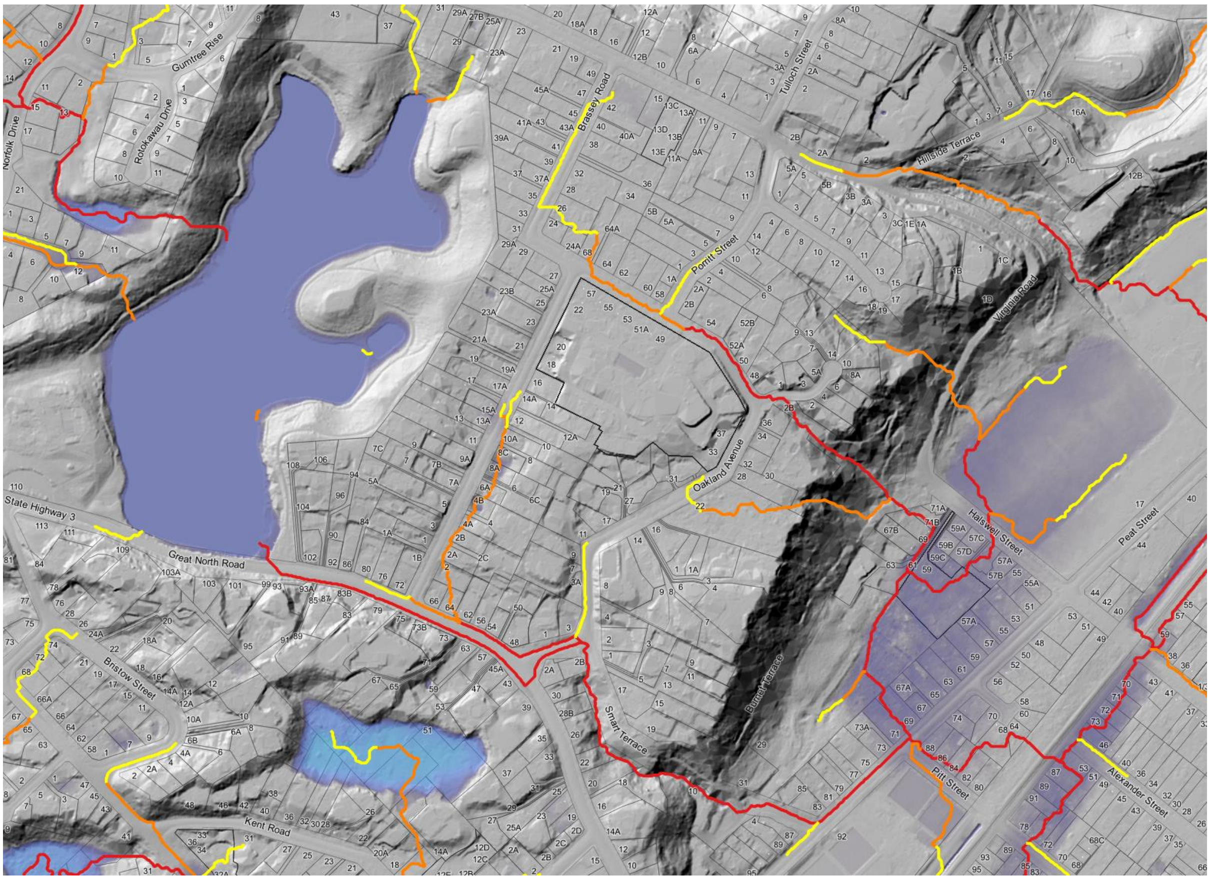

Methodology to Create Overland Flow Paths using Hydrological Modelling Tools in QGIS

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Last Revised: 02/11/2021

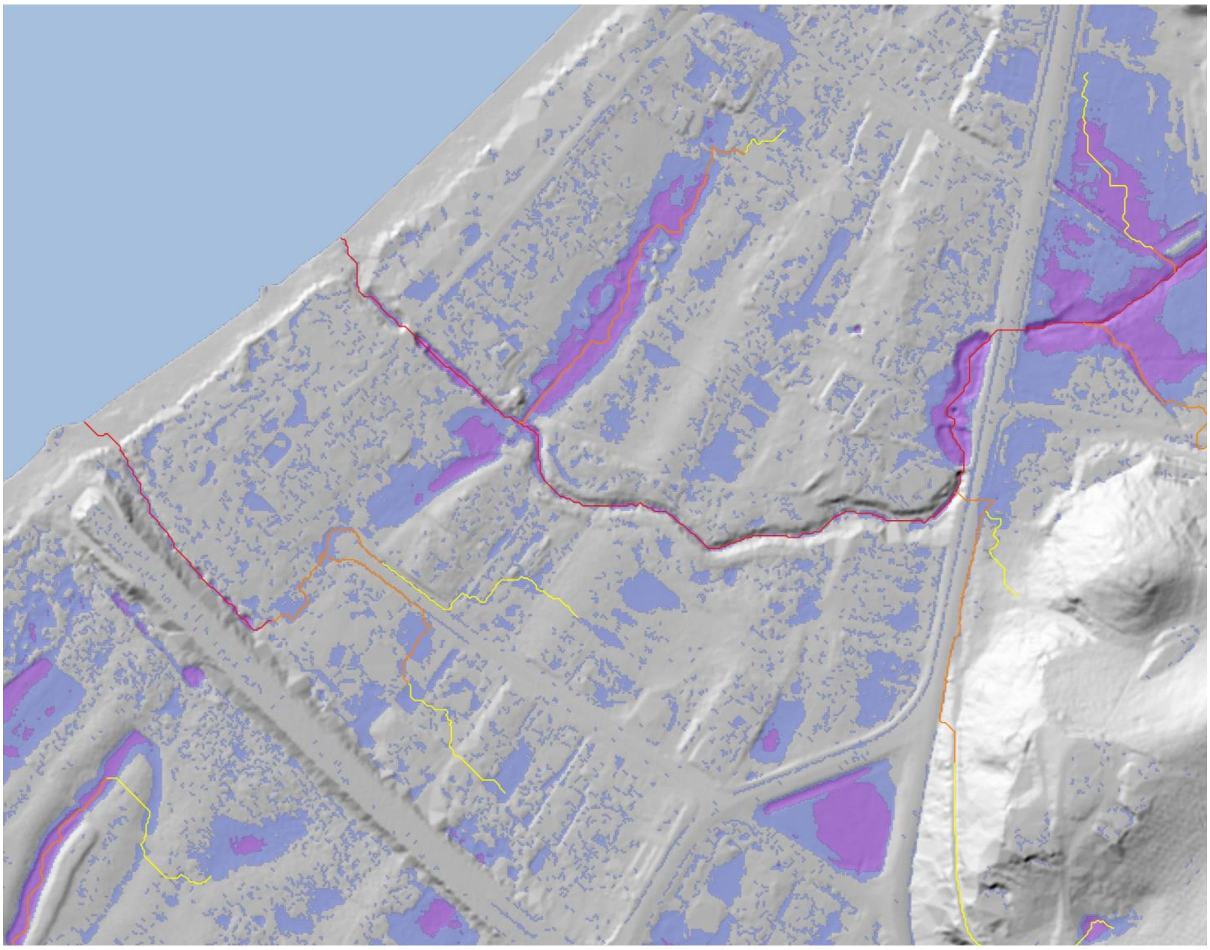
Contents

1 Introduction

Overland flow paths are a common way of representing the predicted path of stormwater as it flows over the topography. Depression areas map the potential extent of stormwater ponding if the stormwater network is full or failure occurs within the network.

Overland flow paths require a Digital Elevation Model (DEM) that is representative of the ground surface. The DEM is obtained from LiDAR, a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light. LiDAR is typically recorded from an aircraft where the laser picks up multiple levels (deemed returns); the last return is usually taken to represent the ground surface. This return does not include building elevations, and above ground features are removed so as to not influence the topographical path of overland flow or ponding in depression areas.

This document describes the methodology used in QGIS to import a Digital Elevation Model (DEM), hydrologically correct it to ensure flow and then extract new vector lines from it that represent the overland flow paths across the DEM. In addition the methodology used to extract the depression areas from the DEM is detailed.



2 Project Setup

2.1 Processing Requirements

Data:

- Gridded DEM derived from 2020/2021 LiDAR Survey.
  This dataset is supplied in GeoTIFF format.
  An Airborne Laser Scanner survey was conducted over the Whanganui urban area and Whangaehu River area of interest totalling approximately 443 km2. One of the deliverables from this survey is a Gridded ground surface (1 m separation grid) with hydro flattening and breaklines for water bodies, streams and rivers. The LiDAR survey was captured on the following dates: 8 September 2020, 2 December 2020, 4 January 2021, 27 January 2021, 3 February 2021

- All spatial data for this project provided in terms of New Zealand Transverse Mercator 2000 (NZTM2000) horizontal and New Zealand Vertical Datum (NZVD2016).

Software:

- QGIS Desktop Version 3.20.3 (64bit)
  https://qgis.org
- WhiteboxTools Version 1.5.0
  https://www.whiteboxgeo.com/geospatial-software/

Platform:

- Microsoft Windows 10 Enterprise
- HP Z2 Tower G4 Workstation
- 128Gb RAM
- Intel Xeon E-2136 CPU @ 3.30GHz (6 Cores, 12 Logical Processors)

- NVidia Quadro P2000 GPU (5GB Dedicated RAM)

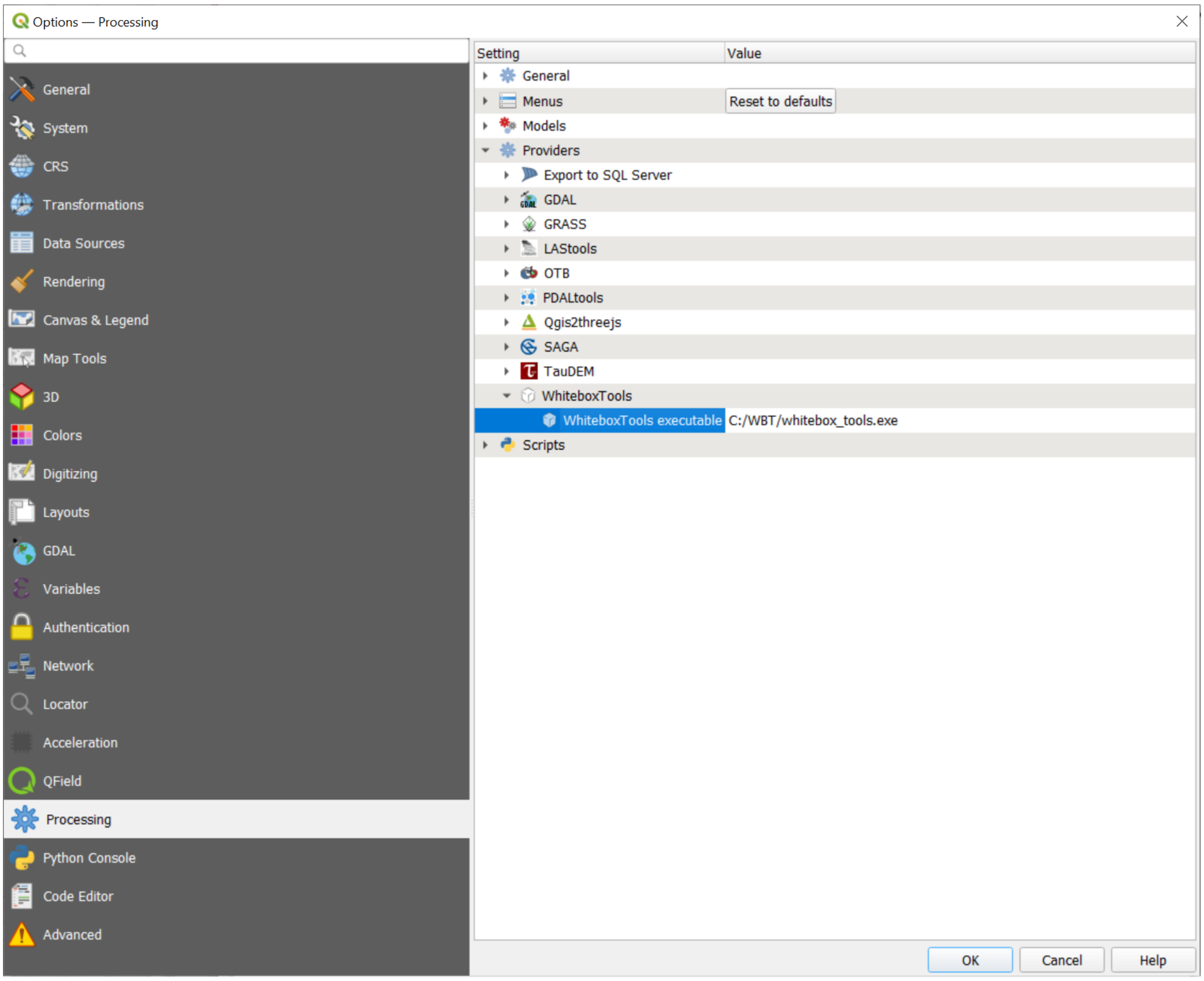
2.2 QGIS Setup

1. Download and Install Whitebox tools

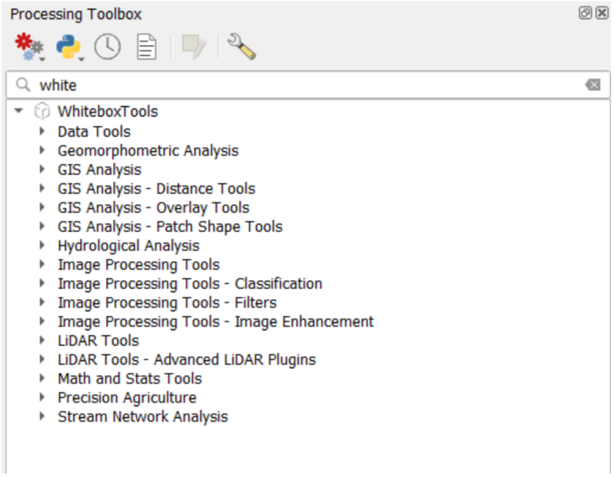
https://www.whiteboxgeo.com/download-whiteboxtools

2. Setup Whitebox Processing Provider in QGIS

https://www.whiteboxgeo.com/manual/wbt_book/qgis_plugin.html



Additional Tools become available in the QGIS Processing Toolbox:


Processing Toolbox
white
WhiteboxTools
Data Tools
Geomorphometric Analysis
GIS Analysis
GIS Analysis - Distance Tools
GIS Analysis - Overlay Tools
GIS Analysis - Patch Shape Tools
Hydrological Analysis
Image Processing Tools
Image Processing Tools - Classification
Image Processing Tools - Filters
Image Processing Tools - Image Enhancement
LiDAR Tools
LiDAR Tools - Advanced LiDAR Plugins
Math and Stats Tools
Precision Agriculture
Stream Network Analysis

3 Processing Steps

3.1 Overland Flow Paths

1. Identify Sinks
2. Breach Single Cell Pits
3. Breach Depressions (Method 1 – Least Cost)
4. Fill Remaining Depressions
5. Calculate Flow Accumulation and Flow Pointer
6. Extract Overland Flow Paths and Vectorise
    a. Contributing Area >= 5ha
    b. Contributing Area >= 2ha < 5ha
    c. Contributing Area >= 1ha < 2ha
7. Clip Vector results using Hydro Mask

3.2 Depression Areas

1. Calculate Depth in Sinks for original DEM
2. Calculate areas greater than or equal to 300mm and polygonise
3. Calculate areas less than 300mm and polygonise
4. Clip Vector results using Hydro Mask

4 Processing Algorithms Used

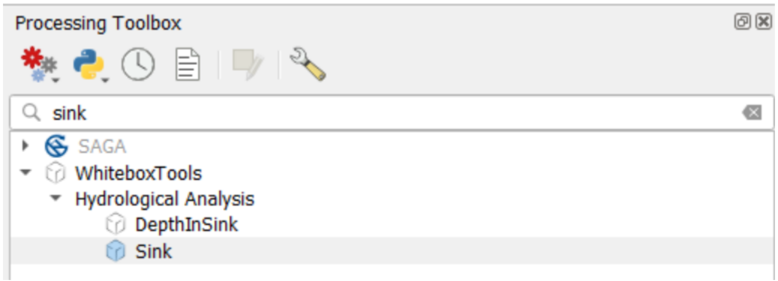
4.1 Investigate DEM for Sinks

Determine if the DEM is hydrologically enforced; does the DEM have sinks (i.e. topographic depressions).

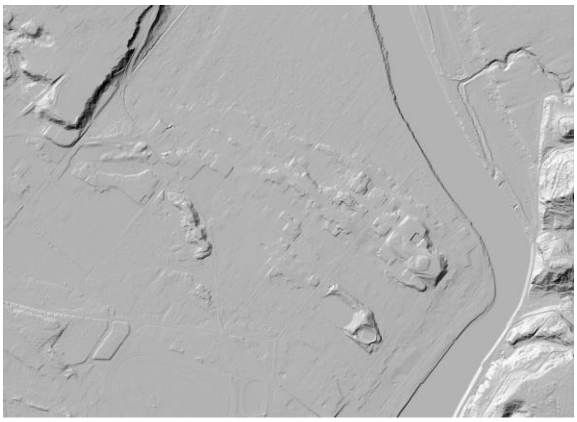
4.1.1 Identify Sinks

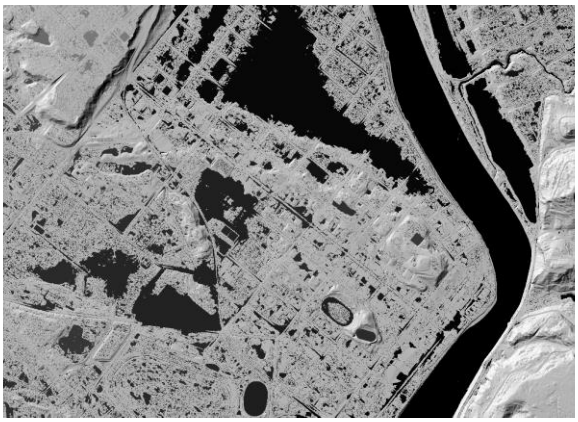
In QGIS, run the Whitebox **Sink** tool on the DEM, to identify each sink (i.e. topographic depression).

> *A sink, or depression, is a bowl-like landscape feature, which is characterized by interior drainage. Each identified sink in the input DEM is assigned a unique, non-zero, positive value in the output raster.*



Execution completed in 91.91 seconds (1 minute 32 seconds)



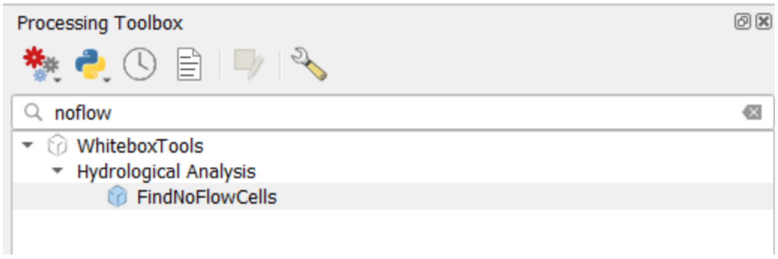


WhiteboxTools command:

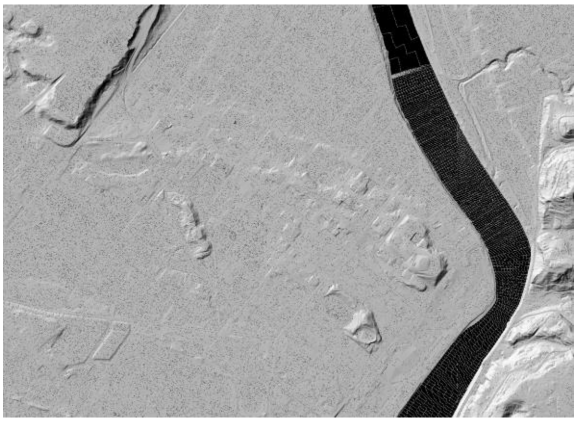
```
"C:/WBT/whitebox_tools.exe" -v --run=Sink --
dem="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\lidar2020_dem_1m.tif" --
zero_background="False" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\sinks.tif"
```

4.1.2 Find No Flow Cells

Finds grid cells with no downslope neighbours



Execution completed in 33.73 seconds



WhiteboxTools command:

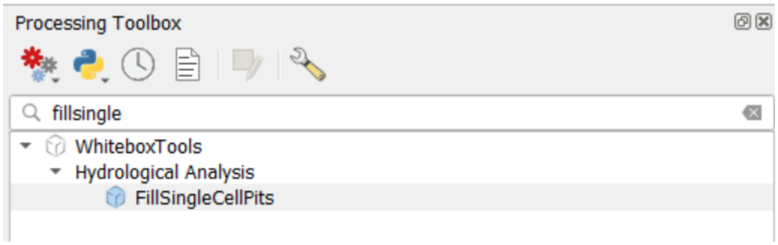
```
"C:/WBT/whitebox_tools.exe" -v --run=FindNoFlowCells --
dem="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\lidar2020_dem_1m.tif" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\no_flow_cells.tif"
```

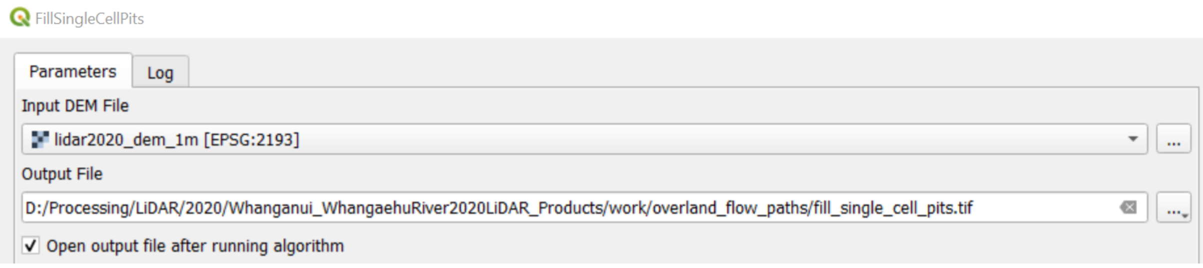
4.2 Hydrological Enforcement using Fill Depressions methodology

The DEM is not hydrologically enforced as there are many sinks within the DEM. We now have a decision to make on how to create the hydrologically enforced model. There is the typical **fill** approach which will increase the sink values until they are just a little bit lower than their neighbouring cells, or we can take the **breach** approach which will maintain the sink heights, but will build channels to cut through the DEM and make sure that all the depressions are connected so that every cell can flow into another cell. There is also a secondary type of breaching called **breach least cost** which as it says, will breach the DEM with more control parameters based on the cost to breach the depressions.

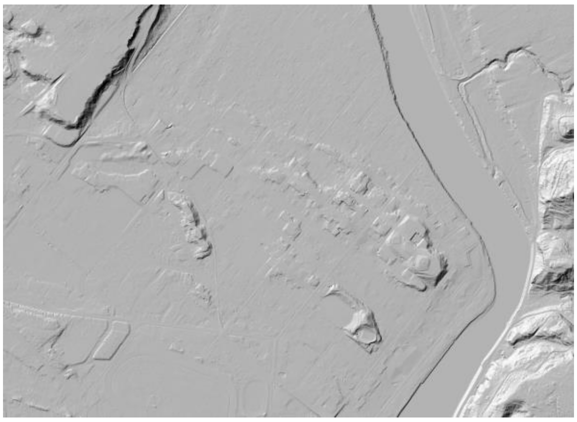
4.2.1 Fill Single Cell Pits

Raises pit cells to the elevation of their lowest neighbour





Execution completed in 84.56 seconds (1 minute 25 seconds)

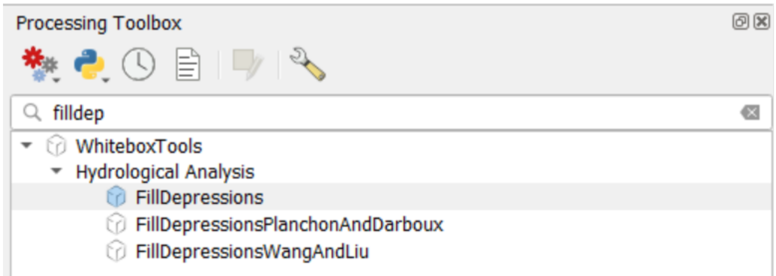


WhiteboxTools command:

```
"C:/WBT/whitebox_tools.exe" -v --run=FillSingleCellPits --dem="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\lidar2020_dem_1m.tif" --output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths\fill_single_cell_pits.tif"
```

4.2.2 Fill Depressions

Fills all of the depressions in a DEM.



Note that we use **Fix flat areas** and we apply a very small **Flat increment value**. This will allow us to define a flow path across flat areas that more accurately follows the actual terrain (rather than a straight line directly across the flat area).

Execution completed in 119.76 seconds (1 minute 60 seconds)

WhiteboxTools command:

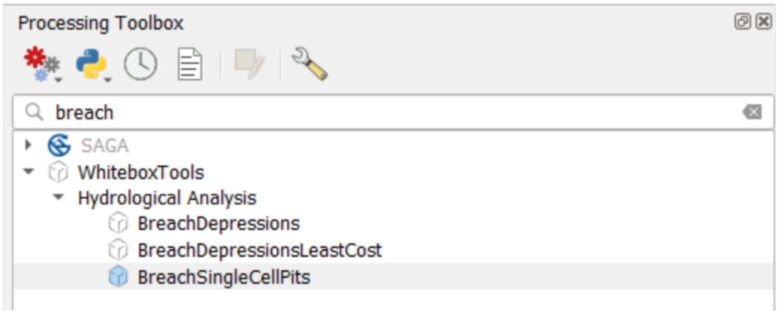
```
"C:/WBT/whitebox_tools.exe" -v --run=FillDepressions --
dem="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths
\fill_single_cell_pits.tif" --fix_flats="True" --flat_increment=0.0001 --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\fill_depressions.tif"
```

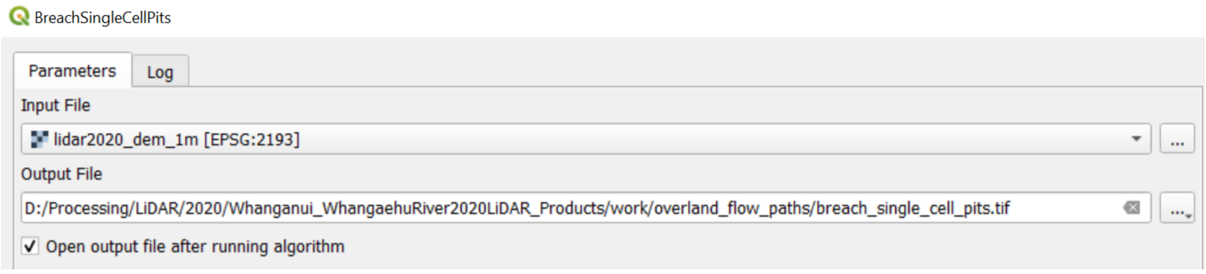
4.3 Hydrological Enforcement using Breaching methodology

4.3.1 Breach Single Cell Pits

First apply a breach action on individual pits. This acts to get rid of single cell depressions first before we breach depressions that are larger than one pixel in size.

Removes single-cell pits from an input DEM by breaching





Execution completed in 90.24 seconds (1 minute 30 seconds)

WhiteboxTools command:

```
"C:/WBT/whitebox_tools.exe" -v --run=BreachSingleCellPits --
dem="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\lidar2020_dem_1m.tif" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\breach_single_cell_pits.tif"
```

4.3.2 Breach Depressions

4.3.2.1 Method 1 – Breach Depressions Least Cost

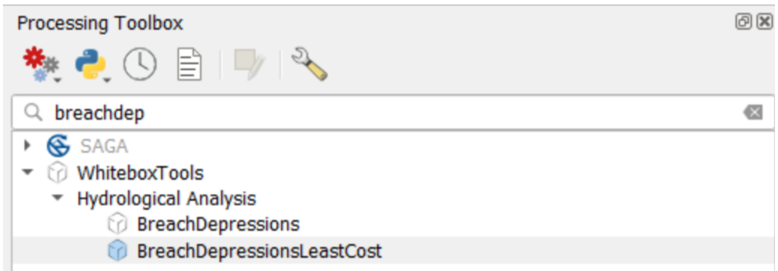
Breaches the depressions in a DEM using a least-cost pathway method.

Using the **breach depressions least cost** algorithm we are able to effectively cut through road obstructions which would normally utilise culverts to channel water underneath them.

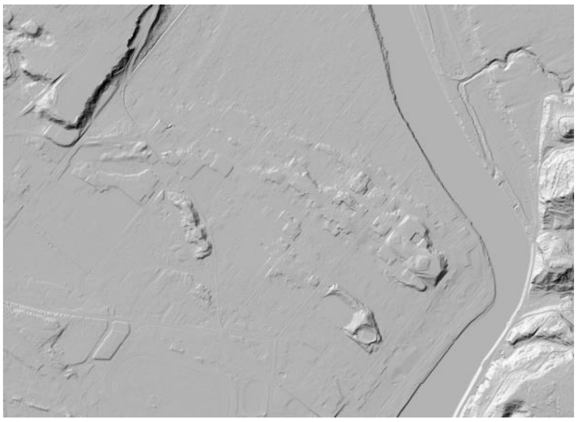
> *This tool is actually performing a least-cost based region growing operation centred on each of the pit cells contained in the input DEM. This operation grows outwardly from the pit until a target (lower) cell is identified, at which point a breach channel is carved, and which follows the least-cost path connecting the pit and target cell. This search distance parameter will effectively stop the region-growing operation when the current shortest potential least-cost path is longer than this radius parameter. This is probably the most important parameter for this tool, because breaching, when not constrained with a maximum breach length, can result in very long breach channels that dig through significant ridges.*

Multiple Runs were carried out to determine which combinations of breaching parameters to use that best suited the Whanganui DC topology.

Most Suitable Run



Execution completed in 3617.46 seconds (1 hour 0 minute 17 seconds)

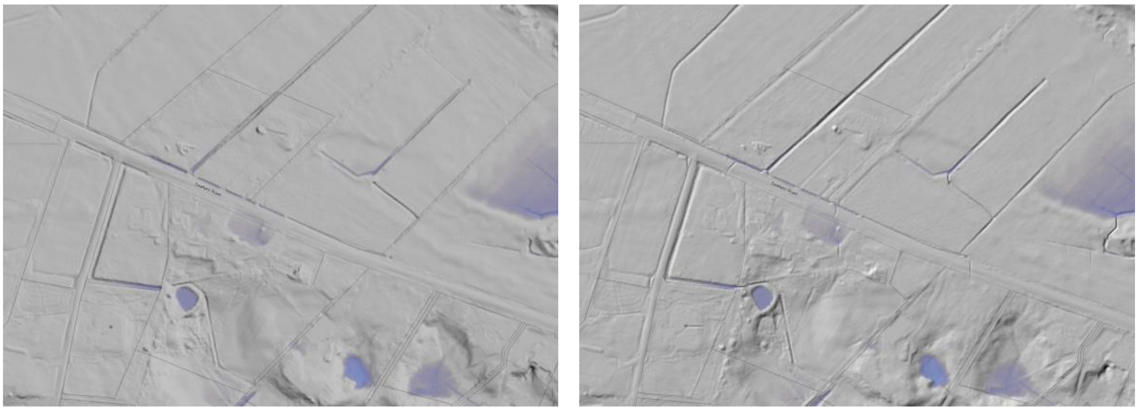


WhiteboxTools command:

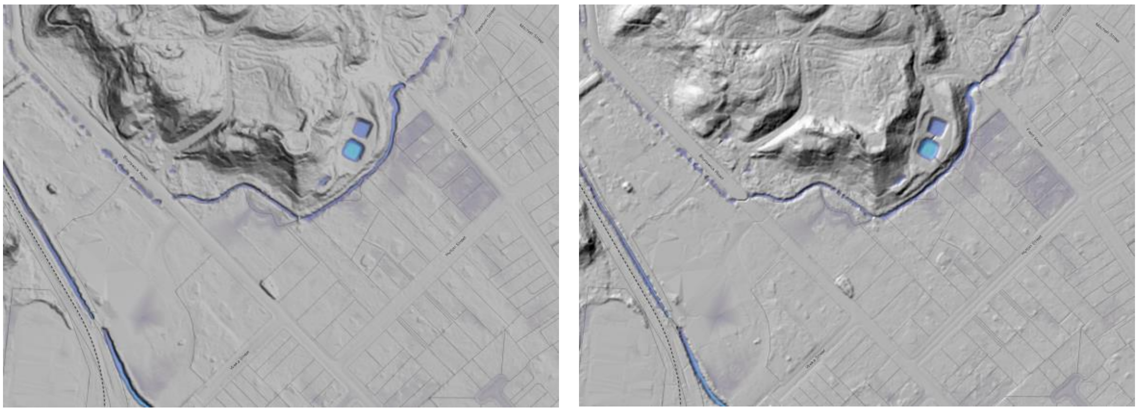
```
"C:/WBT/whitebox_tools.exe" -v --run=BreachDepressionsLeastCost --
dem="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths
\breach_single_cell_pits.tif" --dist=30 --min_dist="True" --flat_increment=0.0001 --fill="False" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\breach_depressions_least_cost.tif"
 < 03BreachDepressions_30cells_00002flatinc.tif
```

Examples of the affect of using the breach depressions least cost algorithm, with original DEM on the left and breached DEM on the right

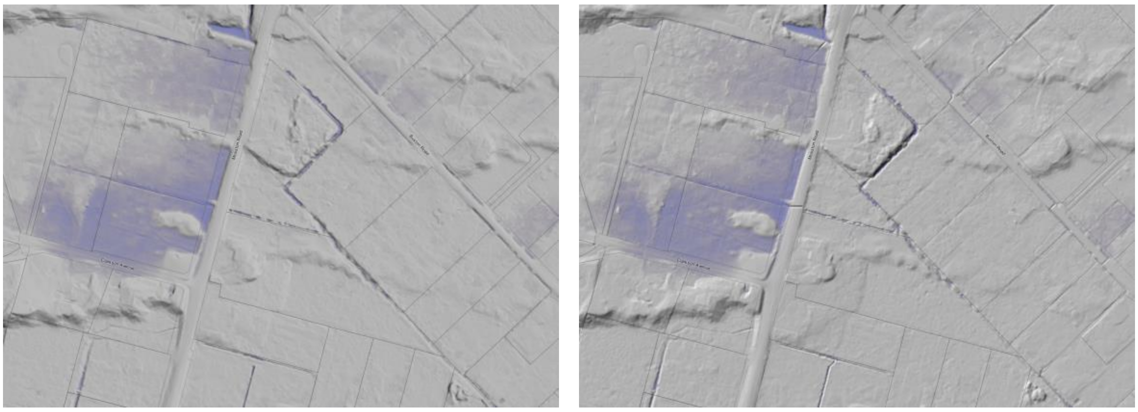
Seafield Road:



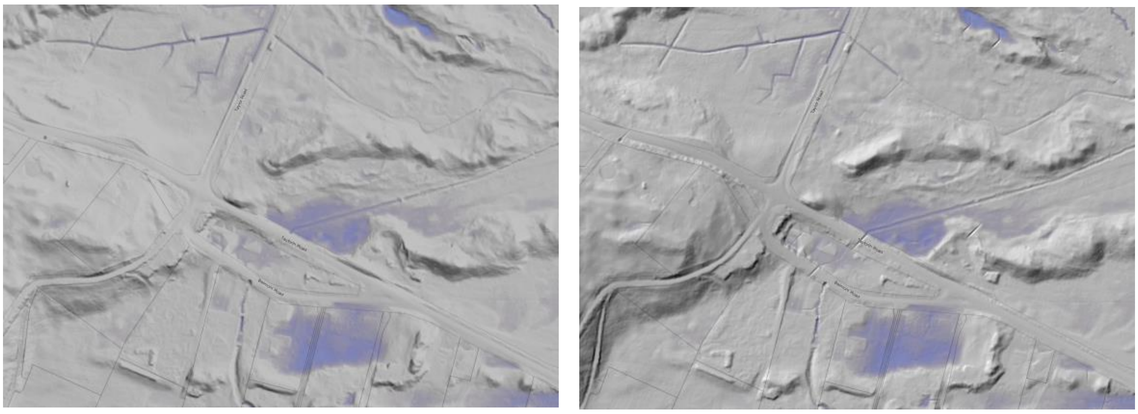
Brunswick Road:



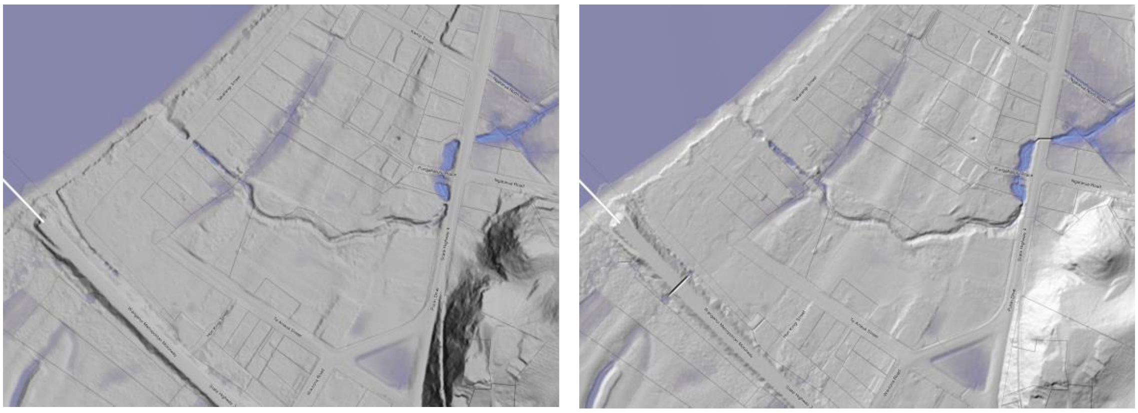
Mosston Road



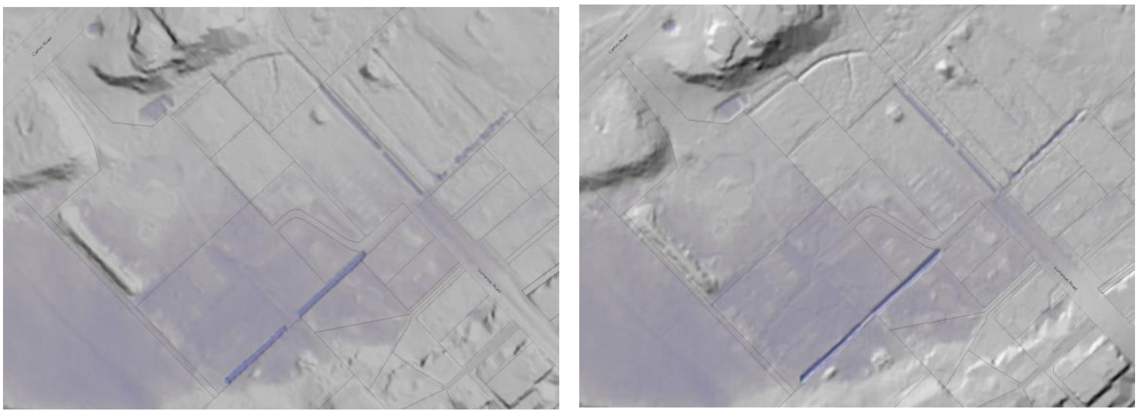
Tayforth Road



Putiki



Somerset Road

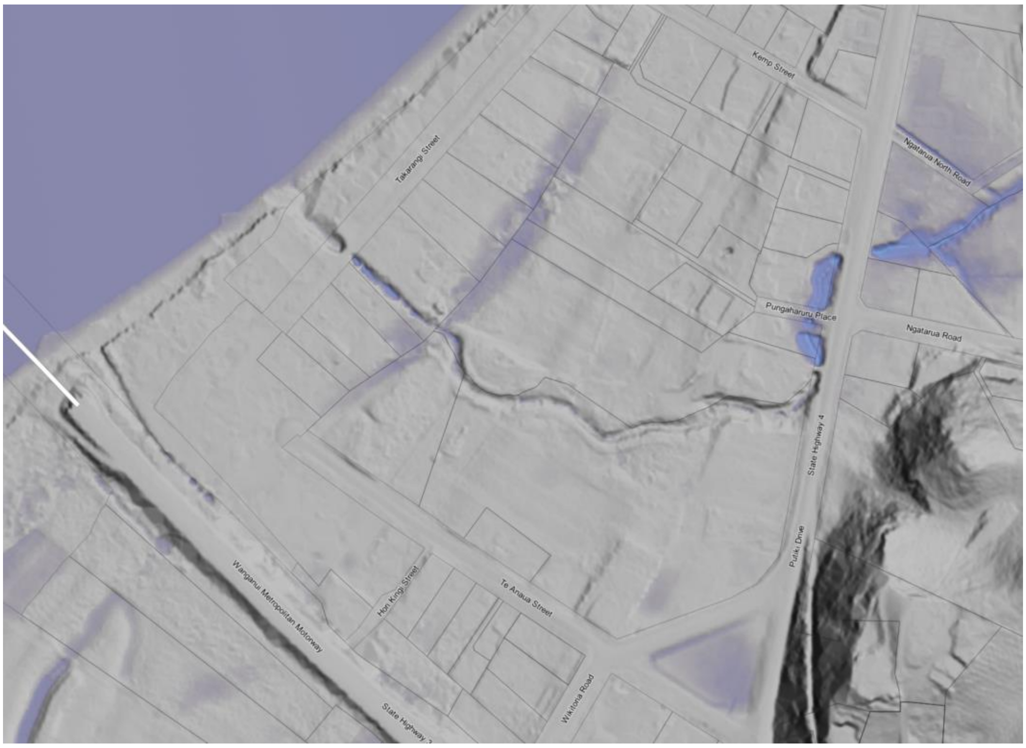


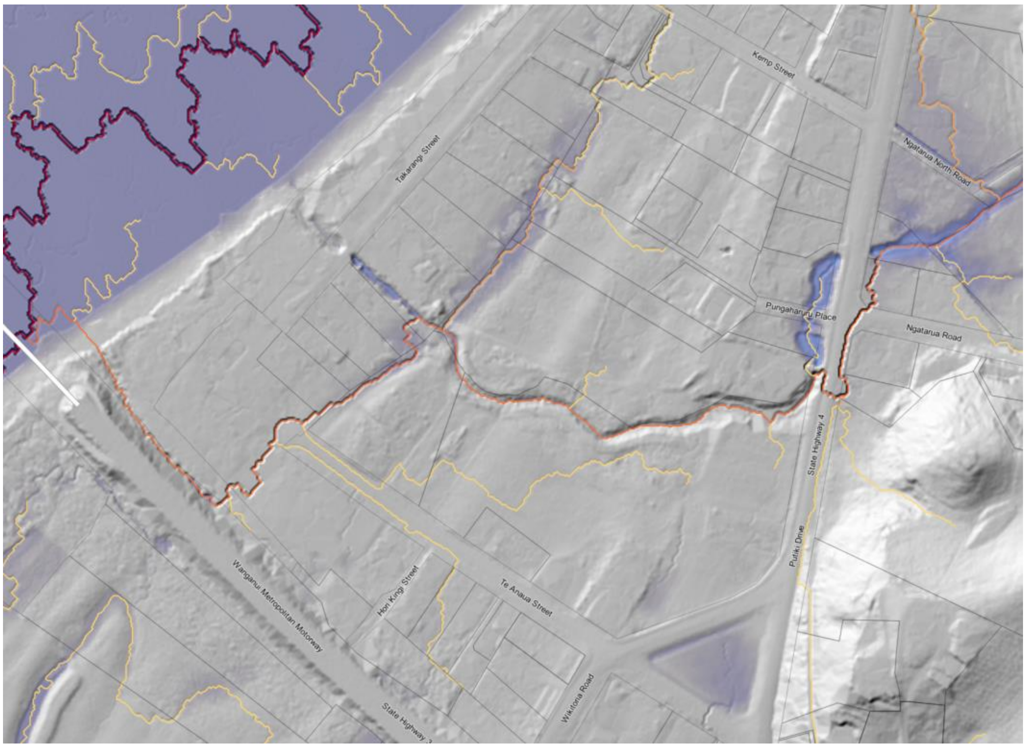
4.3.2.2 Method 2 – Breach Depressions

In comparison with the Breach Depressions Least Cost tool, this breaching method often provides a less satisfactory, higher impact, breaching solution and is often less efficient. It has been provided to users for legacy reasons and it is advisable that users try the Breach Depressions Least Cost tool to remove depressions from their DEMs first. The Breach Depressions Least Cost tool is particularly well suited to breaching through road embankments. Nonetheless, there are applications for which full depression filling using the Fill Depressions tool may be preferred.

This method can generate significant breaching errors.

For example, the following images show the raw DEM for Putiki, followed by the DEM breached using this method…





Significant errors show up where the stream crosses Putiki Drive and for the location of the Stream outlet to the Whanganui River some 160m southwest of the actual outlet.

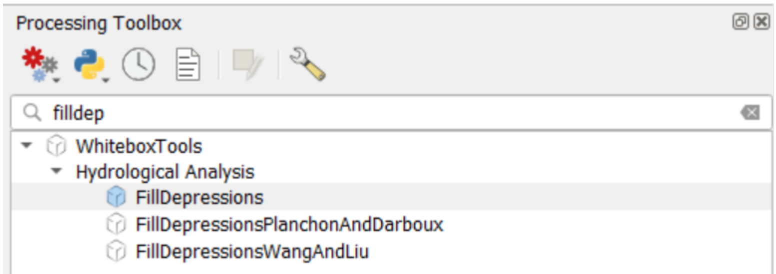
As a result this method was determined to be unsuitable for breaching depressions in the Whanganui DC topology.

4.4 Calculate Flow Accumulation and Flow Pointer

Generate a flow accumulation grid (i.e. catchment area). This algorithm is an example of single-flow-direction (SFD) method because the flow entering each grid cell is routed to only one downslope neighbour, i.e. flow divergence is not permitted.

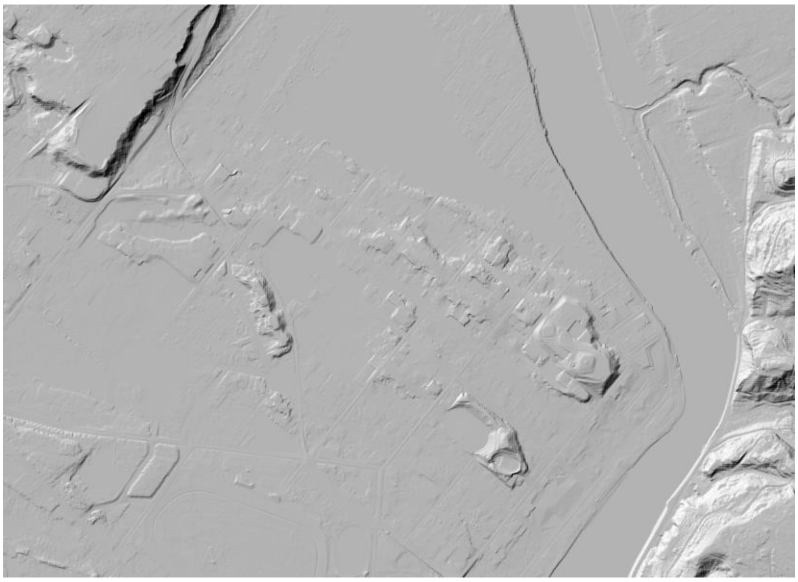
4.4.1 Fill Depressions

Fills all of the remaining depressions in the DEM.



Note that we use **Fix flat areas** and we apply a very small **Flat increment value**. This will allow us to define a flow path across flat areas that more accurately follows the actual terrain (rather than a straight line directly across the flat area).

Execution completed in 108.66 seconds (1 minute 49 seconds)



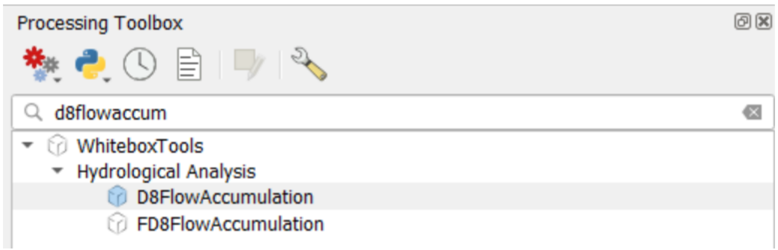
WhiteboxTools command:

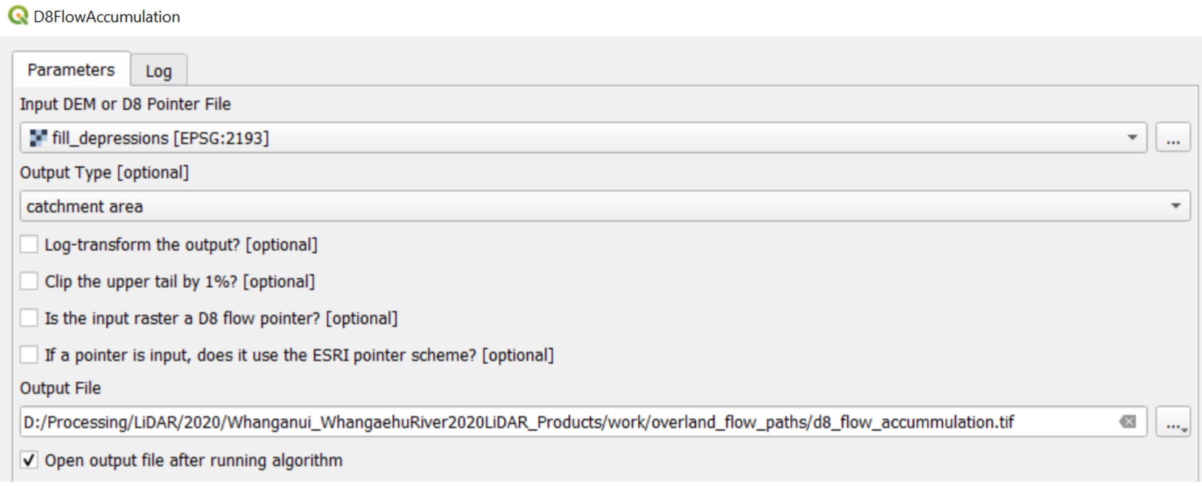
```
"C:/WBT/whitebox_tools.exe" -v --run=FillDepressions --
dem="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths
\breach_depressions_least_cost.tif" --fix_flats="True" --flat_increment=0.0001 --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\fill_depressions.tif"
```

4.4.2 D8 Flow Accumulation

Calculates a D8 flow accumulation (i.e. catchment area) raster from an input DEM or flow pointer.

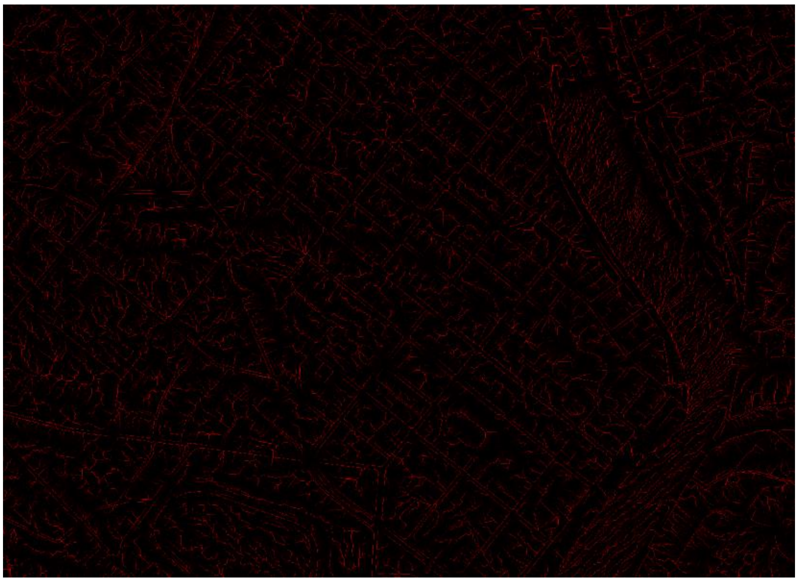
The output flow-accumulation is set to catchment area (i.e. the upslope area)





We use **Catchment area** as the **Output Type** so that we can extract out 1ha, 2ha and 5ha catchment overland flow paths later.

Execution completed in 198.04 seconds (3 minutes 18 seconds)



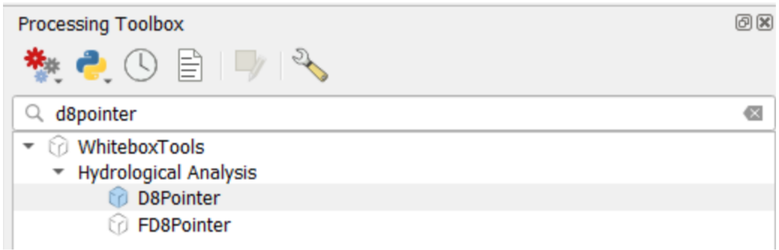
WhiteboxTools command:

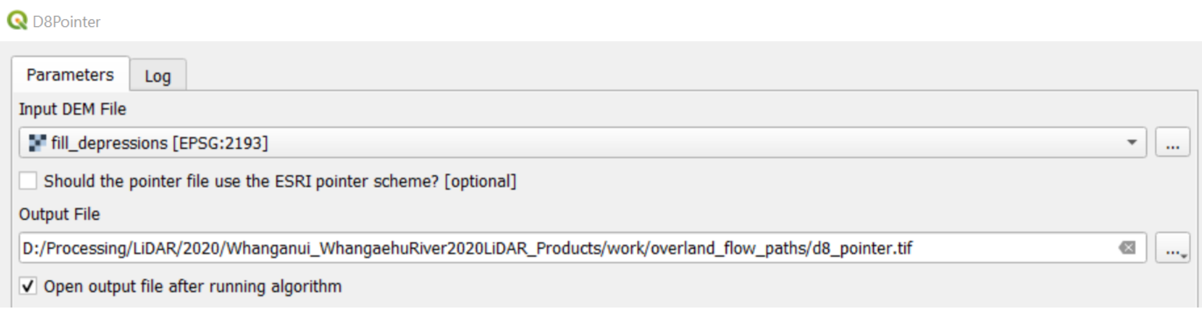
```
"C:/WBT/whitebox_tools.exe" -v --run=D8FlowAccumulation --
input="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_path
s\fill_depressions.tif" --out_type="catchment area" --log="False" --clip="False" --pntr="False" --esri_pntr="False"
--
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\d8_flow_accummulation.tif"
```

4.4.3 D8 Pointer Flow Direction

Now that we have created the accumulation raster's, we need to extract the pointer raster to determine flow direction of the raster.

Calculates a D8 flow pointer raster from an input DEM





Execution completed in 95.39 seconds (1 minute 35 seconds)

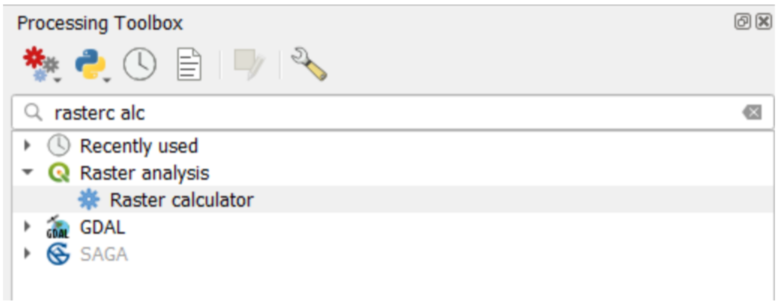
WhiteboxTools command:

```
"C:/WBT/whitebox_tools.exe" -v --run=D8Pointer --
dem="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths
\fill_depressions.tif" --esri_pntr="False" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\d8_pointer.tif"
```

4.5 Extract Overland Flow Paths

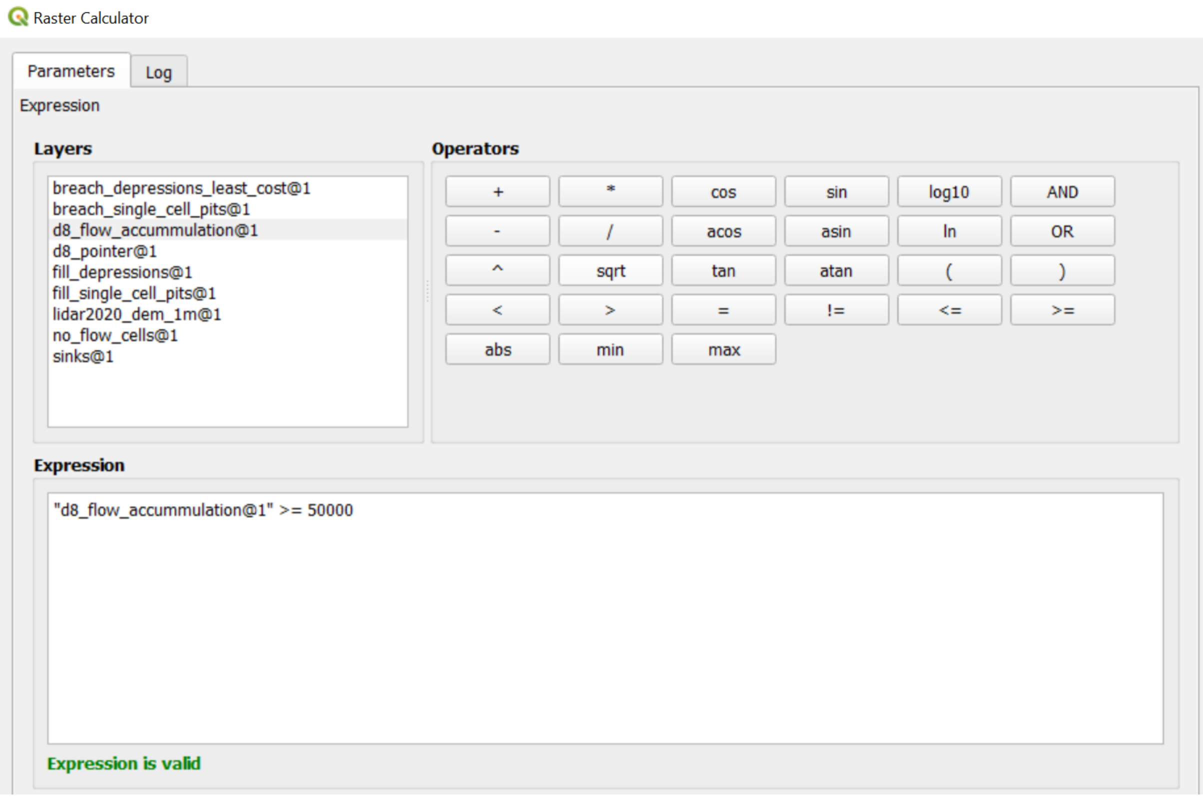
4.5.1 QGIS Raster Calculator

The QGIS Raster Calculator allows performing algebraic operations using raster layers. The resulting layer will have its values computed according to an expression.

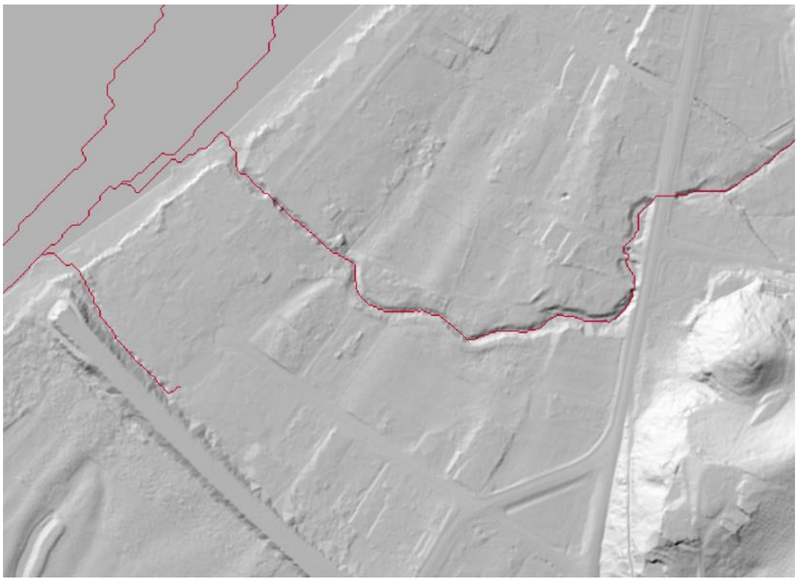


4.5.1.1 Contributing Area >= 5ha

Calculate overland flow path with a contributing area of greater than or equal to 5.0 ha

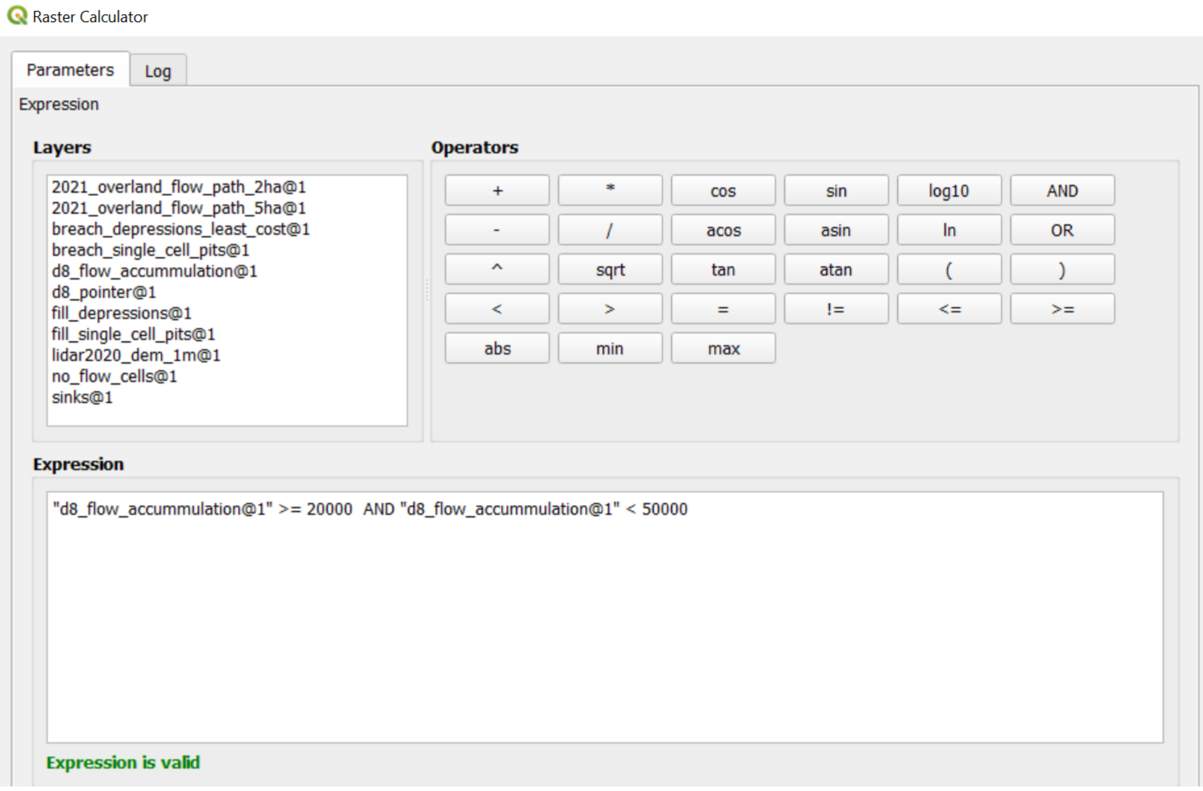


Execution completed in 86.02 seconds (1 minute 26 seconds)

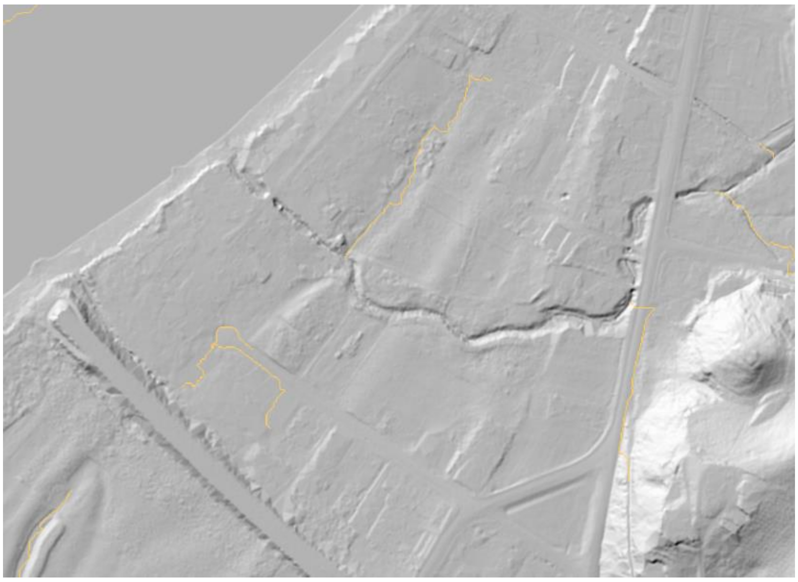


4.5.1.2 Contributing Area >= 2ha < 5ha

Calculate overland flow path with a contributing area of greater than or equal to 2.0 ha and less than 5ha

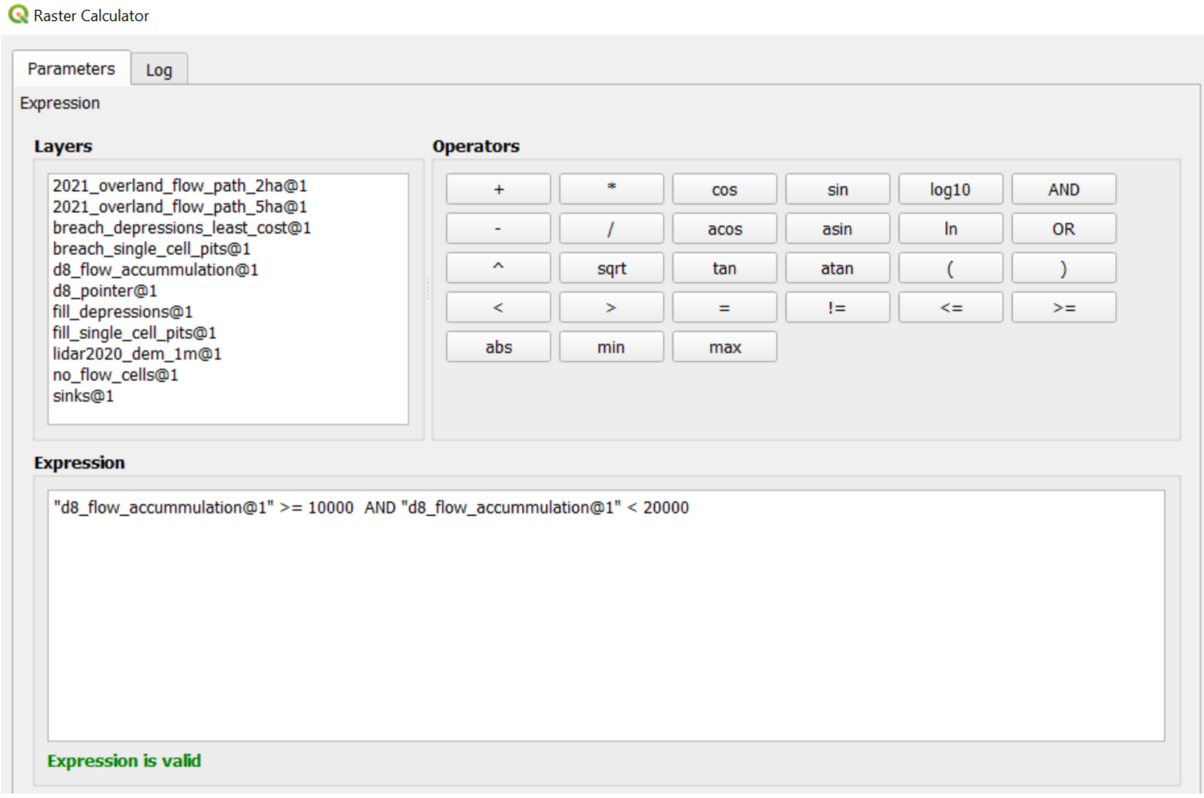


Execution completed in 108.47 seconds (1 minute 48 seconds)

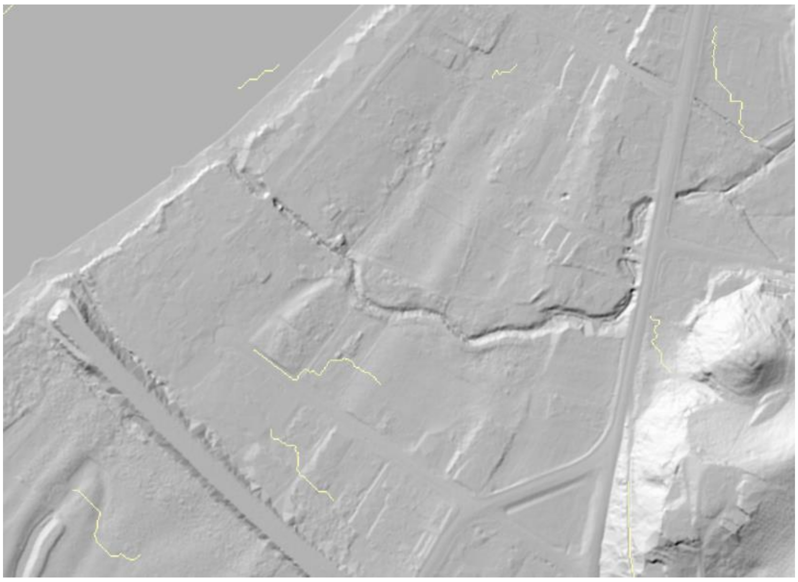


4.5.1.3 Contributing Area >= 1ha < 2ha

Calculate overland flow path with a contributing area of greater than or equal to 1.0 ha and less than 2ha

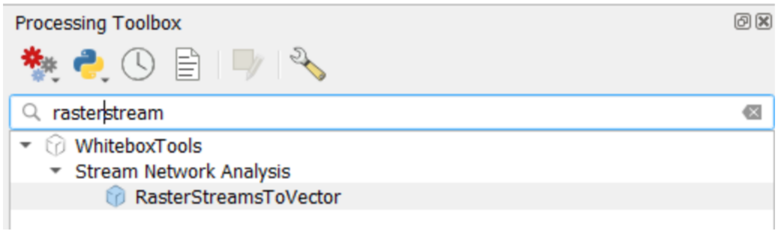


Execution completed in 96.99 seconds (1 minute 37 seconds)



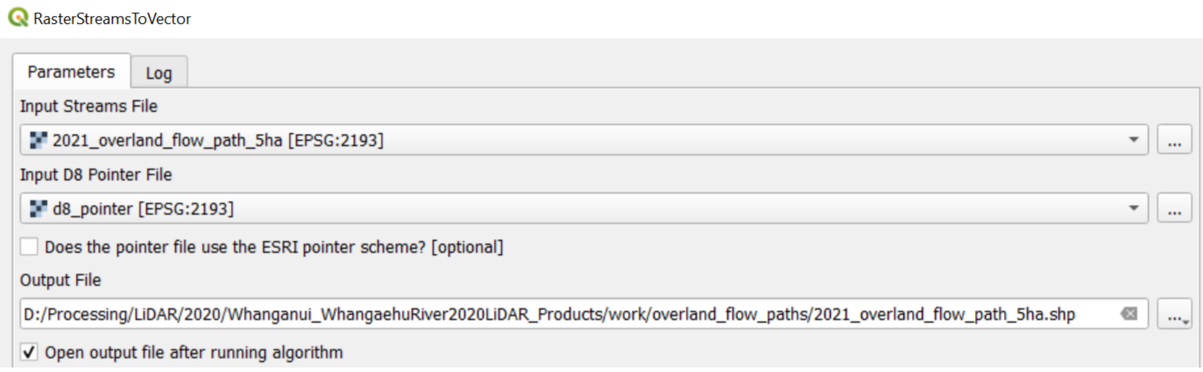
4.5.2 Convert Raster Streams to Vector

Convert the raster stream files into a vector files.

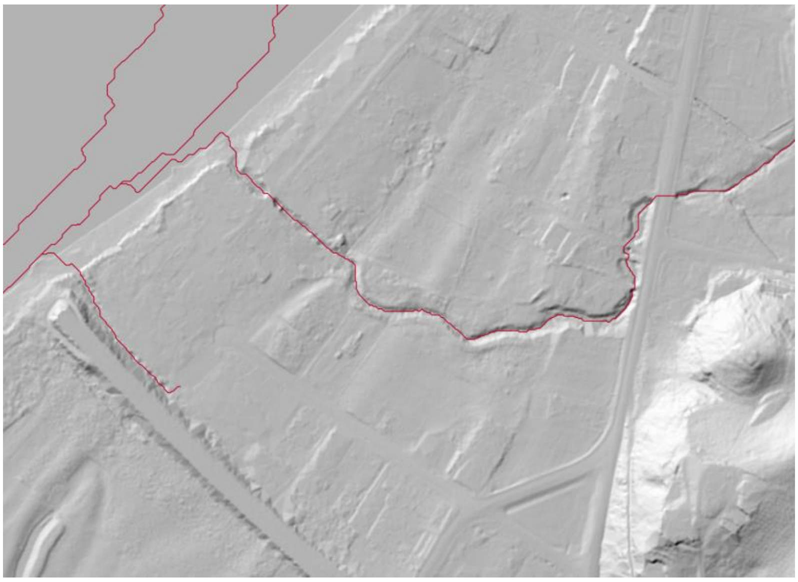


4.5.2.1 Contributing Area >= 5ha

Convert overland flow path with a contributing area of greater than or equal to 5.0 ha to vector



Execution completed in 27.36 seconds

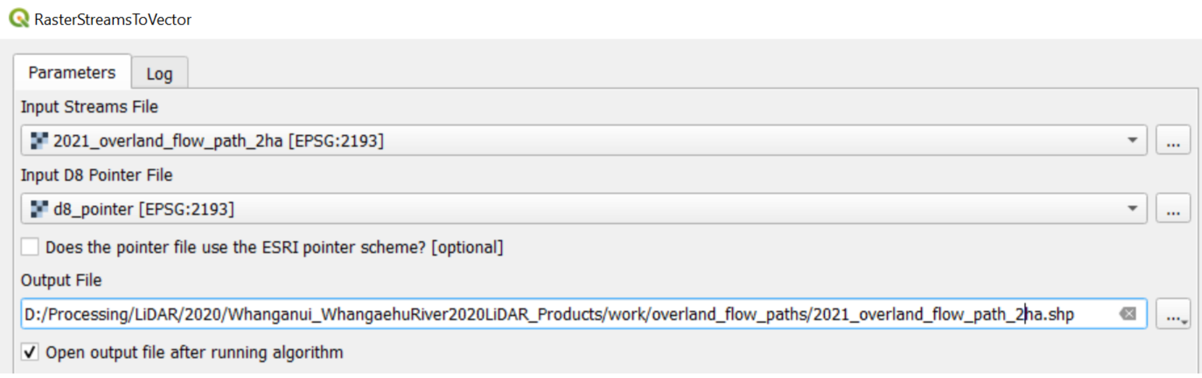


WhiteboxTools command:

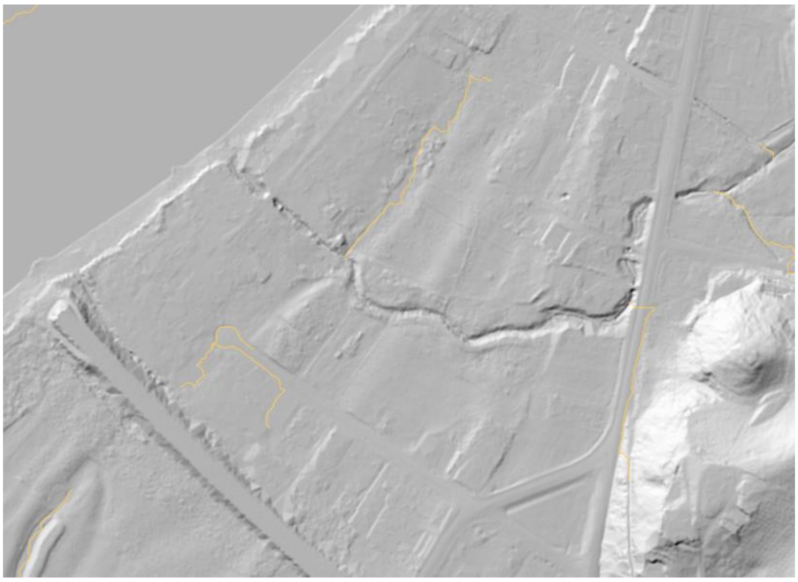
```
"C:/WBT/whitebox_tools.exe" -v --run=RasterStreamsToVector --
streams="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pa
ths\2021_overland_flow_path_5ha.tif" --
d8_pntr="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_p
aths\d8_pointer.tif" --esri_pntr="False" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\2021_overland_flow_path_5ha.shp"
```

4.5.2.2 Contributing Area >= 2ha < 5ha

Convert overland flow path with a contributing area of greater than or equal to 2.0 ha and less than 5ha to vector



Execution completed in 27.18 seconds



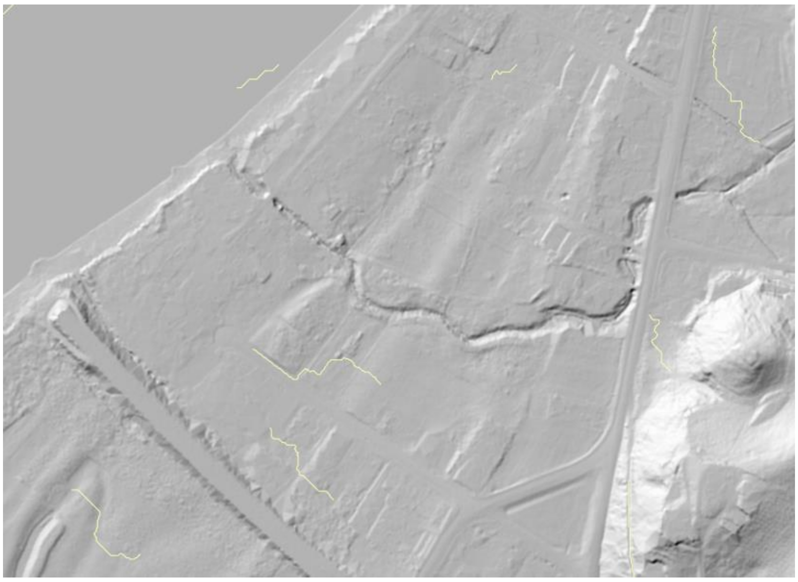
WhiteboxTools command:

```
"C:/WBT/whitebox_tools.exe" -v --run=RasterStreamsToVector --streams="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths\2021_overland_flow_path_2ha.tif" --d8_pntr="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths\d8_pointer.tif" --esri_pntr="False" --output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths\2021_overland_flow_path_2ha.shp"
```

4.5.2.3 Contributing Area >= 1ha < 2ha

Convert overland flow path with a contributing area of greater than or equal to 1.0 ha and less than 2ha to vector

Execution completed in 53.53 seconds



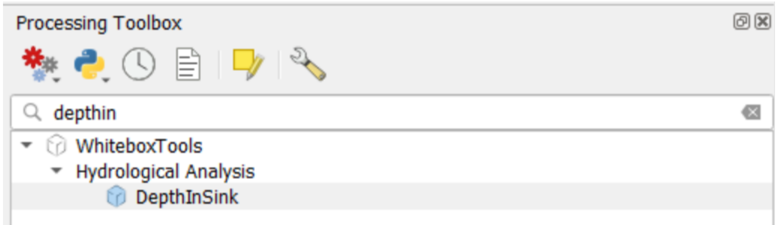
WhiteboxTools command:

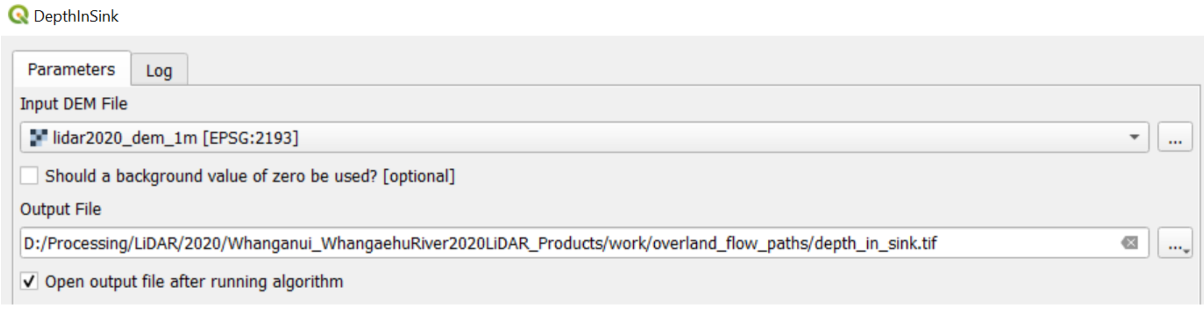
```
"C:/WBT/whitebox_tools.exe" -v --run=RasterStreamsToVector --
streams="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pa
ths\2021_overland_flow_path_1ha.tif" --
d8_pntr="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_p
aths\d8_pointer.tif" --esri_pntr="False" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\2021_overland_flow_path_1ha.shp"
```

4.6 Depression Areas

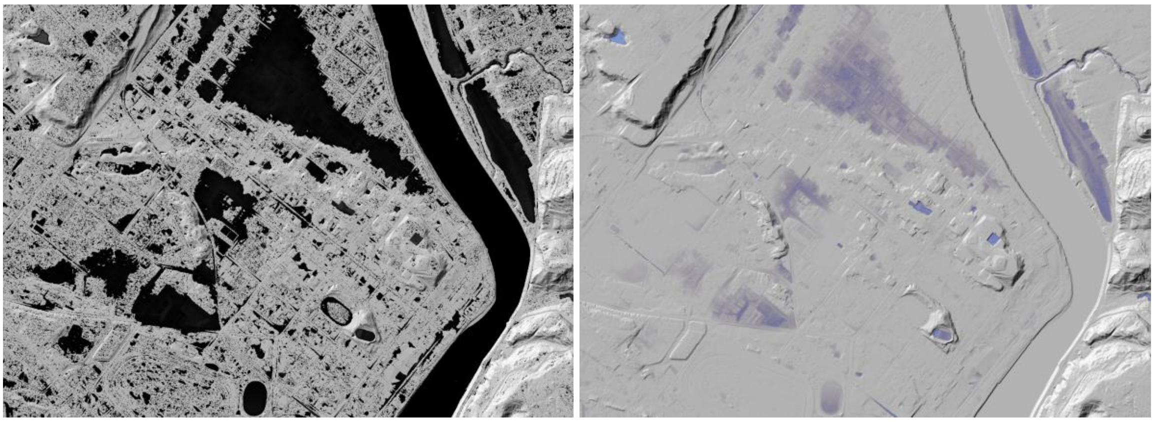
4.6.1 Depth in Sink

Measures the depth of sinks (depressions) in a DEM





Execution completed in 104.75 seconds (1 minute 45 seconds)



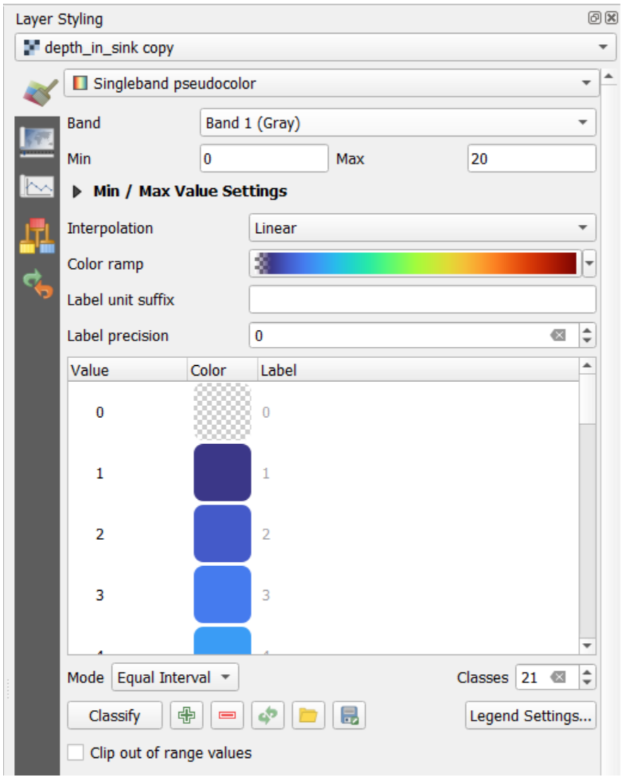
WhiteboxTools command:

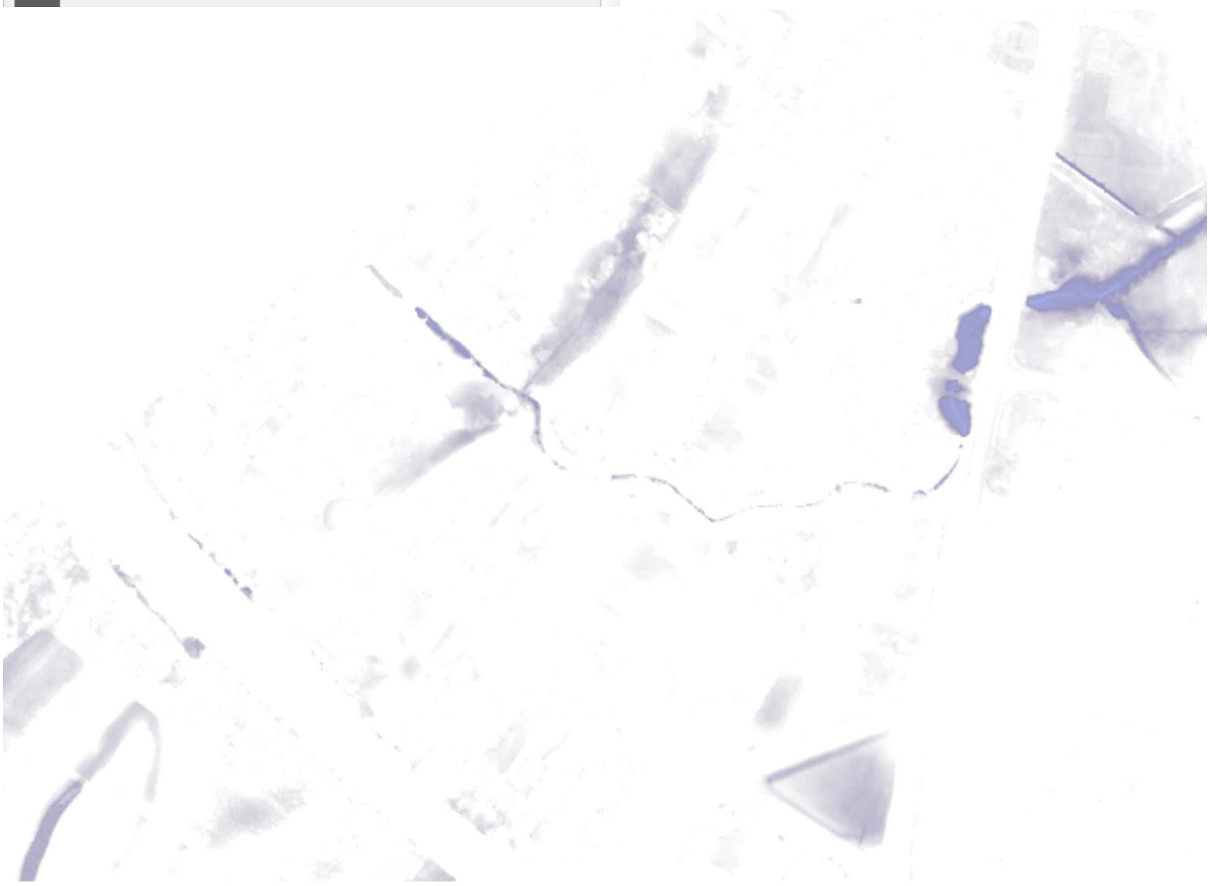
```
"C:/WBT/whitebox_tools.exe" -v --run=DepthInSink --
dem="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\lidar2020_dem_1m.tif" --
zero_background="False" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\depth_in_sink.tif"
```

4.6.2 QGIS Raster Styling of Depression Areas

4.6.2.1 Linear range of classified values

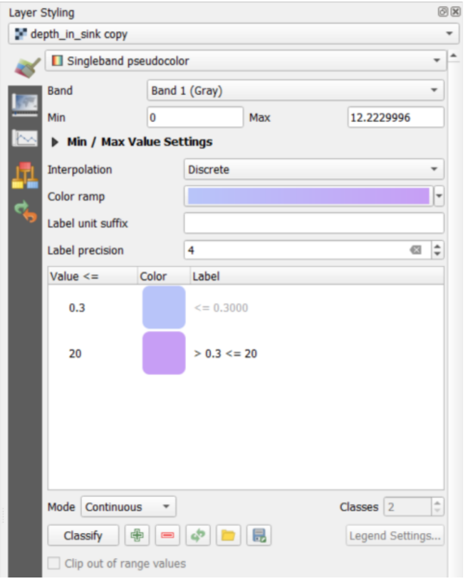
This style allows better representation of the variable depth of a Depression Area.

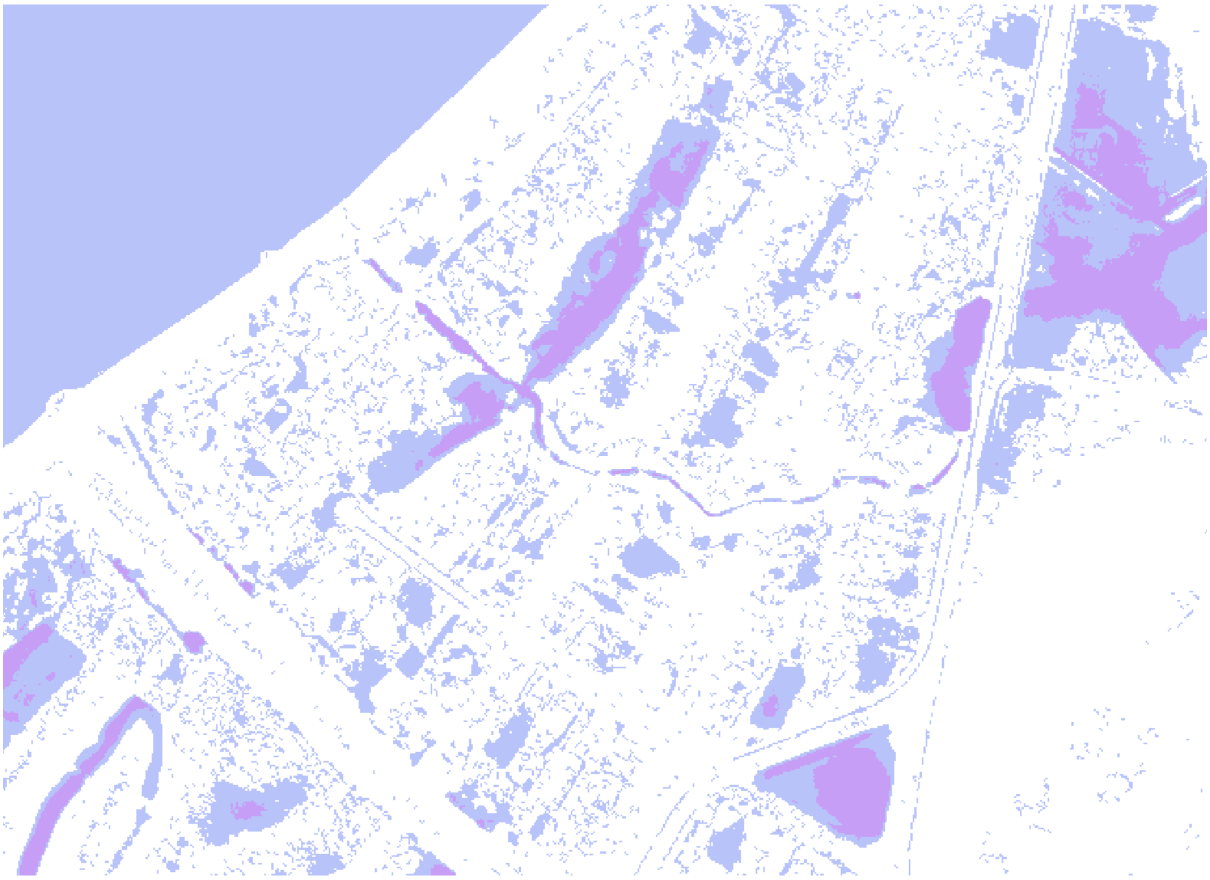




4.6.2.2 Discrete Categories

This style allows the portrayal of defined value categories

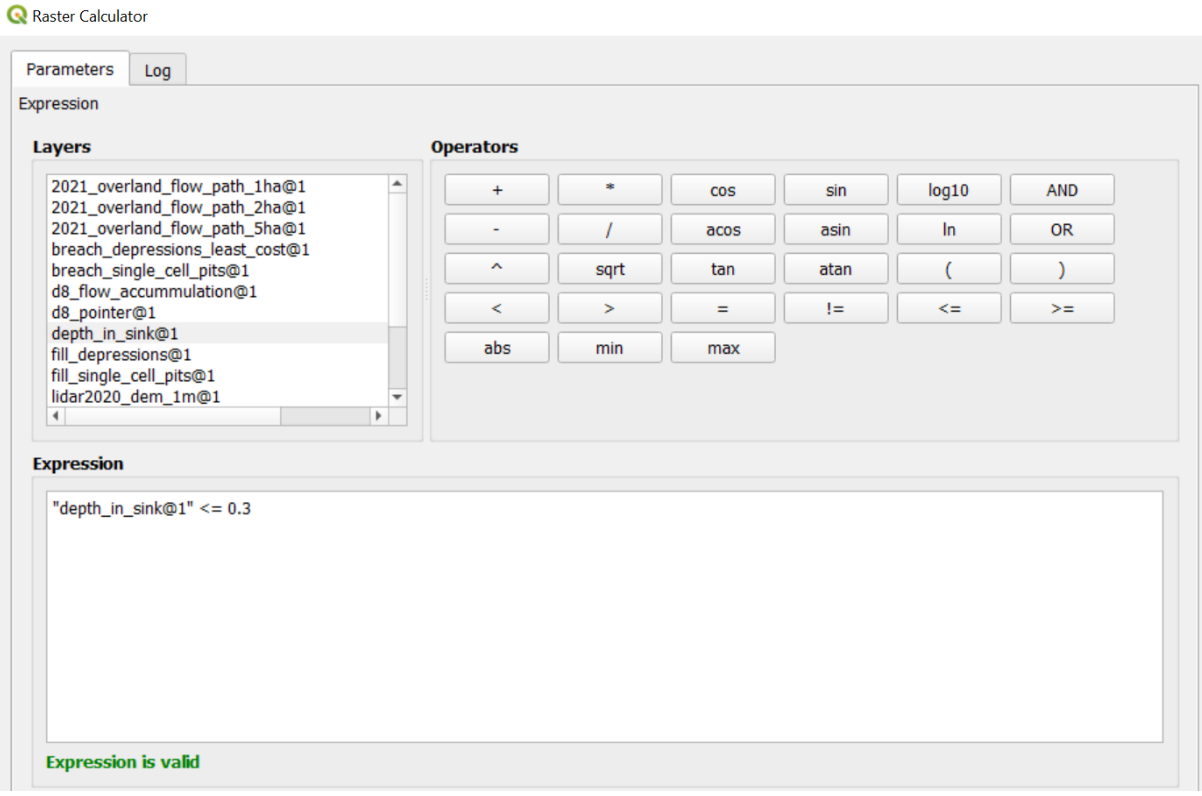


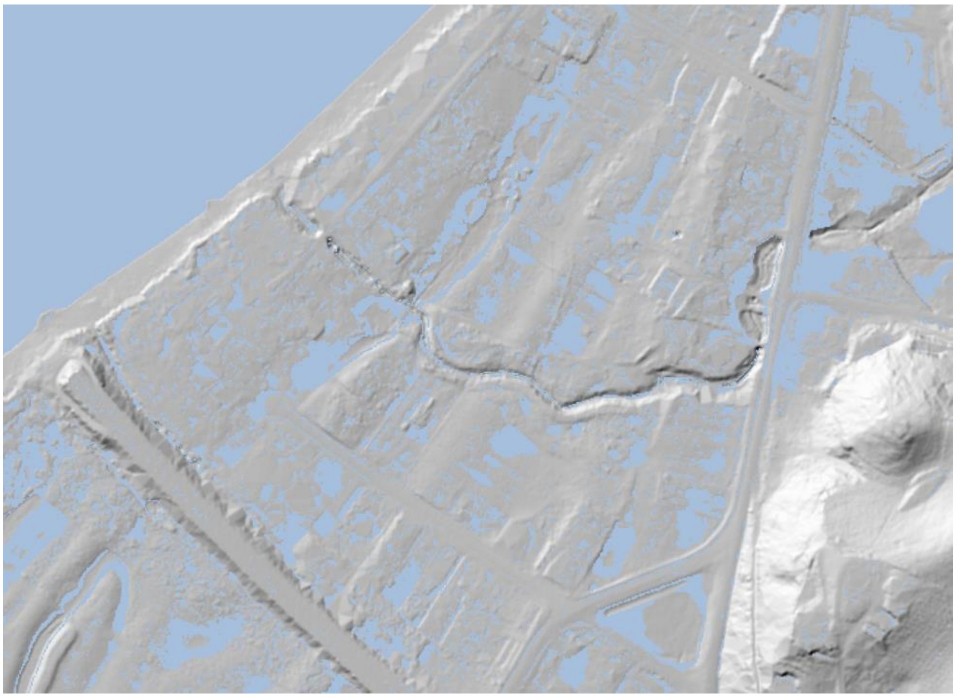


4.6.3 Polygonise Depression Areas <= 0.3m

4.6.3.1 Extract Depth <= 0.3m

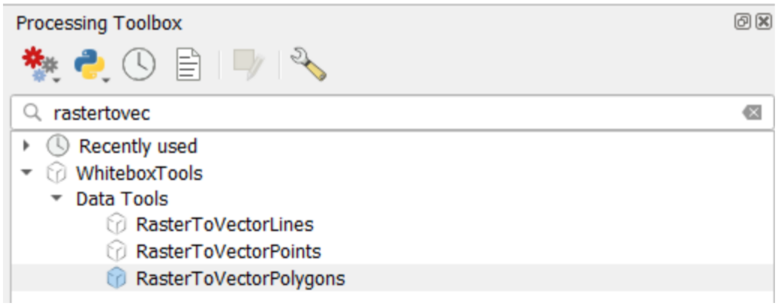
Use QGIS Raster Calculator to extract Depression Areas with depth <= 0.3m

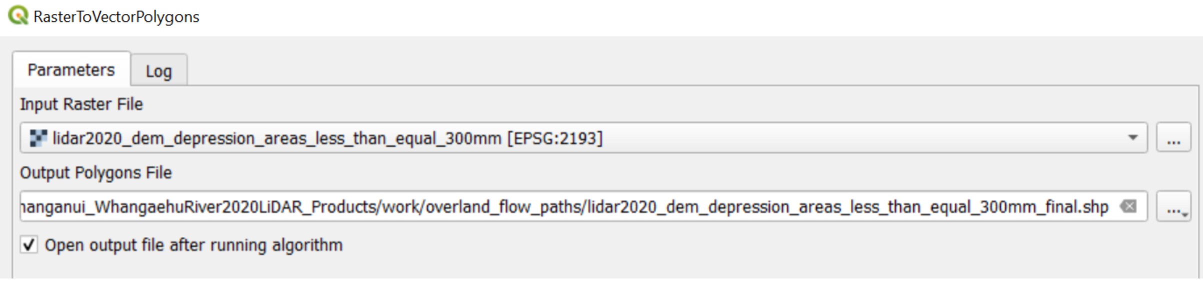




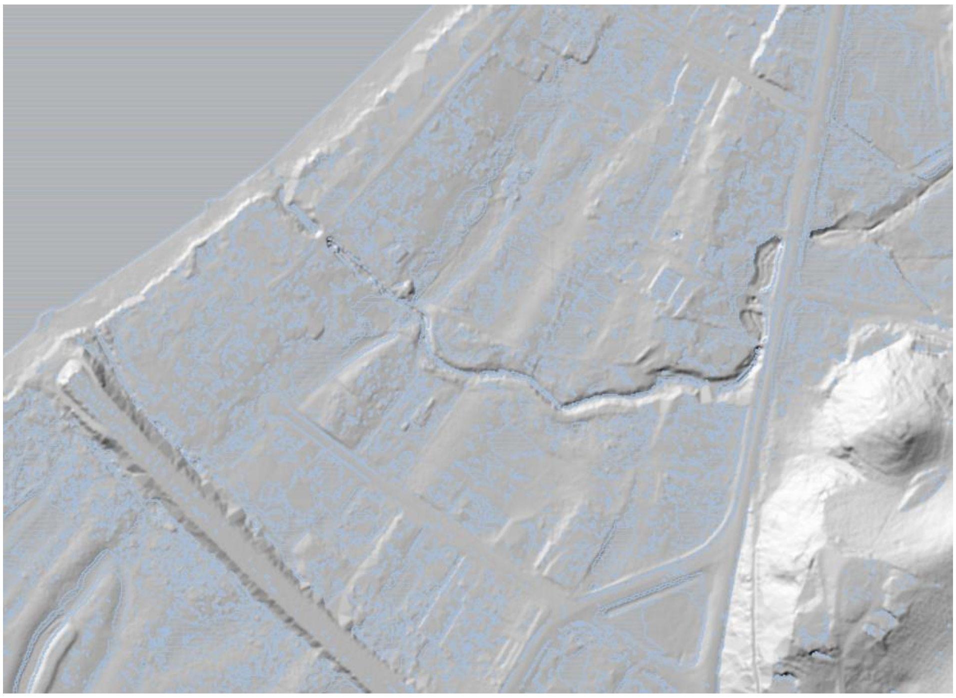
4.6.3.2 Convert to Vector

Polygonise the result using the Whitebox **Raster to Vector Polygons** algorithm.





Execution completed in 4294.95 seconds (1 hour 11 minutes 35 seconds)

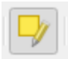


WhiteboxTools command:

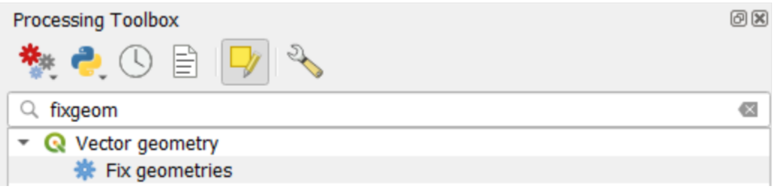
```
"C:/WBT/whitebox_tools.exe" -v --run=RasterToVectorPolygons --input="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths\lidar2020_dem_depression_areas_less_than_equal_300mm.tif" --output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_paths\lidar2020_dem_depression_areas_less_than_equal_300mm_final.shp"
```

4.6.3.3 Fix Geometries

Select the **lidar2020_dem_depression_areas_less_than_equal_300mm_final** vector layer in the QGIS layer panel:

Enable the  **Edit features in place** tool

Run **Fix geometries**



Note that a progress bar is displayed along the top of the map

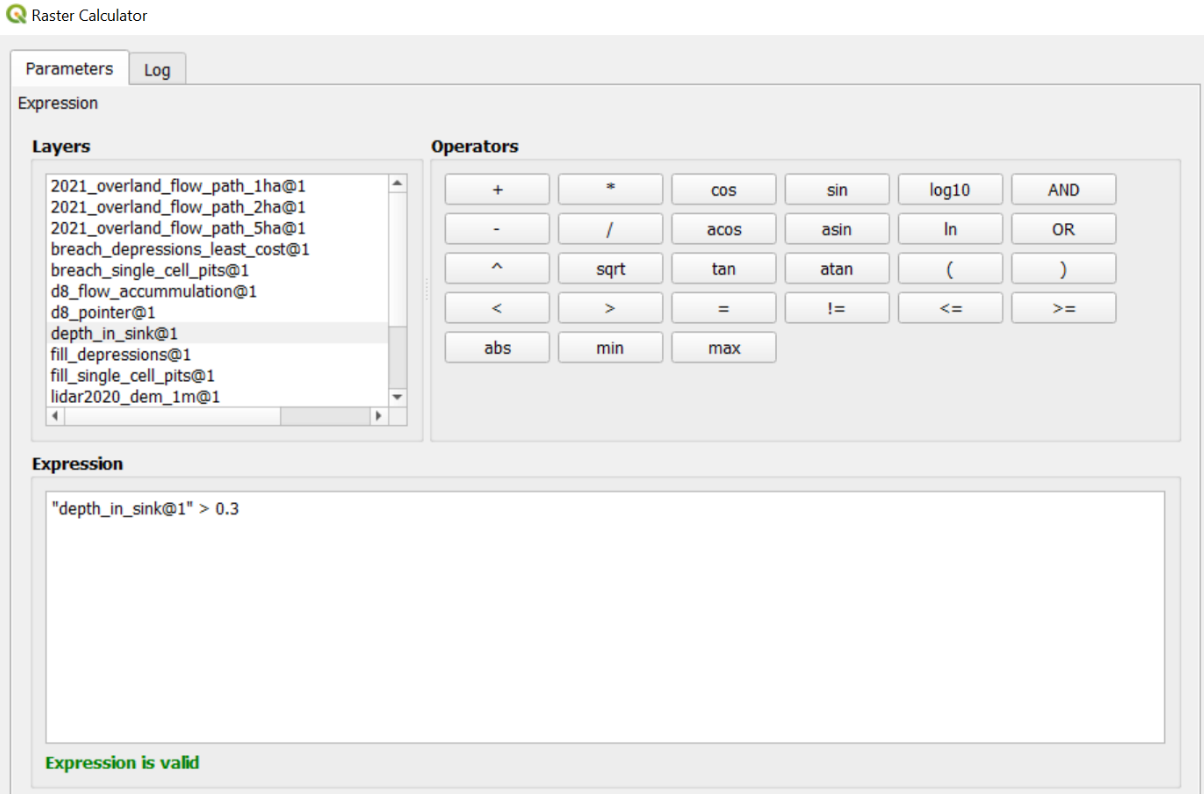
Save the changes 

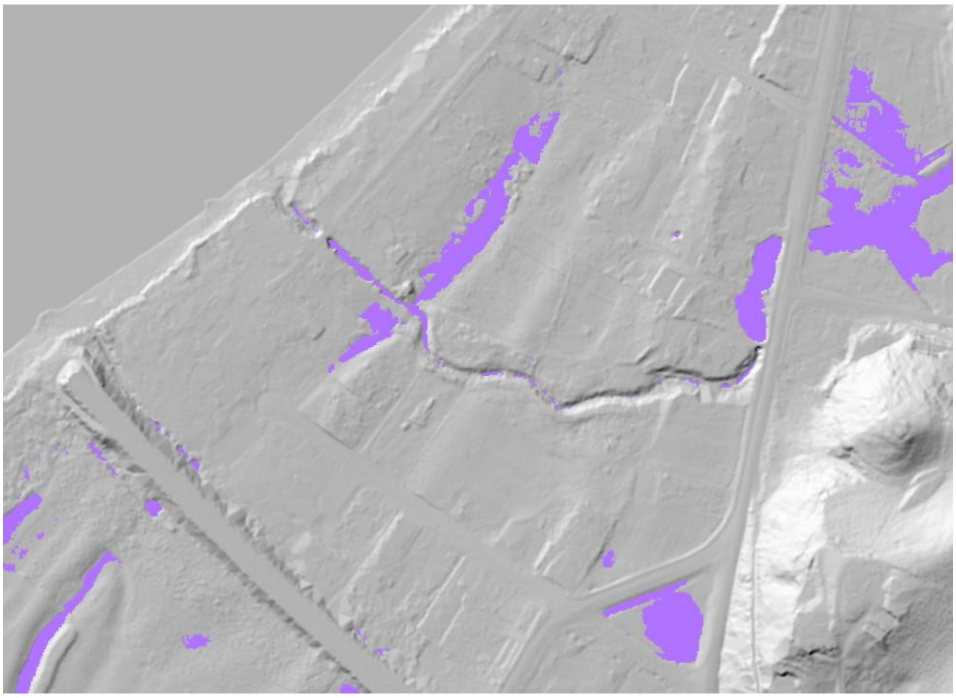
On completion, **disable** the  **Edit features in place** tool

4.6.4 Polygonise Depression Areas > 0.3m

4.6.4.1 Extract Depth > 0.3m

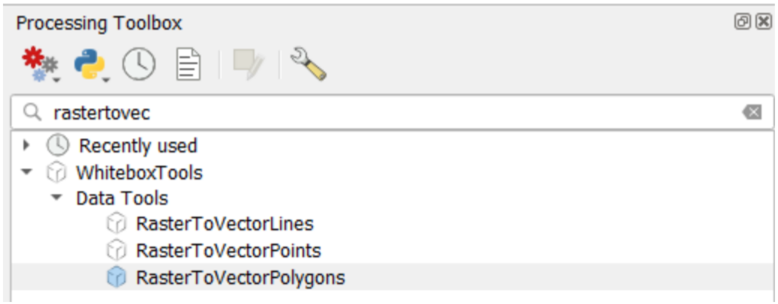
Use QGIS Raster Calculator to extract Depression Areas with depth > 0.3m

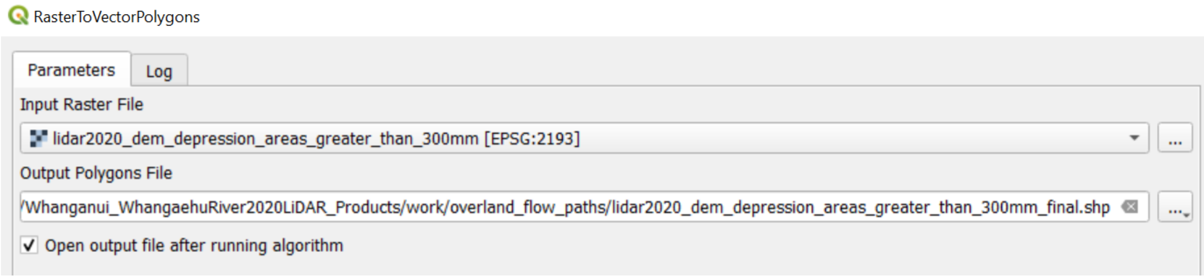




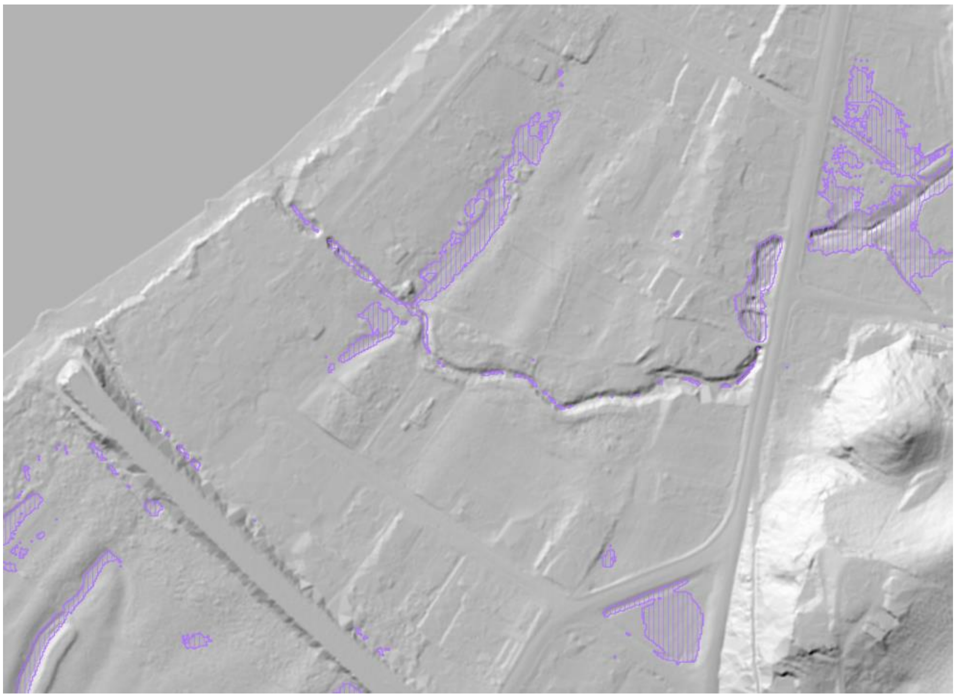
4.6.4.2 Convert to Vector

Polygonise the result using the Whitebox **Raster to Vector Polygons** algorithm.





Execution completed in 79.83 seconds (1 minute 20 seconds)

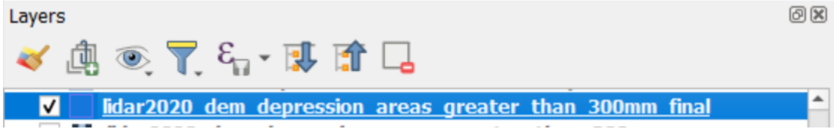


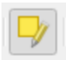
WhiteboxTools command:

```
"C:/WBT/whitebox_tools.exe" -v --run=RasterToVectorPolygons --
input="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_path
s\lidar2020_dem_depression_areas_greater_than_300mm.tif" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\lidar2020_dem_depression_areas_greater_than_300mm_final.shp"
```

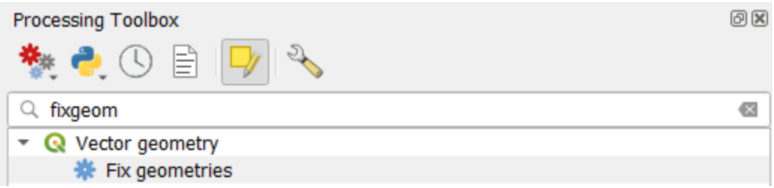
4.6.4.3 Fix Geometries

Select the **lidar2020_dem_depression_areas_greater_than_300mm_final** vector layer in the QGIS layer panel:



Enable the  **Edit features in place** tool

Run **Fix geometries**



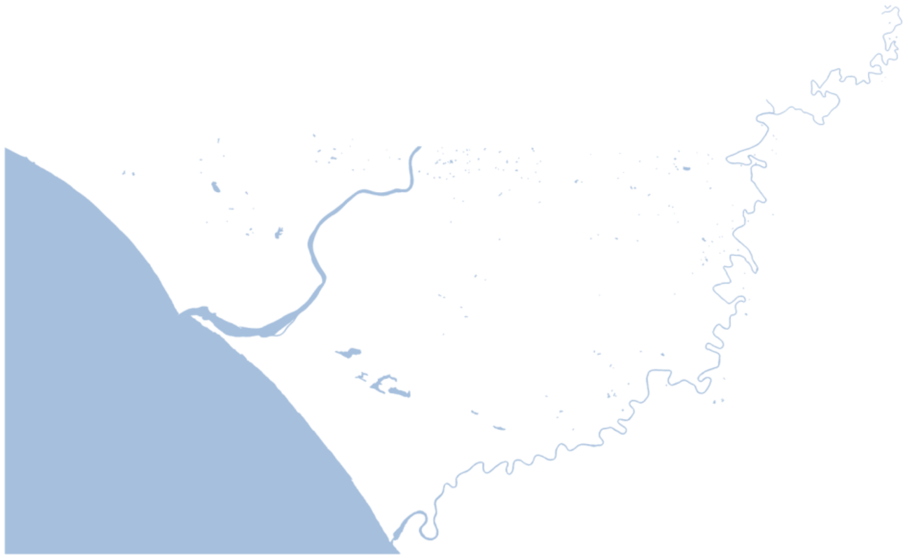
Note that a progress bar is displayed along the top of the map

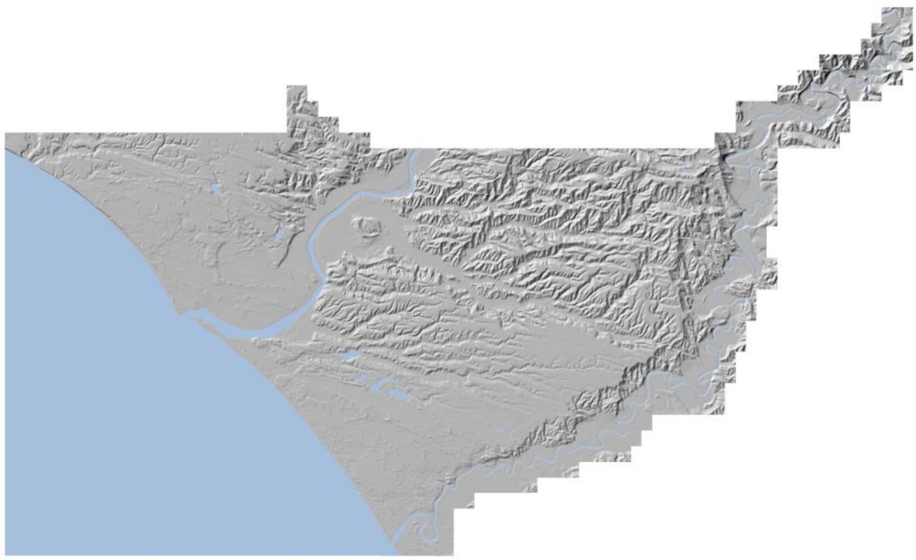
Save the changes 

On completion, **disable** the  **Edit features in place** tool

4.7 Hydro Clipping

A Hydro Mask polygon layer has been derived from the 2021 LIDAR Hydro Flattening Polygons and Breaklines.

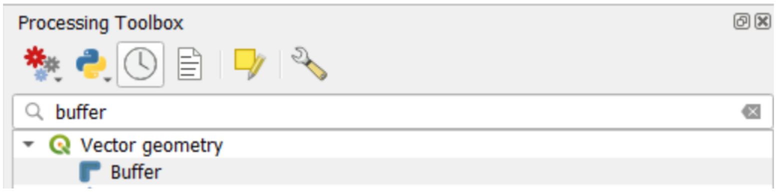


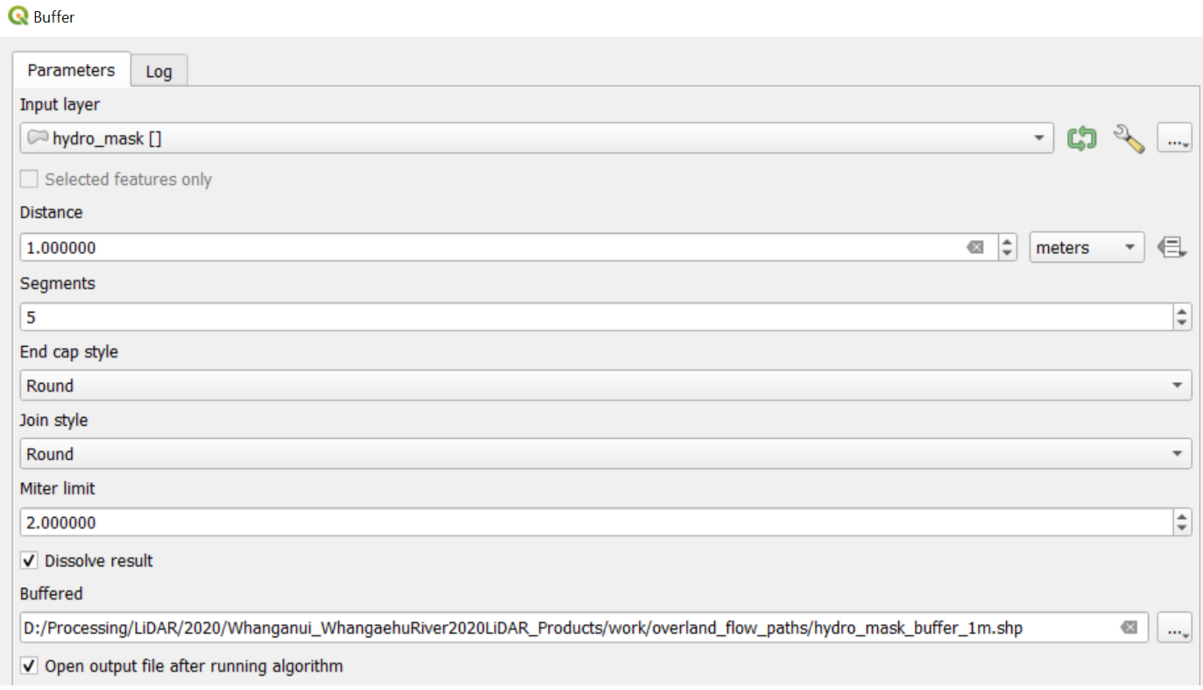


The Hydro Mask is used to remove the Overland Flow Path and Depression Area results from areas defined as hydro (e.g. Rivers, Lakes and Sea).

4.7.1 Buffer hydro mask

This algorithm computes a buffer area for all the features in an input layer, using a fixed or dynamic distance.

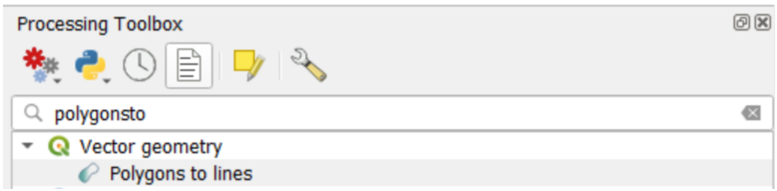


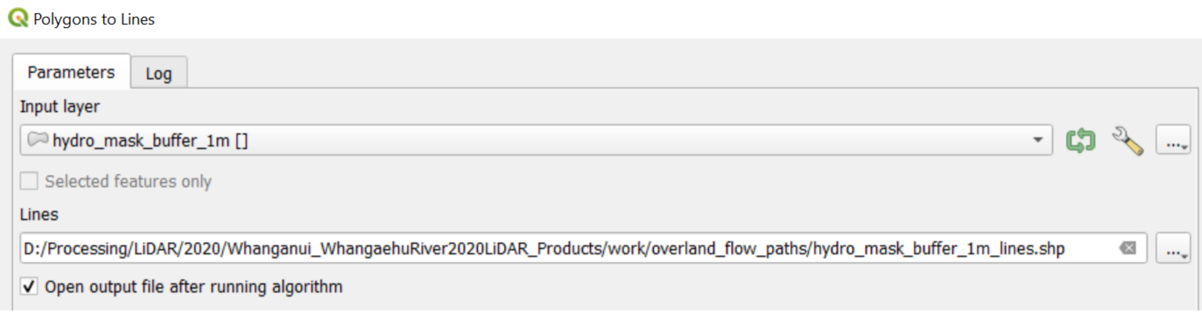


Execution completed in 0.44 seconds

4.7.2 Convert buffer to Lines

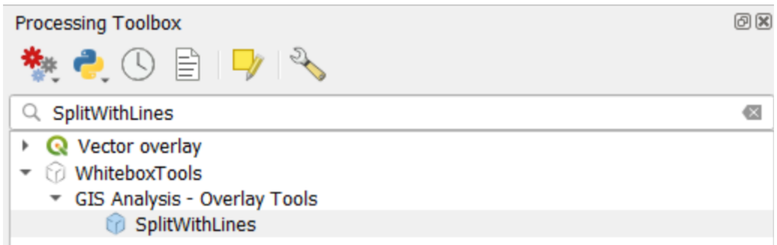
Converts polygons to lines





Execution completed in 0.39 seconds

4.7.3 Split each Overland Flow Path using Buffer Line



4.7.3.1 Contributing Area >= 5ha

Split overland flow path with a contributing area of greater than or equal to 5ha using hydro mask buffer line

Execution completed in 571.63 seconds (9 minutes 32 seconds)

4.7.3.2 Contributing Area >= 2ha < 5ha

Split overland flow path with a contributing area of greater than or equal to 2 ha and less than 5ha using hydro mask buffer line

Execution completed in 274.04 seconds (4 minutes 34 seconds)

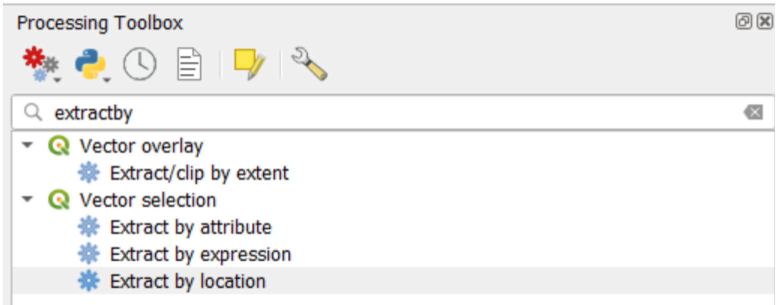
4.7.3.3 Contributing Area >= 1ha < 2ha

Split overland flow path with a contributing area of greater than or equal to 1 ha and less than 2ha using hydro mask buffer line

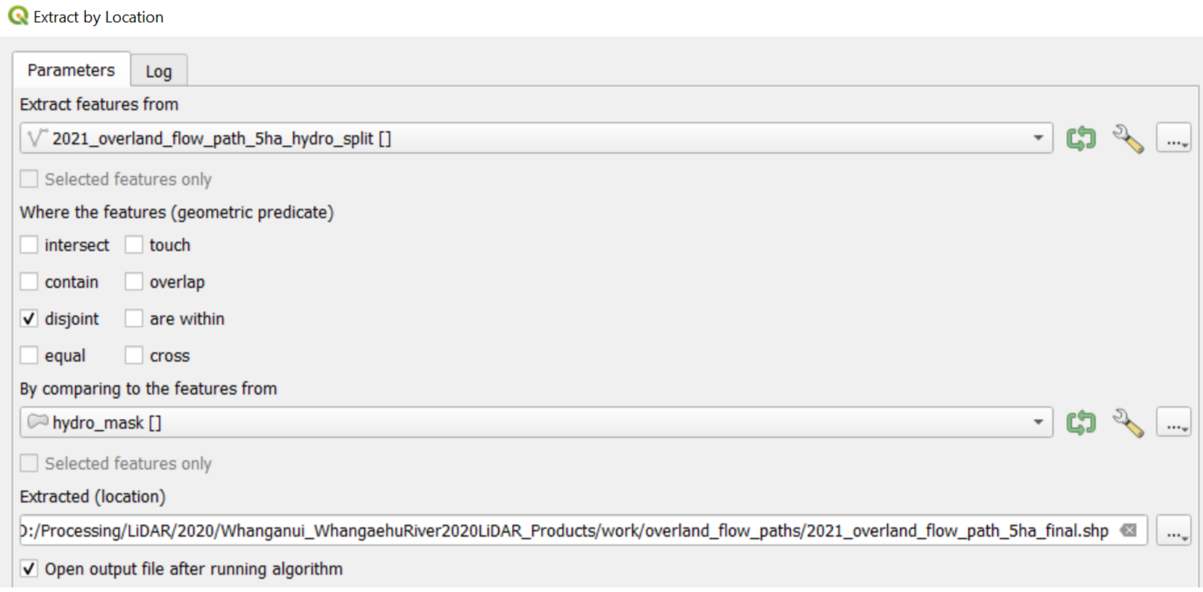
Execution completed in 291.47 seconds (4 minutes 51 seconds)

4.7.4 Extract Overland Flow Path Features that do not Intersect Hydro Mask

This algorithm creates a new vector layer that only contains matching features from an input layer. The criteria for adding features to the resulting layer is defined based on the spatial relationship between each feature and the features in an additional layer.

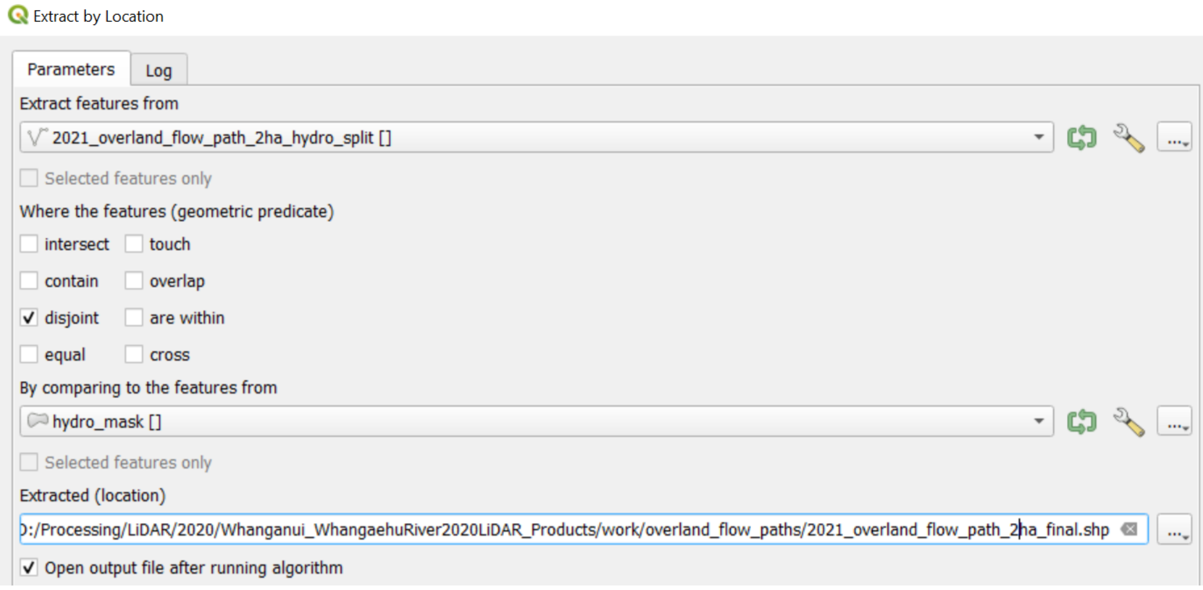


4.7.4.1 Contributing Area >= 5ha



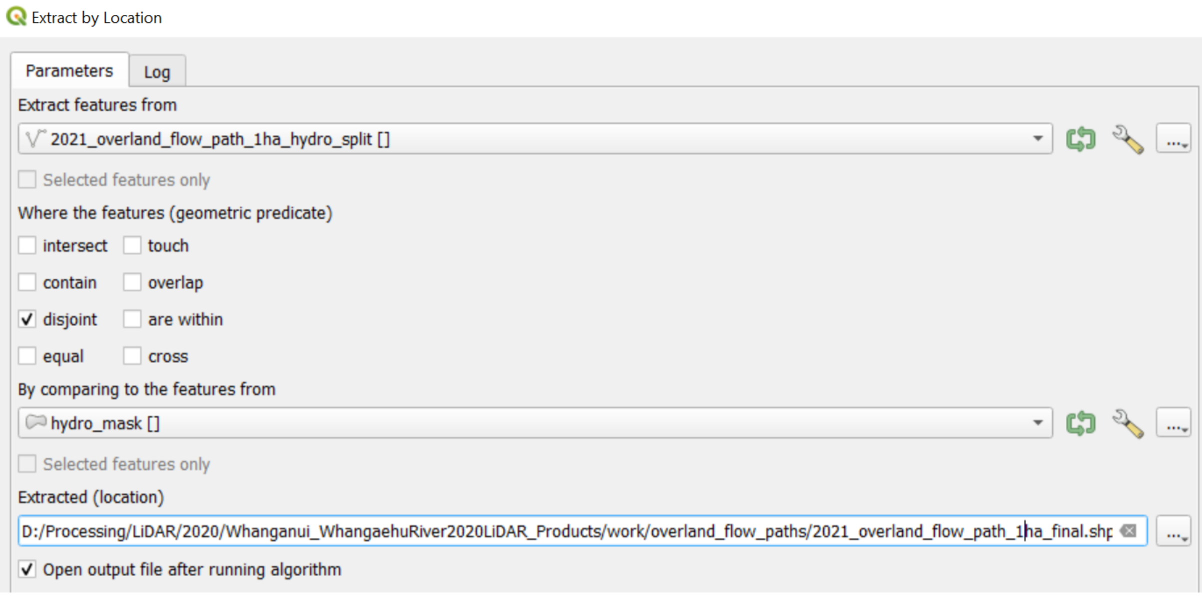
Execution completed in 2.82 seconds

4.7.4.2 Contributing Area >= 2ha < 5ha



Execution completed in 1.68 seconds

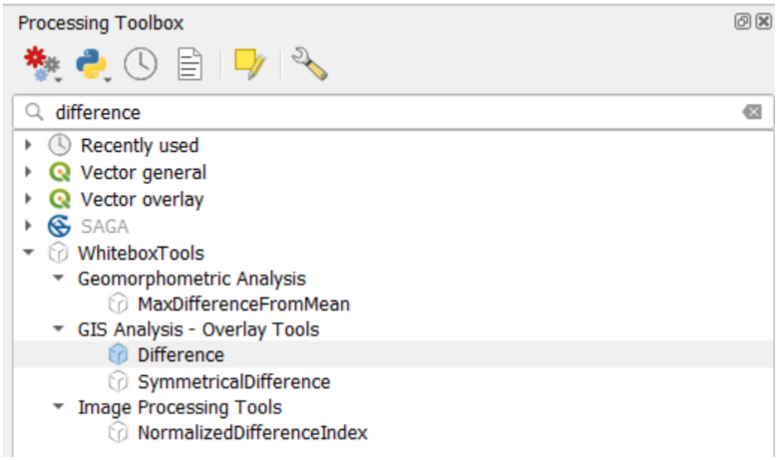
4.7.4.3 Contributing Area >= 1ha < 2ha



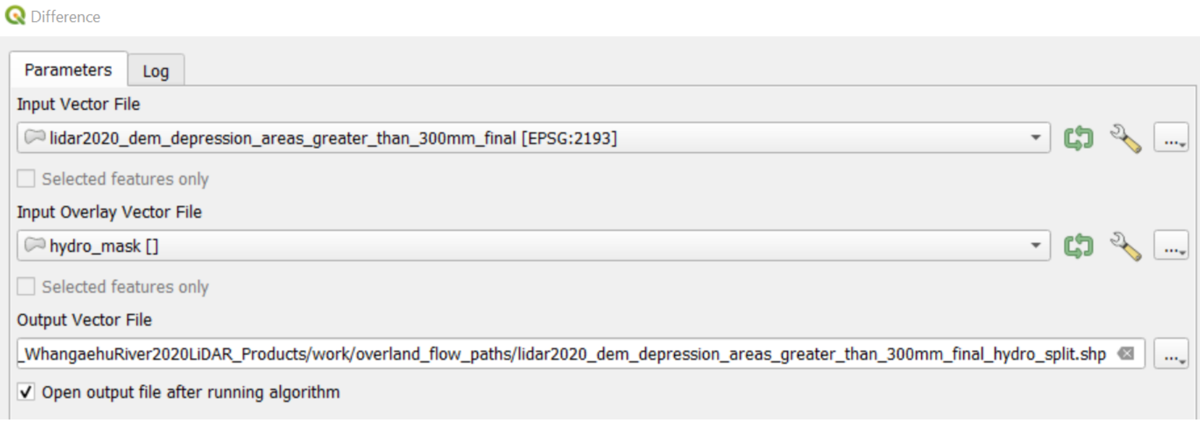
Execution completed in 1.68 seconds

4.7.5 Extract Difference of each Vector Depression Area with Hydro Mask

The Whitebox Difference Algorithm outputs the features that occur in one of the two vector inputs but not both, i.e. no overlapping features.



4.7.5.1 Depression Area Depth > 0.3m



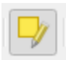
Execution completed in 731.59 seconds (12 minutes 12 seconds)

WhiteboxTools command:

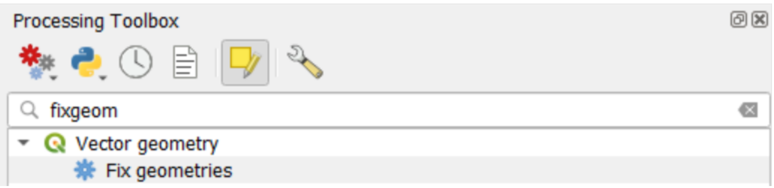
```
"C:/WBT/whitebox_tools.exe" -v --run=Difference --
input="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_path
s\lidar2020_dem_depression_areas_greater_than_300mm_final.shp" --
overlay="C:\qgis_output\processing_ybtstw\fa9c8560e8a74e62af35cb459c0f39fa\overlay.shp" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\lidar2020_dem_depression_areas_greater_than_300mm_final_hydro_split.shp"
```

4.7.5.2 Fix Geometries

<u>Select</u> the **lidar2020_dem_depression_areas_greater_than_300mm_final_hydro_splt** vector layer in the QGIS layer panel:

<u>Enable</u> the  **Edit features in place** tool

Run **Fix geometries**



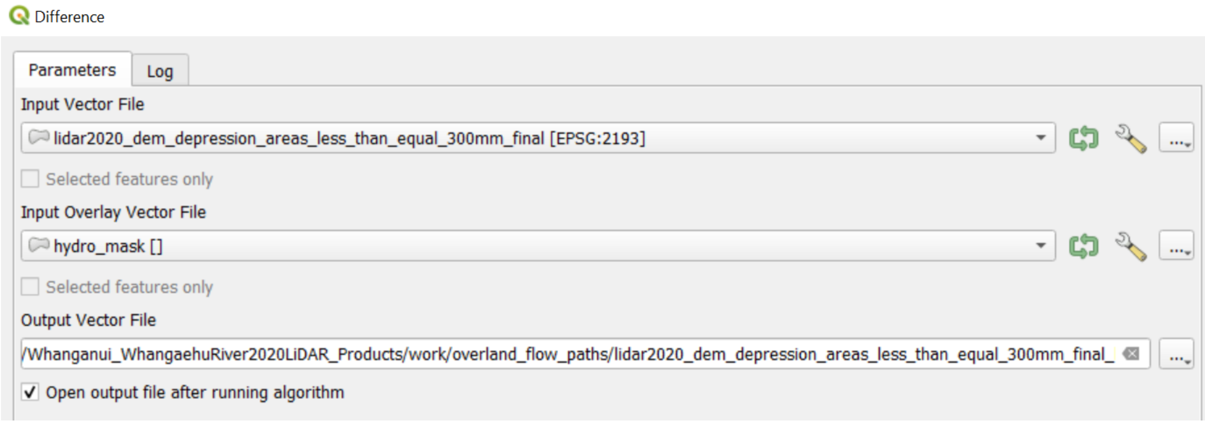
Note that a progress bar is displayed along the top of the map

<u>Save</u> the changes 

On completion, **<u>disable</u>** the  **Edit features in place** tool

Note – you may need to repopulate the **fid** column with the **row_number** to allow unique values if you intend to push this dataset to PostGIS or other spatial database and use the fid column as a primary key.

4.7.5.3 Depression Area Depth <= 0.3m



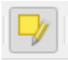
Execution completed in 184553.77 seconds (51 hours 15 minutes 54 seconds)

WhiteboxTools command:

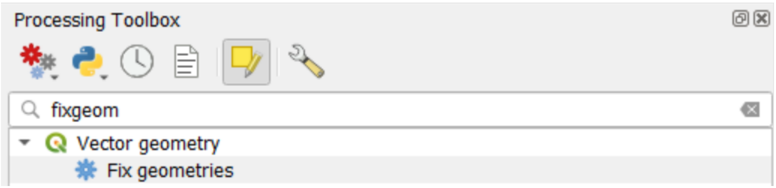
```
"C:/WBT/whitebox_tools.exe" -v --run=Difference --
input="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_path
s\lidar2020_dem_depression_areas_less_than_equal_300mm_final.shp" --
overlay="C:\qgis_output\processing_ybtstw\a0c60de62cd64b1e8106e56915c8122a\overlay.shp" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\lidar2020_dem_depression_areas_less_than_equal_300mm_final_hydro_split.shp"
```

4.7.5.4 Fix Geometries

<u>Select</u> the **lidar2020_dem_depression_areas_less_than_equal_300mm_final_hydro_splt** vector layer in the QGIS layer panel:

<u>Enable</u> the  **Edit features in place** tool

Run **Fix geometries**



Note that a progress bar is displayed along the top of the map

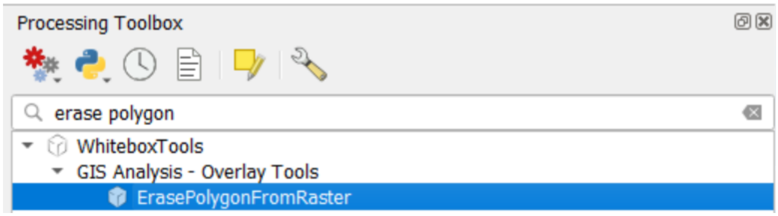
<u>Save</u> the changes 

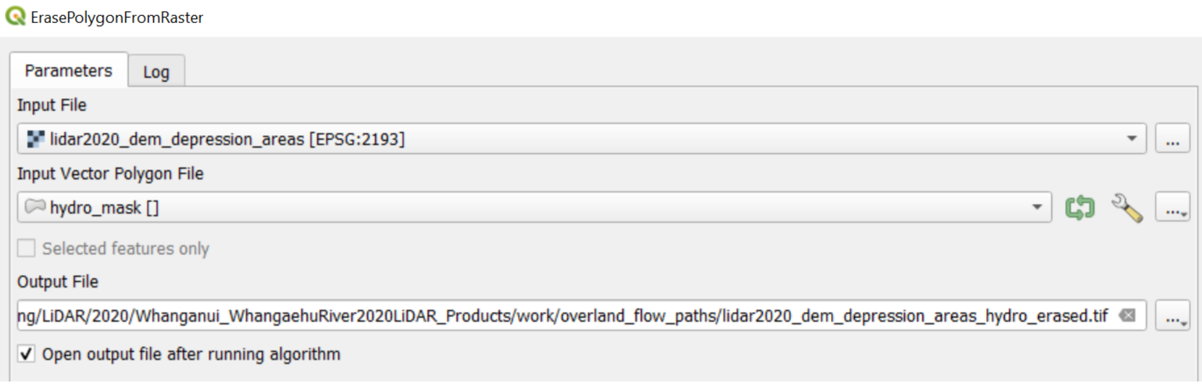
On completion, **<u>disable</u>** the  **Edit features in place** tool

Note – you may need to repopulate the **fid** column with the **row_number** to allow unique values if you intend to push this dataset to PostGIS or other spatial database and use the fid column as a primary key.

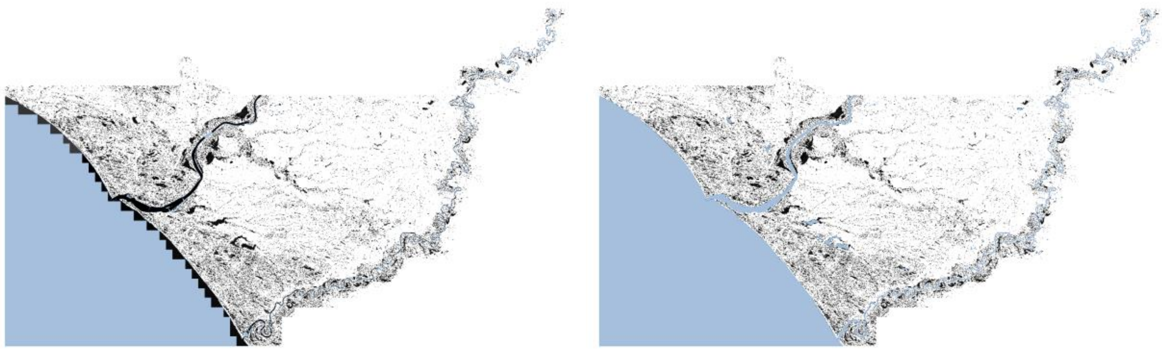
4.7.6 Erase Hydro Mask polygon from Raster Vector Depression Area

Erases (cuts out) a vector polygon from a raster





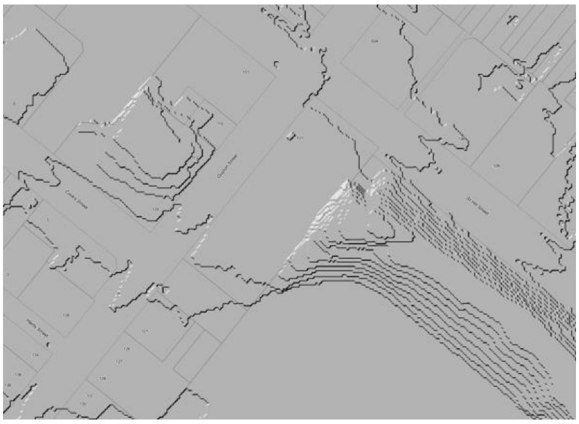
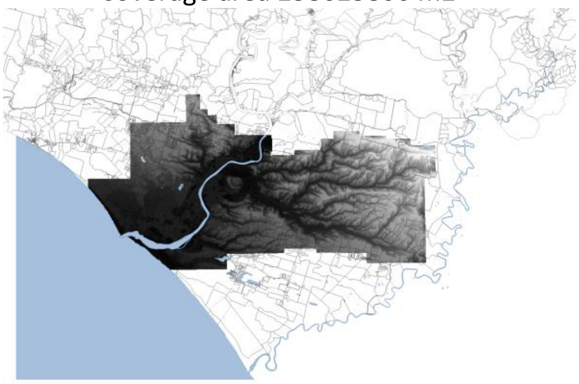
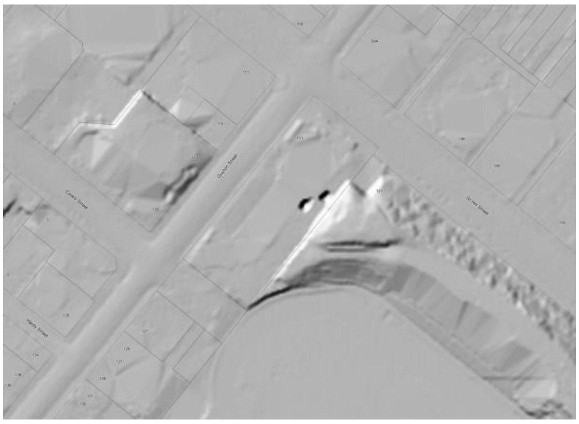
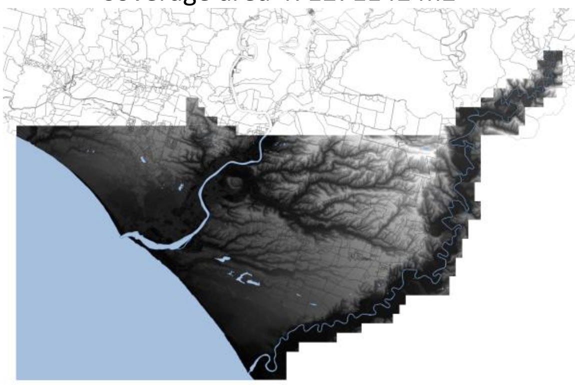
Execution completed in 13944.44 seconds (3 hours 52 minutes 24 seconds)



WhiteboxTools command:

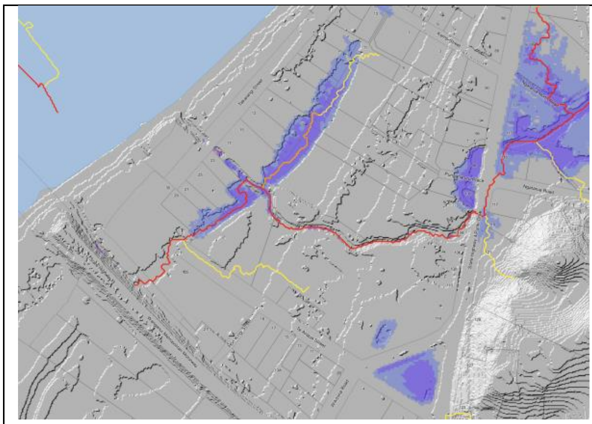
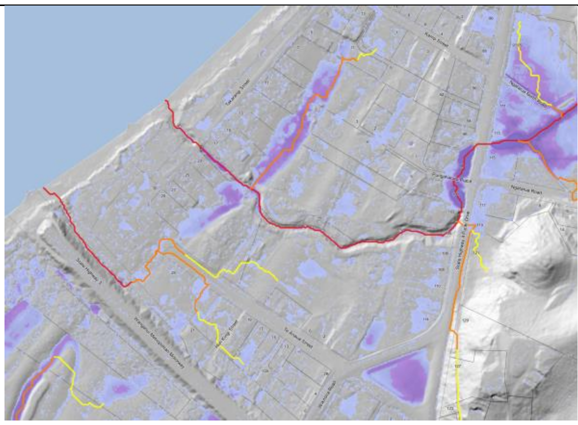
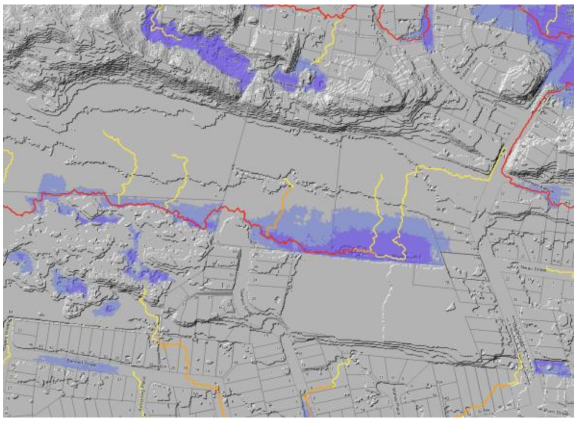
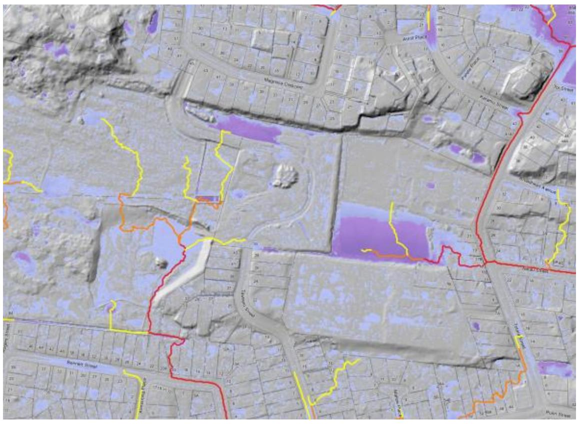
```
"C:/WBT/whitebox_tools.exe" -v --run=ErasePolygonFromRaster --
input="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_path
s\lidar2020_dem_depression_areas.tif" --
polygons="C:\qgis_output\processing_VZslLO\aa151b9ae45645dca9c0b4dd8f651b5b\polygons.shp" --
output="D:\Processing\LiDAR\2020\Whanganui_WhangaehuRiver2020LiDAR_Products\work\overland_flow_pat
hs\lidar2020_dem_depression_areas_hydro_erased.tif"
```

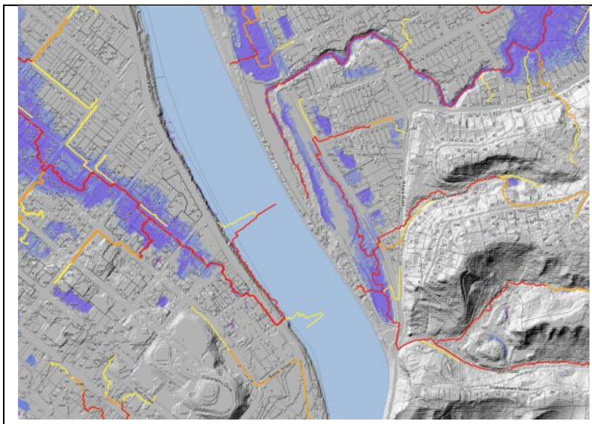
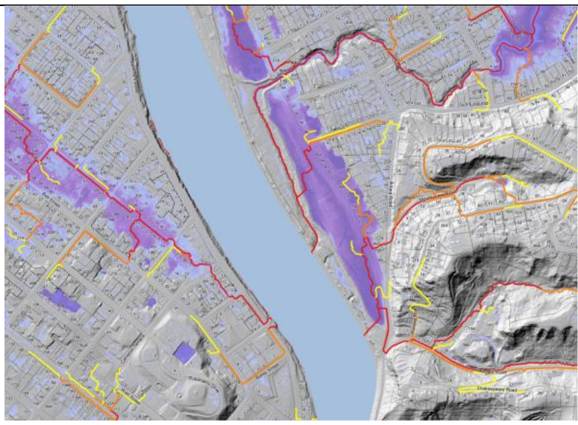
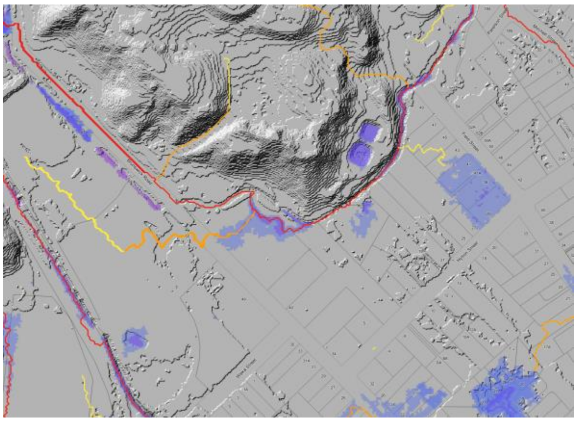
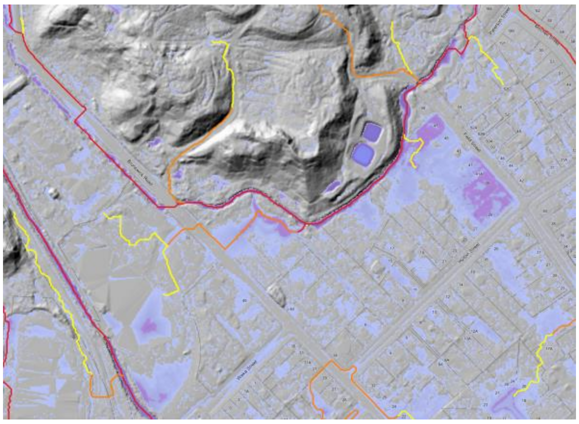
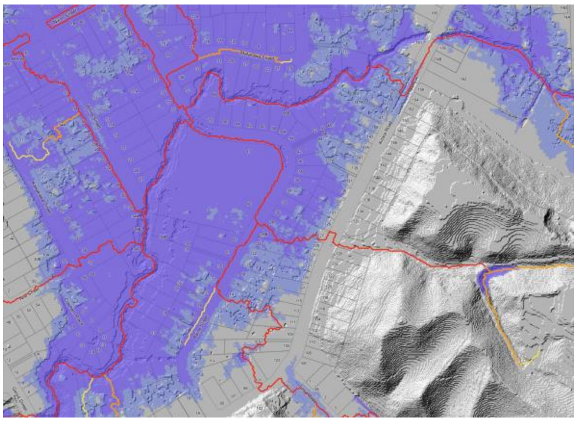
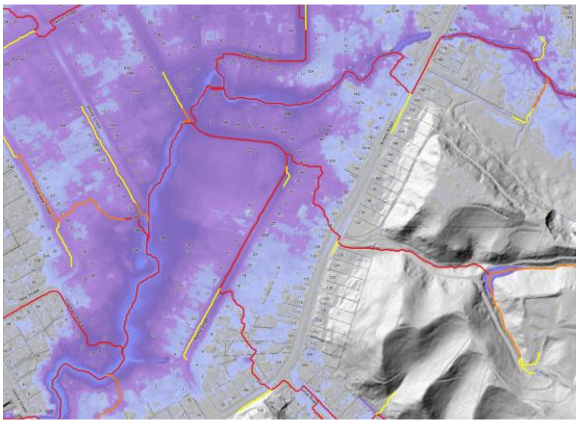
5 Comparison to previous Overland Flow Path Dataset

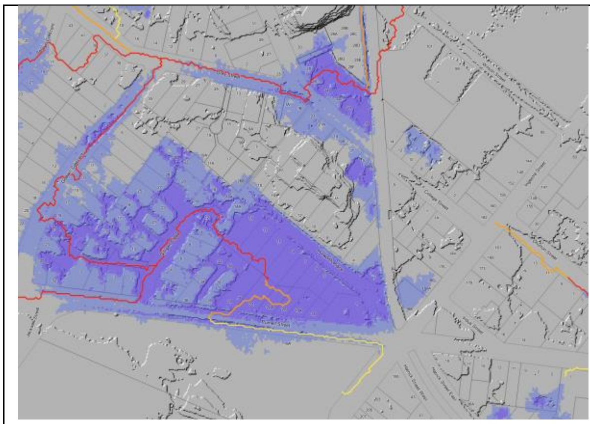
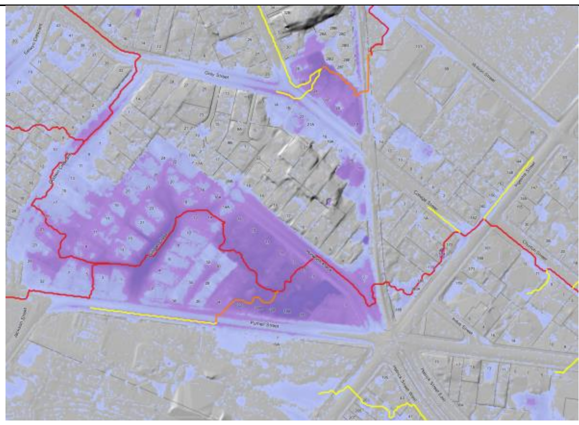
2013 Overland Flow Paths	2021 Overland Flow Paths
In 2013, Wanganui District Council (WDC) commissioned Pattle Delamore Partners Ltd (PDP) to map overland flow paths for the Churton Creek catchment and other catchments in the Whanganui City area. https://hubble.whanganui.govt.nz/site/inf/waterm/Overland%20Flowpaths%20LIDAR%20Churton%20Creek.pdf	In-house mapping of overland flow paths and depression areas carried out Sept/Oct 2021 by GIS Lead.
Input: • 2x2m DEM derived from LiDAR 2013  • Coverage area 258625806 m2 	**Input**: • 1x1m DEM derived from LiDAR 2021  • Coverage area 471271142 m2 

Output:
• Three overland flow path series, generated from:
  ○ Contributing Area >= 1ha < 2ha
  ○ Contributing Area >= 2ha < 5ha
  ○ Contributing Area >= 5ha
• Depression areas:
  ○ Area exceeding 500 m^2
  ○ Volume exceeding 50 m^3
	Output:
	• Three overland flow path series, generated from:
	  ○ Contributing Area >= 1ha < 2ha
	  ○ Contributing Area >= 2ha < 5ha
	  ○ Contributing Area >= 5ha
	• Depression areas:
	  ○ Depth <= 0.3m
	  ○ Depth > 0.3m

<table>
<tr><td>Max depth exceeding 0.3m</td><td></td></tr>
<tr><td>Limitations:
The following limitations apply to overland flow paths:
Only the elevation of the topography is considered, there are no allowances for underground reticulation or land use. For example, stormwater reticulation may convey overland flow paths beneath the ground surface, and impervious areas are more likely to generate overland flow paths for pervious areas of a similar size;
Overland flow paths do not map the entire width of the flow, only what is likely to be its deepest point;
Velocity, depths and flows are not included; and
Buildings are not incorporated.
Limitations of depression area mapping include:
Depressions have been mapped to their maximum extent. In some instances, the depressions may have a volume that exceeds that generated by a design storm event (such as the 1% AEP). The extent of fill for each generated depression area could be calculated, using design storm parameters and the catchment area raster;
No underground infrastructure has been included in the assessment, culverts would provide relief for depression areas; and,
Depression areas that intersect the physical house (not just the land parcel) may have a maximum potential depth of less than 300 mm and therefore may not be of concern. This could be addressed by checking each property listed to identify whether or not the physical house intersects the mapped depression area.</td><td>Limitations:
The same limitations apply for both overland flow paths and depression areas to the 2021 dataset as were identified for the 2013 dataset.</td></tr>
<tr><td colspan="2">Comparisons</td></tr>
<tr><td>Putiki</td><td>Putiki</td></tr>
</table>

 The PDP 2013 Overland Flow Paths dataset does show potential errors.	 Depression Areas are more clearly defined due to a higher resolution DEM
Tawhero Street 	Tawhero Street  The effect of development in this area is clearly displayed.
Anzac Parade 1 	Anzac Parade 1  Depression Areas are more clearly defined due to a higher resolution DEM
Anzac Parade 2	Anzac Parade 2

	 Depression Areas are more clearly defined due to a higher resolution DEM
Brunswick Road	Brunswick Road
	 Depression Areas and Overland Flow Paths are more clearly defined due to a higher resolution DEM
Ikitara Road	Ikitara Road
	
College Estate	College Estate

	 Depression Areas and Overland Flow Paths are more clearly defined due to a higher resolution DEM