dynamic input is stored in PCRaster time-series maps. These maps have the properties described in section 4.1. By default three parameters are used: (1) *P* for precipitation, (2) *PET* for potential evapotranspiration and (3) *T* for temperature (optional). If a model is to be run 5 timesteps (e.g. days) and no snow is to be modelled, the following input should be provided:

- Precipitation: P0000000.001, P0000000.002, P0000000.003, P0000000.004, P0000000.005
- Evapotranspiration: PET00000.001, PET00000.002, PET00000.003, PET00000.004, PET00000.005

Note: the total length of a file-name should be not more or less than 8 characters!

4.1.4.1 Generate dynamic input from FEWS

A FEWS-configuration is available with TRMM rainfall and EUWATCH evapotranspiration. Dynamic data can be extracted from this configuration by (1) modification of the grid definition FEWS to the WFlow grid (see section 4.1.2), (2) importing TRMM and WATCH data in FEWS and (3) exporting the dynamic maps by running the export workflow in FEWS

1. Modification of grid-definition in FEWS
   - Open *Grids.xml* located in: *…\FEWS_WFLOW\Config\RegionConfigFiles* and the *Grids.xml* in the mask-folder, created by CreateGrid.exe in a text-editor

- Overwrite the “wflow_mask” grid-definition in *…\FEWS_WFLOW\Config\RegionConfigFiles\Grids.xml* (line 260-270) by the definition in *mask\Grids.xml*, created by CreateGrid.exe (see Figure 4.3)
- Save *…\FEWS_WFLOW\Config\RegionConfigFiles\Grids.xml*

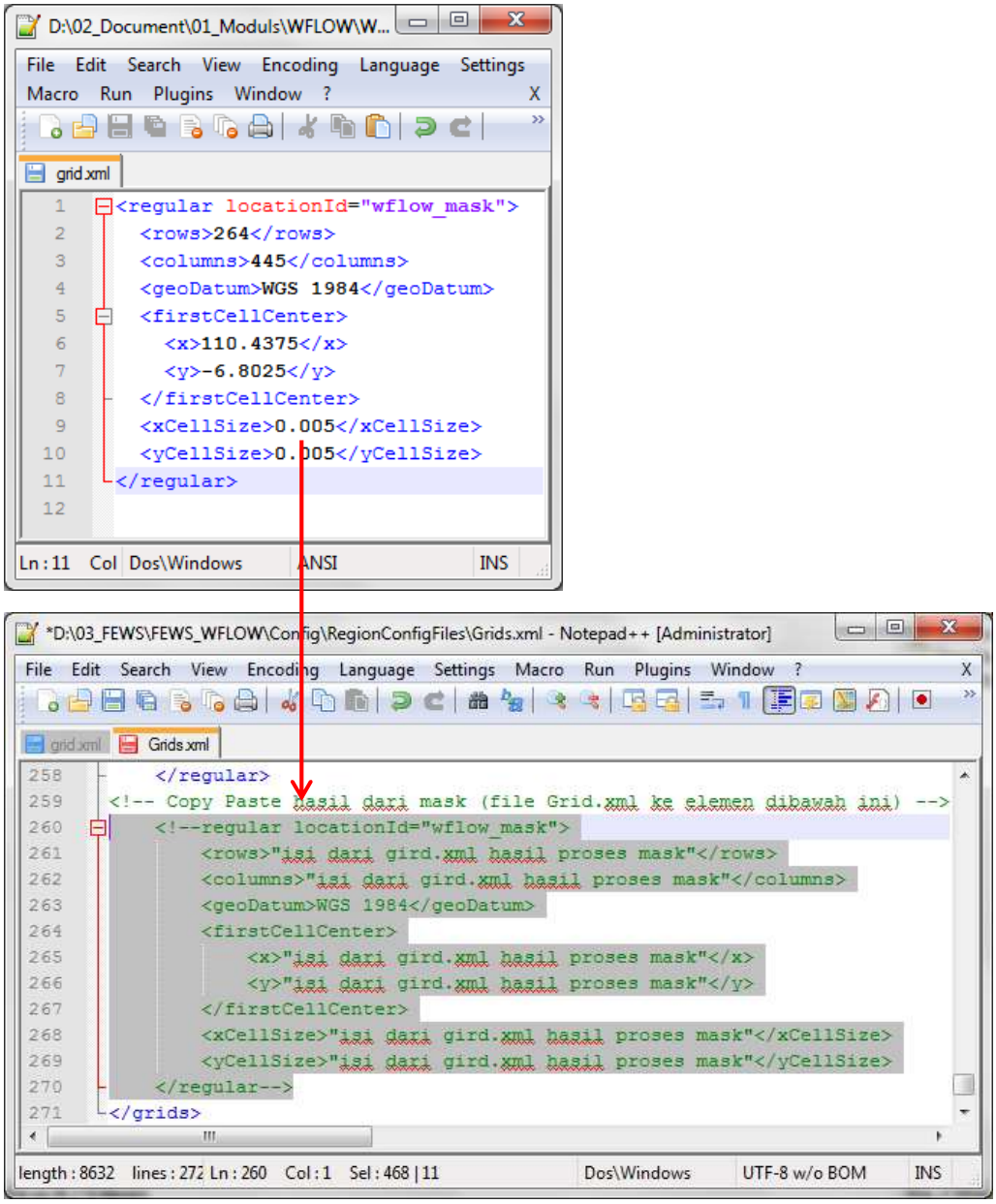


Figure 4.3 Copy and Paste Grid definition

2. Import TRMM and WATCH in FEWS

- Start FEWS by double clicking the executable in the bin-folder
- Open workflow window by clicking Manual Forecast button
- The *Manual Forecast* window will appear. Select (1) *Import global data* workflow. Please make sure you enter correct date in Single forecast T0, as we will import 2009 data, (2) fill T0 with *31-12-2009 00:00:00*. (3) Click *run* to execute the workflow.

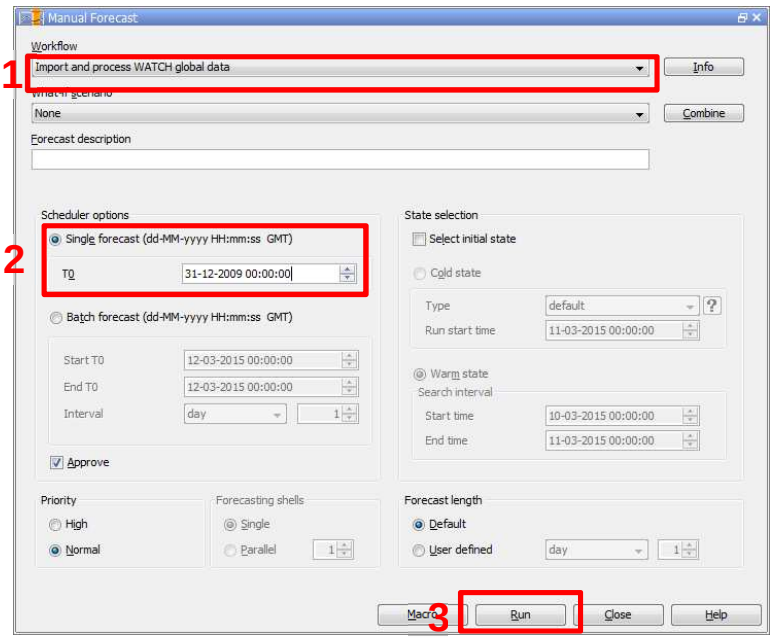


Figure 4.4 Import WATCH data

3. Export WFlow forcing data
   After importing TRMM and WATCH forcing data, you can now export the data for WFlow
   - Select the workflow *Export forcing to WFlow*. Set (1), the T0 setting at (or later than) the T0 of the Import WATCH data. Click (2) *Run* (see Figure 4.5).
   - If all steps where successful, you can find P and PET map already exported in *…\FEWS_WFLOW\modules\wflow\wflow_mask\inmaps* directory. You should have 365 map file for P and 365 maps file for PET (see Figure 4.6). You can view the maps using Aguila (see annex 0)

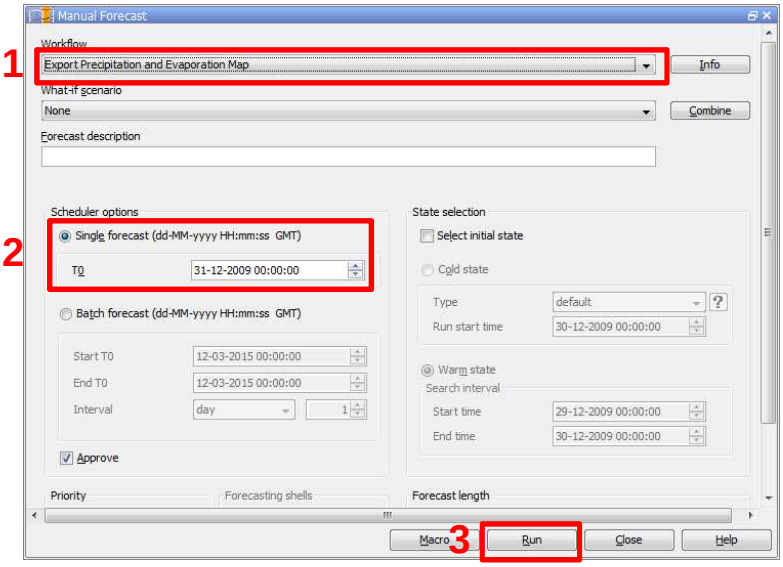


Figure 4.5 Import TRMM data

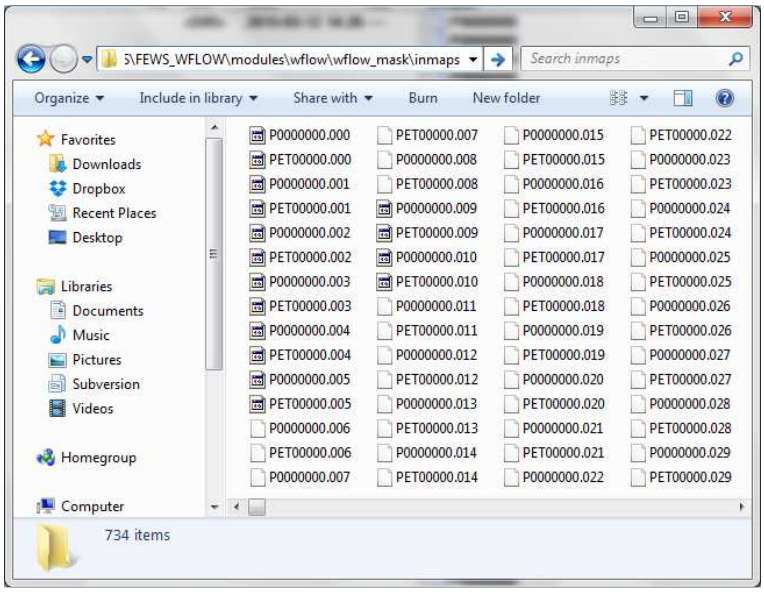


Figure 4.6 P and PET maps

4.1.4.2 *Generate dynamic input from Earth2Observe*

-

4.1.4.3 *Conversion scripts for data-sources*

-

4.2 Tables: WFlow parameterisation

Tables are used to link landuse, sub-catchments and soiltype maps to model parameters. Please also visit: http://ops-wflow.sourceforge.net/1.0RC7/wflow_sbm.html#guidelines-for-wflowsbm-model-parameters.

A description of the PCRaster table-format can be found on the PCRaster website: http://pcraster.geo.uu.nl/pcraster/4.0.0/doc/manual/secdatbase.html#table-format

4.2.1 Parameters and typical ranges

More on the meaning of different WFlow parameters can be found at http://ops-wflow.sourceforge.net/1.0RC7/wflow_sbm.html#guidelines-for-wflowsbm-model-parameters. In Table 4.1 typical ranges for WFlow parameters are given. Parameters can be related to a landuse and soiltype classification as will be explained in the next section.

Table 4.1 – WFlow parameters, typical values and relations

Name	Unit	Value range (default)	Related to	Source	Description
Albedo	-	0-1	Land use	(Lutz Breuer, 2003)	The reflecting power of a surface.
Beta	-	0.6	Single value	(Schellekens, 2011)	Used in the kinematic wave function.
CanopyGapFraction	-	0-1	Land use	(Schellekens, 2011)	Fraction of the surface which is not covered by a canopy.
EoverR	-	0-1	Single value	(Schellekens, 2011)	Ratio of average wet canopy evaporation rate over average precipitation rate.
FirstZoneCapacity	mm	0-20000	Single value	(Schellekens, 2011)	Maximum capacity of the saturated store.
FirstZoneKsatVer	mm/day	0-10000	Soiltype	(Natural Resources Conservation Service)	Saturated conductivity of the store at the surface.
FirstZoneMinCapacity	mm	0-400	Soiltype	(Decagon Devices, 2012)	Minimum capacity of the saturated store.
InfiltCapPath	mm/day	5	Single value	(Schellekens, 2011)	Infiltration rate of the compacted soil (or paved area) fraction of each gridcell.
InfiltCapSoil	mm/day	25-750	Soiltype	(Brouwer, 1990)	Infiltration capacity of the non-compacted soil fraction (unpaved area) of each gridcell.
LeafAreaIndex	-	0-10	Land use	(Lutz Breuer,	One half the total green leaf area per unit

Name	Unit	Value range (default)	Related to	Source	Description
				2003)	ground surface area.
M	-	20-2000	Single value	(Schellekens, 2011) (Brooks, Boll, & McDaniel, 2004)	Soil parameter determining the decrease of saturated conductivity with depth.
MaxCanopyStorage	mm	0-10	Land use	(Lutz Breuer, 2003)	The maximum canopy storage.
N_River	-	0.01-0.6	Land use	(Chow 1983, Alfred J. Kalyanapu1, 2009)	Manning roughness parameter for river flow
N	-	0.02-0.15	Single value	(Schellekens, 2011)	Manning roughness parameter for surface flow
PathFrac	-	0-1	Land use	(AMEZQUITA Edgar)	Path frac is compacted area per grid cell.
RootingDepth	mm	0-5000	Land use	(Kazuhito Ichii, 2009)	Rooting depth of the vegetation.
thetaR	-	0.001-0.1	Soiltype	(Wikipedia) (Fisher, 2000)	Theta R is residual water content.
thetaS	-	0.2-0.5	Soiltype	(Wikipedia) (Fisher, 2000)	Theta S is water content at saturation.

4.2.2 The structure of a tbl-file

The tbl-file (.tbl) is a text-file with four columns separated by spaces or tabs. The first three column are *key fields*; they refer to a certain landuse class, sub-catchment or soiltype. The fourth column contains the parameter value:

- Column 1: the landuse class(es) to which the parameter value is assigned
- Column 2: the subcatchment(2) to which the parameter value is assigned
- Column 3: the soiltype class(es) to which the parameter value is assigned
- Column 4: the parameter value

A *key field* contains a single value, or a range of values, where a range of values is typed as: ‘[‘ or ‘<’ ,minimum value, comma ‘,’, maximum value, ‘]’ or ‘>’. The minimum and maximum values are included in the range if square brackets (‘[‘ and ‘]’) are used, they are not included if point brackets (‘<’ or ‘>’) are used.

An example is given in Figure 4.7:

- For landuse class 3 (included) and larger, all sub-catchments and soiltype 1, the parameter value is 250
- For landuse classes smaller than 3 (excluded), all sub-catchments and soiltype 1, the parameter value is 500
- For all landuse classes, sub-catchments and soiltype 2, the parametervalue is 350
- For all landuse classes, sub-catchments and soiltypes larger than 3 (included), the parameter value is 400

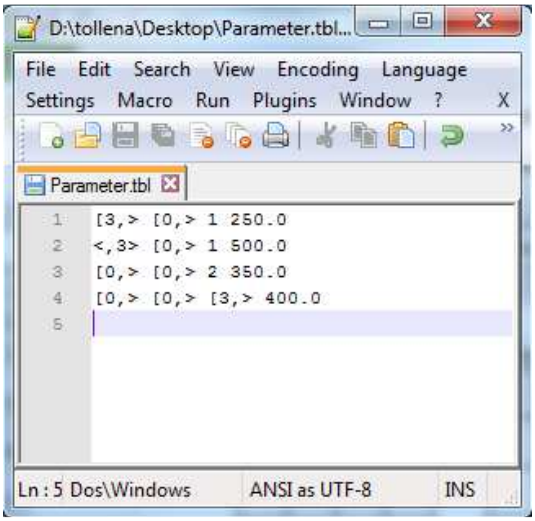


Figure 4.7 Example tbl-file

4.2.3 The result

Figure 4.8 shows a resulting parameter raster, based on the staticmaps (1) wflow_landuse.map, (2) wflow_subcatch.map, (3) wflow_soiltype.map and the tbl-file shown in Figure 4.7 for an arbitrary parameter. The table serves as a 'lookup' between the three input maps and the parameter result map.

The parameter maps will be written in the sub-directory outsum located in the run-directory after completion of a WFlow simulation (see section 5.3).

wflow_landuse.map

2	2	1	1
2	2	1	1
3	2	1	1
3	1	5	1
3	3	5	5
3	5	5	5

wflow_subcatch.map

1	2	2	2
1	2	2	2
1	1	2	2
1	1	2	2
1	1	2	2
1	1	2	2

wflow_soiltype.map

3	3	3	2
3	3	3	2
3	1	2	2
1	1	1	2
1	1	1	5
1	1	1	5

result: parameter

400	400	400	350
400	400	400	350
400	500	350	350
250	500	250	350
250	250	250	400
250	250	250	400

Figure 4.8 Parameter values, linked to landuse, sub-catchment, soiltype by a table file

5 WFlow simulation

When all WFlow input is generated, the model can be run. In Figure 5.1 this step is indicated in the model-setup scheme.

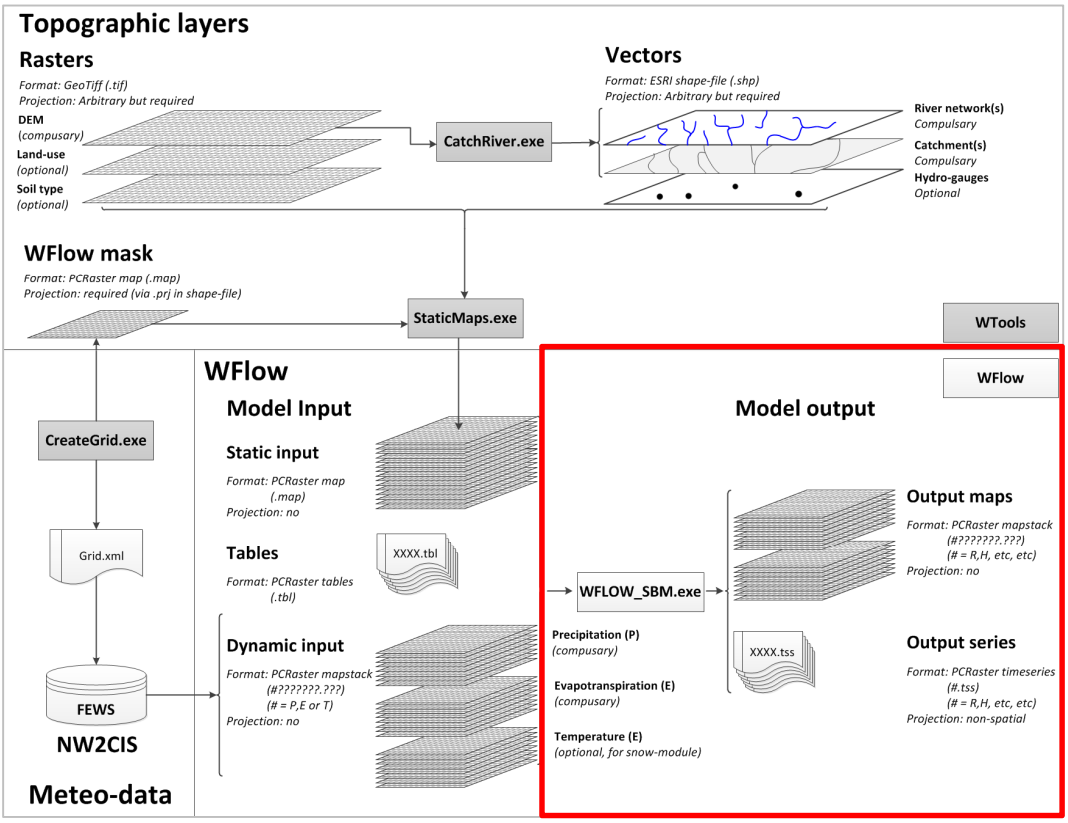


Figure 5.1 WFlow model run indication in model-setup scheme with a red box

5.1 Directory structure

A WFlow project should be setup with the following directory structure:

- *bin*: directory with the WFlow software
- *MyCatchment*: the case-directory, where all data is stored for a particular catchment. The directory contains at least the following sub-directories:
  - *inmaps:* folder containing dynamic input (see section 4.1.4)
  - *instate:* folder where an initial state are stored (optional, derived from a model run)
  - *intbl:* folder where all tables are stored (optional, see section 4.2)
  - *staticmaps: folder containing static input (see section 4.1.3)*

  Also an ini-file should be supplied depending on the hydrological concept used:
  - *wflow_sbm.ini:* settings for a WFlow-SBM model
  - *wflow_hbv.ini:* settings for a WFlow-HBV model

5.2 Running WFlow

The WFlow software is stored in the bin-directory. A catchment model can be run via the DOS command-line (see Figure 5.2). In annex E.1 a full list of (advanced) command-line options is given to run a WFlow model. In this section we only discuss necessary options to start a model.

5.2.1 The ‘standard’ model run

The model-start is shown in Figure 5.2, uses the following options:

-C: to specify the case-directory (see previous section)

-R: to specify the run-directory where all results will be stored (see section 5.3)

-f: option to force overwriting existing results (if the run-directory already exists and you want to overwrite all data)

-T: option to specify the amount of time steps to be run (by default the timesteps will be determined from the amount of dynamic input maps, see section 4.1.4)

-s: timestep (seconds) in which the model is run (and dynamic input is supplied)

In Figure 5.3, the last lines are shown of a successful model-run with the arguments as supplied in Figure 5.2.

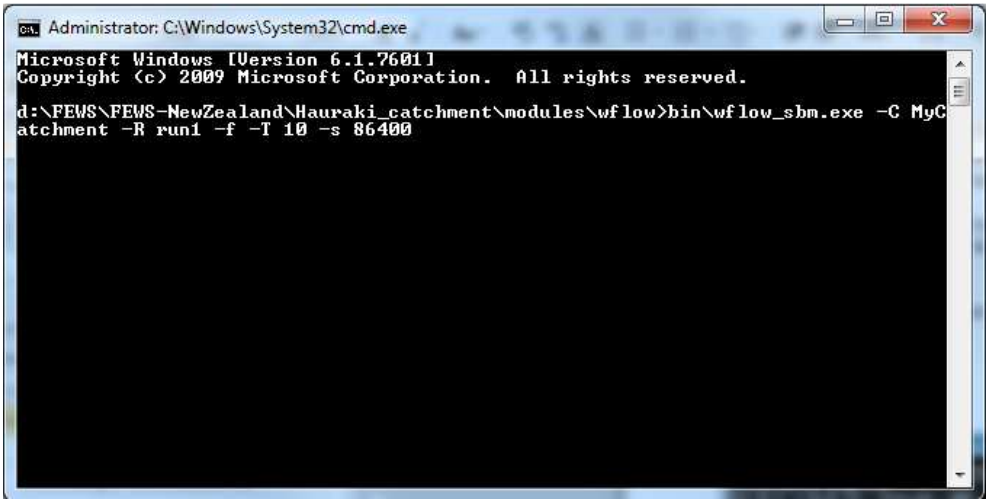


Figure 5.2 Configuring a model-run

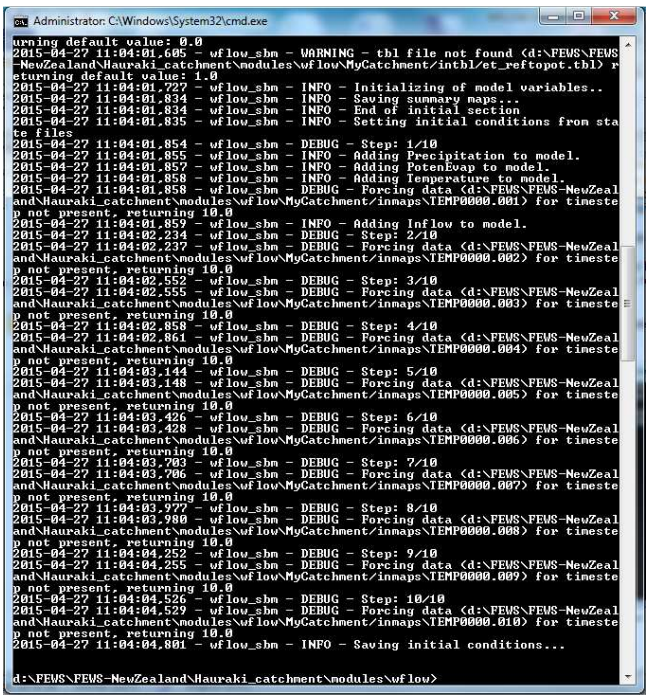


Figure 5.3 Successfully completed run

5.2.2 The 'FEWS' model run

Besides exporting dynamic input, a runinfo.xml can be exported with FEWS. The amount of timesteps can be read from this file. As example:

bin\wflow_sbm.exe -C MyCatchment -R FEWS -F MyCatchment\inmaps\runinfo.xml -f -s 86400

Where:
-F: reference to the runinfo.xml where the timesteps will be read

5.3 Run-directory

Each model run, generates a run-directory, where output is stored. This folder is stored in the case-directory. The default name of the directory is *run_default*, which can be overwritten using the *–R* argument.

The run-directory contains the following sub-directories:

- *Intbl:* a copy of the intbl-directory in the case-directory
- *outmaps:* directory where all output maps, specified in the ini-file are stored
- *outstate:* directory where the model state of the last timestep will be stored
- *outsum:* directory containing PCRaster maps with the water balance, (cumulative) fluxes and modelparameters
- *runinfo:* directory containing a copy of the ini-file and the configuration of the model-run

The run-directory contains a *wflow.log* file where all command-line messages are written to. If set in the ini-file, the directory contains csv (.csv) or tss files (.), where time-series results are stored.

A Software installation

A.1 WFlow

WFlow is a distributed hydrological modeling platform WFlow is part of the Deltares OpenStreams project (www.openstreams.nl). WFlow consists of a set f python programs that can be run on the command-line and perform hydrological simulations. The models are based on the PCRaster python framework (www.pcraster.eu, see section 0).

WFlow can be downloaded at http://sourceforge.net/projects/ops-wflow/ (last visited 22-04-2015). There a 64 bit version can be downloaded via the download button:

The zip-file contains a folder with all binaries and dlls required to run WFlow models. No installation is required.

On the code-section of the web-page the source-code can be downloaded. 32 Bit versions of the software can be compiled on request. Please send an email to: daniel.tollenaar@deltares.nl or jaap.schellekens@deltares.nl for such requests.

A.2 WTools

WTools is a set of tools for deriving static input (see section 4.1.3) for the WFlow model from topographic information stored in a GIS data-base.

WTools is supplied in a zip-file containing a folder with all binaries and dlls required to run WTools. No installation is required.

A.3 PCRaster

PCRaster Is a collection of free software targeted at the development and deployment of spatio-temporal environmental models (see www.pcraster.eu, last visited 22-04-2015). It is used to run WFlow and WTools.

The latest release can be downloaded from the website in a 32 bit and 64 bit version in a zip-file. The content of the zip-file can be extracted any-where on your computer, most logically in the “program files” directory. After installation an update of the windows environment variables is required (see section A.5)

A.4 QGIS

QGIS is a free and open source Geographic Information System (GIS). The software can be downloaded at www.qgis.org (last visited 22-04-2015). In this chapter we will discuss basic GIS-data handling techniques, required to process GIS data for WTools and WFlow.

The newest version of QGIS can be downloaded from www.qgis.org. QGIS can be downloaded for multiple operating systems in a 64 bit and 32 bit version. You can follow a normal installation procedure. After installation of the software an update of the windows environment variables is required (see section A.5)

A.5 Updating Windows environment variables

After installation of PCRaster and QGIS, an update of the Windows Environment Variables is required for a proper execution of WFlow and WTools:

1. Right-click on *Start*, and then *Open Windows Explorer.*
2. Right-click on *Computer*, then *Properties.*
3. In the System Control Panel, click *Advanced System Settings.*
4. Click the *Advanced* tab (see Figure appendix 1).
5. Click *Environment Variables* (see Figure appendix 1).
6. Be careful with the following two steps, and do not delete or modify one or more of the existing entries (unless you really know what you are doing)
7. In the *User variables* section, either select the *PATH* variable and click edit, or add a new variable and name it *PATH* (see Figure appendix 1).
8. Add the path of the *bin* directory of the extracted PCRaster and the QGIS package to the *Variable value* field, e.g:

   c:\Program Files\pcraster-4.0.2_x86-64\bin; c:\Program Files\QGIS Wien\bin\;

   Add the path at the beginning of the field. Note the extra semicolon (;) at the end, it is required to separate various entries. Do not add spaces around the semicolon.
9. Add a new variable *gdal_data* and add the path to the folder where the file *gcs.csv* is located, e.g.:

   c:\Program Files\QGIS Wien\share\epsg_csv\;

10. You should now be able to run on command prompt: *pcrcalc, gdal_translate, gdalwarp and gdal_rasterize* from the command-line. Go to *Start* and type *cmd*. In the program 'command-prompt' you can execute the commands listed above (see Figure appendix 2). Note, some systems have to be rebooted first.

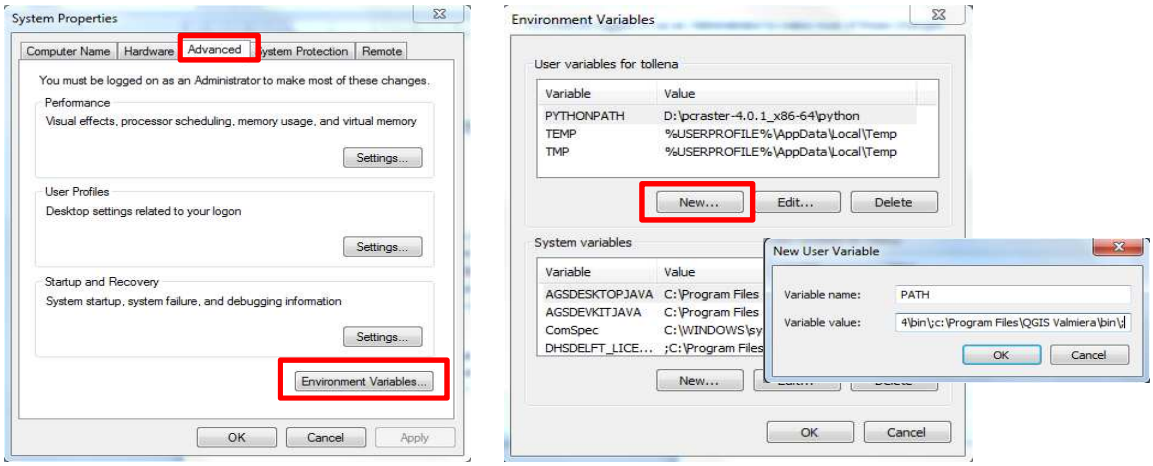
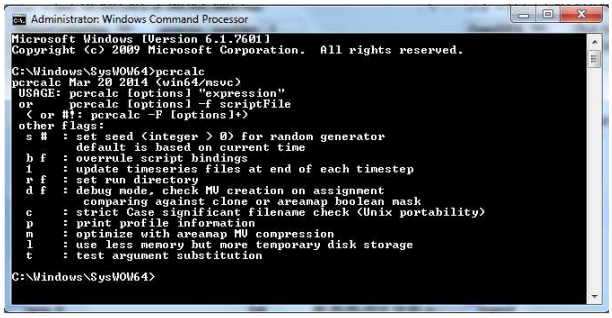
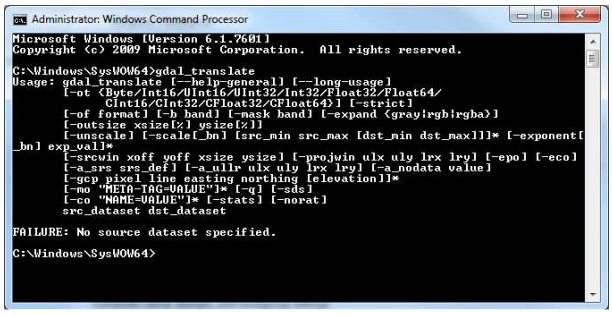
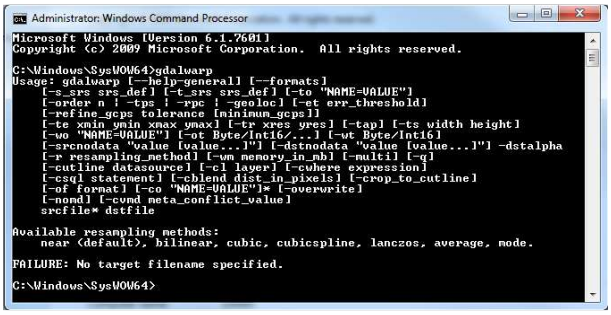


Figure appendix 1 – Adding environment variables







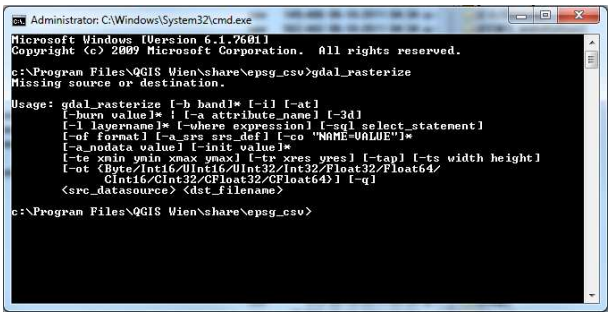


Figure appendix 2 – Running pcrcalc, gdal_translate, gdalwarp and gdal_rasterize on the command-line

B QGIS

If QGIS has to be installed, please read section A.4 and A.5 first. In this appendix some techniques in handling vector-data and raster-data will be explained required to derive input for WTools and WFlow. All material is generated using QGIS 2.8 Wien. On the QGIS website (www.qgis.org) abundant documentation can be found on how to work with GIS data. Some material in this annex is copied from the user manual on the QGIS website.

Note: this documentation does contain a brief description on QGIS functionality which is required for WFlow and WTools only. For a deeper understanding about QGIS, please visit the website

B.1 Projections

A coordinate reference system (CRS) is a geographical coordinate-based mapping system allowing for referencing spatial information in a plane ore on a globe (ellipsoid). A location is expressed by coordinates in X,Y,Z. All geographic data used in WFlow and WTools, such as rainfall, elevation, land-use, etc. are projected in a CRS. This CRS can using degrees (latitude\longitude) or metres as unit for XY coordinates and meters + datum for the Z-coordinate.

Note: all data should be projected in the same CRS!

B.1.1 WGS84

The most widely known CRS using latitude and longitude (degrees) is the World Geodetic System (WGS84). A XY-coordinate of a location in the WGS84 CRS is expressed in degrees longitude (X) and latitude (Y). De distance between two points in X-direction reduces from the equator to the poles. At the equator, one degree equals:

1 degree = 40,075.017 Km* 1/360degrees ≈ 111.32Km

1 degree can be subdivided into arcminutes (‘) and arcseconds (‘’). At the equator:

1 arcsec (=or 1’’) = 40,075.017 Km* 1/360degrees *1/60min * 1/60sec ≈ 0.0309 Km ≈ 30.9 m

B.1.2 UTM

The most widely known CRS to geo-reference a point in a plane is the Universal Transverse Mercator (UTM) system. A XY-coordinate of a location in a UTM CRS is expressed in meters from its origin. Where WGS84 is one system to describe any location in the world, UTM is divided in 60 zones for the northern and southern hemisphere (see Figure appendix 3).

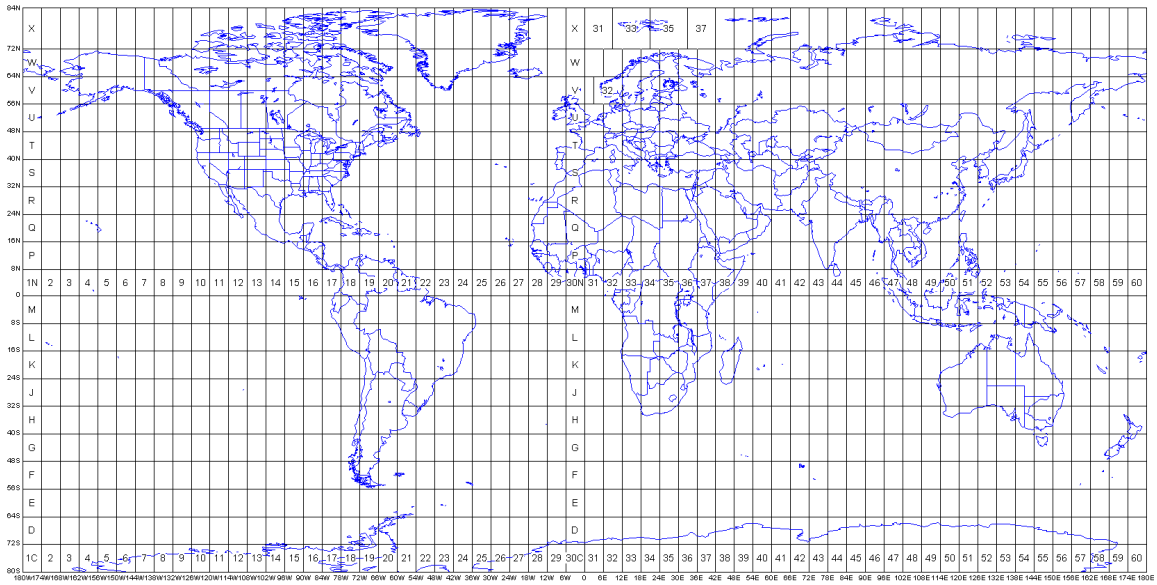


Figure appendix 3 – UTM zones

B.1.3 Exercise: assigning a projection to a shapefile

In this exercise you will learn how to assign a Coordinate Reference System (CRS) to an existing shapefile. The data can be found on *A_Exersise_data\Exercise_B.1.3*, where you can find the following files:

- Catchment_Citarum.dbf containing the attributes
- Catchment_Citarum.shp containing geometries
- Catchment_Citarum.shx linking the attributes to the geometries

We are missing a .prj file, containing the CRS of the shapefile. We will assign in this exercise using QGIS:

1. *Add vector layer* and locate *A_Exersise_data\Exercise_B.1.3\ Catchment_Citarum.shp*. The warning box of "CRS was undefined, defaulting to CRS EPSG-4326 – WGS" will pop up (see Figure appendix 4).
2. In the menu, go to (1) *Vector* → *Data Management Tools* → *Define Current Projection* (see Figure appendix 5)
3. Choose Use *predefined spatial reference system* and click on box *Choose*. The gialog box of Coordinate Reference System selection will appear (see Figure appendix 6).
4. Search for WGS84 *(EPSG:4326),* and press *OK.* When processing is completed, the file *Exersise_data\Exercise_B.1.3\ Catchment_Citarum.prj* will be created. The CRS of the shapefile can now be found by GIS software.

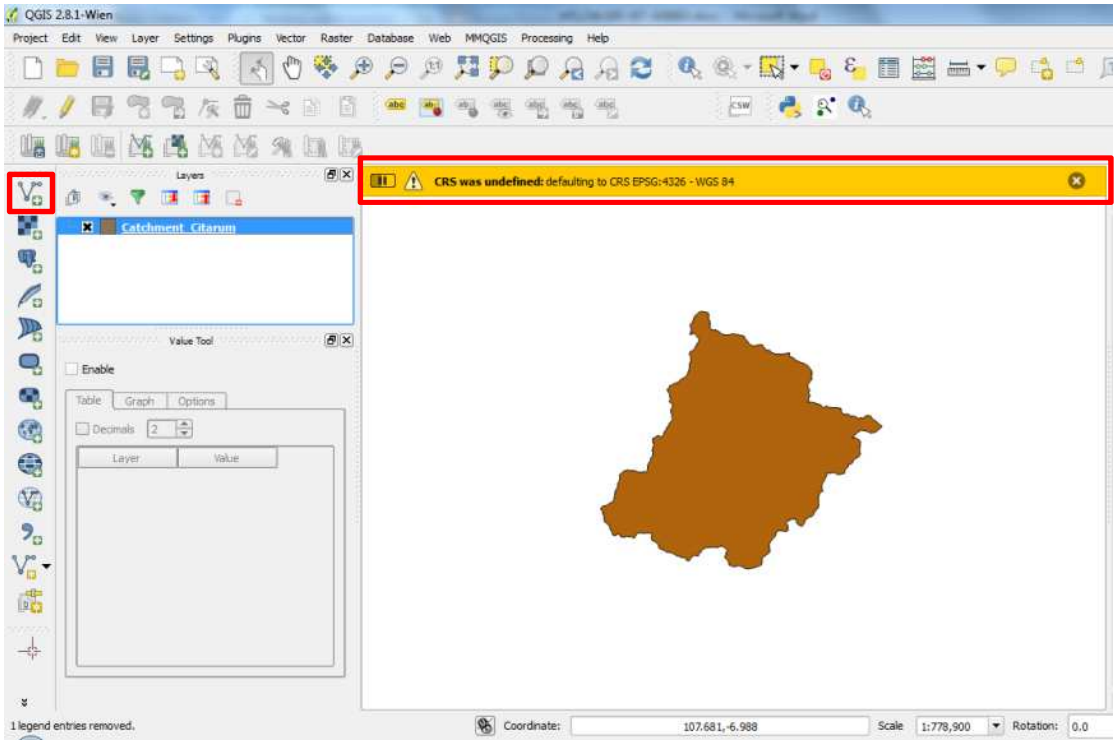


Figure appendix 4 – Defaulting CRS by QGIS

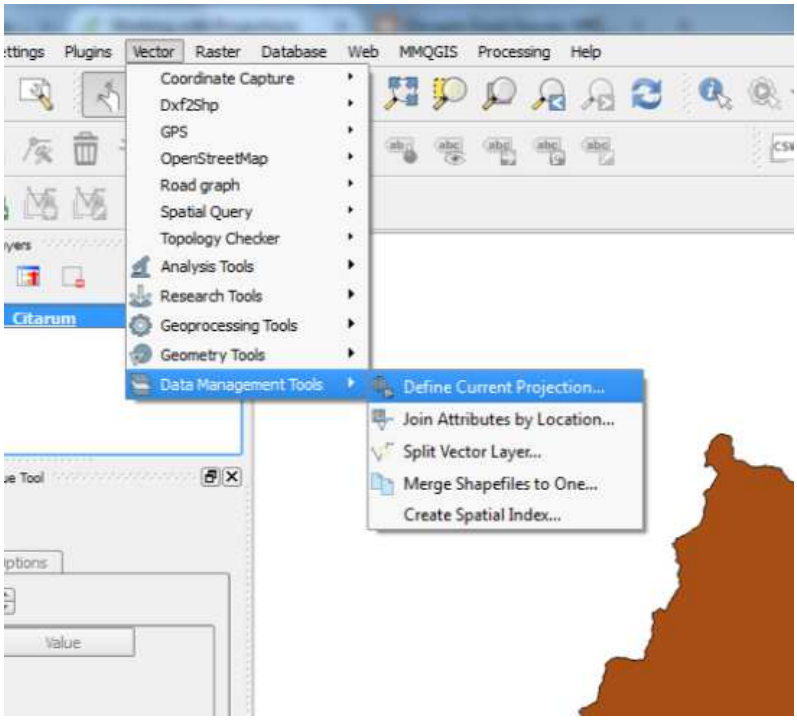


Figure appendix 5 – Define Current Projection

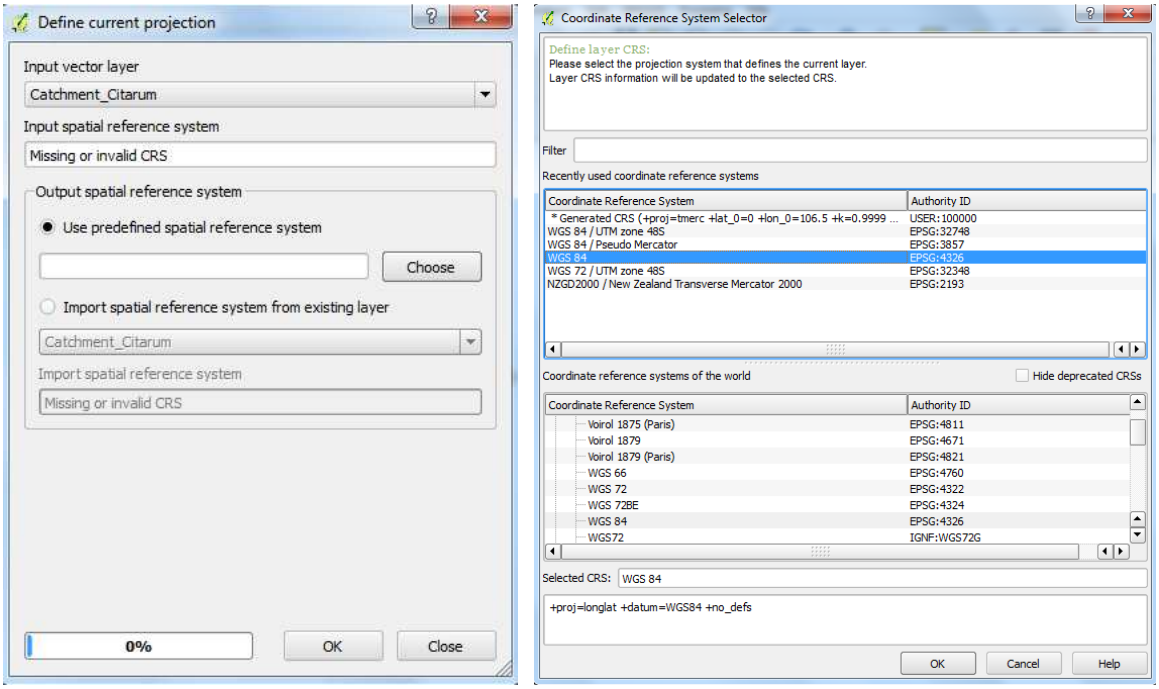


Figure appendix 6 – Choosing CRS

B.1.4 Exercise: assigning a projection to a raster

For this exercise we will use a .map file for Pemali Comal sub catchments.

1. Click *Raster* → *Add Raster Layer* or click on symbol → select *wflow_subcatch.map* in *A_Exersise_data\Exercise_B.1.4* → click Open. The picture below will appear. Click OK without selecting a CRS.

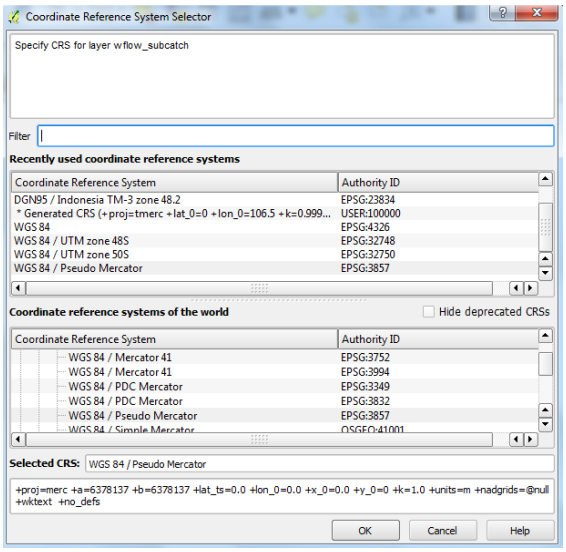


Figure appendix 7 – Choosing CRS for raster

2. We know that the CRS of the raster is *WGS 84 (EPGS:4326)*, but not assigned to the raster yet. To assign the projection click *Raster* → *Projections* → *Assign Projections…* → select the input file -> choose the desired *SRS* as *WGS 84 (EPGS:4326)* -> click OK (see Figure appendix 7) . The next time you load wflow_subcatch.map in QGIS, it can be projected with other layers, which may not have the same CRS.

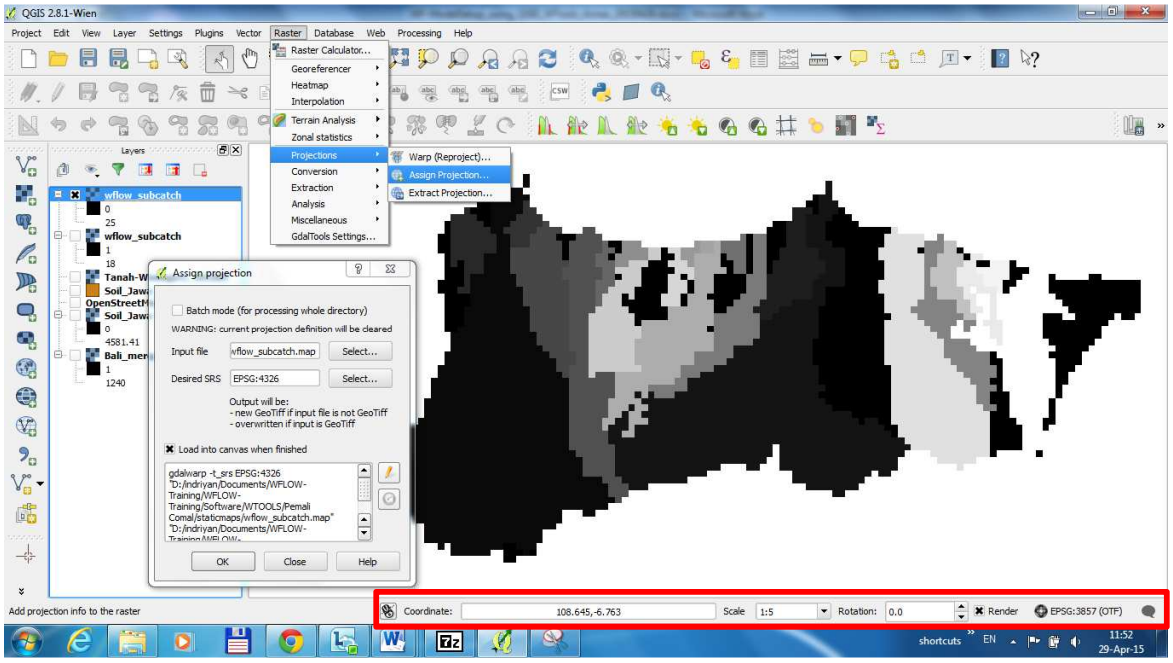


Figure appendix 8 – Assigning projection to a raster

B.2 Figure appendix 1 – Projected rasterWMS (OpenLayers plugin)

In QGIS you can use online maps (WMS) like google maps or open street layers as a base map. Note, for this exercise you need internet access!

1. *Add vector layer* and locate *A_Exersise_data\Exercise_B.2\ Citarum_Contours.shp*
2. Install the OpenLayers plugin by clicking Plugins → Manage and Install Plugins…. Search for *OpenLayers Plugin*, select *OpenLayers Plugin* and click *Install plugin* (see Figure appendix 9).
3. After finishing installing the plugin, you can open an online map via *Web → OpenLayers plugin* and choose a map you want to use. In Figure appendix 10 the final result is shown.

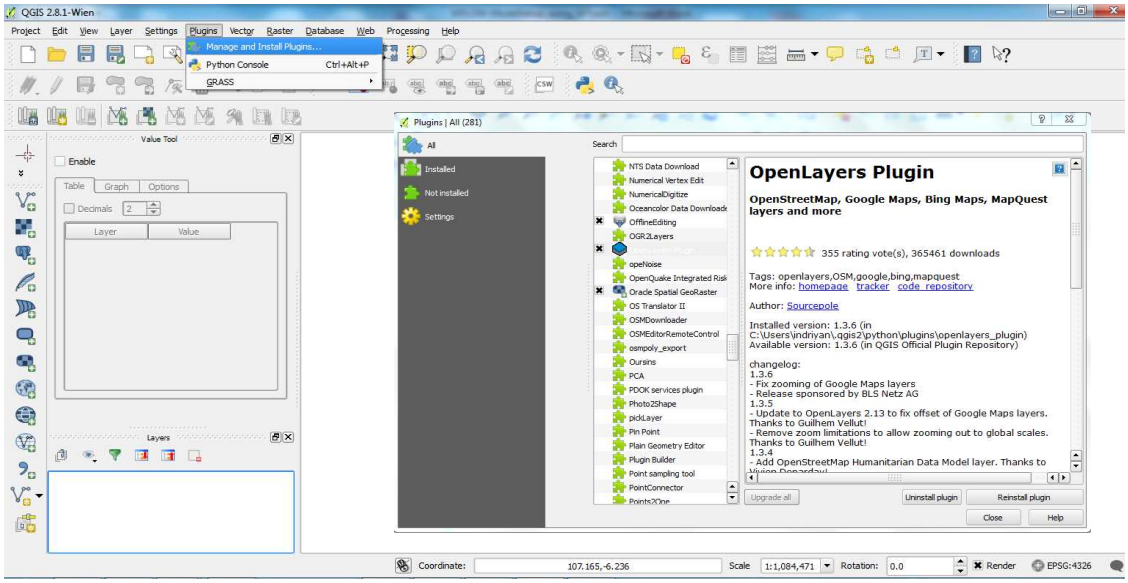


Figure appendix 9 – Installation of the OpenLayers plugin

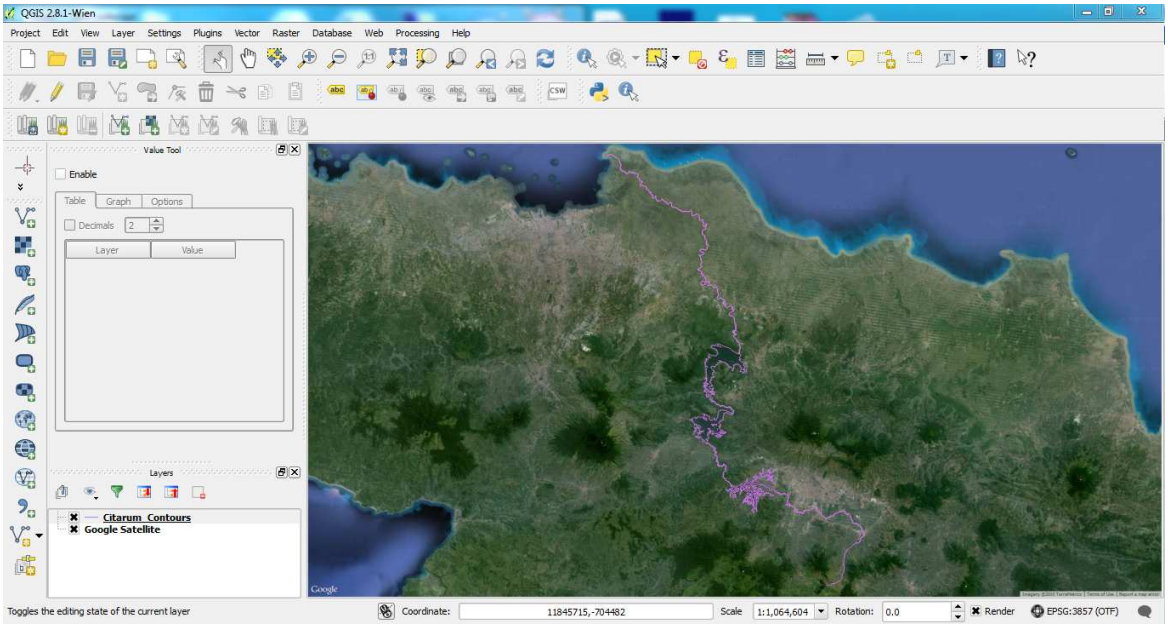


Figure appendix 10 – Cisadane_Countours and Google Satellite layer

B.3 Vectors

B.3.1 Exercise: generate a new shapefile

In this exercise you will create a new shapefile using QGIS:

1. Go to menu *Layer* → *Create Layer* → *New Shapefile Layer* (see Figure appendix 11). Alternatively, you can press command *CTRL+shift+N*, or press the button on the layer toolbar . A dialog will appear (see Figure appendix 12).
2. Choose the vector-type of your shapefile, *point*, *line* or *polygon*, we choose polygon (see Figure appendix 12).
3. Select the CRS of your shapefile by clicking , selecting *WGS84, EPSG:4326* and pressing *OK* (see Figure appendix 12).
4. Add a new attribute *Catchment*, containing text-data with a maximum length of 80 characters. Press *Add to attributes list* to add the attribute (see Figure appendix 12).
5. Press *OK* and save the shapefile in the folder *Exersise_data\Exercise_B.3.1\ Catchment_Citarum.shp* (see Figure appendix 13)

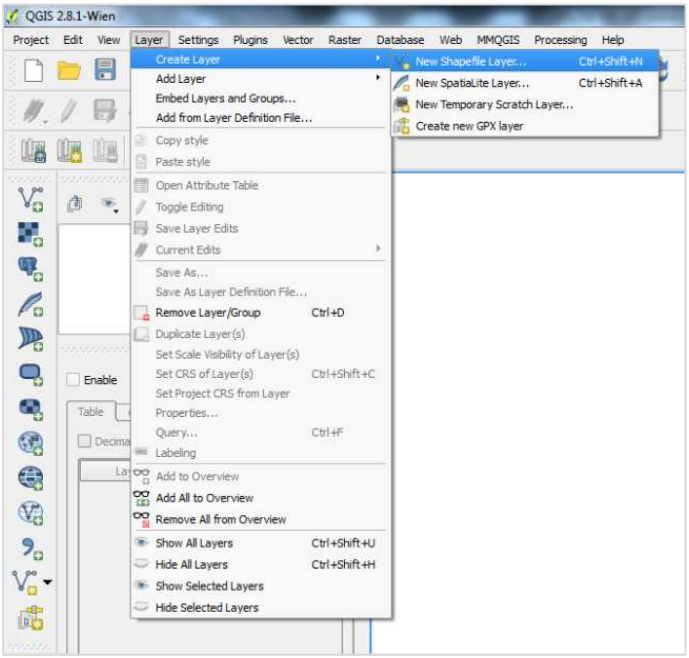


Figure appendix 11 – Create New Shapefile Layer

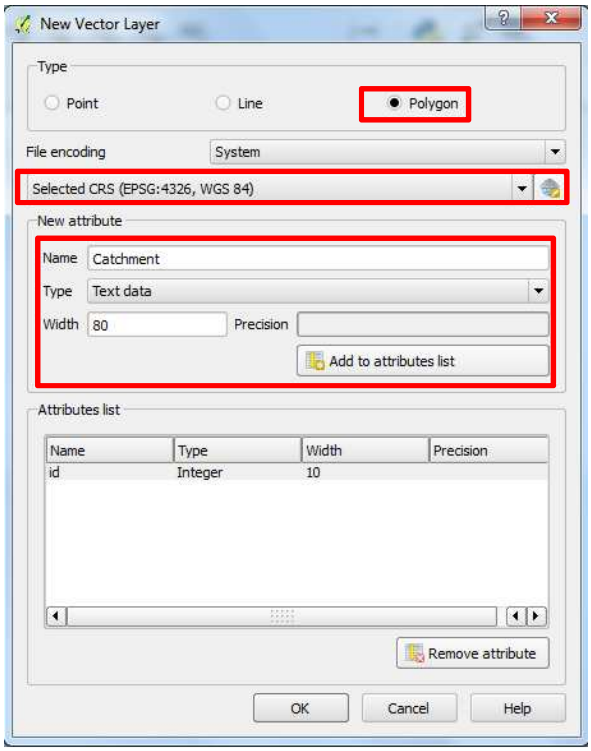


Figure appendix 12 – Dialog Box New Vector Layer

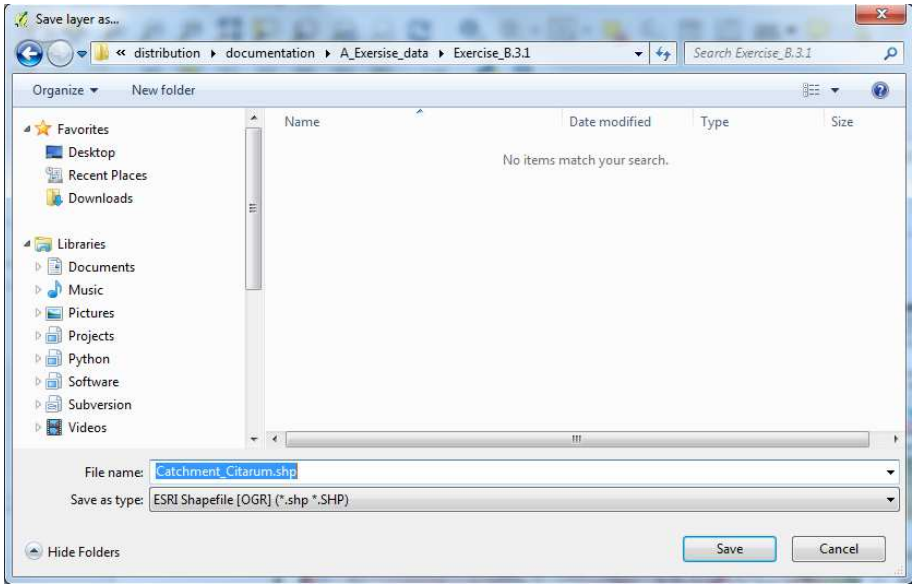


Figure appendix 13 – Dialog Box Save New Vector Layer

B.3.2 Exercise: edit a shapefile

In this exercise, you will edit the shape-file generated in exercise B.3.1. As a background a GeoTiff will be used:

1. Click the *add raster layer* icon to add the raster *Exersise_data\Exercise_B.3.2\Catchment_Upper_Citarum.tif*
2. Click the *add vector layer* icon to add the shapefile *Exersise_data\Exercise_B.3.2\ Catchment_Citarum.shp*
3. If the layer does not appear, right click on the shape or raster file in QGIS and click *zoom to layer*. Your result should be similar to Figure appendix 14.

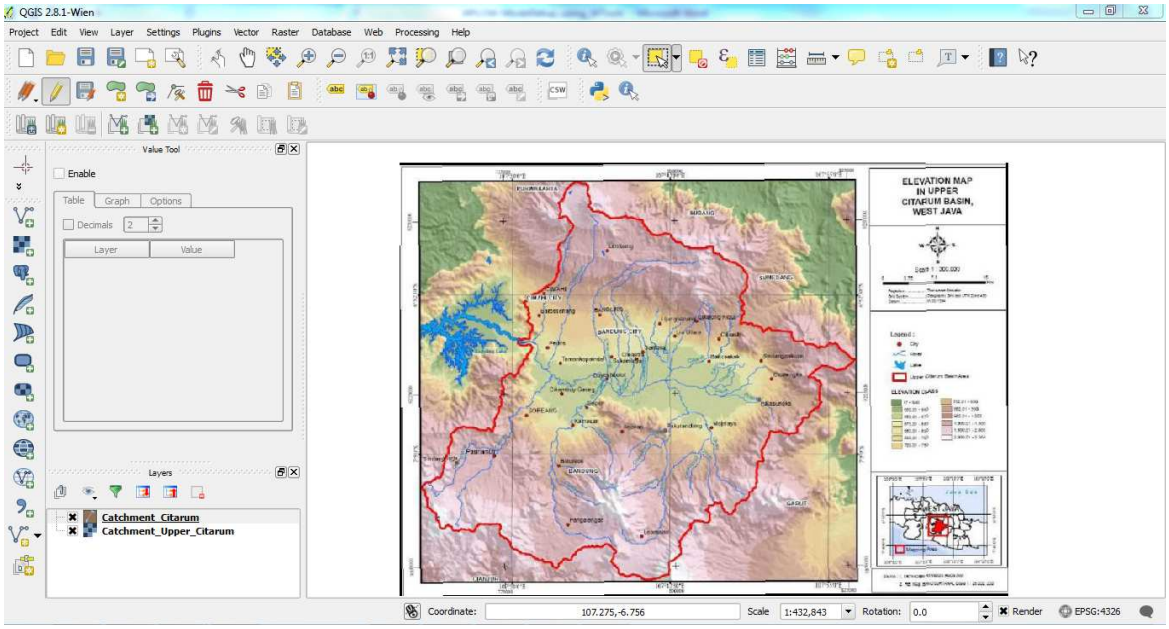


Figure appendix 14 – Preparing Background Layer

4. To start editing the shapefile, select the *Catchment_Citarum* shapefile and press *toggle editing* .
5. By clicking *add feature* you can start creating a new polygon. By left-clicking on the boundary line, you start drawing your polygon. If you are finished, you can finalize your polygon by a right-click. The window shown in Figure appendix 15 will pop up in which you can type *Upper Citarum* in to fill in the *Catchment* attribute
6. To stop editing, click the *toggle editing* button once more . Choose *save* to confirm saving the changes to your shapefile. The result should be similar to Figure appendix 16.

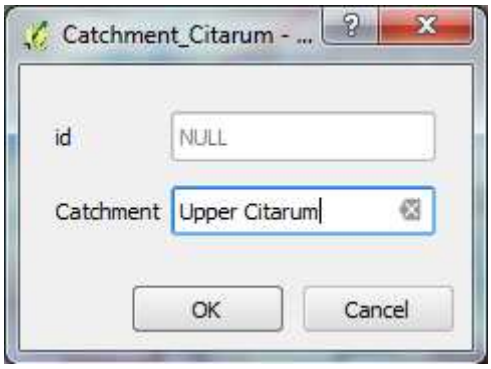


Figure appendix 15 – Add Layer Attribute

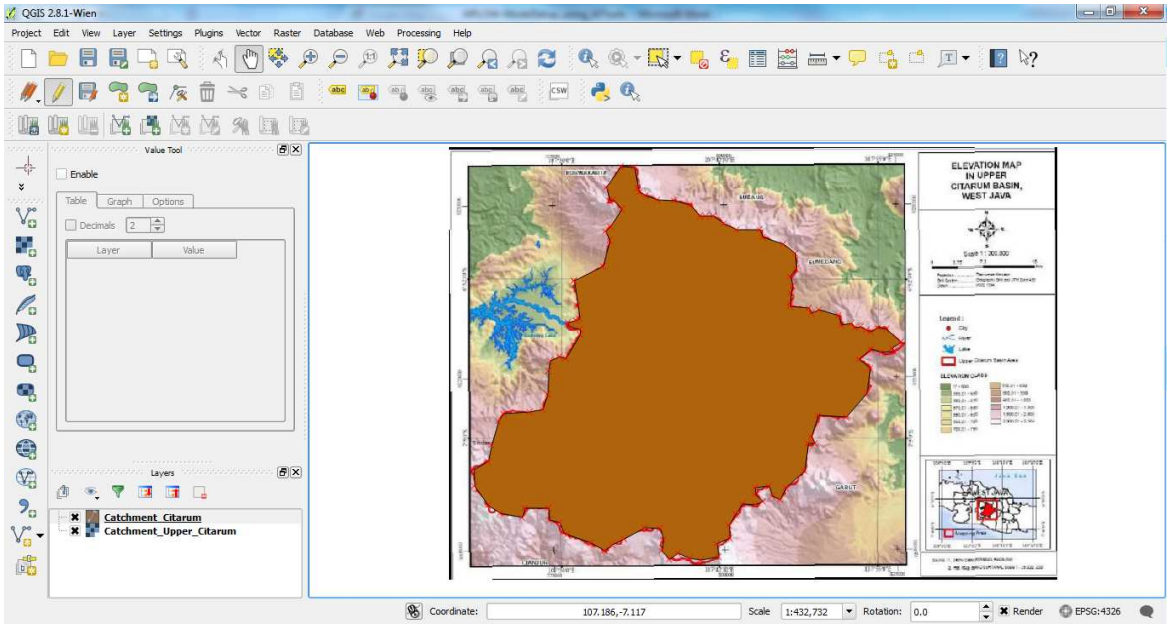


Figure appendix 16 – Result

When *toggle editing* is activated, there are other features activated:

- *Move feature* button is used to move your feature.
- *Node tool* allows you to edit nodes (vertex) in the polygon.

B.3.3 Exercise: Change format (kml to ESRI shapefile)

Keyhole Markup Language (kml) is geographic information file which is generated and displayed in Google earth or Google maps. As Google Earth is a free source of map-information you may use it to generate points, polylines or polygons which you save in a kml. How to generate a kml will not be described in this annex.

In QGIS, we can convert this file with format kml into shapefile (.shp):

1. Press *Add vector layer* and open the file *Exersise_data\Exercise_B.3.3\ Gauges.kml.* and click *Open* (see Figure appendix 17). The layer *Gauges* will appear.
2. Right click on the *Gauges* layer, and select *save as*. The new layer "Gauges" will appear.

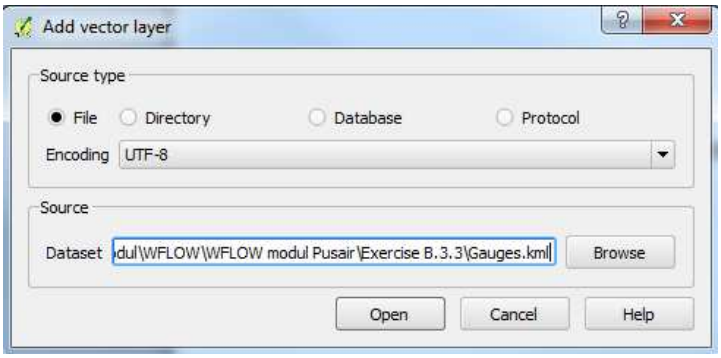


Figure appendix 17 – Open KML File

3. Right click on the *Gauges* layer, and select *save as*. In the *Save vector layer as…* window, choose *ESRI Shapefile* as *Format*, *Save as Exersise_data\Exercise_B.3.3\ Gauges.shp* and choose *EPSG:4326 (WGS84)* as *CRS.* Press *OK* to save the file.

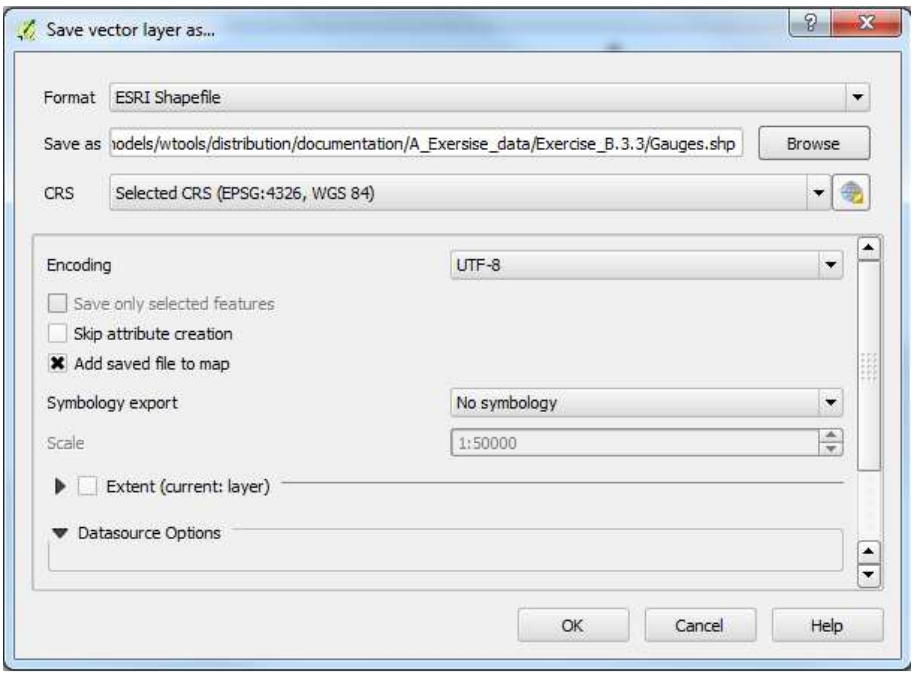


Figure appendix 18 – Save KML into Shapefile (shp)

B.3.4 Exercise: re-projecting a shapefile

In this exercise you will re-project a shapefile:

1. Press *Add vector layer* and open the file *Exersise_data\Exercise_B.3.4\ Administrative_Upper_Citarum.shp*
2. Go to the menu *processing* → *Toolbox*. The toolbox will now appear, shown in Figure appendix 19.

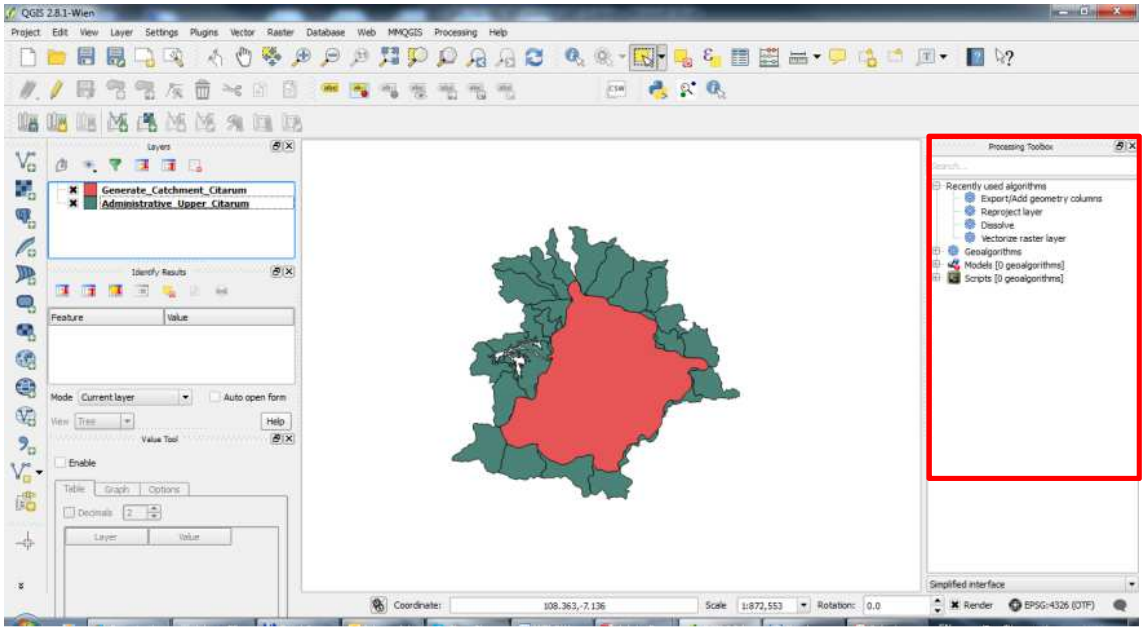


Figure appendix 19 – Toolbox

3. In the search dialog, type reproject. Double-click on *Vector general tools* → *Reproject Layer*. The dialog box for reproject layer will appear.
4. Choose *Administrative_Upper _Citarum* as the input layer. Choose *WGS 84 / UTM zone 48S* as the target CRS. In the box *Reprojected layer* choose *Save to File* and choose *Exersise_data\Exercise_B.3.4\Administrative_Upper_Citarum_UTM.shp* (see Figure appendix 20). Click *run*; the layer *Administrative_Upper_Citarum_UTM* will appear.

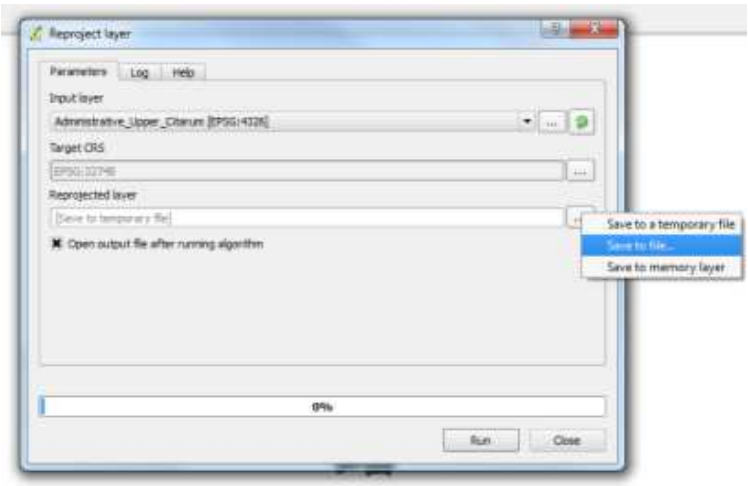


Figure appendix 20 – Reproject Layer Dialog Box

B.3.5 Exercise: selecting attributes

1. Press *Add vector layer* and open the file *Exersise_data\Exercise_B.3.5\ Administrative_Upper_Citarum.shp*
2. Richt click on the *Administrative_Upper_Citarum* layer and select *Open attribute table*. An attribute table window will pop up (see Figure appendix 21).
3. You can select features by selecting rows in the attribute table. Alternatively you can select the *select Feature(s)* button and click on polygons in the QGIS main window
4. Click on the *select by expression* button in the attribute table. In the select by expression window type *AREA > 300* as expression (see Figure appendix 22).
5. Right click on the *Administrative_Upper_Citarum* layer, and select *save as*. In the *Save vector layer as…* window, *Save as Exersise_data\Exercise_B.3.5\ Administrative_Upper_Citarum_select.shp.* Make sure you check the *Save only selected features* checkbox (see Figure appendix 23). Press *OK* to save the file. You will have a new layer with only the selected features (see Figure appendix 24).

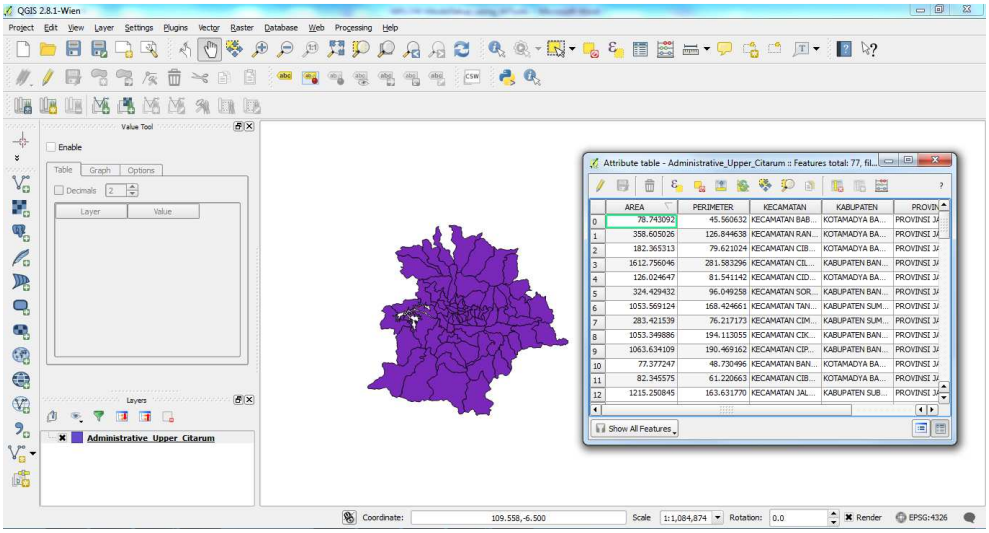


Figure appendix 21 – Attribute Table

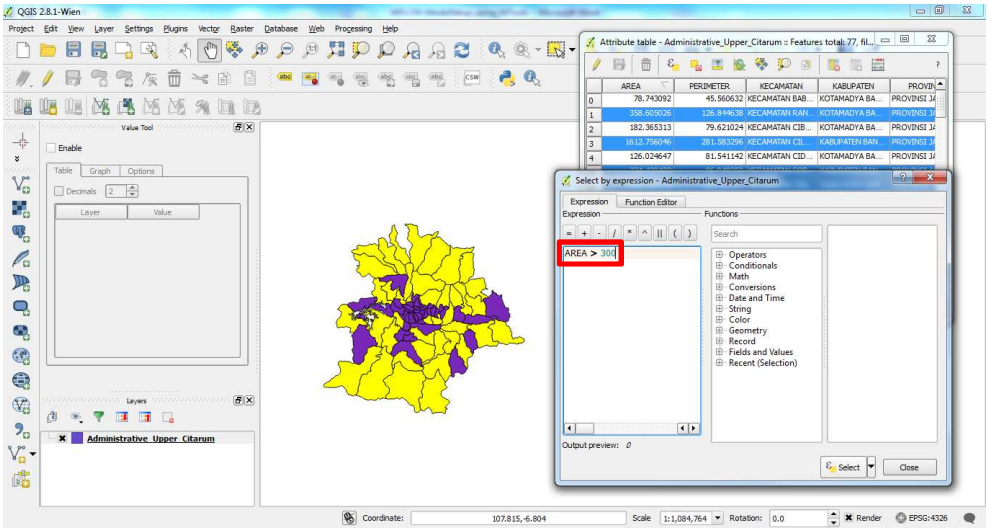


Figure appendix 22 – Area > 300 selected

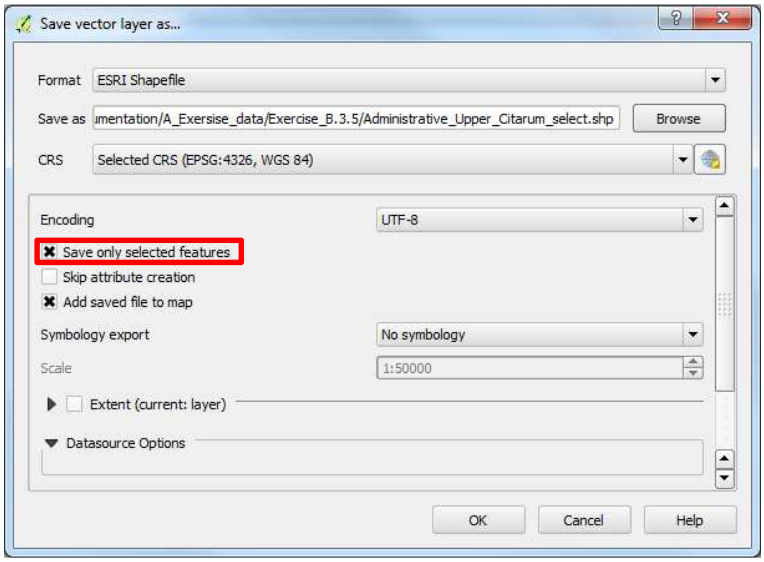


Figure appendix 23 – Save selection

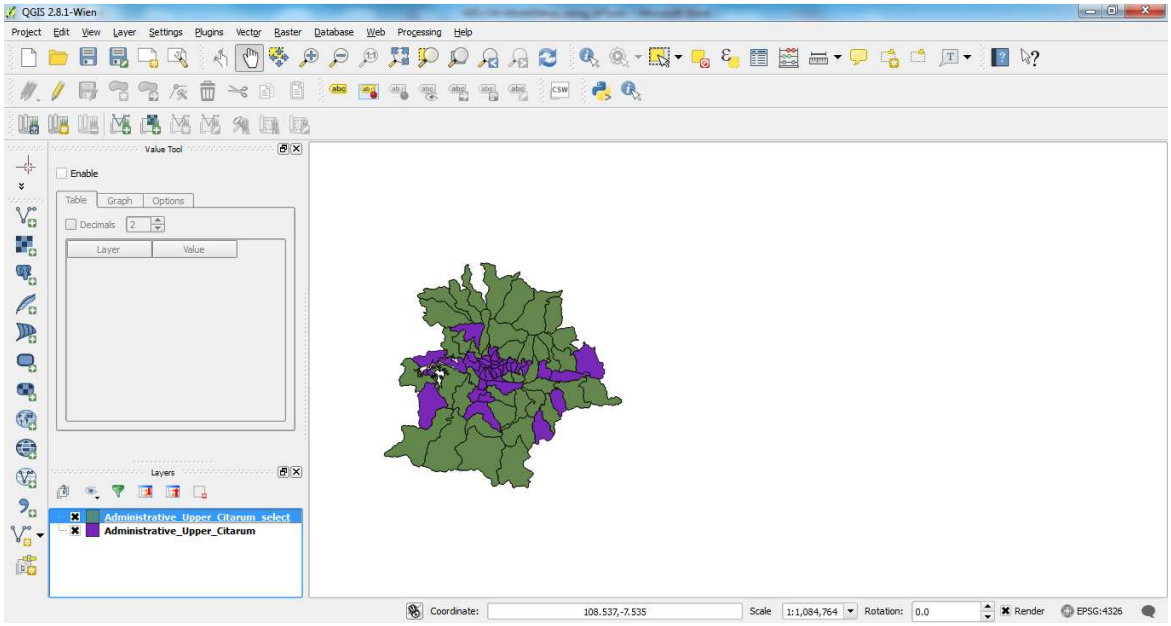


Figure appendix 24 – Administrative_Upper_Citarum_select

B.4 Rasters

B.4.1 Exercise: convert raster format

In this exercise we will convert a PCRaster map format into a GeoTIFF (.tif). We will use the same file as Exercise B.1.4 (wflow_subcatch.map).

1. Open raster vile via *Raster* → *Add Raster Layer* → *select file* -> click *Open* -> choose *Exersise_data\Exercise_B.4.2\wflow_subcatch.map*. As CRS choose *WGS 84 (EPGS:4326)*.
2. From the menu, choose *Raster* → *Conversion* → *Translate (convert format)* as shown in the picture below.
3. Select the input file → name the output file and choose *GeoTIFF* as the file extension → select *Target SRS* → choose *WGS 84 (EPGS:4326)* for the projection and click *OK*.

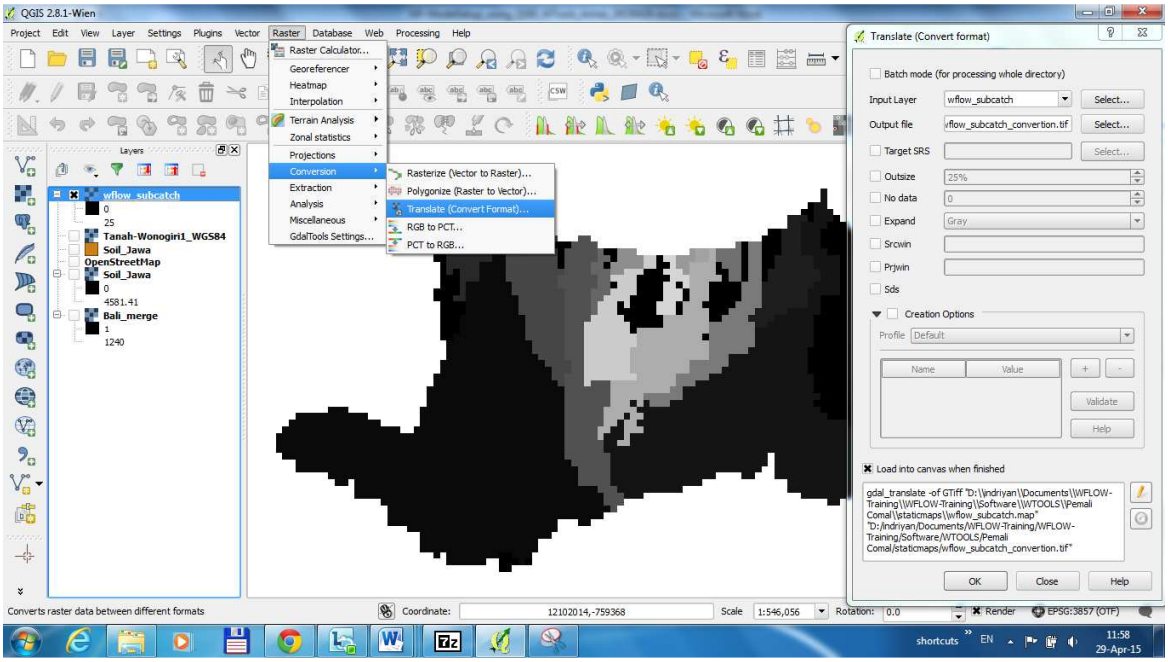


Figure appendix 25 – Converting raster format

B.4.2 Exercise: convert a shapefile to a raster

In this exercise we will use a shape containing soil classifications for the Indonesia Island of Java (see Figure appendix 26). Here are the steps to convert a vector to a raster layer:

1. Press *Add vector layer* and open the file *Exersise_data\Exercise_B.4.2\Soil_Jawa.shp*
2. Go to the menu *Raster* → *Conversion* → *Rasterize (vector to raster)* (see Figure appendix 27).

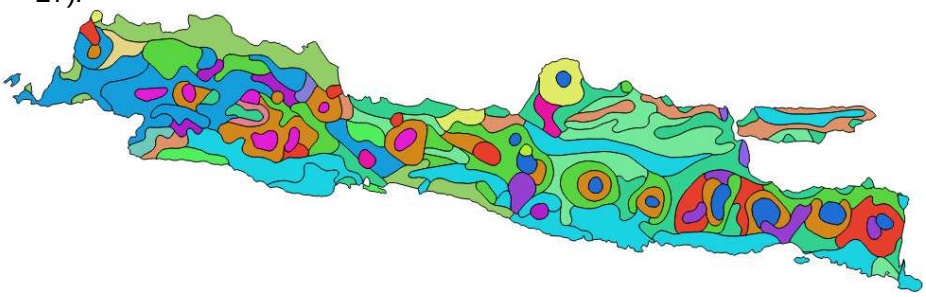


Figure appendix 26 – Soil map for Java in a vector format

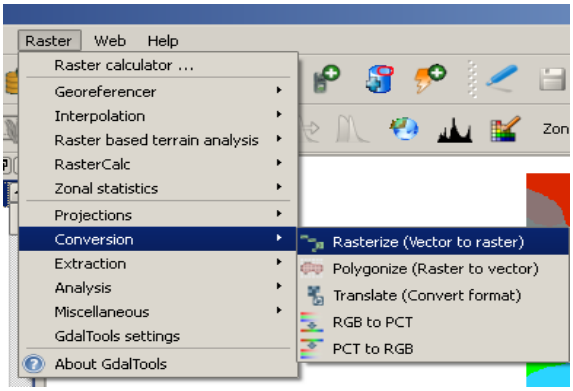


Figure appendix 27 - Selection of the Vector to Raster function

3. The screen shown in Figure appendix 28 will show up
4. Select your input vector layer, in this exercise *Soil_Jawa*.
5. Choose attribute in the atrtribute field which you want to rasterize. In this exercise, choose SQKM.
6. Select your output file, save into same directory Exersise_data\Exercise_B.4.2 and name it as Soil_Jawa with GeoTIFF file extension.
7. To determine the pixel size, select Raster resolution in map size units per pixel. Use pixel size of 0.009 in degree.
8. The new raster map of the selected layer, shown in Figure appendix 29, will appear. The visualization of the colours depends on the range values defined in the colour map)

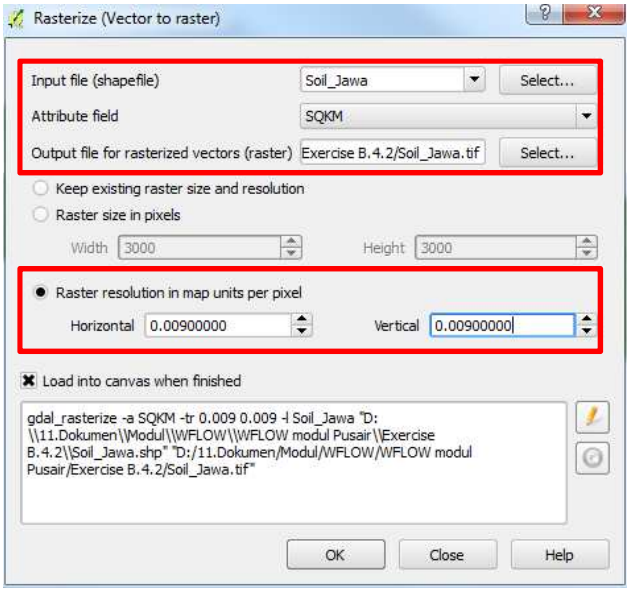


Figure appendix 28 - Definition of the Rasterize function

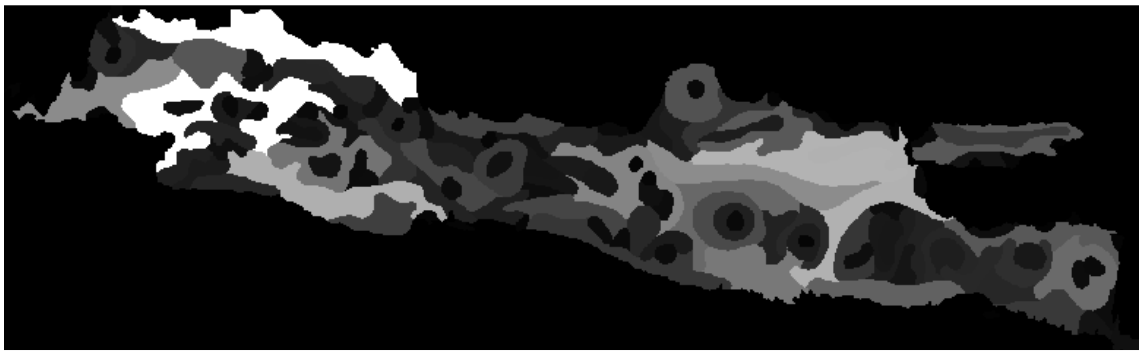


Figure appendix 29 - The raster visualization of the DMSW for Java

B.4.3 Exercise: clip a raster by a shapefile

In this exercise you will make a selection (or clipping) from Soil_Jawa raster layer using Citarum catchment boundary vector layer which were created in the previous exercise. Use the instruction provided for below for the clipping raster layer process by using a shapefile:

1. Click the *add raster layer* icon to add the raster *Exersise_data\ Exercise_B.4.3_B.4.4\Soil_Jawa.tif*

2. Press *Add vector layer* and open the file *Exersise_data\Exercise_B.4.3_B.4.4\ Catchment_Citarum.shp.*
3. Select the Clipper tool via *Raster* → *Extraction* → *Clipper* (Figure appendix 23).
4. In the *Input file*, choose raster layer *Soil_Jawa*. As the *output file*, save in the directory *Exersise_data\Exercise_B.4.3_B.4.4* and name it as *Upper_Citarum_Soil* and choose GeoTIFF as the file extension.
5. In the clipping mode, choose *Mask layer* and select *Catchment_Citarum* as the mask layer (Figure appendix 30). Click *OK*.

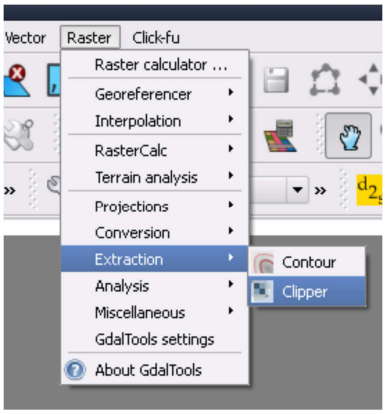


Figure appendix 31 - Clipping a raster.

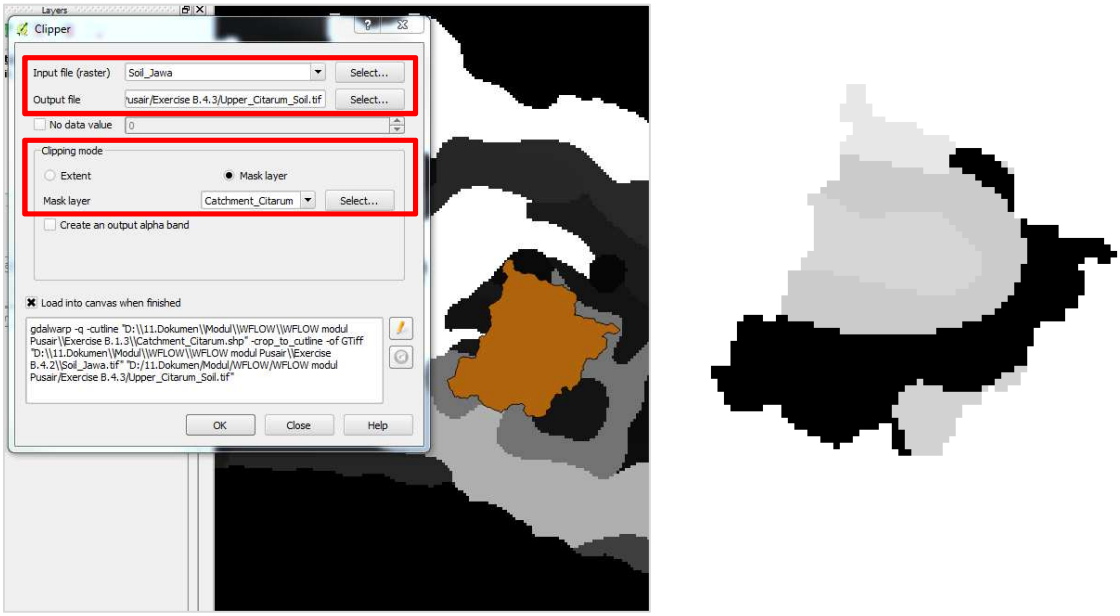


Figure appendix 32 – Clipper and Clipping Result

B.4.4 Exercise: clip a raster to your window extent

QGIS also provide feature to clip raster layer by using window extent. Please follow procedure.

1. Please add vector layer of Catchment_Citarum.shp and raster Soil_Jawa.tif in the directory *Exersise_data\Exercise_B.4.3_4.4* to QGIS.
2. Right click on the layer Catchment_Citarum and choose *zoom to layer*.

3. Right click on the layer *Soil_Jawa* and select *save as*.
4. Dialog box of *save raster layer* will pop up (Figure appendix 27). Now save the clipped raster layer in directory *Exersise_data\Exercise_B.4.3_4.4* and name it as *Upper_Citarum_Soil_byExtent*. And select the designated CRS. In this exercise, use *WGS 84*.
5. Select *Map view extent*. Click *OK*

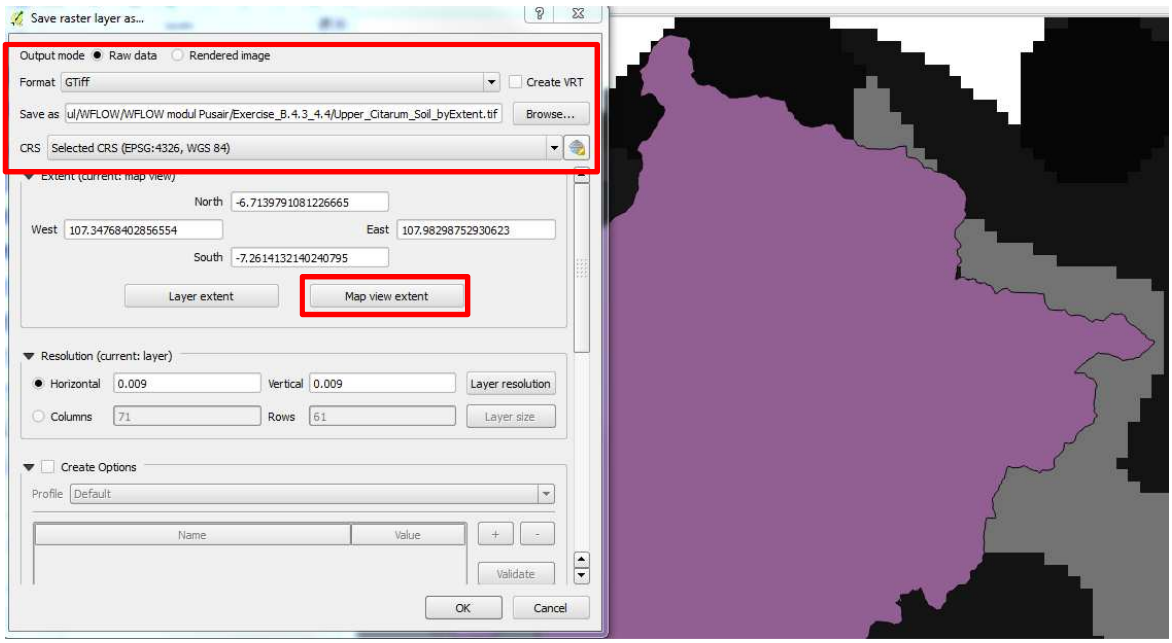


Figure appendix 33 – Clipping Raster by Extent

Here is the difference between the result of this exercise (left) and the previous exercise (right)

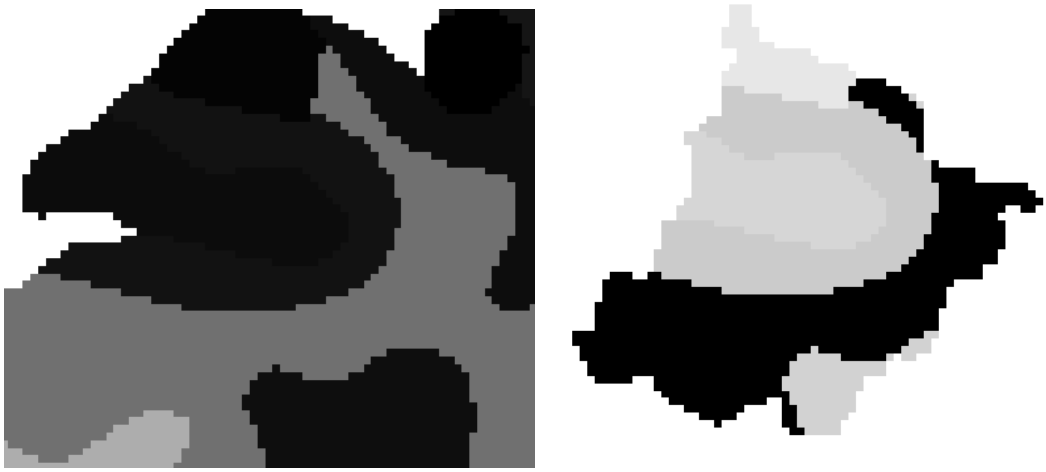


Figure appendix 34 – Difference between Window Extent and Mask Layer Clipping

B.4.5 Exercise: reclassify a raster

For the exercise, you can find a small size data of Citarum land use raster file in *A_Exersise_data\Exercise_B.4.5.* In the original raster there is a code in integer value that describes the land use category. There are 17 categories of land use and you will reclassify them based on the table below.

Figure appendix 35 – Difference between Window Extent and Mask Layer Clipping

Table appendix 1 – Land use reclassification

Land use Code	Category	Class	Category
1	Fresh water	1	Open water
2	Brackish water	1	Open water
3	Ponds	1	Open water
4	Salt pan	2	Paved / bare areas
5	Sand (beach)	2	Paved / bare areas
6	Sand	2	Paved / bare areas
7	Rock	2	Paved / bare areas
8	Bare / grass	2	Paved / bare areas
9	Builtup / settlement	2	Paved / bare areas
10	Dry agriculture	2	Paved / bare areas
11	Garden / plantation	3	Grassland / shrubland
12	Bush / shrub	3	Grassland / shrubland
13	Sawah rainfed	4	Rainfed Agriculture
14	Sawah irrigated	5	Irrigated Agriculture
15	Swamp	6	Forest
16	Swamp forest	6	Forest
17	Forest	6	Forest

1. Make sure that the GRASS plugin has been installed by clicking *Plugins -> Manage and Install Plugins…* → select *GRASS* → click *Install plugin* → *Processing* → *Options....* In the GRASS commands make sure that the GRASS GIS is integrated with Sextante pluggin to enable GRASS algorithms.
2. Click *Processing* → *Toolbox* → change *Simplified interface* to *Advanced interface* → search *r.reclass* → double click on *r.reclass* option.
3. In the r.reclass window select the input raster layer file and reclass rule file → name the output raster file → click run. For our land use case, type the rules below for reclass rules file.

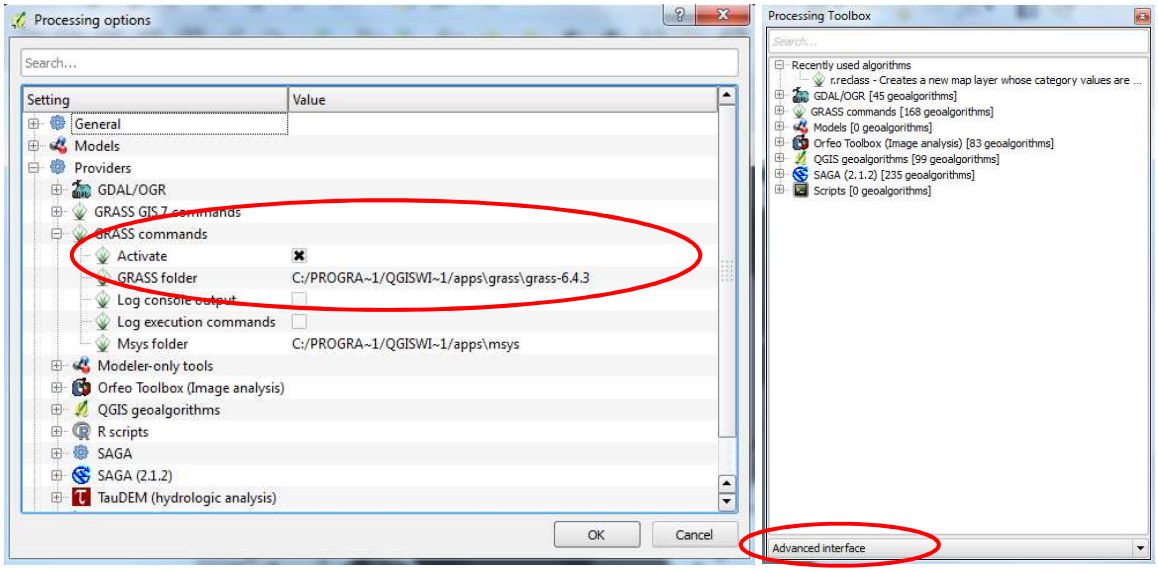


Figure appendix 36 – Difference between Window Extent and Mask Layer Clipping

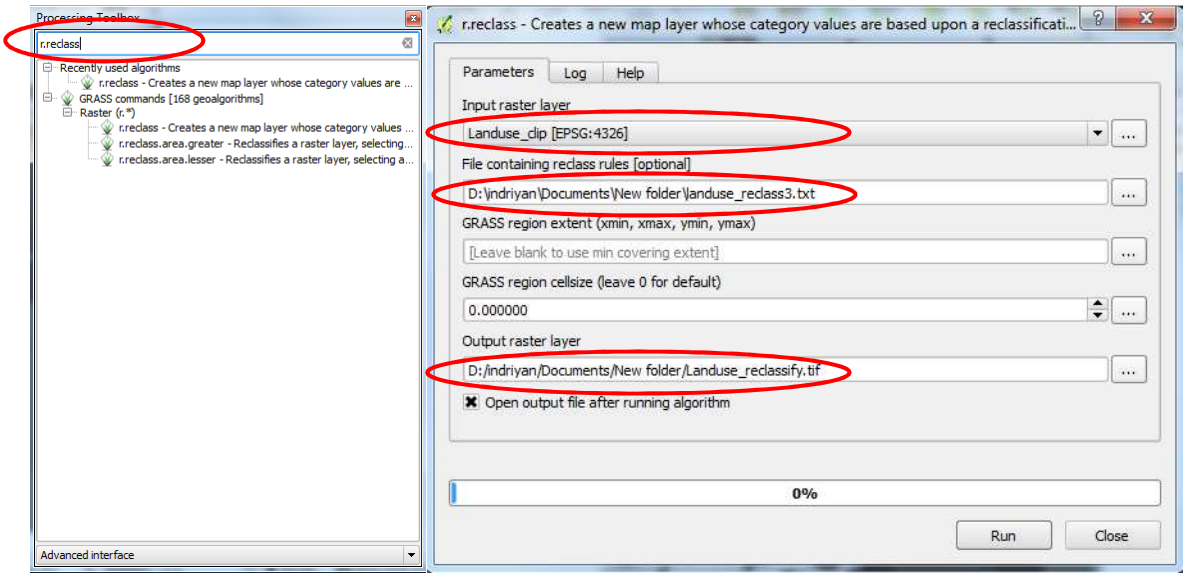


Figure appendix 37 – Difference between Window Extent and Mask Layer Clipping

```
1 2 3 = 1 OpenWater
4 5 6 7 8 9 10 = 2 Paved/BareAreas
11 12 = 3 Grassland
13 = 4 RainfieldAgriculture
14 = 5 IrrigatedAgriculture
15 16 17 = 6 Forest
```

Figure appendix 38 – Difference between Window Extent and Mask Layer Clipping

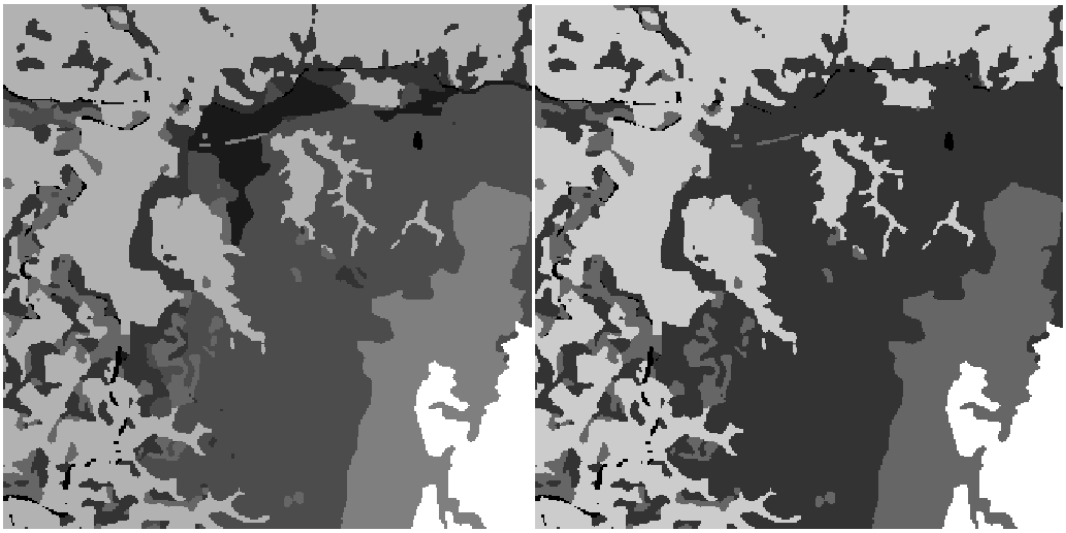


Figure appendix 39 Comparison between original land use (left) and reclassified land use (right)

B.4.6 Exercise: merge existing rasters

1. Click *Raster* → *Miscellaneous* → *Merge*
2. Select the SRTM layers to be merged in *A_Exersise_data\Exercise_B.4.6* → give the name to the new output file (e.g. *Bali_merged*) → select *Load into canvas* when finished → click OK.
3. Close the Merge window when finished and inspect the result. Remove the individual SRTM tiles from your project.

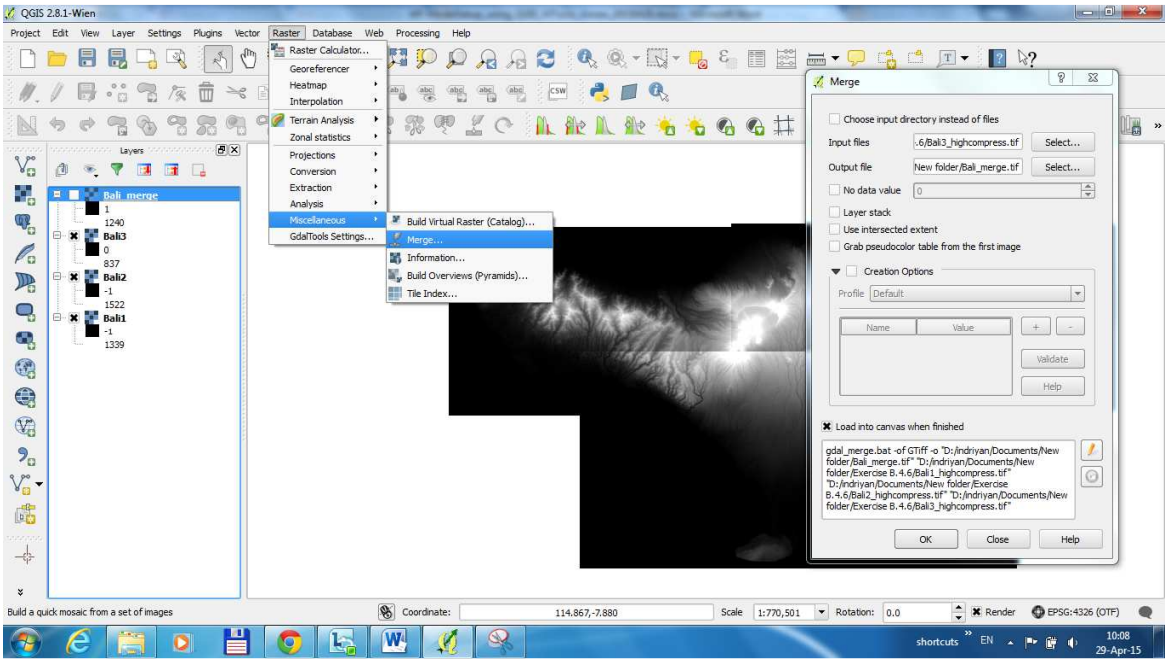


Figure appendix 40 Merging rasters

Note! you will need to carry out the merge on the original SRTM tiles with the WGS84 projection. If you merge re-projected SRTM tiles it is possible that the edges of the individual tiles consist of missing data values which will be included in the merged raster. This is not desirable

B.4.7 Exercise: re-project a raster

For reprojecting exercise, we use a *DEM file* of *Bali_merged* from *Exercise B.4.6*.

1. Click *Raster* → *Projections* → *Warp (Reproject)…* as shown in the screenshots below.
2. Select the input file -> name the output file and choose GeoTIFF as the file extention → select *Source SRS as WGS84 (EPGS:4326)* → select *Target SRS* -> choose *WGS 84 / UTM 50S (EPGS:32750)* for the projection → choose the resampling method as *Cubic* → click OK.
3. To check the coordinate and pixel size, right click on the file → Properties → Metadata → go to Properties column. Your will see the differences as in Figure appendix 42.

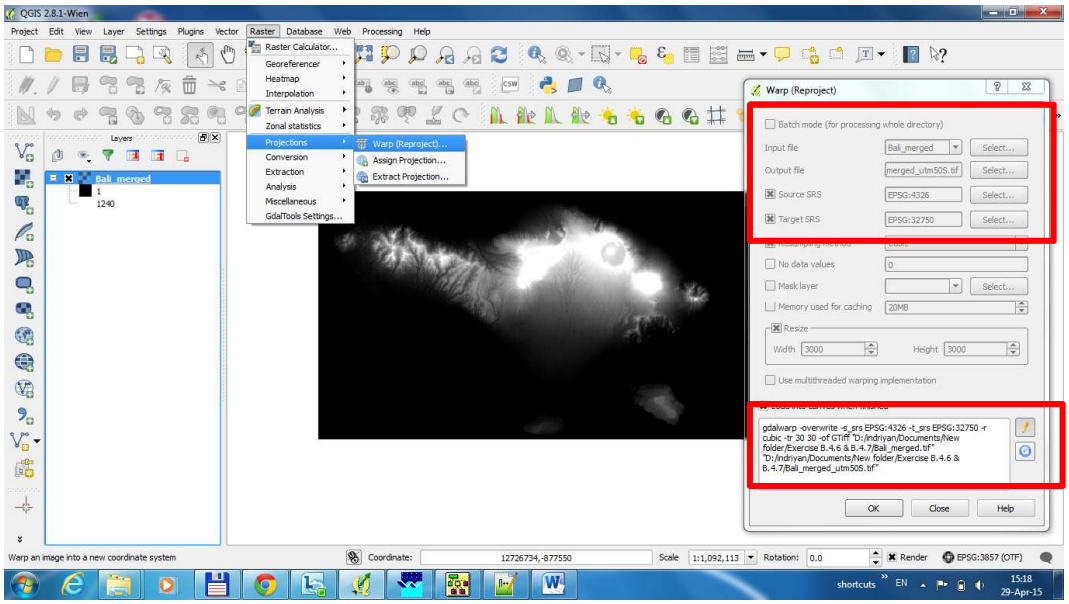


Figure appendix 41 – Re-projecting raster

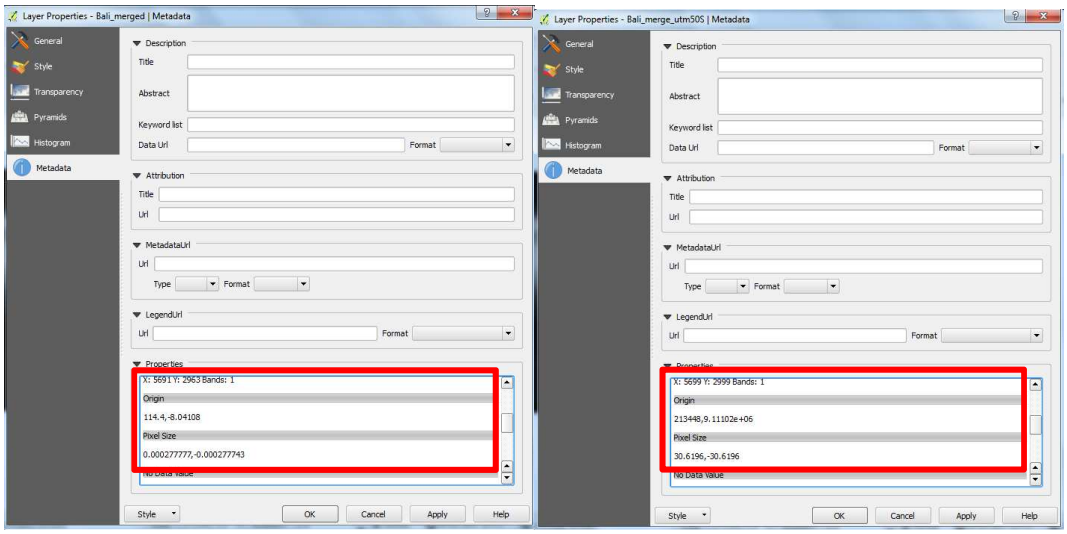


Figure appendix 42 – Coordinate and pixel size of original (left) and re-projected data (right)

C WTools

In this annex, the use of WTools is explained. WTools requires the installation of QGIS and PCRaster (see A.2-A.5).

C.1 WTools and WFlow

WTools is a set of open-source python-based tools to derive WFlow models from a set of topographic layers (see *Figure appendix 43*).

Tools is developed to:

- Simply model setup. Less knowledge about GIS-processing is required since maps are processed automatically once topographic layers are derived. Model setup is an easier and faster process.
- Uniform model setup. All WFlow models will have common characteristics, as they all have the same origin.
- Generate models including multiple catchments. Models can cover more than one catchment if required.

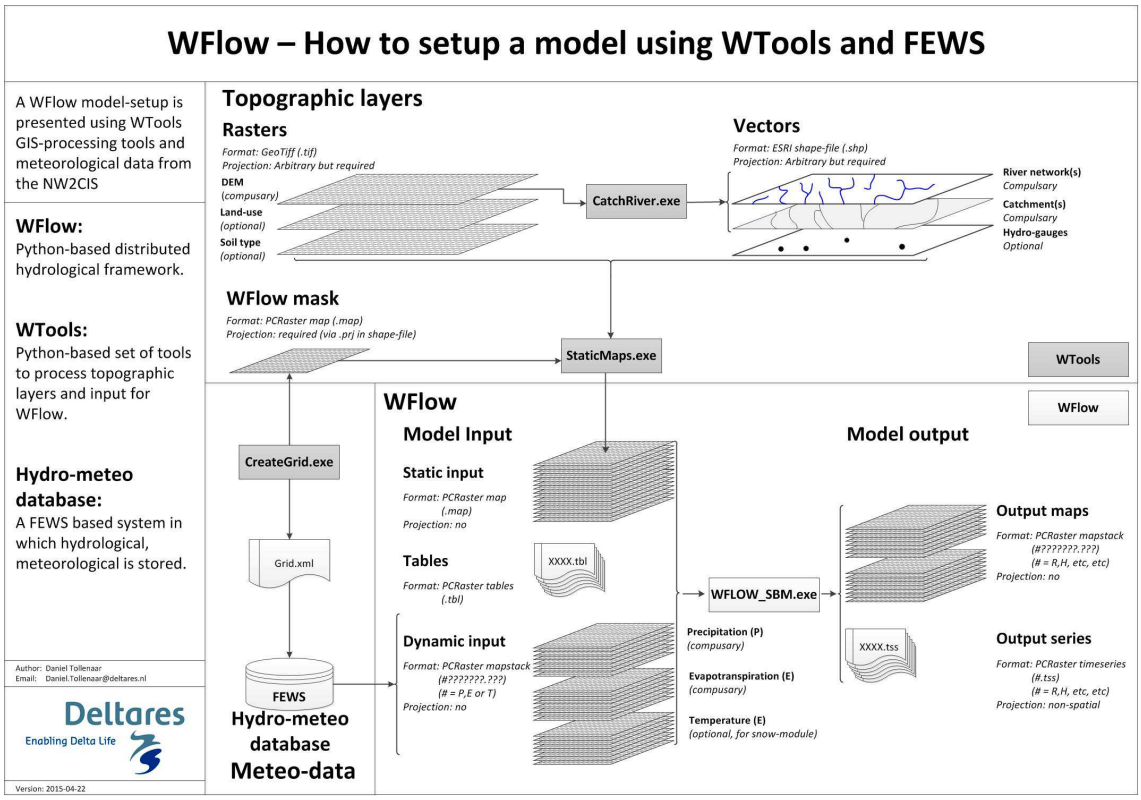


Figure appendix 43 – How to derive a WFlow model with WTools

The current version of WTools (19-03-2015) allows automatic generation of WFlow *static input* via 'command-line tools'. It also simplifies the generation of *dynamic input*, as it generates a grid-definition for FEWS.

- Improve StaticMaps.exe to include reclassification of raster input, etc, etc.
- Automatic integration of WFlow models in FEWS
- Automatic coupling of WFlow with Ribasim and Sobek
- Integration of WTools in QGIS and DeltaShell

C.2 CatchRiver.exe

CatchRiver.exe can be used to derive (a) river-network(s) and catchment(s). These two products will be stored in the folder *\CatchRiver* as ESRI shapefiles. The program requires at least a DEM stored in a GeoTiff with a projection included (if not, no projection will be assigned to the output). The following options can be set:

-d *rasterfile (GeoTiff)*
Raster-file with digital elevation model. Projection definition preferred (will be assigned to output shapefiles)

-l *shapefile (ESRI shapefile)*
(Optional) shapefile with polylines (rivers\drains) which will be burned in raster before catchment deliniation

-p *shapefile (ESRI shapefile)*
(Optional) shapefile with points (outlets) which will be burned in raster before catchment delineation

-F *integer*
(Optional) factor by which DEM will be rescaled before it is processed into a river network. Using a higher scale-factor will speed-up process-time, but reduce the scale of the output (default=1).

-O *integer*
(Optional) minimum strahler-order which will be included in the output river shapefile (default=3)

-s (Optional) setting to snap points (-p) to lines (-l) prior to burning (default=no)

-R *shapefile (ESRI shapefile)*
(Optional) name for output shapefile (default=river.shp)

-C *shapefile (ESRI shapefile)*
(Optional) name for output shapefile (default=catchment.shp)

-B *integer*
(Optional) burn value which will be used to lower dem at polylines, points and areas if -l, -p or -a are set

-S (Optional) if set, the local drainage direction network (ldd) will not be recreated. Use this option e.g. if you want to change output-names, or strahler-order and your dem, burn layers and burn-value haven't changed (-l, -p, -a, -B)

-K (Optional) setting to keep all rivers in the domain of the input DEM (default=no)

Example 1:

wtools\CatchRiver.exe -d input\srtm_Citarum_90m.tif -O 6 -F 3

rivers will be derived on a scaled version of the dem (180x180 meter instead of 90m). Only rivers with a strahler-order larger than 6 will be included in the output shapefile

Example 2:

wtools\CatchRiver.exe -d input\srtm_Citarum_90m.tif -p input\outlets.shp -l input\lines.shp -R river_burned.shp -C catchment_burned.shp -O 6

Prior to the generation of the river network, the outlets and lines will be burned to the DEM. The river network will be stored in *\CatchRiver\river_burned.shp* and the catchment in *\CatchRiver\catchment_burned.shp* .Only rivers with a strahler-order larger than 6 will be included in the output shapefile

Example 3:

wtools\CatchRiver.exe -d input\srtm_Citarum_90m.tif -p input\outlets.shp -l input\lines.shp -R river_burned_snap.shp -C catchment_burned_snap.shp -O 6 -s

Same as example two, but prior to the burning process, the points will be 'snapped' on the lines.

C.3 CreateGrid.exe

CreateGrid.exe is used to derive the grid of WFlow. It generates output in the folder \mask. Here the mask.map file can be found, which will be used to clip the topographical layers with the StaticMaps program. The StaticMaps program will use the mask.shp to read the model projection. In Grid.xml the mask grid-definition can be found which can be used to generate dynamic input from FEWS. The following options have to be set:

-f *ESRI shapefile or rasterfile (GeoTiff)*
Input-file from which extent will be derived. Note, the extent will be derived from the file-properties, not from the data-extent.

-c *integer*
Cellsize of the output in the units of the input-file (metres of degrees).

Example:

CreateGrid.exe -f CatchRiver\catchment_burned_snap.shp -c 0.01

For the extent of the file *CatchRiver\catchment_burned_snap.shp (projected in WGS84, lat lon) a grid will be generated with a cellsize of 0.01 (degrees).*

C.4 StaticMaps.exe

StaticMaps.exe is used to generate all static input for WFlow in the \staticmaps folder. The following options can be set:

-i *text-file (see staticmaps.ini as example)*
File containing settings for StaticMaps.exe

-r *polyline-file (ESRI shapefile)*
File containing the river network(s) for WFlow

-c *polygon-file (ESRI shapefile)*
File containing the catchment(s) for WFlow

-d *rasterfile (GeoTiff)*
File containing the DEM for WFlow

-g *point-file (ESRI shapefile)*
(Optional) file containing gauges for WFlow. If not specified, only the outlet will be provided as gauge.

-l *rasterfile (GeoTiff)*
(Optional) file containing the land-use land-cover data to be used in WFlow. If not specified, one map will be generated with one class (1)

-s *rasterfile (GeoTiff)*
(Optional) file containing the soil type data to be used in WFlow. If not specified, one map will be generated with one class (1)

-C (Optional) option to remove all .xml files from the \staticmaps folder (default=no)

-A (Optional) option to burn catchments “all touching”. All cells inside or crossed will be assigned to the catchment. This option can be used when a large cell-size is chosen and the catchment itself is narrow. When a catchment is ‘narrow’ and the cell-size is large, the option can avoid ‘broken’ drainage paths. (default=no)

Example 1:

StaticMaps.exe -i StaticMaps.ini -d input\srtm_Citarum_90m.tif -r CatchRiver\river_burned_snap.shp -c CatchRiver\catchment_burned_snap.shp -C

Static maps will be derived from an ini-file (-i), dem raster (-d), river network shapefile (-r) and catchment shapefile (-c). After processing, all xml-files in the \staticmaps folder will be deleted (-C)

Example 2:

StaticMaps.exe -i StaticMaps.ini -d input\srtm_Citarum_90m.tif -r CatchRiver\river_burned_snap.shp -c CatchRiver\catchment_burned_snap.shp -l input\BIG_LandUse_0507_Citarum_resampled.tif -C -A

Same as example 1. Instead of one class (1) the staticmaps\wflow_landuse.map will now have the classes from a land-use raster (-l). The catchment is rasterized ‘all touched’ (-A)

D PCRaster

D.1 Pcrcalc

With the tool pcrcalc you can do simple to complex computations on PCRaster maps. An example of a very simple command, where the sum of two commands is calculated, is shown in Figure appendix 44. How the calculation works is shown in Figure appendix 45.

There many by which new PCRaster maps can be calculated from input maps. A full list can be found on: http://pcraster.geo.uu.nl/pcraster/4.0.0/doc/manual/operations.html

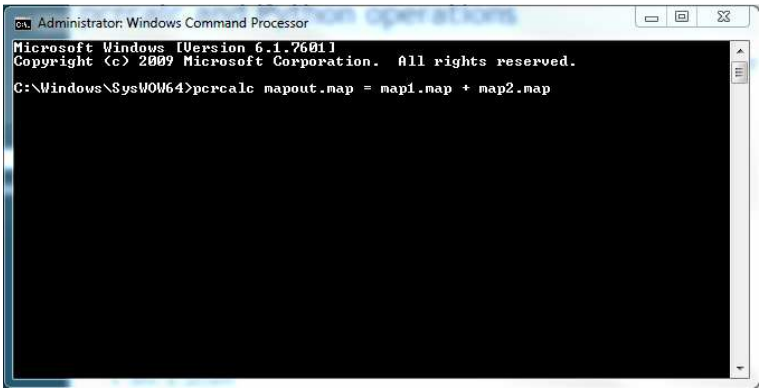


Figure appendix 44 – Simple calculation using pcrcalc

map1.map

40.2	16.1	8.0	27.5
29.2	48.6	11.3	24.9
49.4	13.5	36.4	22.9
23.0	42.4	26.1	8.1
0.8	26.3	11.1	29.7
17.6	8.3	41.6	24.5

map2.map

26.1	7.6	41.8	43.4
42.6	16.8	7.8	12.0
8.3	27.0	4.9	1.6
35.0	31.7	3.4	40.6
46.0	1.2	19.4	32.5
30.3	42.0	28.3	32.3

result: mapout.map

66.3	23.7	49.8	70.9
71.8	65.4	19.1	36.9
57.7	40.5	41.3	24.5
58.0	74.1	29.5	48.7
46.8	27.5	30.5	62.2
47.9	50.3	69.9	56.8

Figure appendix 45 – result of simple calculation

D.2 Aguila

Aguila is a viewer for PCRaster data, most commonly PCRaster maps. The result shown in Figure appendix 45 opened in Aguila is shown in Figure appendix 46. The command-line argument used to open the file is shown in Figure appendix 46.

A description of Aguila functionality can be found on: http://pcraster.geo.uu.nl/pcraster/4.0.2/doc/aguila/QuickStart.html

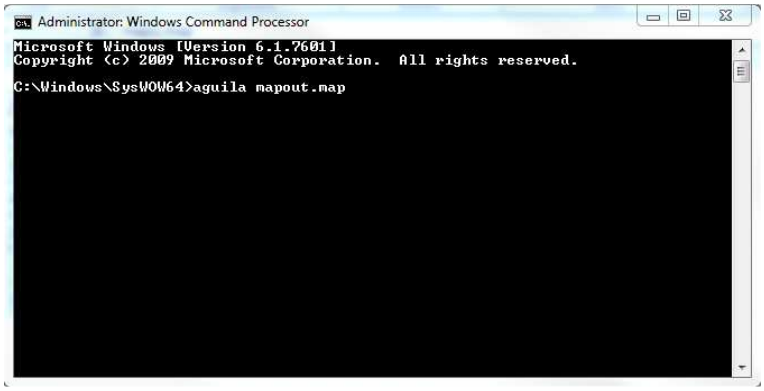


Figure appendix 46 – opening mapout.map with Aguila

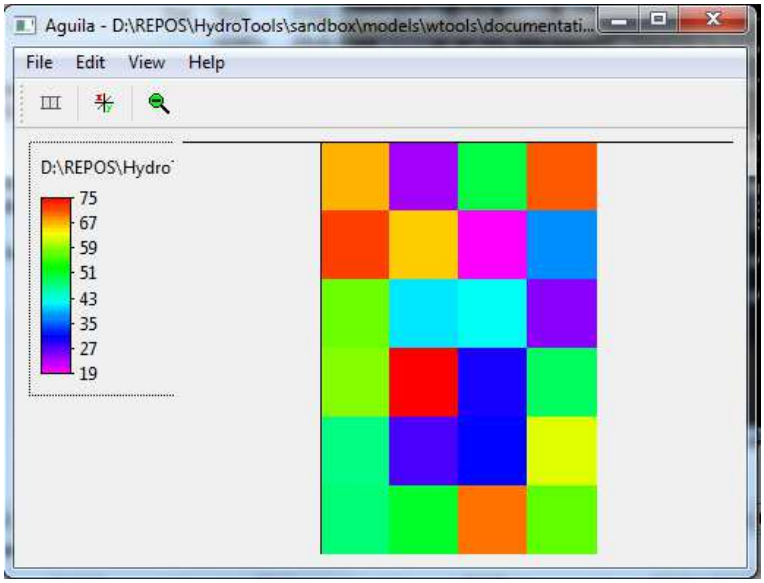


Figure appendix 47 – mapout.map opened in Aguila

E WFlow

In this annex, the WFlow command-line arguments are described and an example ini-file is given.

E.1 Command-line arguments

```
-F: if set wflow is expected to be run by FEWS. It will determine
    the timesteps from the runinfo.xml file and save the output initial
    conditions to an alternate location. The runinfo.xml file should be
located
    in the inmaps directory of the case.
-X: save state at the end of the run over the initial conditions at the
start
-f: Force overwrite of existing results
-T: Set last timestep
-S: Set the start timestep (default = 1)
-N: No lateral flow, use runoff response function to generate fast runoff
-s: Set the model timesteps in seconds
-I: re-initialize the initial model conditions with default
-i: Set input table directory (default is intbl)
-x: run for subcatchment only (e.g. -x 1)
-C: set the name  of the case (directory) to run
-R: set the name runId within the current case
-L: set the logfile
-E: Switch on reinfiltration of overland flow
-c: name of wflow the configuration file (default: Cassename/wflow_sbm.ini).
-h: print usage information
-W: If set, this flag indicates that an ldd is created for the water level
    for each timestep. If not the water is assumed to flow according to the
    DEM. Wflow will run a lot slower with this option. Most of the time
    (shallow soil, steep topography) you do not need this option. Also, if
you
    need it you migth actually need another model.
-U: The argument to this option should be a .tss file with measured
discharge in
    [m^3/s] which the program will use to update the internal state to match
    the measured flow. The number of columns in this file should match the
    number of gauges.
-u: list of gauges/columns to use in update. Format:
    -u [1 , 4 ,13]
    The above example uses column 1, 4 and 13
    Note that this also sets the order in which the updating takes place! In
    general specify downstream gauges first.
-P: set parameter multiply dictionary (e.g: -P 'self.FirstZoneDepth' : 1.2
    to increase self.FirstZoneDepth by 20\%, multiply with 1.2)
-p: set input parameter (dynamic, e.g. precip) multiply dictionary
    (e.g: -p 'Precipitation' : 1.2 to increase Precipitation
    by 20%, multiply with 1.2)
-v: set verbosity level
```

E.2 Ini-file

A description of wflow_sbm.ini and wflow_hbv.ini can be found on: http://ops-wflow.sourceforge.net/1.0RC7/wflow_usage.html#wflow-sbm-hbv-ini-file

A very simple version of the wflow_sbm.ini file, containing the most important model settings and output is shown below.

```
[model]
#AnnualDischarge (average annual discharge at outlet for computation of
riverwidth)
AnnualDischarge=50

[layout]
# if set to zero the cell-size is given in lat/long (the default)
sizeinmetres = 0

[outputmaps]
#runoff maps run00000.001,run00000.002,… and actual evaporation maps
aet00000.001, aet00000.002,… will be written in the run-directory\outmaps
folder
self.SurfaceRunoff=run
self.ActEvap=aet

[outputtss_0]
#a runoff tss file will be written in the run-directory
samplemap=staticmaps/wflow_gauges.map
self.SurfaceRunoff=runoff

[outputtss_1]
#sub-catchment average actual ET, PET and precipitation will be written in tss
files in the run-directory
samplemap=staticmaps/wflow_subcatch.map
self.ActEvap=actevapavg
self.Precipitation=precipitationavg
self.PotEvap=potevapavg

[outputcsv_0]
#runoff will be written in a csv file in the run-directory
samplemap=staticmaps/wflow_gauges.map
self.SurfaceRunoff=qsim.csv
```