University of Exeter

Centre for Resilience Environment, Water and Waste

SCORe R Tool Manual

Sewer Catchment Opportunities for Resilience Tool for identifying areas for Nature-based Solutions

CaSTCo

Making sure that people count at the heart of rivers' recovery

South West Water

Ofwat

This tool was developed by Dr Jessica Kitch for the CaSTCo USTU project with the University of Exeter. For more information on CaSTCo visit https://castco.org/

This tool was built and developed using RStudio version 2024.04.0 Build 735

Other packages used include:

dplyr version 1.14

rstudioapi version 0.16.0

sf version 1.0-16

svDialogs version 1.1.0

terra version 1.8-5

whitebox version 2.4.0

Using a different version could result in the tool looking different and some aspects of the tool not working.

The tool will be shared on GitHub (https://github.com/exeter-creww/CaSTCo-USTU-SCORe-Tool). Any changes and updates will be available here.

Contents

1. Introduction

Storm overflows pose a significant environmental challenge (Perry *et al.*, 2024; Muleta and Knolmar, 2025). In the United Kingdom there has been an increase in political and regulatory pressure to reduce the frequency of discharge events. The Storm Overflows Discharge Reduction Plan (Defra, 2023) for England sets stringent targets for water companies to reduce discharges from storm overflows. The final target of this plan is to not permit any storm overflows to discharge above an average of 10 rainfall events by the year 2050.

Traditionally, water companies have employed hard-engineered or 'grey' solutions, such as storm tanks, in order to reduce storm overflows. Now, there is growing recognition that green or nature-based solutions (NbS) can deliver much wider benefits, for example in terms of carbon storage, biodiversity and amenity value. Often when considering green solutions there appears to be little consideration of the potential contribution of runoff from large permeable areas, such as agricultural land, to combined sewer networks. This is partially because there is a lack of understanding with regards to how permeable areas could contribute runoff to combined sewer systems, as well as which permeable areas could be important contributors.

CaSTCo-USTU (Upstream Thinking Upscaled) is part of the wider CaSTCo (Catchment Systems Thinking Cooperative) Ofwat Innovation Fund project. The scope of the CaSTCo-USTU project was to develop tools for the water industry to support decision-making on where catchment or NbS interventions can and cannot be used to help reduce storm overflow discharges. As part of this project, this tool was developed that can be used to identify permeable surfaces such as grassland that could potentially contribute runoff to the combined sewer network.

1.1. Framework Outline

The CaSTCo-USTU framework has been designed to be replicable by the water industry. The framework utilises geospatial analysis and modelling techniques to identify specific areas within wastewater catchments where permeable surface (e.g. fields and parkland) runoff may contribute to storm overflows. This spatial targeting will allow further investigations and resources to be allocated efficiently. At identified sites, modelling could be undertaken to: a) provide quantitative estimates of the rural runoff contribution from these specific areas and b) explore scenarios where green solutions are applied. Geospatial modelling and opportunity mapping can be undertaken at the regional (e.g. water company) scale, whereas hydraulic modelling could be undertaken at the individual wastewater catchment scale. The SCORe Tool is used for the geospatial analysis aspect of the framework. For more information on the other steps and how they might be conducted see section 14.

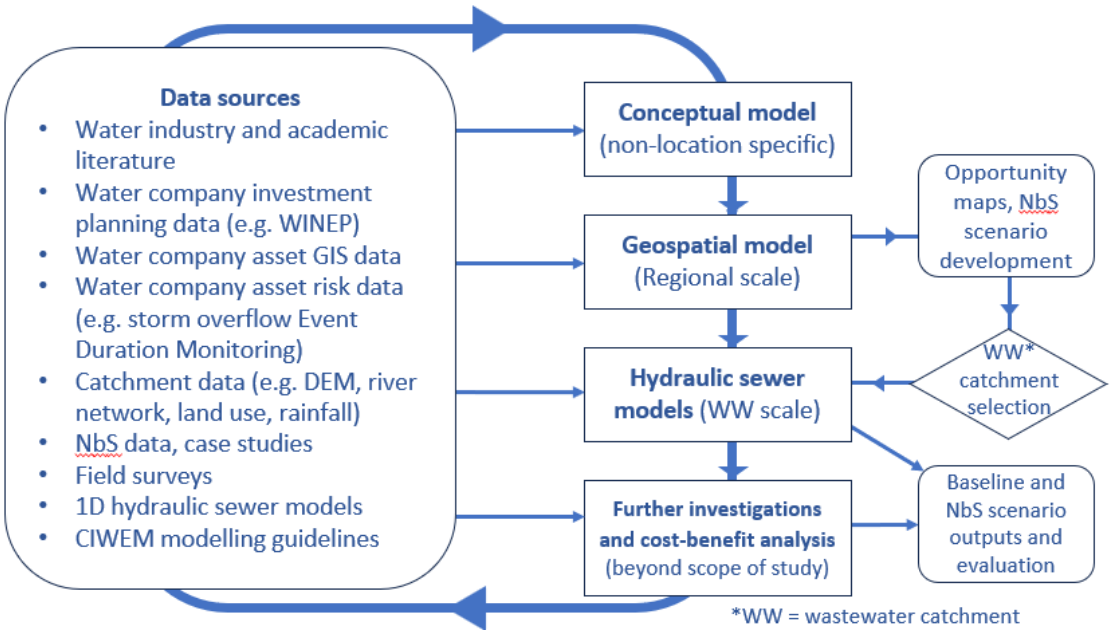
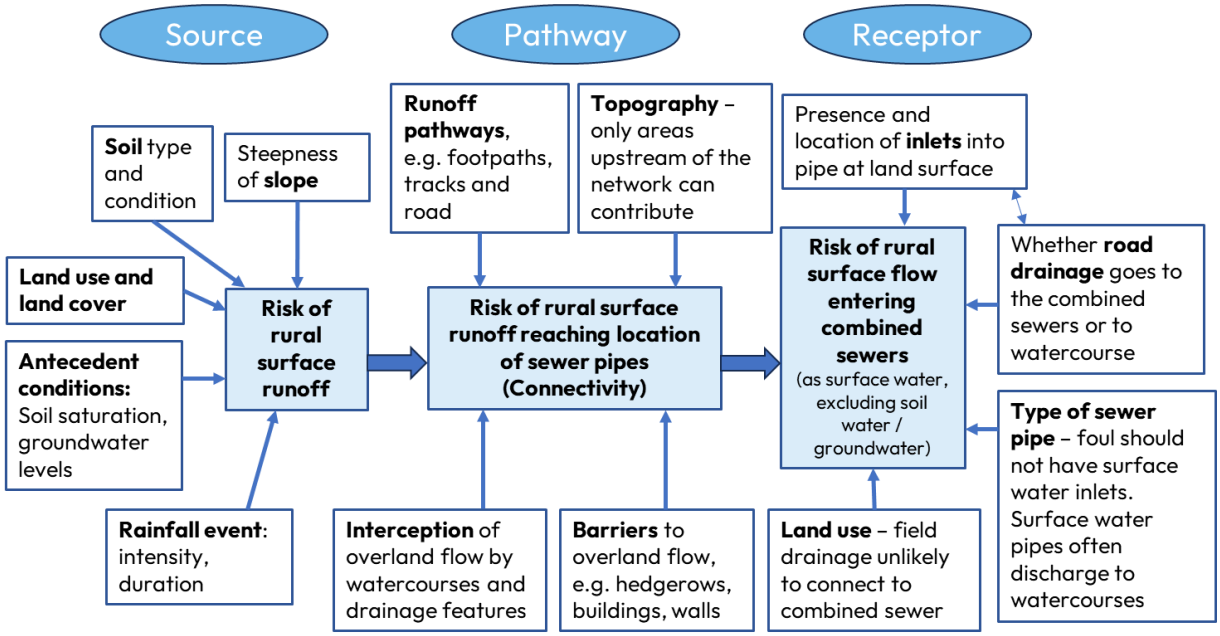


Diagram summarising the CaSTCo-USTU framework

1.2. Conceptual basis for the SCORe tool

Source areas are the opportunity areas for applying green solutions; they are the green space permeable areas that produce runoff that enters the combined sewers. To be a potential opportunity area, the land must produce runoff (be a **source** of runoff), that flows (**pathway**) into a gully or drain that connects into the combined sewers (**receptor**). The main entry points for rural or green space runoff to the combined sewers will be gullies or drains on roads and other paved areas. A key step in identifying opportunity areas is therefore to identify permeable surfaces that potentially drain to roads/gullies that connect to the combined sewers. To do this, however, it is first necessary to determine which areas of land are within the area drained by, or potentially drained by, the combined sewers. This is the topographic catchment or drainage area of the combined sewers, which is largely determined by topography (how the shape and slope of the land determine flow pathways). It is distinct from the term “wastewater catchment”, which refers to an area defined by a sewer network that directs wastewater to a specific sewage treatment works.

It is important to emphasise that most road gullies in England do not drain to the combined sewers. Instead, most drain to separate highway or surface water drainage systems that discharge into local watercourses, roadside ditches or the ground (via soakaways or SuDS). Whilst a road may have a combined sewer pipe running underneath it, this does not mean that road drainage connects into the combined sewer pipe. Similarly, the majority of rural land and green spaces do not drain to combined sewers.



Conceptual diagram underpinning development of the SCORe Tool. The SCORe Tool focuses on establishing topographic connectivity (pathway) to receptors (combined sewer inlets).

1.3. Method behind the SCORe Tool

The SCORe Tool uses and builds upon existing geospatial and hydrological tools that meet the requirements of the USTU framework. To further improve the accuracy of the sub-catchments draining to the combined sewer, the digital surface model (DSM) is processed. The DSM is processed by removing surfaces known not to drain to the combined sewer system (or sewer of interest), as well as the river networks. This is accomplished by converting the sewer network and river network into a barrier, like a wall to flow.

Depending on the availability of data, either the sewer pipe, drain/gully or surface is assigned as the area of interest (here defined as a pour points), which will be used to determine the sub-catchment that drains to this area. For more information of pour points see section 6. This will help ensure only sub-catchments draining to the combined sewer are generated.

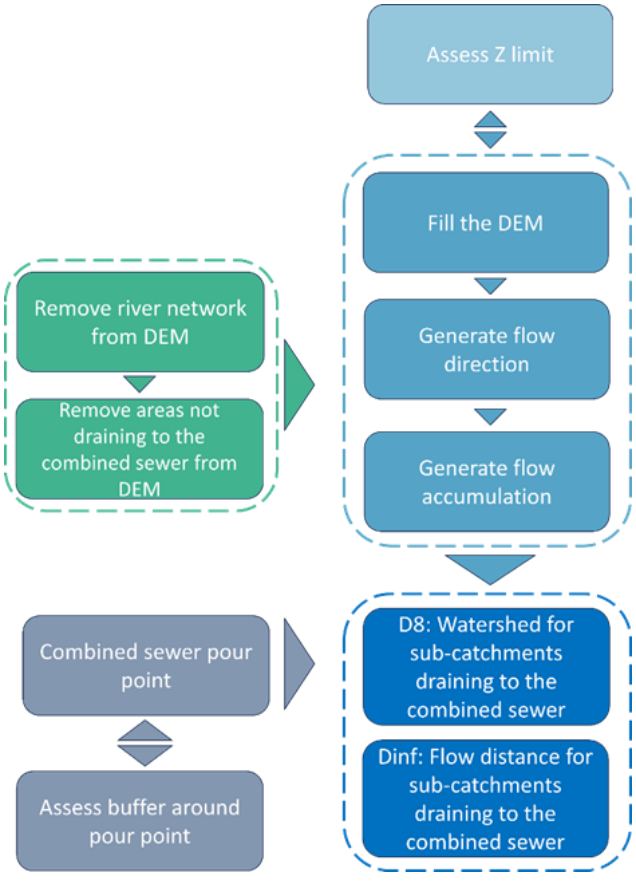


Figure illustrating tool workflow

Next the sewer drainage sub-catchments are generated. The first step for this process is to fill depressions in the surface, this conditions the surface to ensure that it is hydrologically connected where appropriate. We limit the change in elevation that could occur when filling depressions to 20cm, for more information on this see section 7.

With a reconditioned elevation surface, we then calculate the direction of flow along the surface. This can be achieved by two different algorithms, the first of which is called the the Deterministic 8 (D8) flow method. This assumes that water can only flow from a cell to one of the 8 cells that surround it. Alternatively, we can use the D-infinity (DInf) method. The DInf approach works by considering all of the surrounding cells in a 3x3 window to estimate the angle of flow for each cell, which is applied by proportionally assigning water to flow to multiple cells that surround it. For more information on the DInf flow method see section 8. Within the SCORe tool, both of these approaches are available.

For both flow direction algorithms, the outputted flow direction raster is used to generate flow accumulation, which represents the number of upstream cells that flow to each cell on the raster. The flow accumulation can be useful when assessing the flow pathways draining to the combined sewer network and better understand how runoff moves and is stored across the landscape.

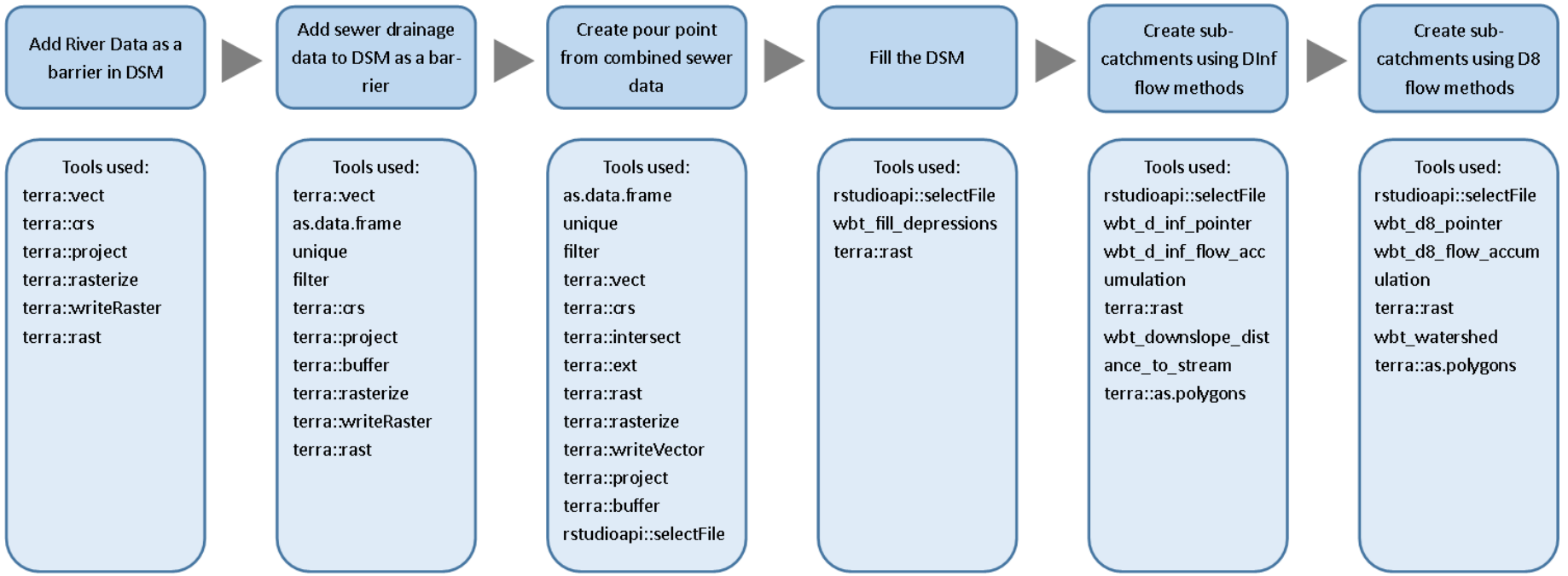


Figure showing each step for the SCORe Tool and the tools available in R that were used

2. Downloading RStudio to run the script

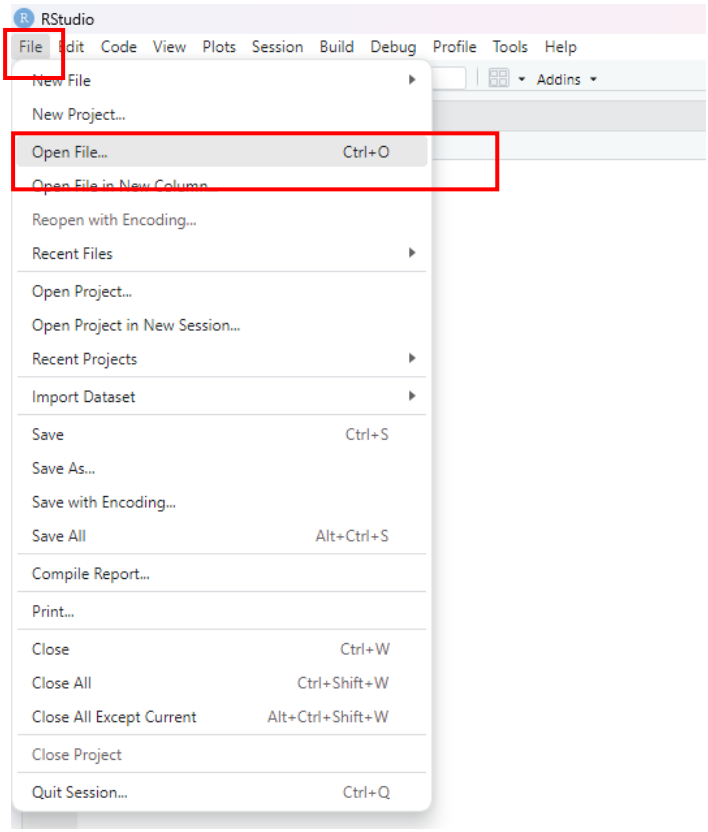
All users will need to ensure they have RStudio downloaded and ready to run to be able to use the tool developed.

If RStudio needs to be downloaded, instructions on how to do this can be found here.

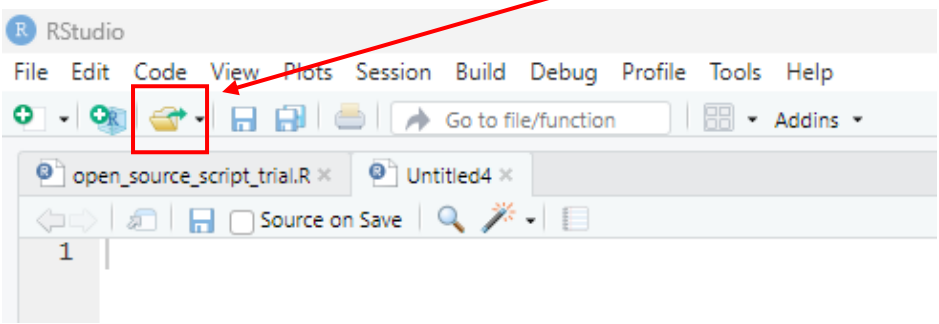
3. Setting up RStudio

Once RStudio has been downloaded the script (SCORe_Tool_R_Script.R) can be loaded and run. Loading scripts can be done in two different ways.

The first way to open a script is to click the 'File' option at the top of the screen, then click open and browse to the script in your folders then select the script.

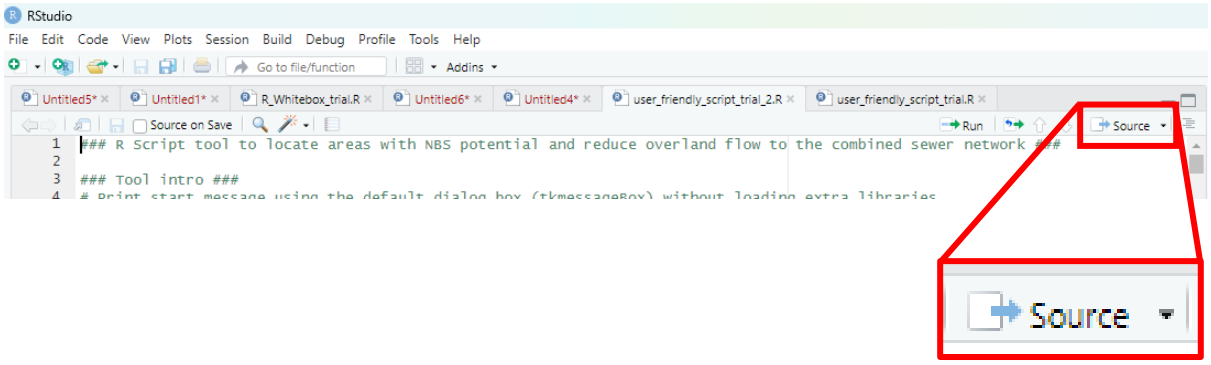


The second option is to select the open file icon  and then browse to the R script.

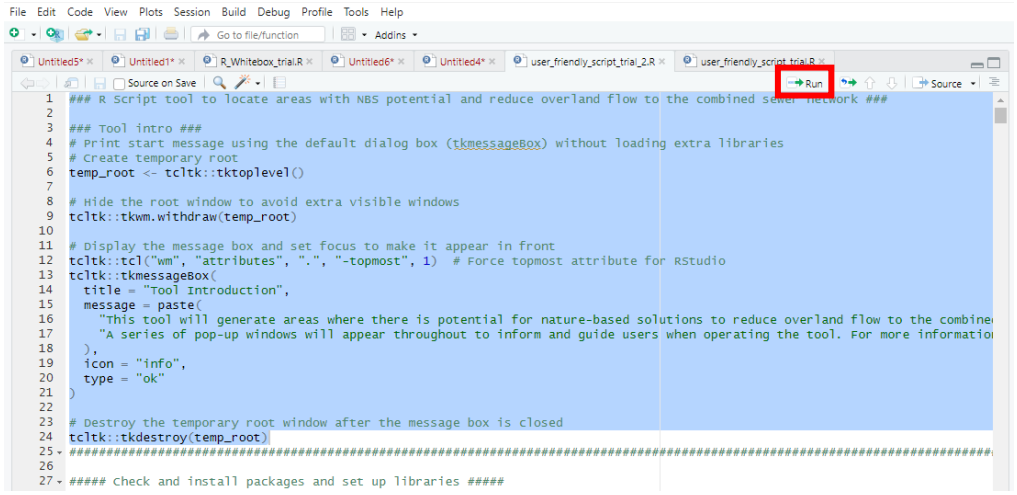


4. Running the R Script

To run the entire script, click the source button.

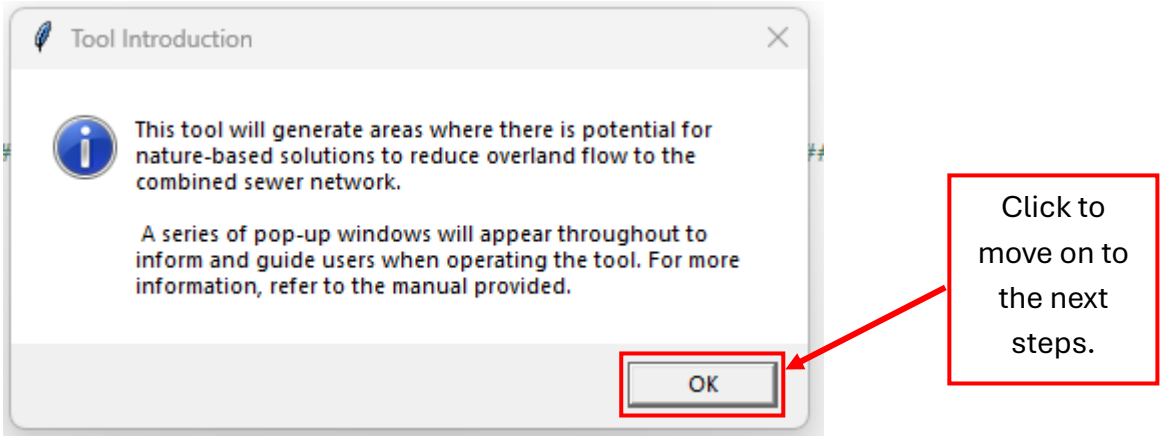


Alternatively, if only a portion of the script is required to run, then just click and highlight the text needed and click run.



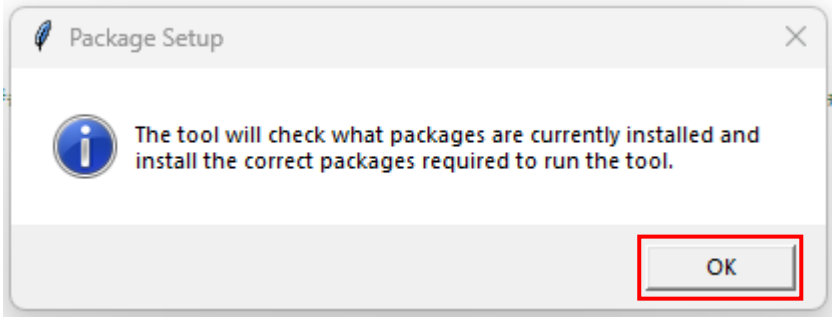
To stop the script, click the  icon

Once the script has been set to run a pop up will appear and provide the user with a brief tool overview. Click 'OK' to move on to setting up the packages and libraries required to run the tool.



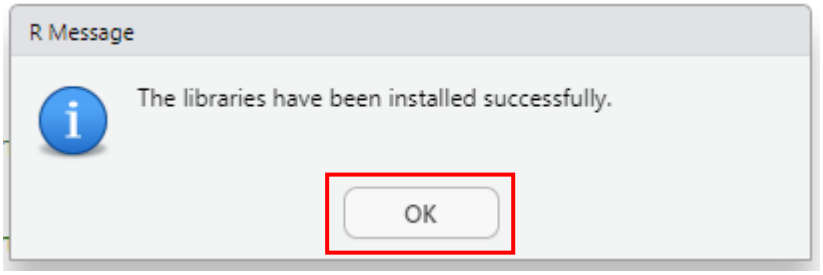
4.1.Setting up the packages and the libraries

The script has been developed to check prior packages and only install the libraries the user doesn't have but requires for running the script. A pop up will appear to inform the user of this. Click 'OK' to move on.

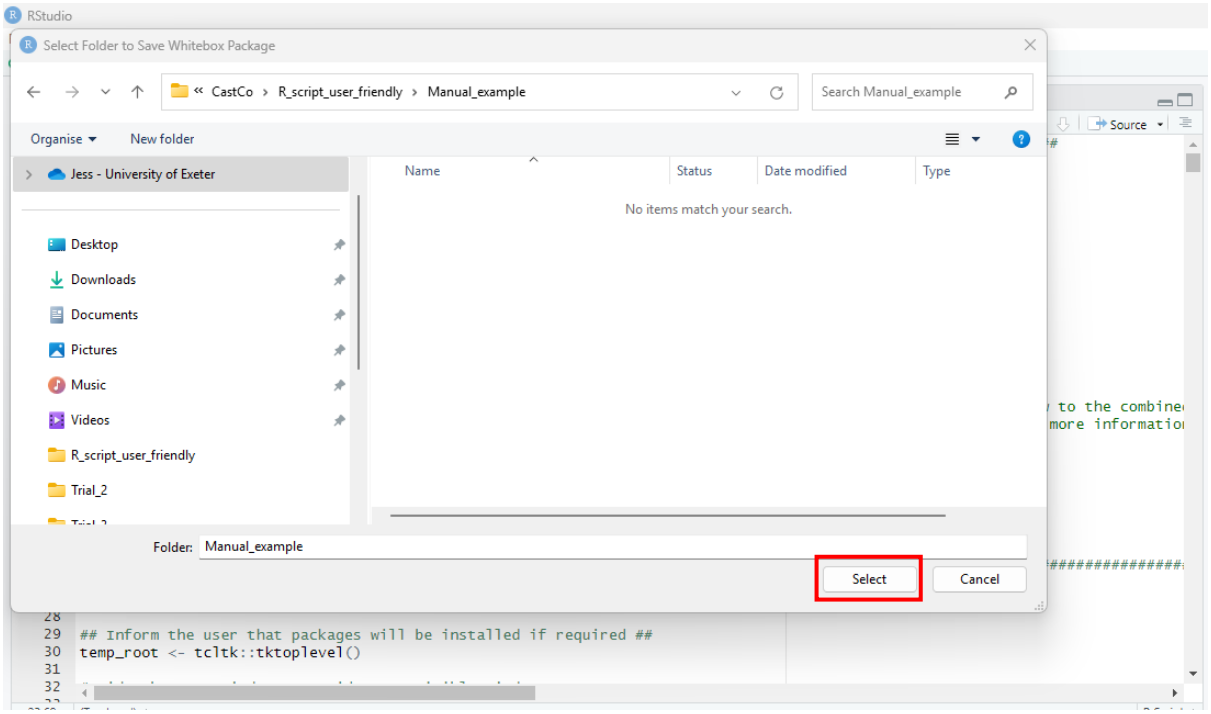


The libraries required include 'dplyr', 'sf', 'svDialogs', 'terra', 'whitebox', 'rstudioapi'. The tool will only install the libraries not already downloaded by the user.

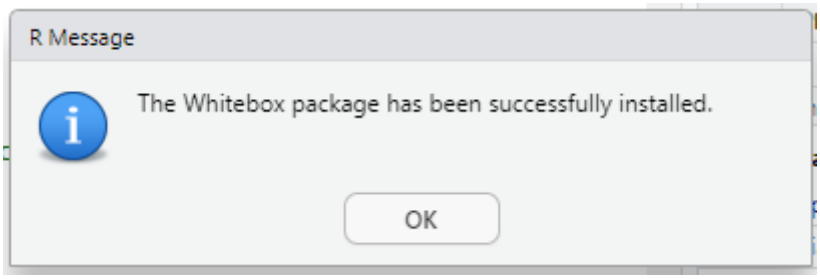
Once the required packages are loaded a message will appear to inform the user of this and all the user is required to do is click 'ok'.



Whitebox is another package required to run the SCORe R tool, but must be downloaded in an alternative way to ensure it will run. For this, the user will need to select a folder to download the whitebox package to. A pop-up window like below will appear and allow the user to use the file explorer to navigate to the correct folder or alternatively create a folder. Once the user has navigated to the correct folder, click select to set this as the folder to use. If the process needs to be aborted and started again, click the cancel button.

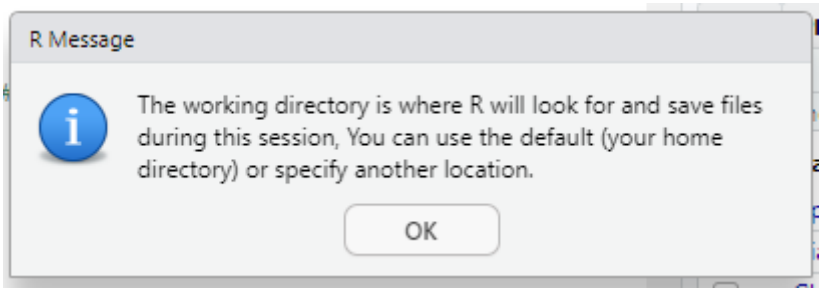


Once Whitebox has been correctly installed a new pop-up window will appear informing the user the process was successful. Like with the previous information pop-up window click 'ok' to continue.

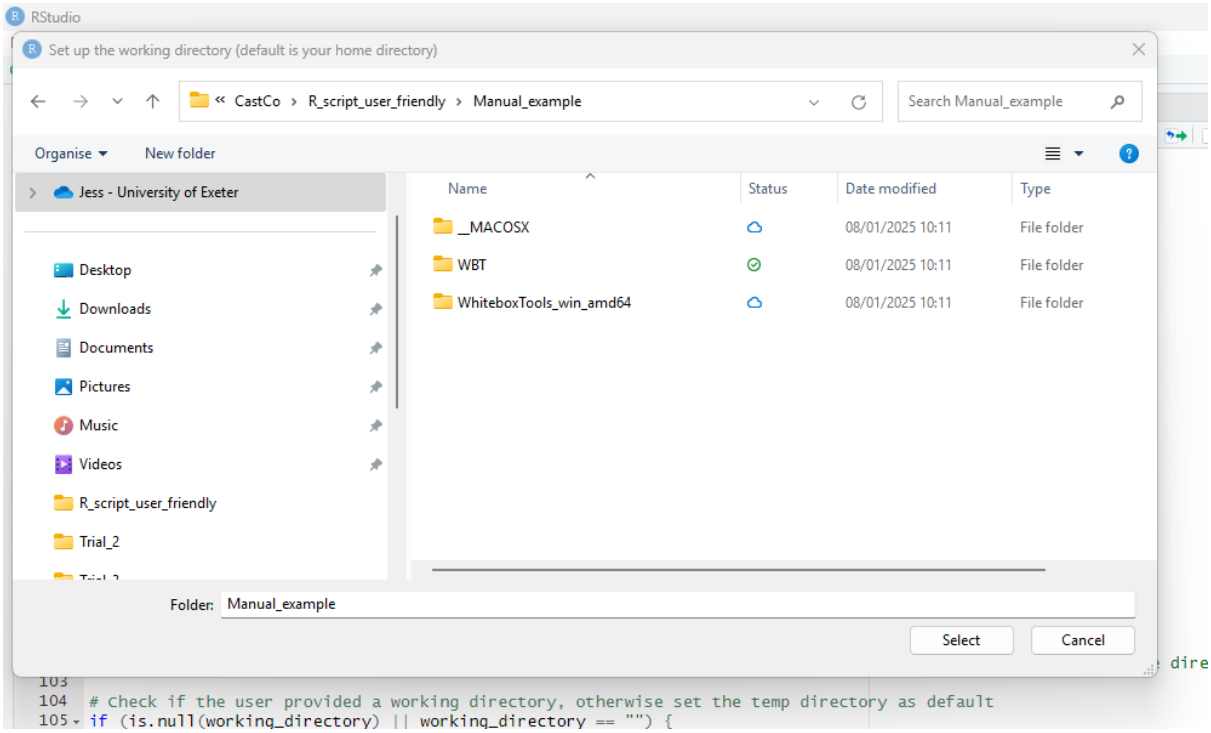


4.2. Set up the working directory

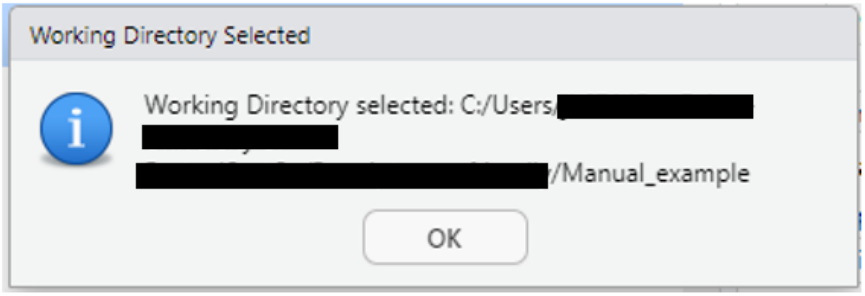
A new pop-up window will appear next to inform the user about what a working directory is and what options can be chosen. It is recommended the user uses the same folder where the outputs will be saved. Again, click 'ok' to move on to the next step.



Another file explorer window will appear allowing the user to browse to the correct folder for the file directory. Once the correct folder has been selected, click 'select'.



Once the working directory has been selected a pop-up window will appear to inform the user where the working directory will be, click 'OK' to move on to the next step.

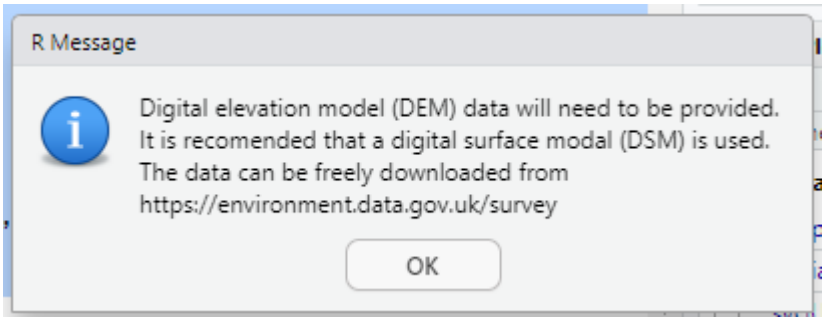


5. Add input data

The SCORe Tool uses two types of data: raster and shapefile. A raster is spatial data represented as a grid of equally sized cells. This data type is often used for digital elevation models, which are data that represents topography. A raster data layer will end in the file extension '.tif'. A shapefile is vector-based spatial data that records the location, shape and attributes of points, lines and polygons. For the SCORe Tool, shapefiles will often be inputs like sewer drainage data. A shapefile data layer will end in the file extension '.shp'.

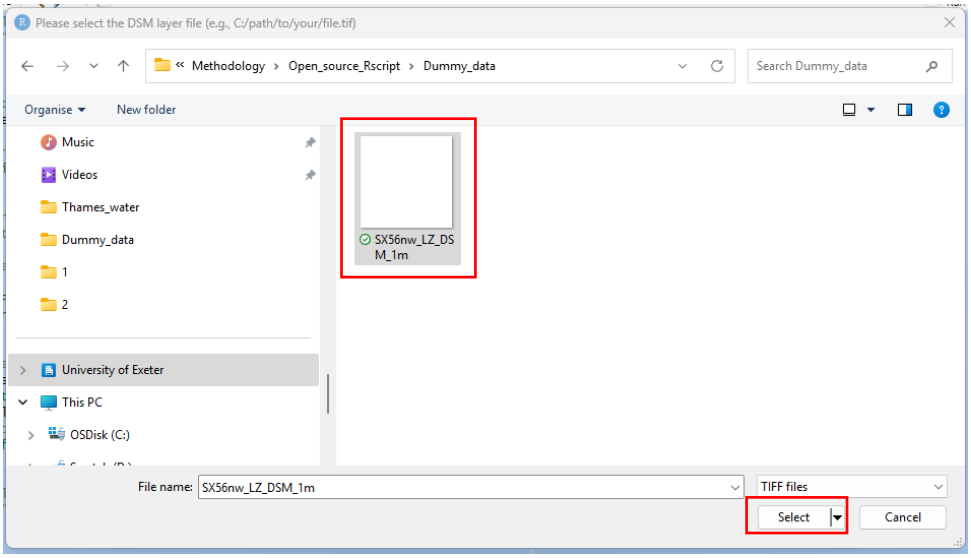
5.1. Add Digital elevation model data

Next a pop-up window will appear informing the user about the first input layer required to run the model. This window will recommend that a digital surface model (DEM) is used and where the user can download this information if they currently do not have it. Click 'ok' to move on.

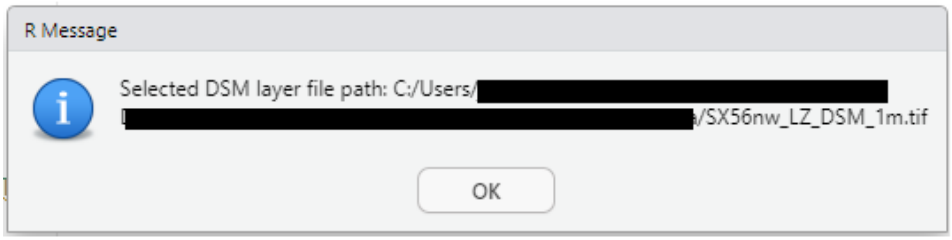


The data can be downloaded from https://environment.data.gov.uk/survey and see section 12~~11~~ on how to do so.

A new file explorer window will appear allowing the user to select the DEM. Only TIFF files will be visible when searching for the DEM input layer, therefore the DEM must be saved with a '. Tif' extension.

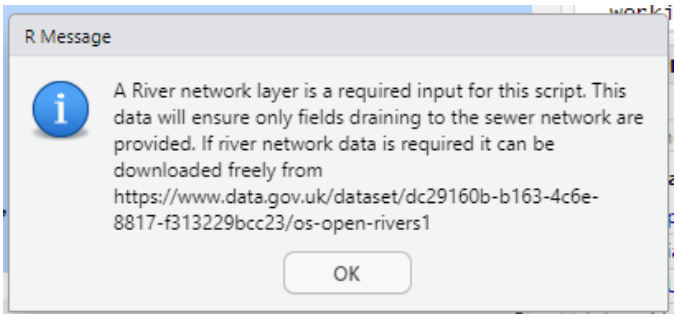


The following pop-up window will appear after the correct DEM is selected. This window will inform the user regarding which DEM was selected. Click 'ok' to move on.

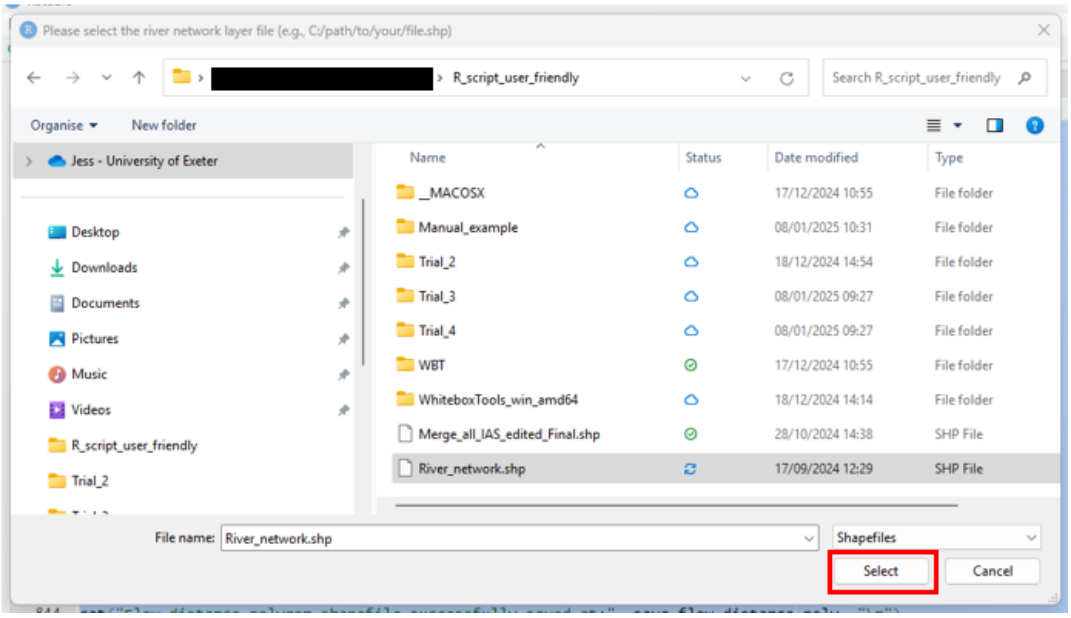


5.2. Add River Network Data

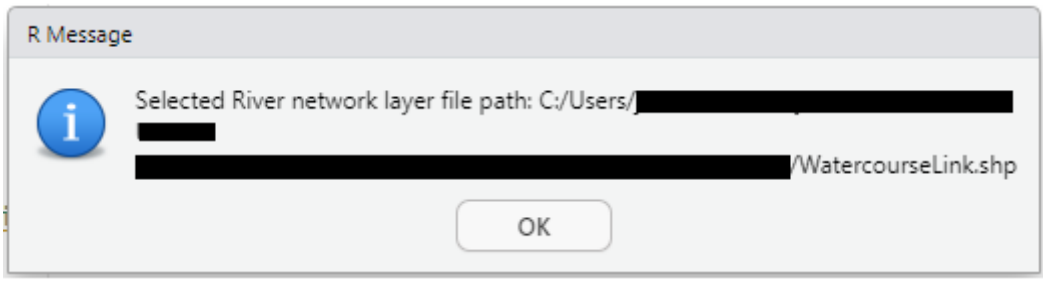
Next the river network layer will be required. A pop-up window will appear to inform the user why the river network data is required and where it can be obtained if the user does not have this data. Click 'ok' to move on. If river network data is required it can be obtained from here. OS Master map is another potential source that could be more detailed for some area, but this is not always freely available. If using an OS MasterMap Watercourse Network layer, it is recommended to first extract only sections of watercourse where the "level" attribute is set to "onGroundSurface", as culverted sections of watercourse will not directly capture surface runoff. The layer of "onGoundSurface" watercourses should then be used as input.



Another file explorer window will pop-up for the user to select the river network layer. Only shapefiles will be visible, therefore any river network data to be used with the tool must be saved with a .shp file extension. Please note that .dbf files associated with .shp files have a 2gb size limit, so if converting your vector file to .shp results in your .dbf file exceeding the 2gb size limit, you would be advised to split your dataset into smaller pieces before converting to a .shp.

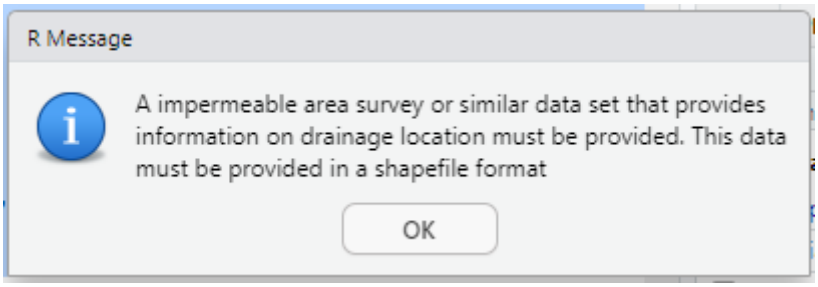


After the correct river network layer has been selected, another window will appear to inform the user which layer was selected and will be used for the river network input. Click the 'ok' button to move on to the next step.



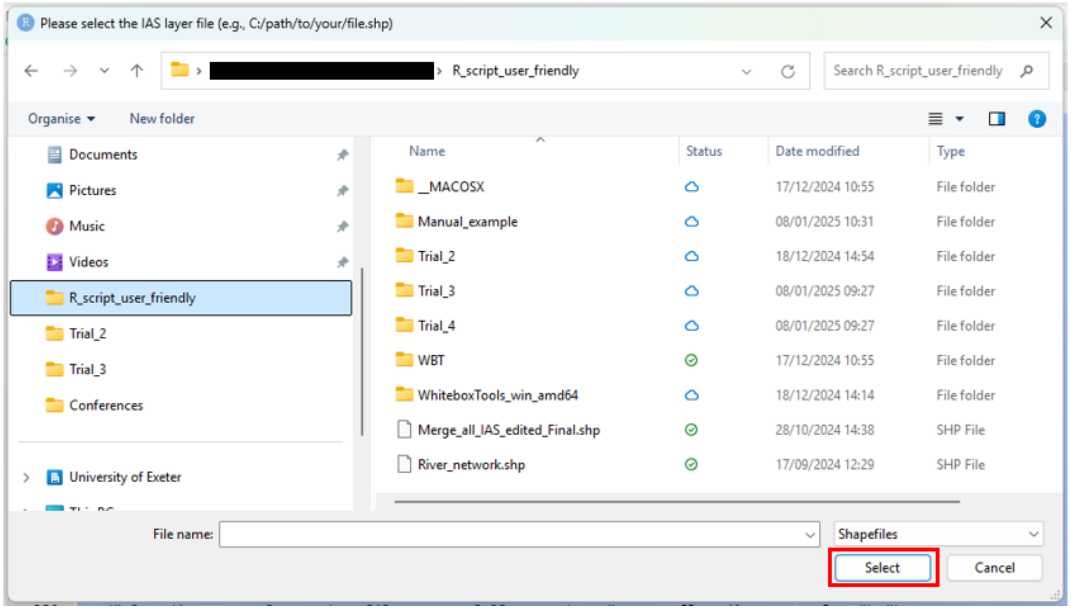
5.3. Add Sewer Drainage data

A window will appear to inform the user that a layer with sewer drainage data will be required. This could be an impermeable area survey (IAS) layer, gully dataset, sewer pipeline dataset or similar. Click 'ok' to move on. This layer must contain the areas, points or lines of interest (pour points) that you want to generate the sewer sub-catchments for. It can also contain features that are known to drain to systems other than the combined sewer system, as long as these can be distinguished by their attribute values. Section 5 describes how to select features from the dataset that drain elsewhere (e.g. to surface water or highways drainage systems). Section 6 describes how to select the pour points of interest, i.e. those points, lines or polygons that drain to the combined sewers, for which you want to generate sewer sub-catchments.

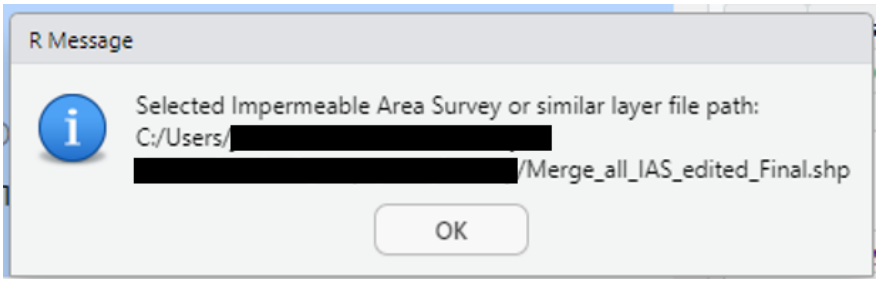


A file explorer window will appear for the user to browse to and select the correct sewer drainage data layer. Only shapefiles will be viable as this is the file type required for the tool, therefore ensure the data layer is saved with a .shp file extension.

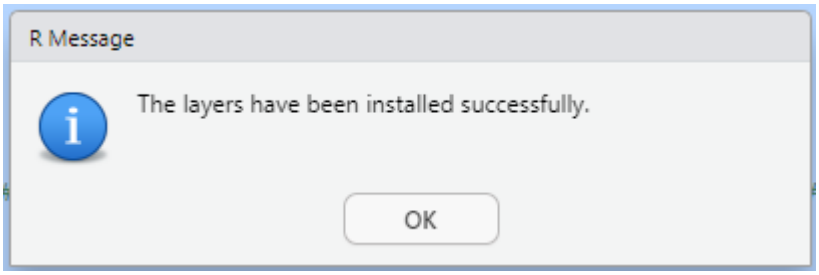
Once the correct layer has been selected, click 'select'.



Once the correct layer has been selected, a pop-up window will appear to inform the user which layer has been selected. Click 'OK' to move on to the next step.



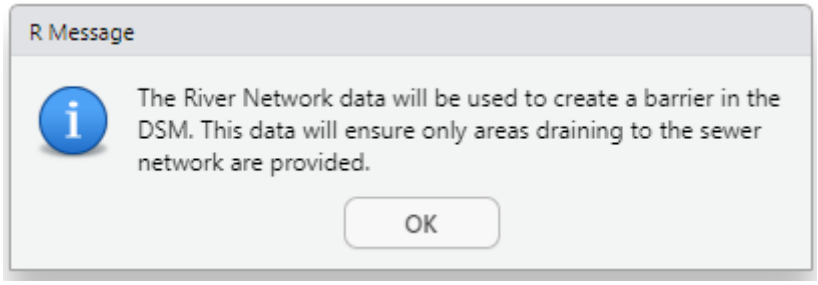
Once all the input layers have loaded into the tool, a pop-up window will appear to inform the user all the layers are loaded. Click ‘OK’ to continue to the next step.



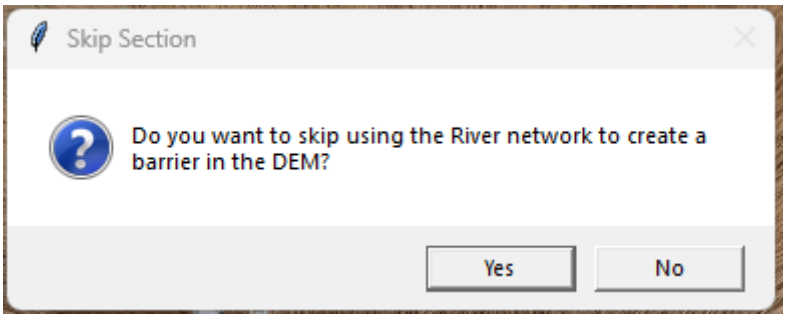
Once the layers have been successfully loaded, the tool will begin to process the layers and provide outputs.

5.4. Processing the River network

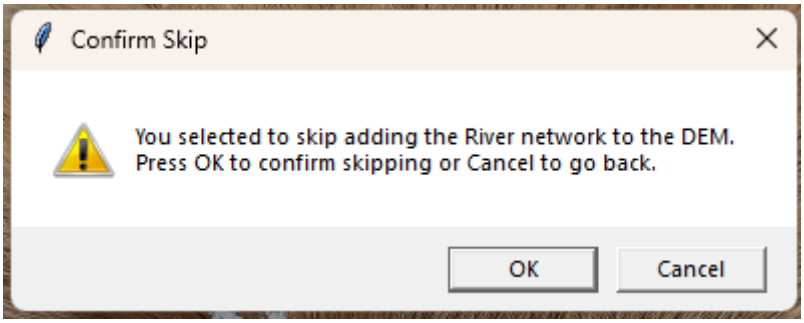
The river network layer will be used to create a barrier to flow in the DSM layer. This is required to ensure permeable areas identified will only be areas draining to the combined sewer network and not a river course. A box will appear to inform the user of this, click ‘OK’ to move on to the next step.



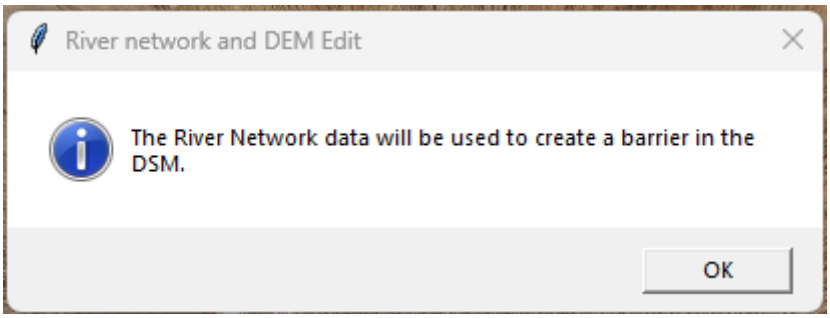
This step is optional, and the user can decide to skip if they do not need to add the river network to the DEM. Click ‘Yes’ to skip this step, and ‘No’ to add the river network to the DEM.



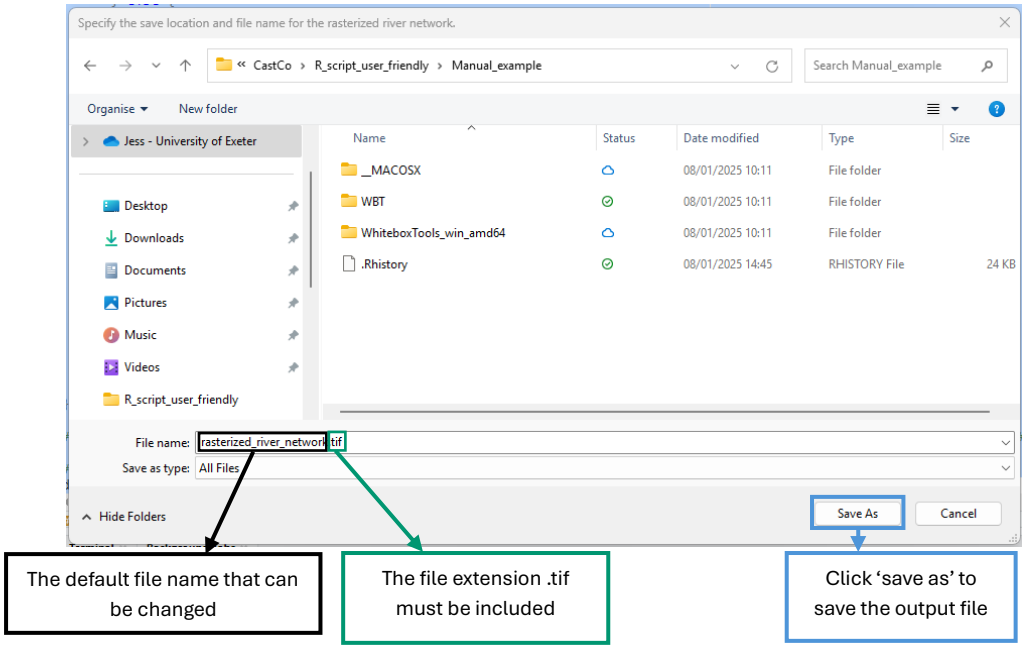
If the user decided to skip the step a window will appear asking the user to confirm the skip. Click ‘OK’ to confirm the skip. If the user decides to not skip, click ‘Cancel’ and the user will be sent back to the previous step where the user is asked if they want to skip.



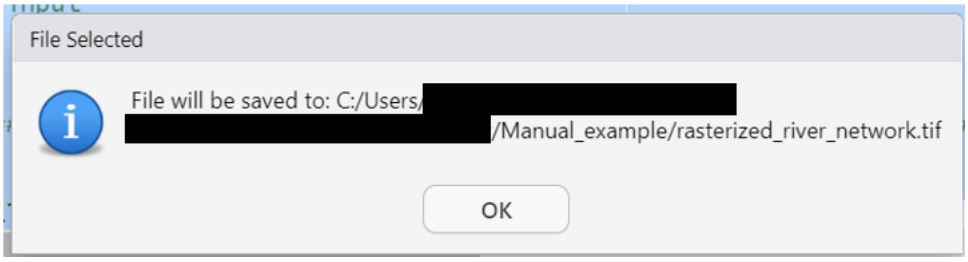
If the user decided to not skip this step the following box will appear, click ‘OK’ to move on.



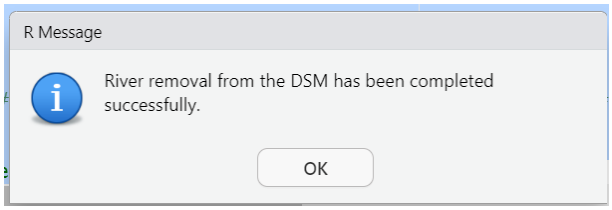
The first output will be a rasterised river network. This is where the shapefile river network will be converted to a raster. A file explorer window will appear for the user to browse to the correct folder to save the output. A default file name will be provided, but the user will need to check if the .tif extension is included. If the file extension (.tif) has not been included, then the user will need to add this to the file name. The default file name can also be changed but it must also include the .tif extension.



Once the rasterised river output location has been set a pop-up window will appear to inform the user where the output layer will be saved. Click 'OK' to move on to the next step.

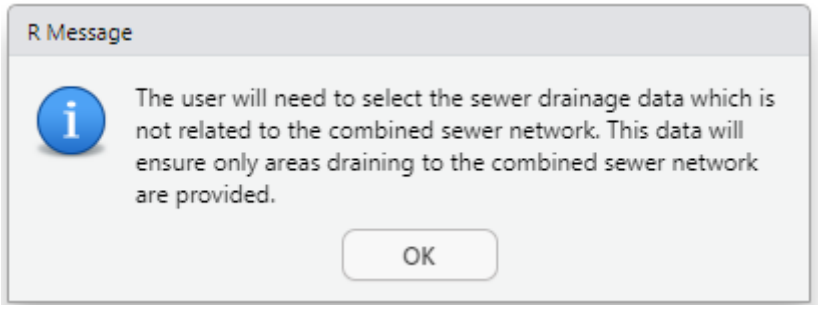


The rasterised river network will then be removed from the input DEM. This will ensure only areas draining to the sewer network are produced and not areas draining to the river network. When this step has been completed a new window will appear to inform the user this has completed. Again, click 'OK' to move on to the next step.



6. Removing sewer drainage data not draining to the combined sewer network from the DEM

The next step involves selecting sewer drainage data that does not drain to the combined sewer. This data will be added to the DSM like the river network data, and ensure the final catchments only drain to the combined sewer network and overland flow is not intercepted by other sewer network drainage types. This section is optional, and a skip option will be available. Click 'OK' to move on.

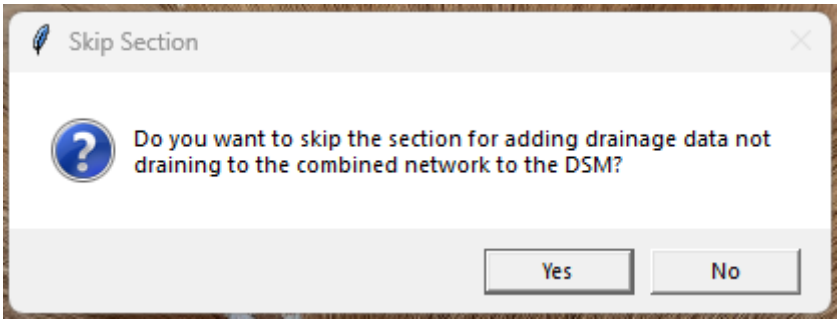


6.1. Option to skip this section

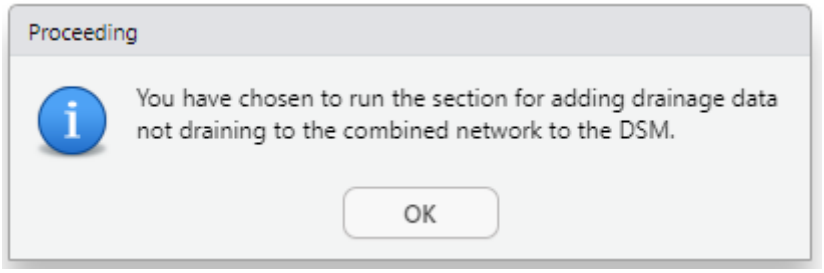
The next section is optional and involves selecting data relating to sewer networks not draining to the combined. The codes in the sewer drainage data relating to networks that are not the combined can be selected during this step and the data will then be

removed from the DSM. The reason this is removed is because it is not related to the drainage system of interest, in this case the combined network. Removing this area is useful as it avoids a situation in which water can drain from the river or surface water drainage network into the combined sewer, when it should not. This is an optional step and can be skipped if not required or the data is not present.

To inform the tool if the user wants to skip this section or continue, a window will appear with the options for the user to select from. Click 'Yes' to skip and 'No' to not skip the step.

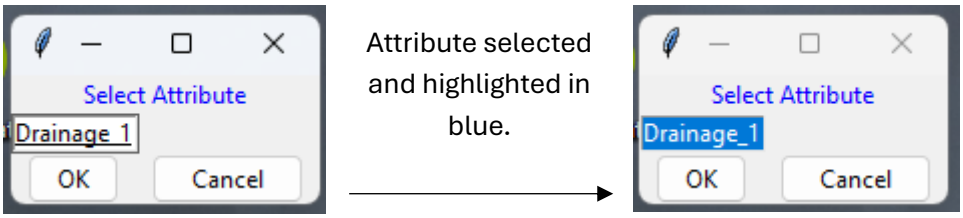


Following this another window will appear informing the user on the option they selected. Click 'OK' to proceed.



6.2. Running this section

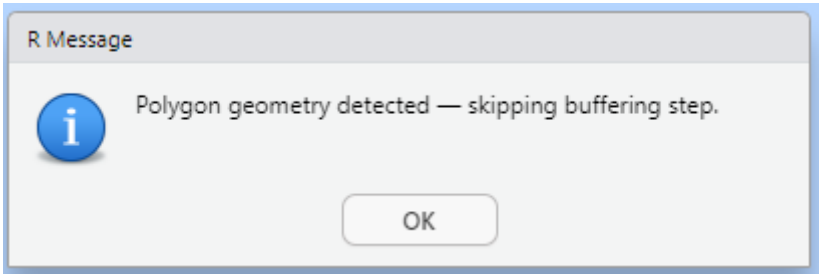
A window will appear prompting the user to select the attribute field relating to the coding that describes the drainage types. Select the correct attribute, once selected the attribute will appear in blue. Only one attribute can be selected, if the wrong one is selected, click the wrong attribute again, if the attribute is no longer highlighted in blue, it has been unselected, then select the correct attribute and click 'OK'. An example can be seen below. If 'Cancel' is selected the whole tool operation will be aborted.



After selecting an attribute , a window will appear asking the user which values they want to select. More than one value can be selected for this option. Click ‘OK’ to move on. If ‘Cancel’ is selected the whole tool operation will be aborted.

6.3. Input data is a Polygon Shapefile

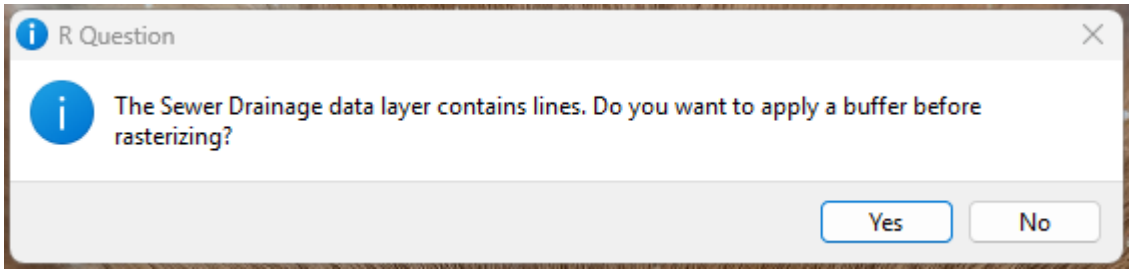
The tool will automatically detect the geometry of the sewer drainage layer and if the geometry is polygon a buffer will not be applied. A buffer will not be applied due to the assumption that the polygon will cover the road area; this would not be the case if the sewer drainage data was a polyline or point shapefile.



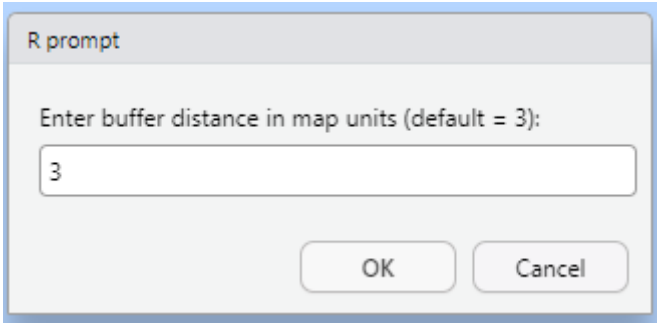
6.4. Input data is a Point or Line Shapefile

If the tool automatically detects the geometry as a point or polyline shapefile, it will ask the user if they want to apply a buffer. This step is optional but provides the user the option to increase the area of the feature to better represent the real-world area. For example, a buffer could be applied to a polyline layer to better represent the area of a road.

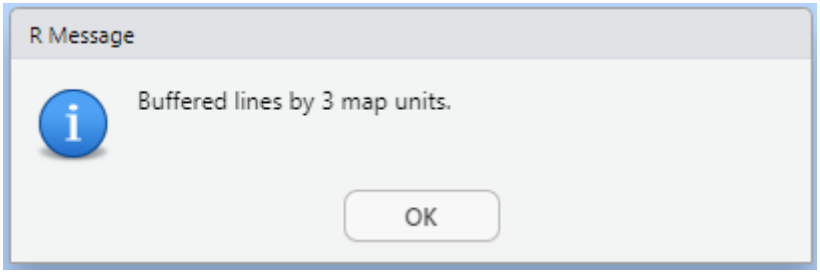
The user will be asked if they want to apply a buffer to the point/polyline input layer. If they wish to apply the buffer type ‘Yes’, this is the default, then click ‘OK’. If a buffer is not required, type ‘No’ then click ‘OK’.



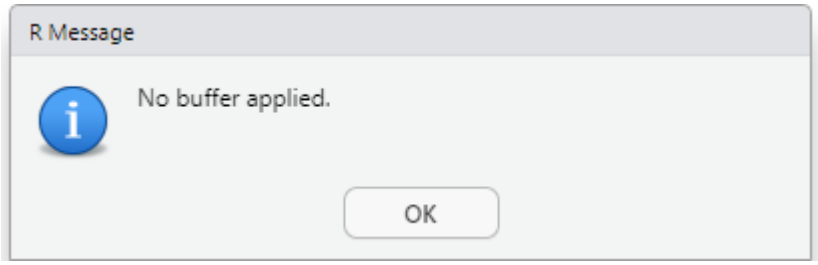
Next the user will be asked to provide a buffer distance in map units most layer projections will be in meters, and therefore the buffer distance would be in meters. For example, the British National Grid projection uses meters. A default of 3 has been provided, but this can be changed to meet the users' requirements. Once the buffer distance has been selected, click 'OK'.



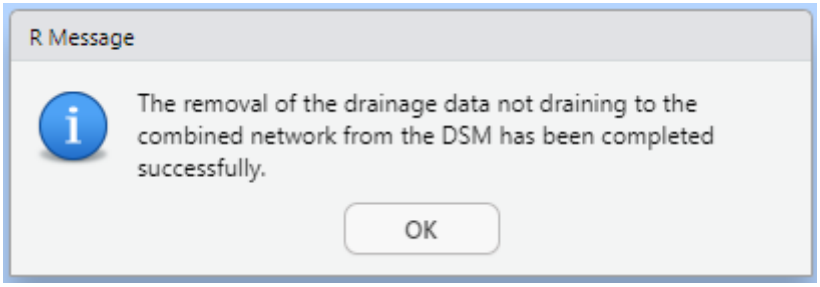
A message will pop up to confirm the buffer size selected by the user, click 'OK' to move on.



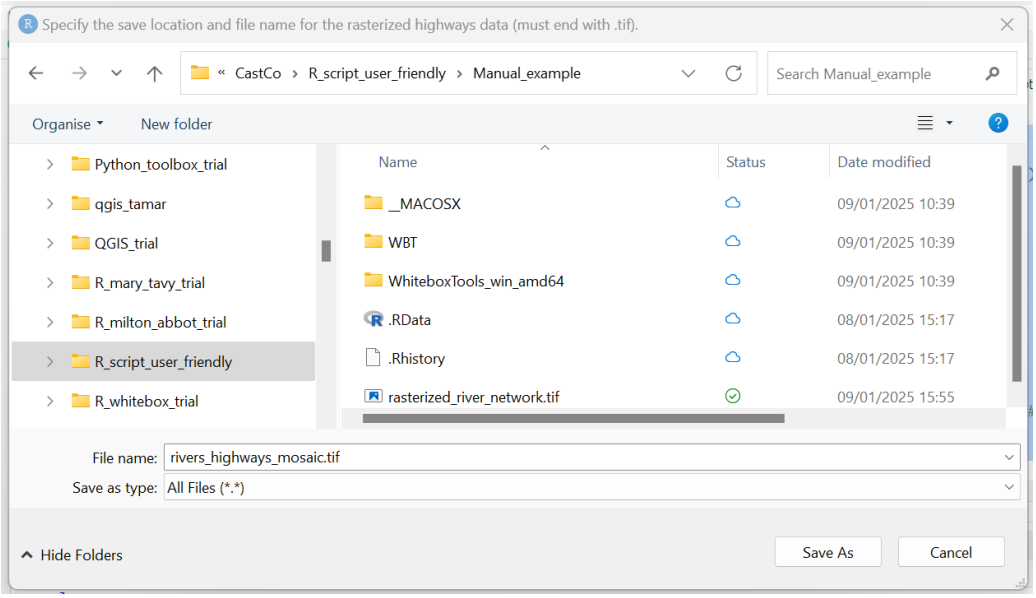
If the user typed 'No' when asked if they wanted to apply a buffer, then a pop up will appear informing the user no buffer was applied. Click 'OK' to move on to the next step.



A file explorer window will open next; this is where the location for saving the DSM with rivers and sewer drainage barriers must be provided. The user can use the file explorer window to navigate to the save location. A name must be provided and the file extension. A default name of 'rivers_highways_mosaic.tif' has been provided but this can be changed to any name the user wants, but it must have the file extension '.tif'.



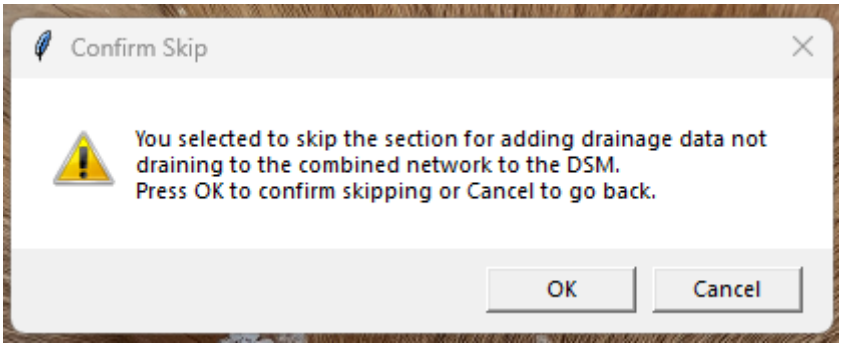
Once the removal of the sewer drainage data not of interest step is completed a window will appear to inform the user of this. Click 'OK' to move on to the next step.



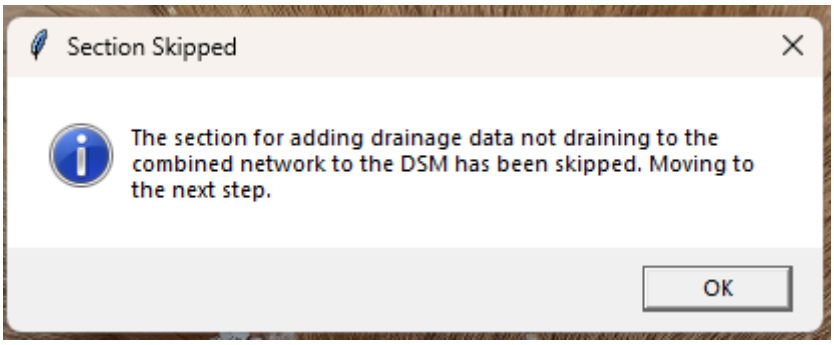
6.5. Skipping this section

If the user wants to skip the removal of highways data from the DEM they will need to type 'Yes' when the skip section window appears. Then click 'ok' to move on.

Another window will appear to check if the user wants to skip this section. If the user selects 'Cancel' they will be redirected to the previous window and asked if they want to skip the section. If the user selects 'Yes' then the section will be skipped.



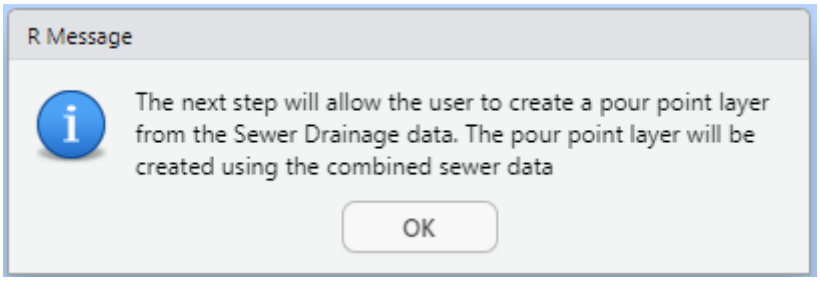
The next window informs the user that they have skipped the section and will be moved on to the next section. Click 'OK' to move on to the next section.



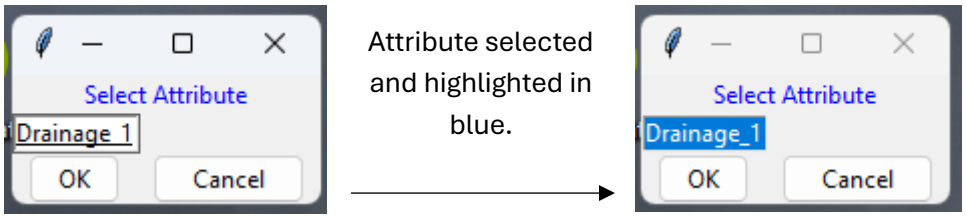
7. Create a pour point layer with only the combined sewer data

A pour point layer needs to be generated to produce the sub-catchments draining to the combined network. A pour point is the point where water flows out of a catchment, these points are then used to delineate drainage sub-catchments from the contributing land.

This section will use the sewer drainage input data to create a pour point layer from the attribute options selected by the user. A pop-up window will appear to inform the user this next section will be on producing a pour point layer. To move on from the information pop up click 'OK'.



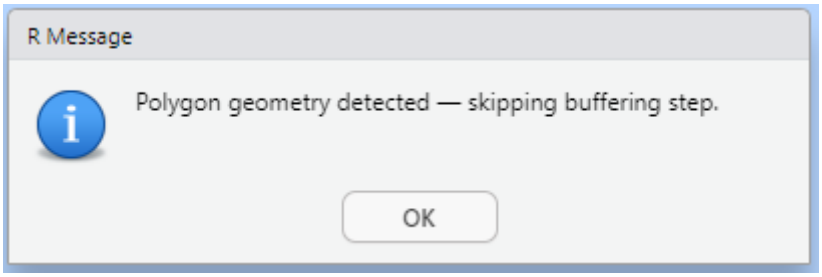
The next pop-up window will ask the user to select the attribute field relating to the coding that describes the drainage types. Select the correct attribute, once selected the attribute will appear in blue. Only one attribute can be selected, if the wrong one is selected, click the wrong attribute again, if the attribute is no longer highlighted in blue, it has been unselected, then select the correct attribute and click 'OK'. An example can be seen below. If 'Cancel' is selected the whole tool operation will be aborted.



After selecting an attribute, a window will appear asking the user which values they want to select. More than one value can be selected for this option. Click 'OK' to move on. If 'Cancel' is selected the whole tool operation will be aborted.

7.1. Input data is a Polygon Shapefile

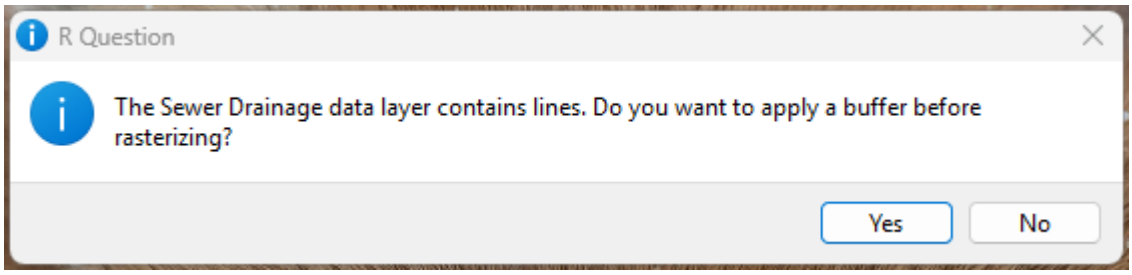
If the tool automatically detects the geometry as a polygon shapefile it will inform the user that the buffer step will be skipped. This occurs as it is assumed the polygon will better represent a drainage area than a point or polyline shapefile input.



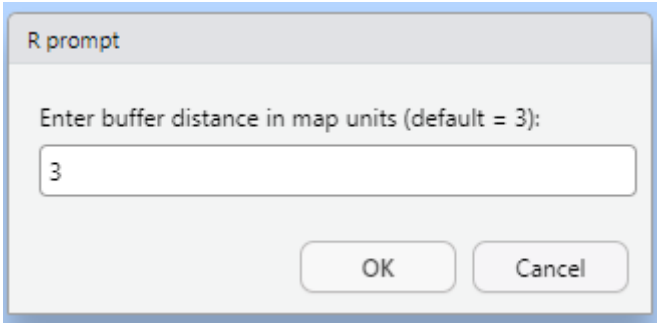
7.2. Input data is a Point or Line Shapefile

If the tool automatically detects the geometry as a point or polyline shapefile it will ask the user if they want to apply a buffer. This step is optional but provides the user the option to increase the area of the feature to better represent the real-world area. For example, a buffer could be applied to a polyline layer to better represent the area of a road.

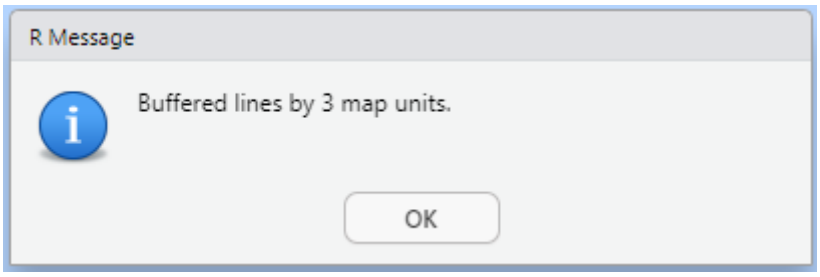
The user will be asked if they want to apply a buffer to the point/polyline input layer. If they wish to apply the buffer click 'Yes'. If a buffer is not required, click 'No'.



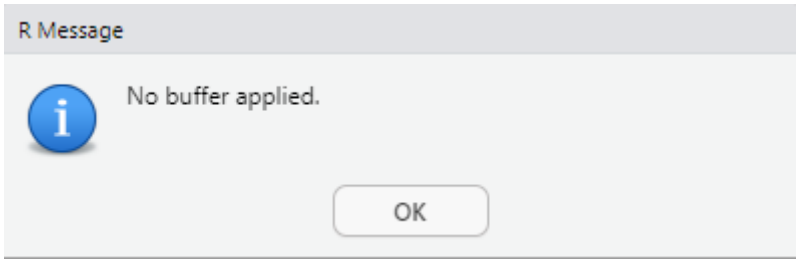
Next the user will be asked to provide a buffer distance in map units. A default of 3 has been provided, but this can be changed to meet the users' requirements. Once the buffer distance has been selected, click 'OK'.



A message will pop up to confirm the buffer size selected by the user, click 'OK' to move on.

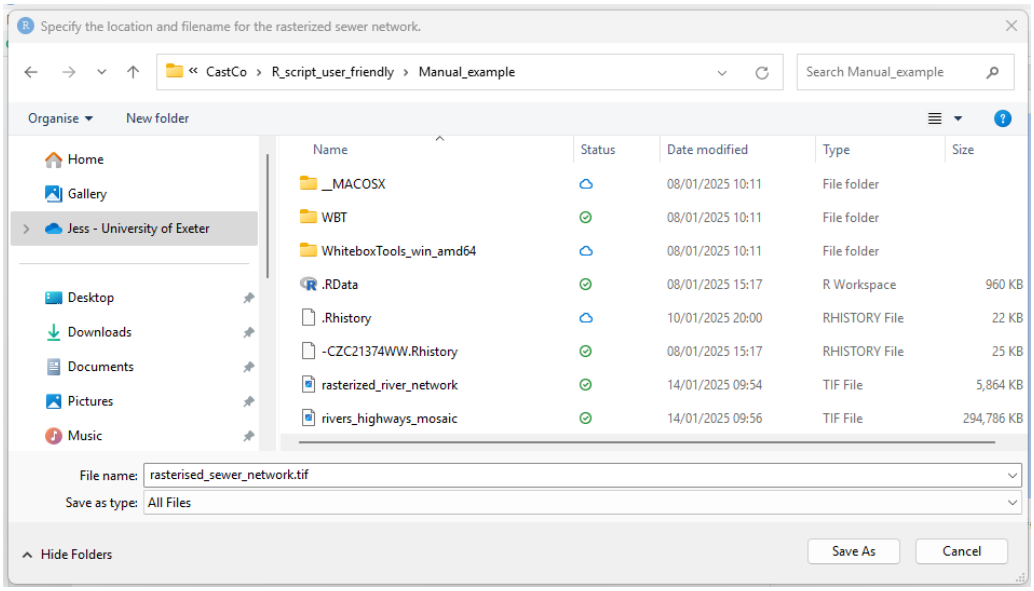


If the user typed 'No' when asked if they wanted to apply a buffer, then a pop up will appear informing the user no buffer was applied. Click 'OK' to move on to the next step.

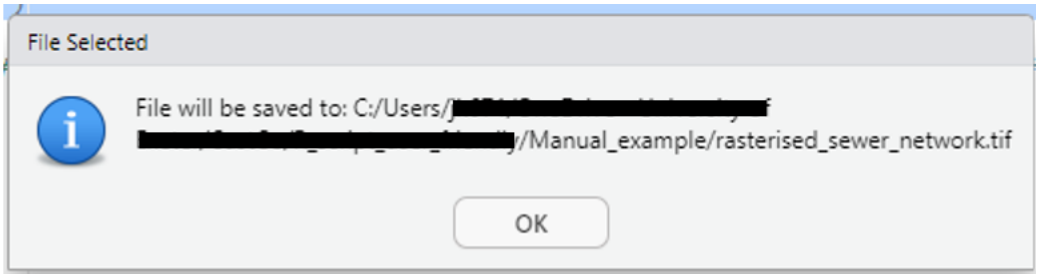


7.3. Saving the Pour Point layer

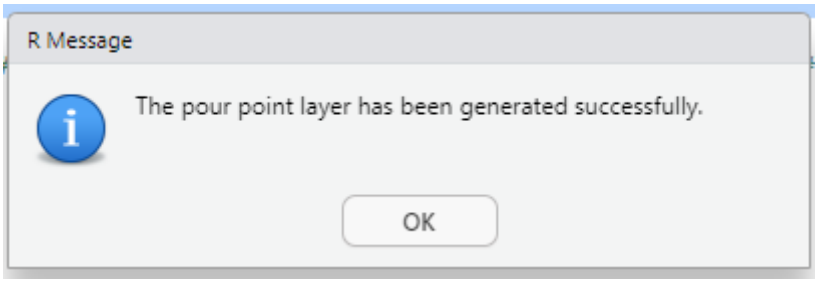
Next a file explorer window will appear for the user to browse to the correct folder to save the rasterised sewer network layer. The user can provide a name for this layer or use the default 'rasterised_sewer_network.tif'. The '.tif' file extension must be used for the layer name. Click 'save as' when the location and name are selected.



A pop-up will appear after the layer name and location have been saved to inform the user of the location, click 'OK' to move on.

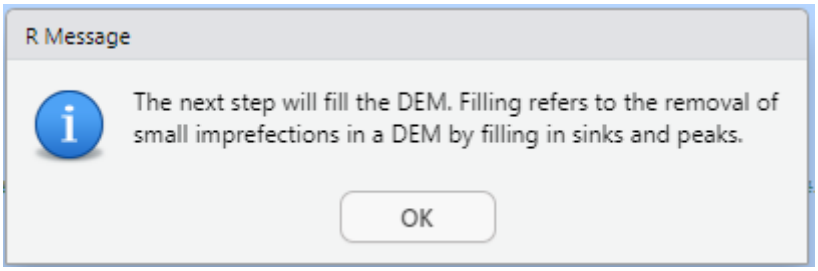


Once the section for generating the pour point layer has finished running a message will appear to inform the user this section has been completed. Click ‘OK’ to move on to the next section of the tool.

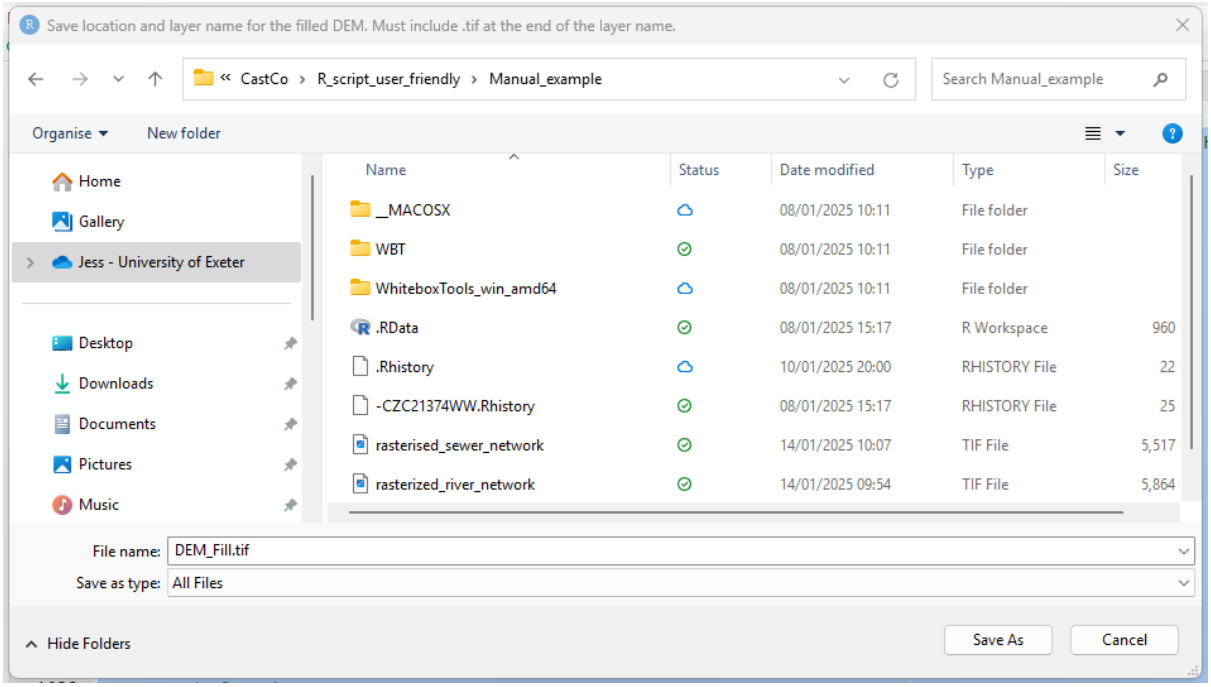


8. Filling in sinks for the DEM

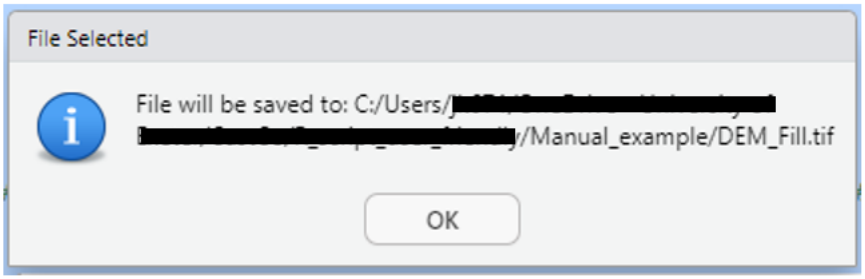
The next section of the tool will focus on filling the DEM. Filling refers to the removal of small imperfections in a DEM by filling in sinks and peaks. A pop-up will appear to inform the user this is the next section of the tool. Click ‘OK’ to move on to running this section.



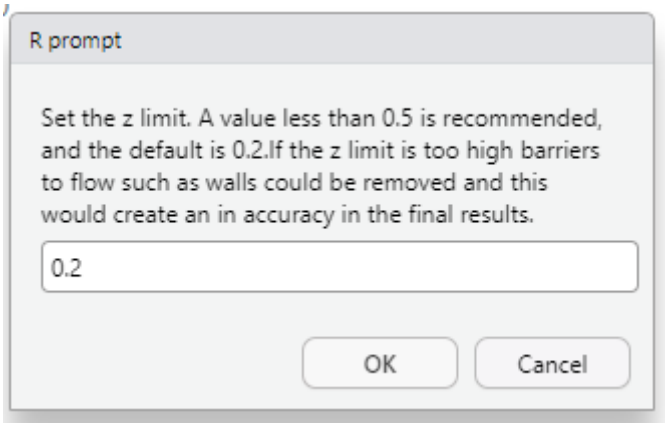
The first step of this section is to set the save location and name. This is done via the file explorer window that will appear. Using the file explorer window, browse to the correct folder and provide a file name. A default file name is provided but can be changed. If the user wants to change the file name, type the new name into the box provided in the file explorer window. Any file name used must end in the file extension ‘.tif’. Click ‘save as’ to move on to the next step.



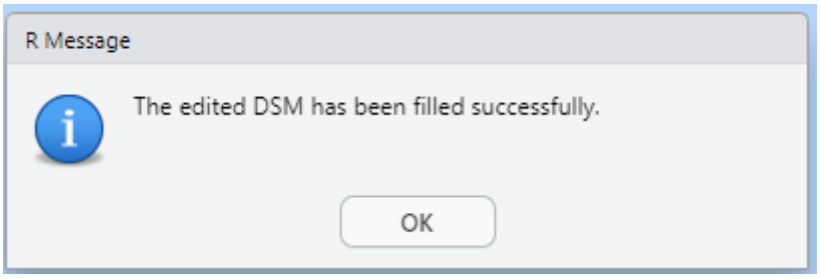
Another window will appear after the layer is saved to inform the user of the save location. Click 'OK' to move on.



A z limit will need to be set by the user for this part of the tool. A z limit refers to the maximum difference specified between the depth of the sink (also known as depression/pit) and the pour point; this value will determine which sinks will be filled. A fill of 0.2 is the default and the recommended value. It is also recommended to not exceed a value of 0.5 as this could lead to barriers (e.g. walls) being removed and this would then allow the flow through, when this would not be the case. A fill less than 0.5 can lead to the removal of barrier features but this is less likely, and this is why the user can specify the value as this may differ across different areas of interest. Click 'OK' to move on.

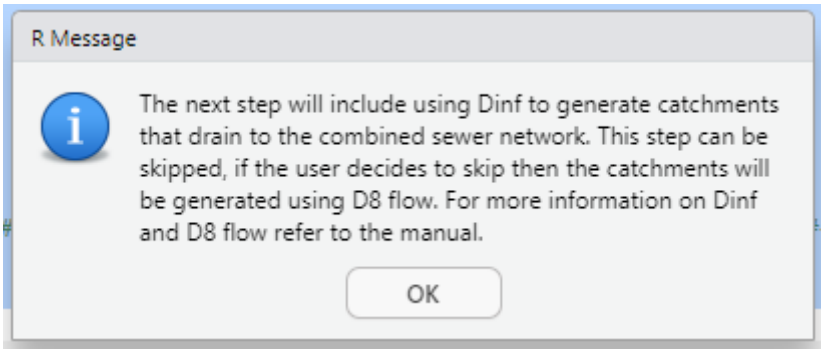


The last window to appear for this section will inform the user the fill was completed, click 'OK' to move on to the next section of the tool.



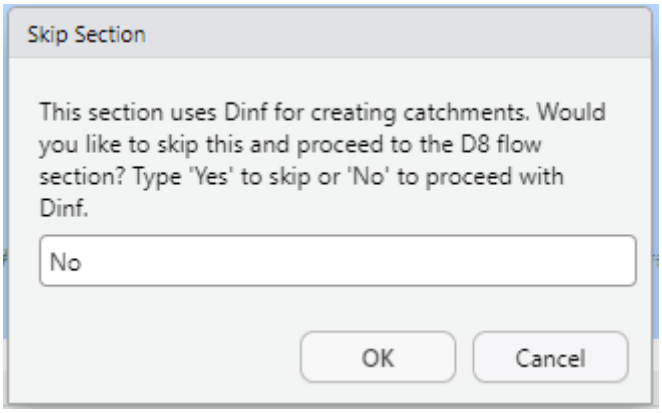
9. Create sub-catchments draining to the combined sewer, using DInf or D8 flow direction methods

The next section provides options for the user to select the type of flow method they want to use. The two flow method options are D-Infintiy (DInf) or Deterministic 8 (D8). The D8 method will model flow direction from each cell to the cells steepest downslope neighbour. This flow method is often used when delineating sub-catchments. Whereas the DInf method will determine flow direction via a grid by identifying the steepest downward slope in a 3x3 cell window. DInf can be more representative of real-world flows as it can consider more flow directions when compared to D8, however it is for the user to decide which flow method is used. A window will appear informing the user of the two flow methods to select from for the next step.

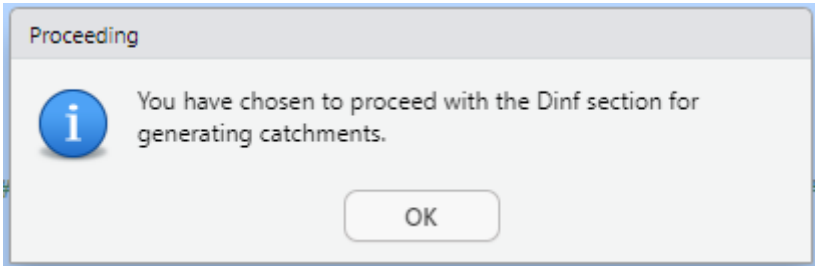


Due the selection between the DInf and D8 flow method, the user can select to skip the DInf method to move on to the D8 flow method, equally they can choose to run the DInf section and skip the D8 section or decide to run both by not skipping any of the steps from this point forward.

If the user wants to skip the DInf flow method section, type 'Yes' into the box provided, then click 'OK'. If the user wants to use DInf as a flow method, they need to type 'No' into the box provided. The default for this selection is 'No'. Once the option has been provided click 'OK' to move on to the next step.



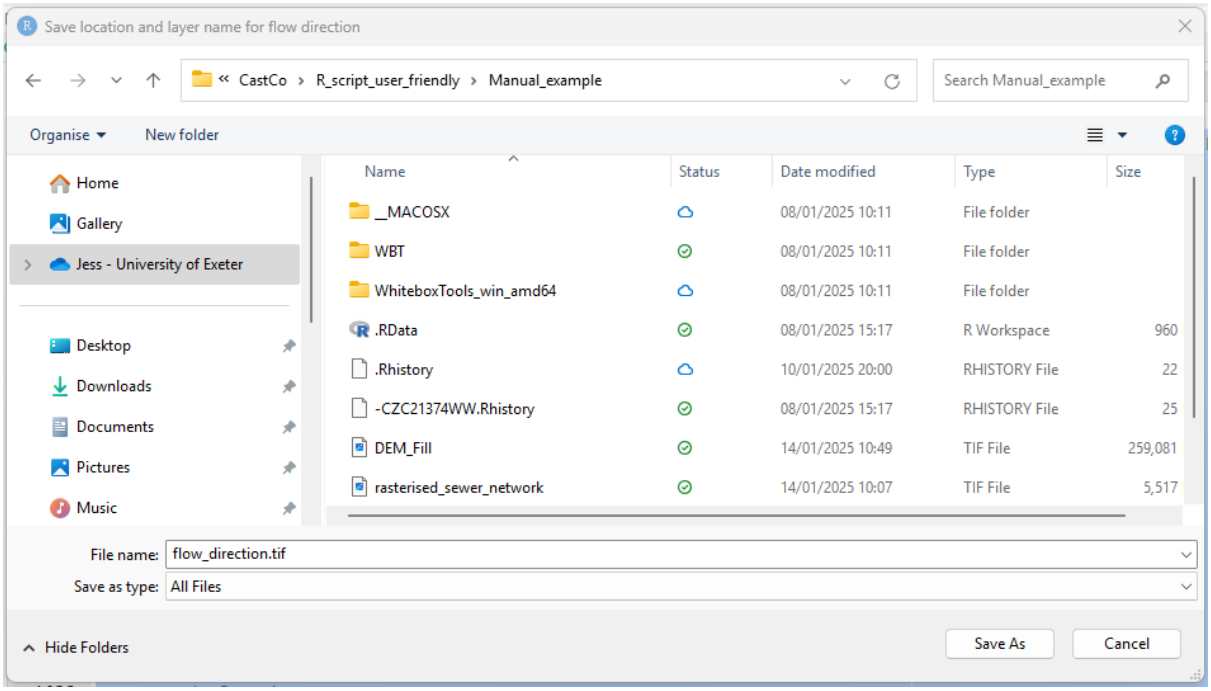
A box will appear to inform the user of the option they selected, click 'OK' to proceed.



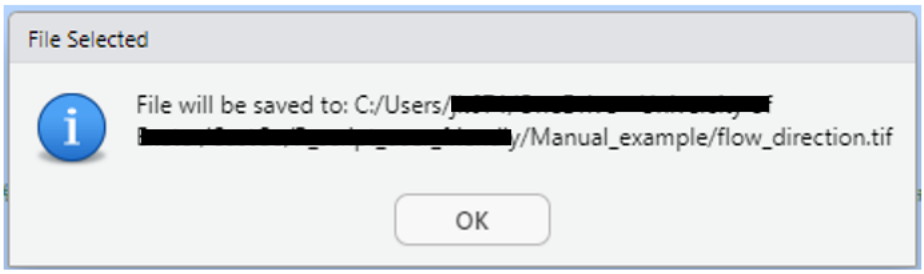
10. Create catchments draining to the combined sewer using DInf flow

10.1. Selecting to run the DInf flow method

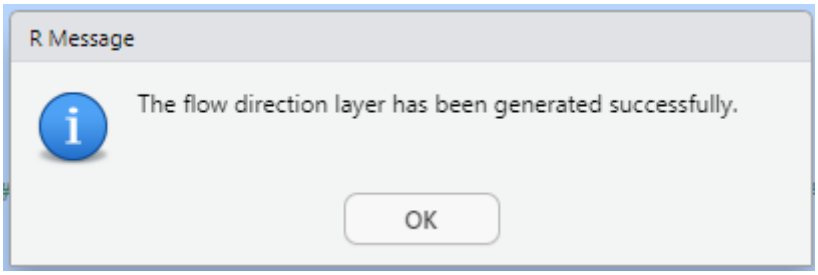
A file explorer window will appear allowing the user to browse to the folder where they want to save the flow direction output. A default name of 'flow_direction.tif' has been set, but the user can choose to change this by typing a new name into the box provided. The name used for this layer must end in the file extension '.tif'. Click 'Save as' to move on to the next window.



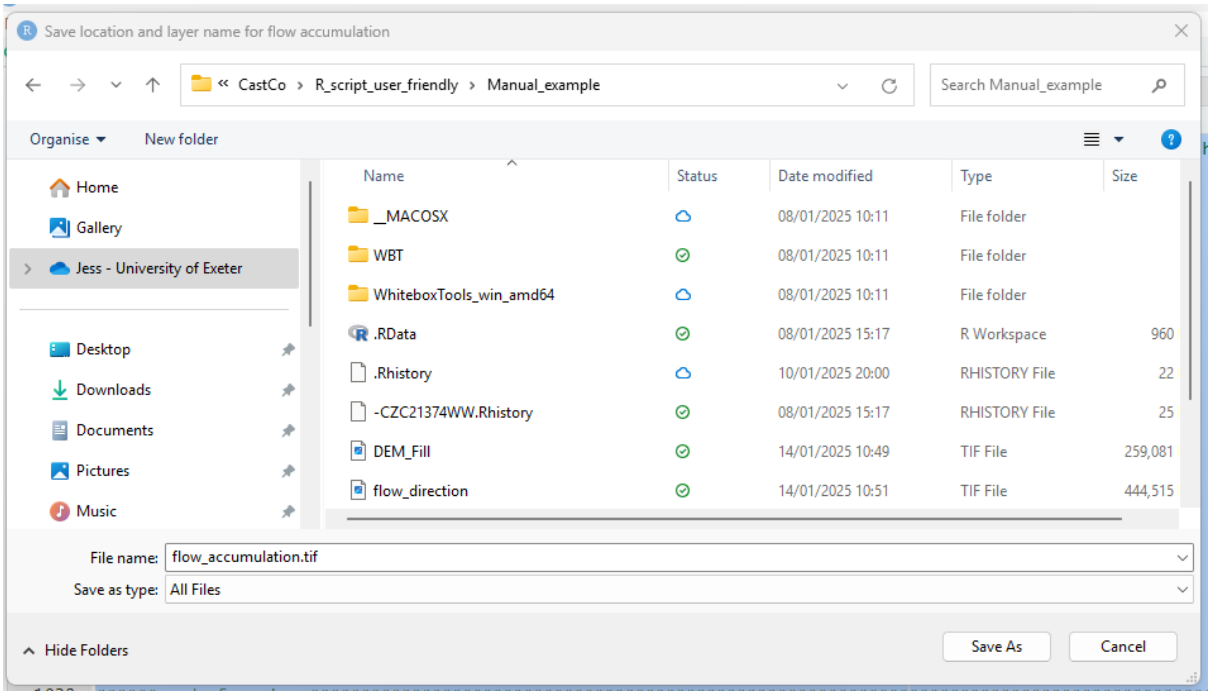
A new window will appear to inform the user where the flow direction layer will be saved. Click 'OK' to move on to the next step.



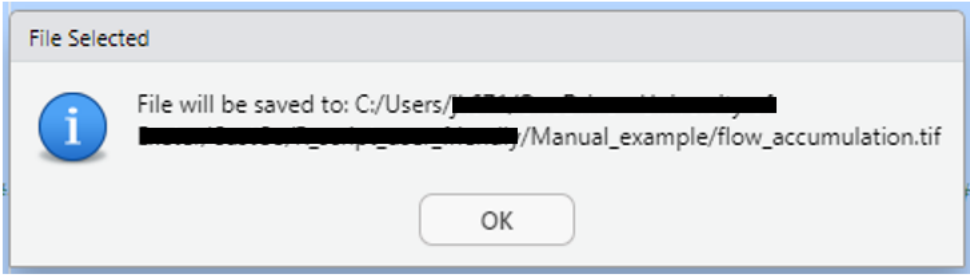
Once the flow direction layer has been produced, a pop-up window will appear to inform the user the process is complete. Click ‘OK’ to move on.



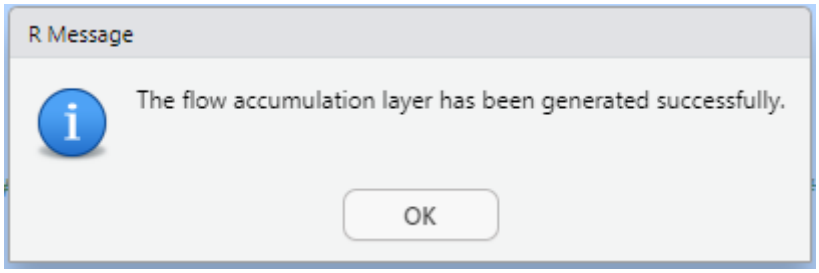
Next a flow accumulation layer will be generated. The flow accumulation layer identifies areas of concentrated flow, such as flow pathways. A window will appear for the user to define the layer name and where it will be saved. Again, the name can be changed and must end with the file extension ‘.tif’. Click ‘Save as’ to move on.



Another window will appear to inform the user where the layer will be saved. Click ‘OK’ to move on.

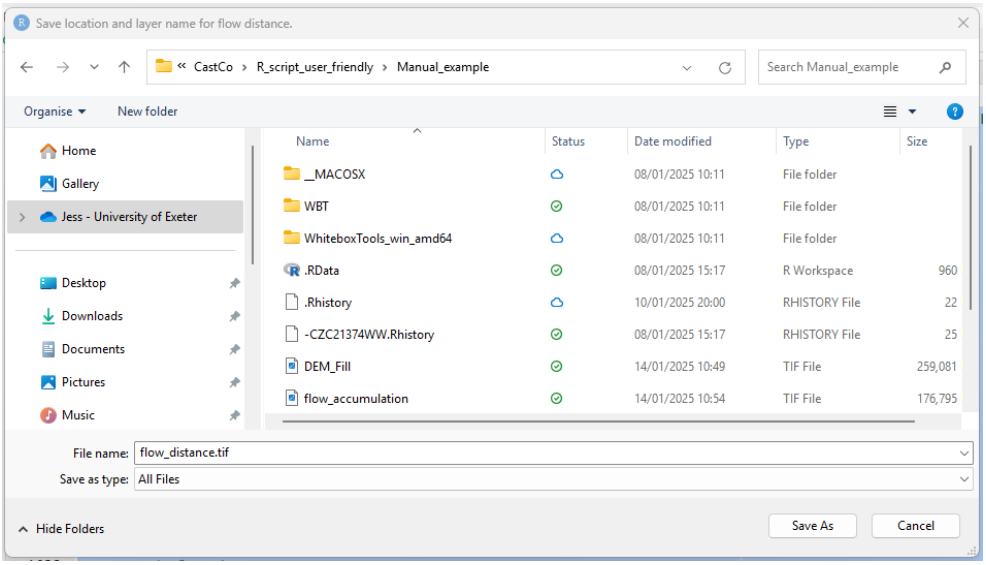


When the flow accumulation layer has been generated and saved a window will appear to inform the user this step has been completed. Click ‘OK’ to move on to the next step of the tool.

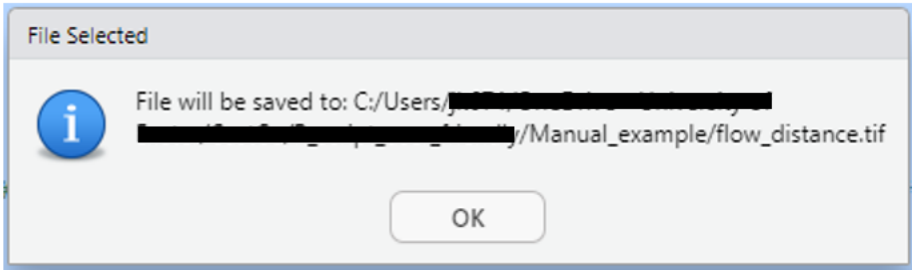


10.2. Flow distance

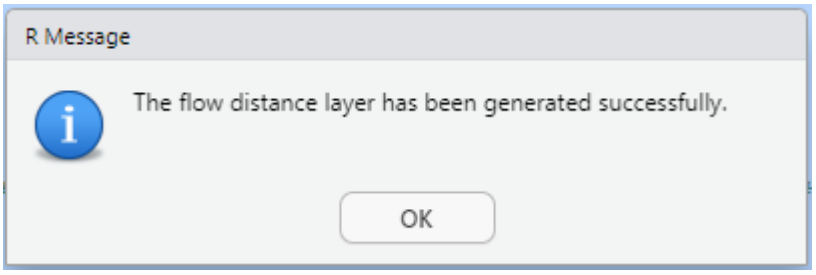
A new file explorer window will appear for the user to set the save location and file name for the flow distance output. The flow distance output will be the layer depicting the potential areas (sub-catchments) contributing to the combined sewer network. A default layer name has been set, and this can be changed by typing the new name into the box provided, however the layer name must end with the file extension ‘.tif’.



Once the user has selected the save location and layer name, a pop-up will appear informing the user of the save location. Click ‘OK’ to move on.

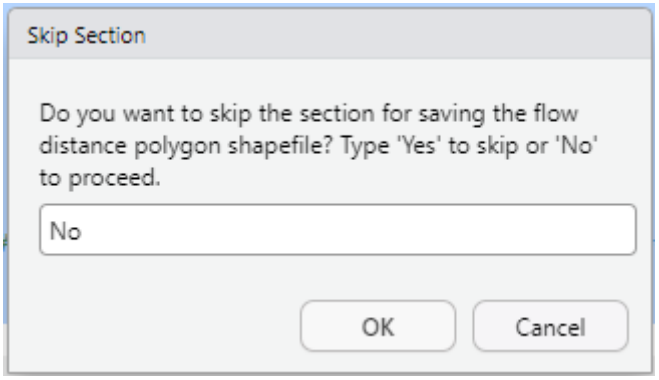


Once the flow distance raster has been generated, a pop-up window will appear to inform the user this section is complete. Click ‘OK’ to move on to the next section.

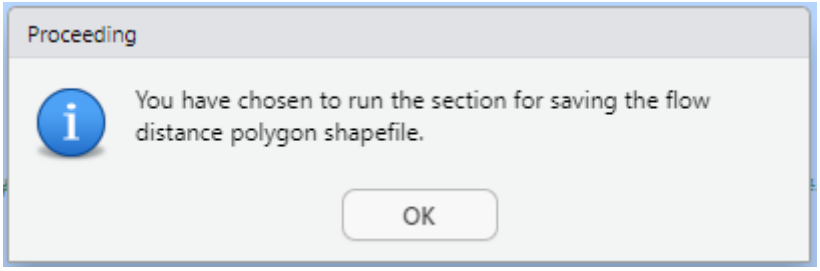


10.3. Save the catchment areas as a polygon

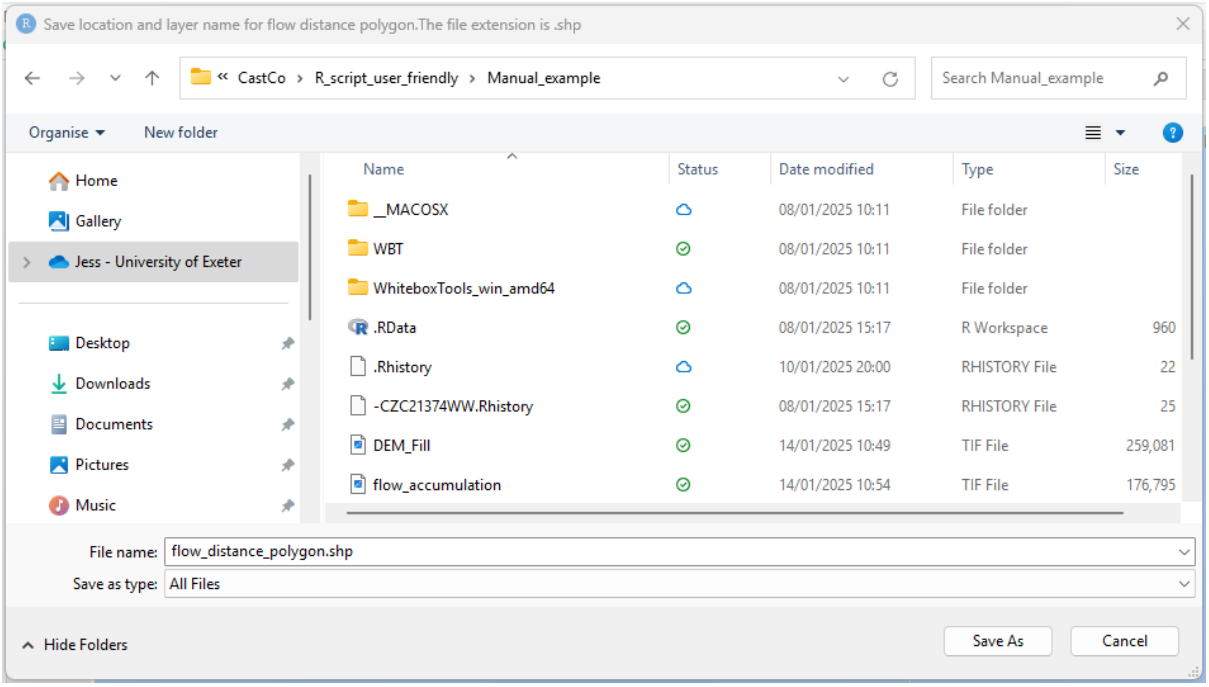
Next the user will be asked if they want to produce a polygon version of the flow distance raster created. If they want to create the shapefile they will need to type ‘No’ when asked if they want to skip this section. If the user wants to skip creating the polygon they need to type ‘Yes’ in the box provided. Once the option has been selected click ‘OK’ to move to the next window.



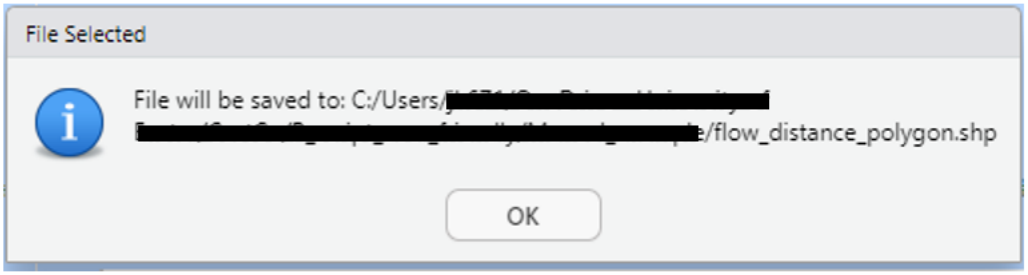
A window will appear informing the user of the option they selected, click ‘OK’ to move on.



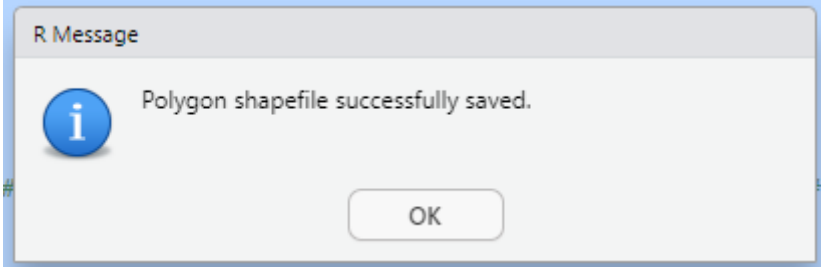
If the user decided to generate the polygon layer a file explorer window will open next. This window allows the user to browse to the save location for the shapefile layer. The user can also set the layer name. A default name of 'flow_distance_polygon.shp' has been provided but the user can change this by typing an alternative name into the box provided. However, any layer name used must include the file extension '.shp'.



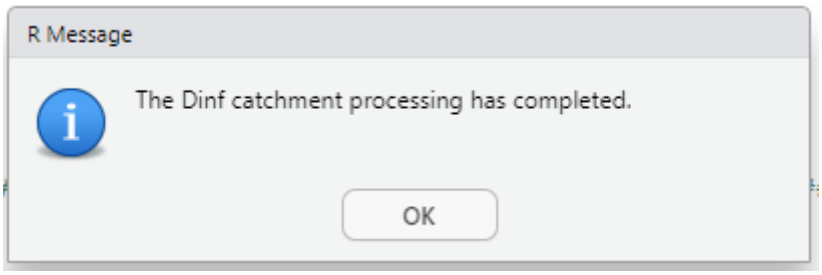
Another pop-up will appear to inform the user of the save location. Click 'OK' to move to the next step.



Once the polygon shapefile layer has been generated and saved, a pop-up window will appear to inform the user the process is complete. Click 'OK' to move on to the next window.

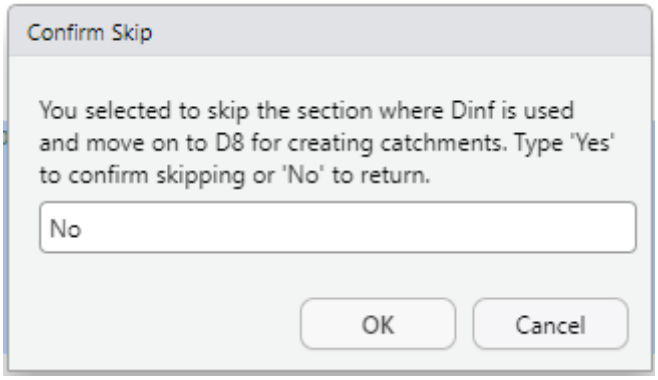


Once the entire DInf section of the tool has completed its run a pop-up will appear to inform the user that section of the tool has finished.

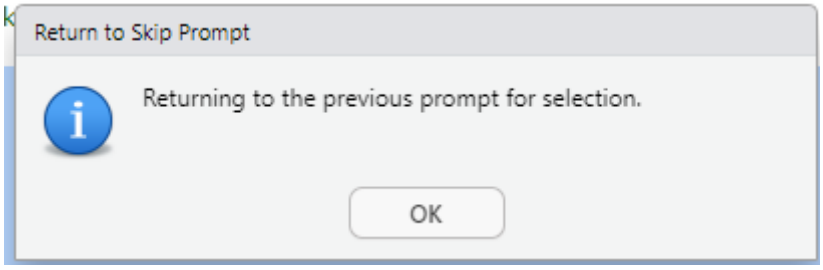


10.4. Skip the section

If the user wants to skip this section, they can by typing 'Yes' in the box and clicking 'OK'. Another pop-up window will appear asking the user is they defiantly want to skip. If the user wants to skip then type 'Yes' into the box, and 'No' if the user doesn't want to skip. If 'No' is selected the user will be redirected to the previous window and asked to decide if they want to skip. When the correct answer has been typed click 'OK' to move on.



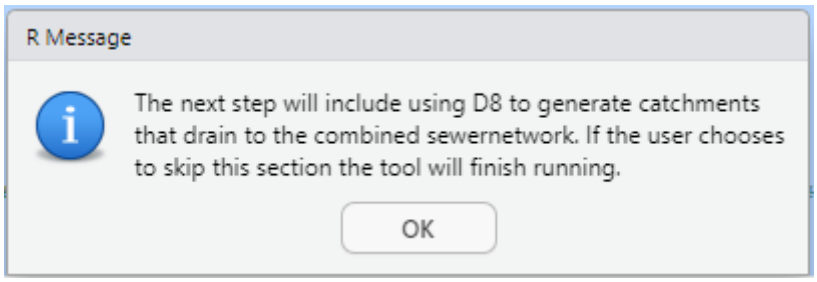
The window below would appear if the user first said they wanted to skip this section, then said 'No' they do not want to skip when asked to confirm the skip. Click 'OK' to be redirected to the first window asking the user if they want to skip the section.



Once it has been decided and the user wants to skip this section a final box will appear to inform the user this section will be skipped. Click 'OK' to move on.

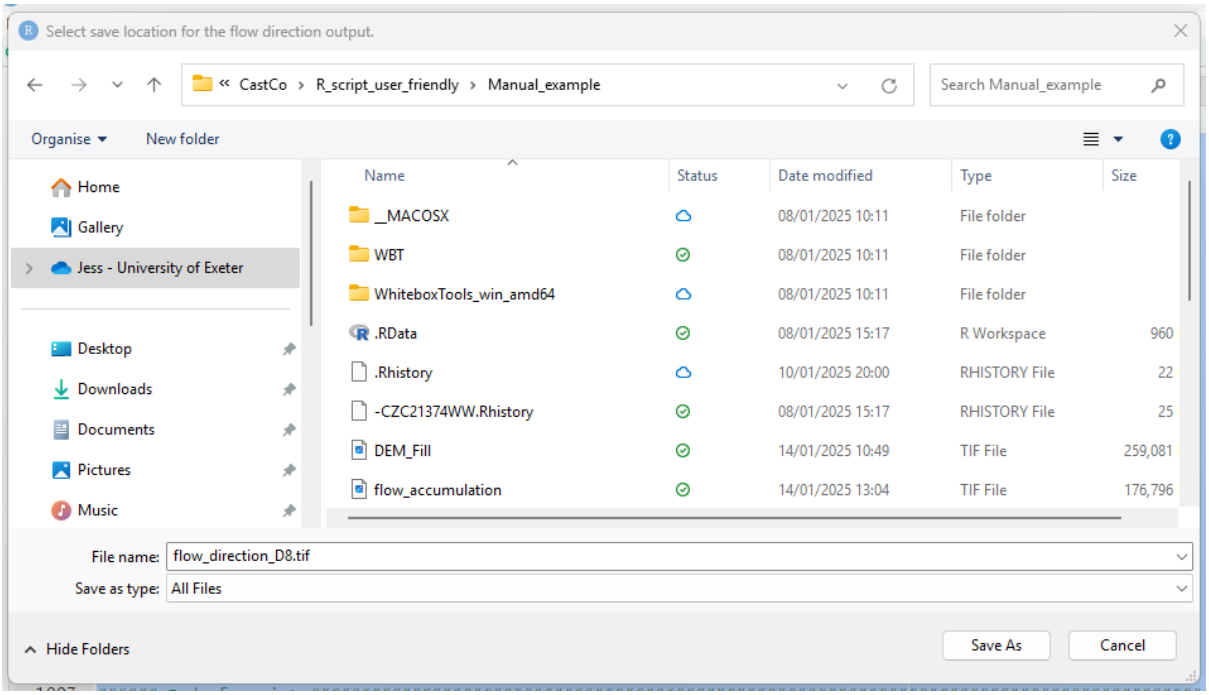
11. D8 Watershed generation

The next section of the tool is also optional. For this section the D8 flow method will be used. For more information on the D8 flow method see section 8. A window will appear at the start of this section informing the user this section will use the D8 flow method. Click 'OK' to move to the next window.

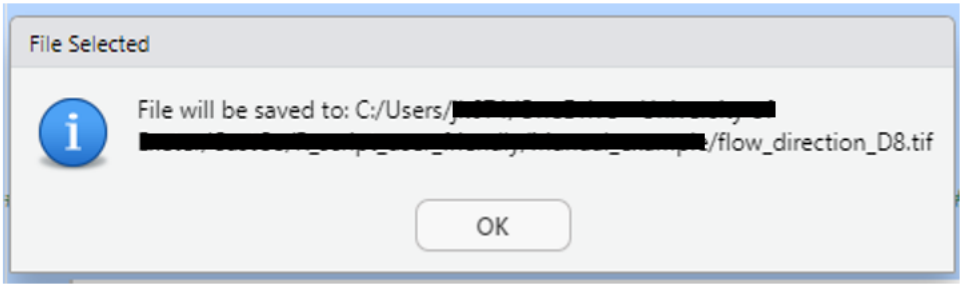


11.1. Running the D8 watershed tool

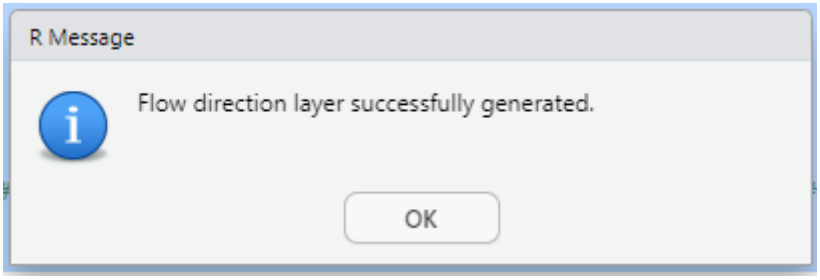
If the user selected to run the D8 flow method section of the tool, a file explorer window will appear asking the user to browse to the correct save location and provide a name for the flow direction new layer. A default layer name has been provided. The user can change the layer name by typing the new name into the box provided. Any layer name used must include the file extension '.tif'. Click 'save as' to move to the next step.



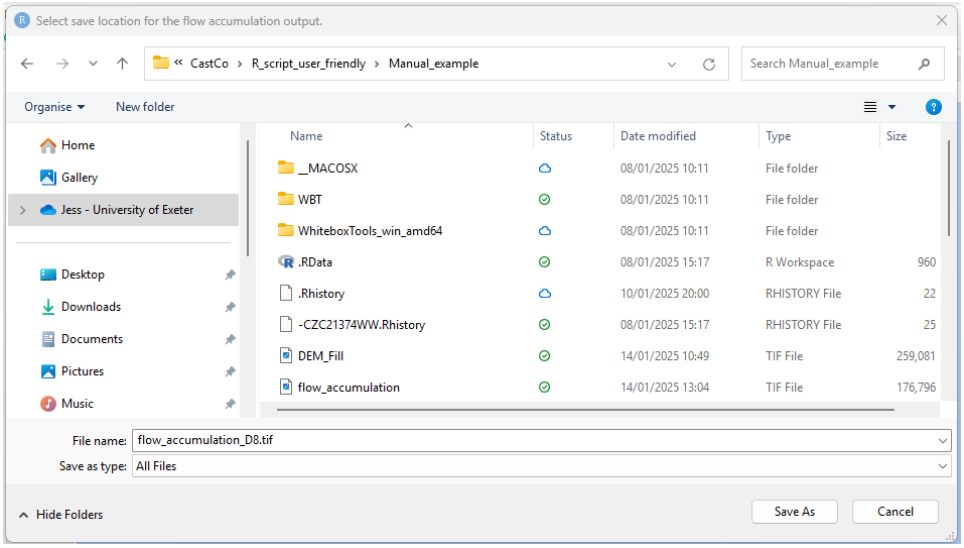
Once the new layer save location and name have been set a pop-up window will appear to inform the user of the location where the layer will be saved. Click 'OK' to proceed.



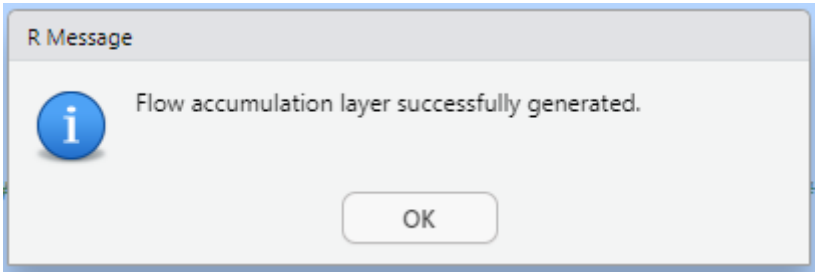
Once the flow direction layer has been generated and saved, a pop-up window will appear to inform the user this step has been completed. Click 'OK' to move on to the next step.



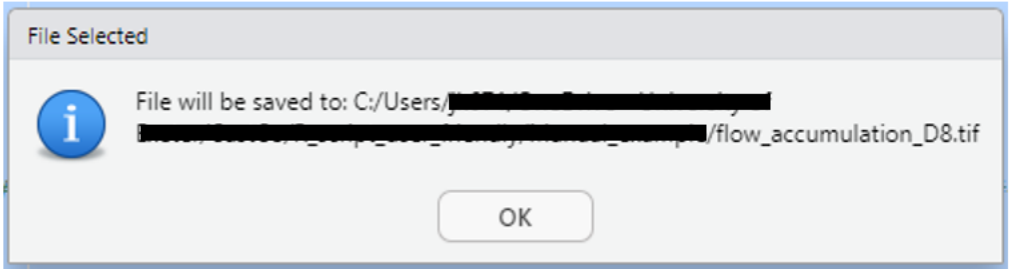
The next layer to be generated is flow accumulation. The flow accumulation layer identifies areas of concentrated flow, such as flow pathways. Another file explorer window will open for the user to browse to the correct save location for the flow accumulation layer. A default name of 'flow_accumulation_D8.tif' has been provided, however the user can change this by typing the new name into the box. Any name used for this layer must end in the file extension '.tif'. Click 'save as' to move on to the next window.



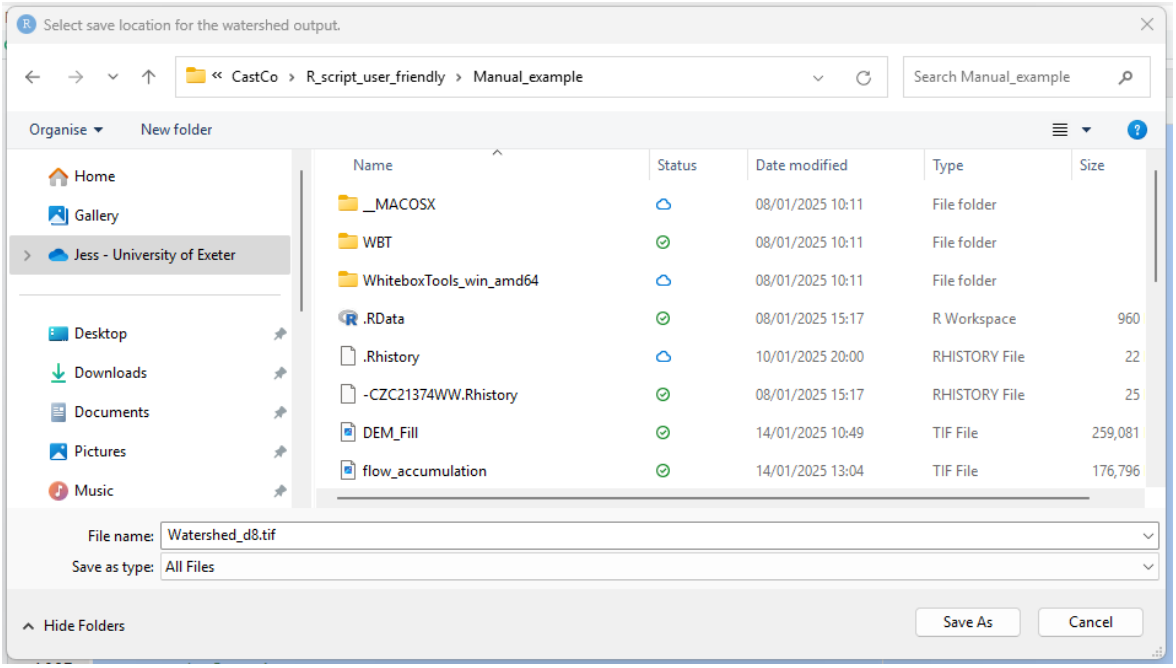
A window will appear to inform the user of the save location for the flow accumulation layer. Click 'OK' to move on the next window.



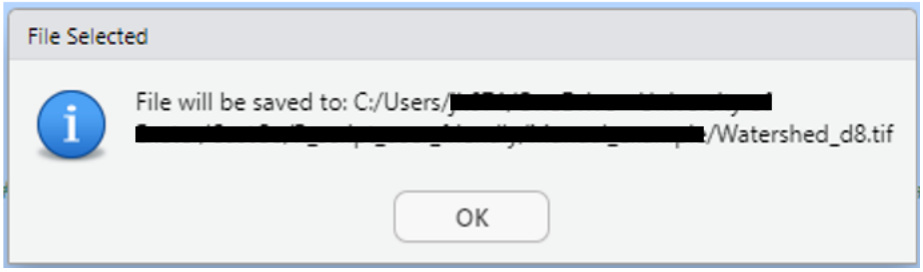
Once the flow accumulation layer has been generated and saved, a pop-up window will appear to inform the user this step is complete. Click 'OK' to move on to the next step.



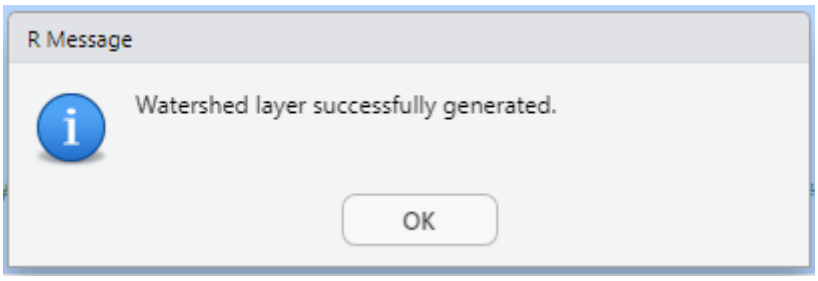
Next the potential contributing catchments layer will be generated using the D8 flow method. A file explorer window will appear allowing the user to set the save location and layer name for the watersheds layer. A default name of 'Watersheds_D8.tif' has been provided, although the user can change this by typing a new name into the box provided. Any name used for this layer must end in the file extension '.tif'. Click 'save as' to move on to the next window.



Once the save location and layer name have been provided, a pop-up window will appear informing the user of the save location for the watershed layer. Click 'OK' to move to the next window.

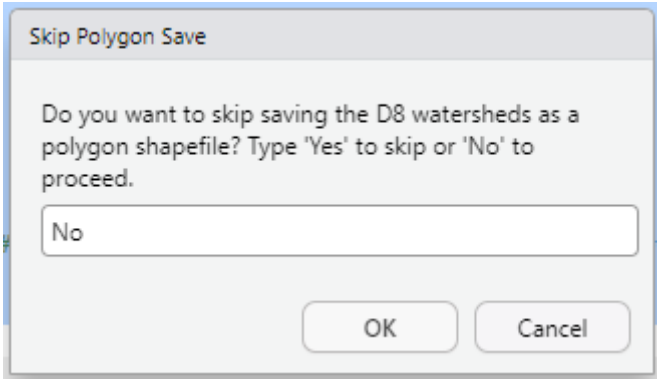


When the watershed layer has been successfully generated and saved, a window will appear to inform the user this step in the tool has been completed. Click 'OK' to move to the next step.

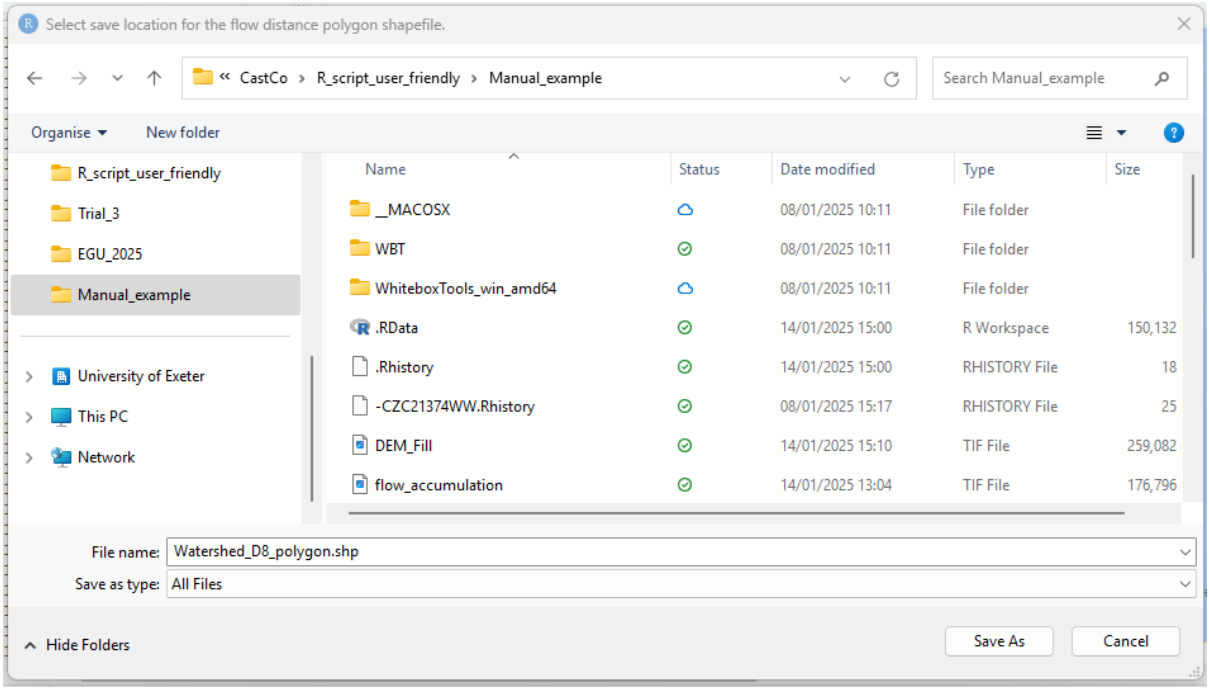


11.2. Save the Watershed output as a shapefile

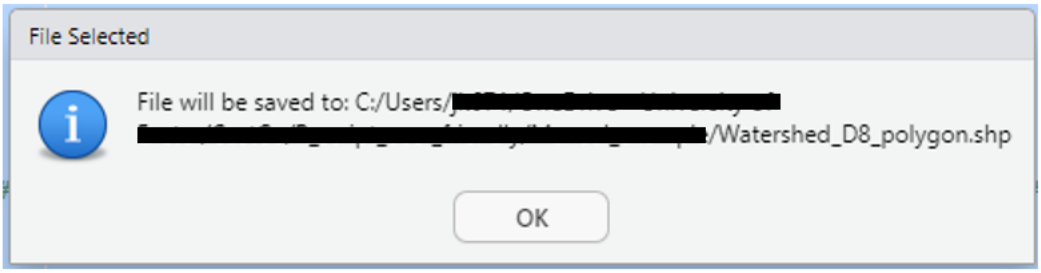
The next step is optional and only required if the user wants to save the raster watersheds output as a polygon layer. If the user wants to generate a polygon layer, then 'No' will need to be typed in the box provided. If the user wants to skip this step, then they need to type 'Yes' into the box provided. Once the selection has been made click 'OK' to move on to the next window.



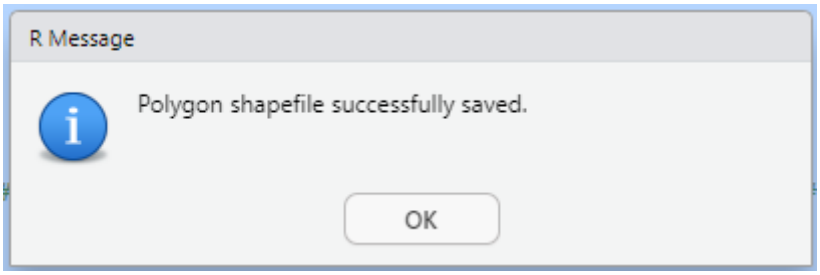
If the user selected to not skip this section a file explorer window will appear. This window will allow the user to select the save location for the shapefile output, as well as the name of the layer. A default name has been provided, but if the user wants to change the name, then type a new name in the box provided and use the extension '.shp' at the end of the name. Click 'Save as' to move to the next window.



Once the user has provided the save location and name, a new window will appear providing the full file pathway. Click 'OK' to move on.

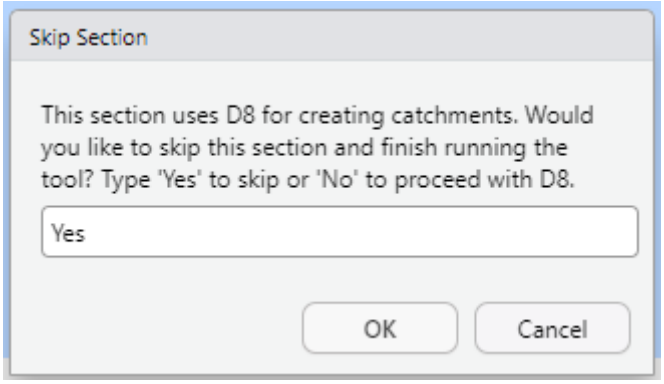


Once the polygon layer has been generated and saved successfully a pop-up window will appear to inform the user the process has completed. Click 'OK' to move on to the next step.

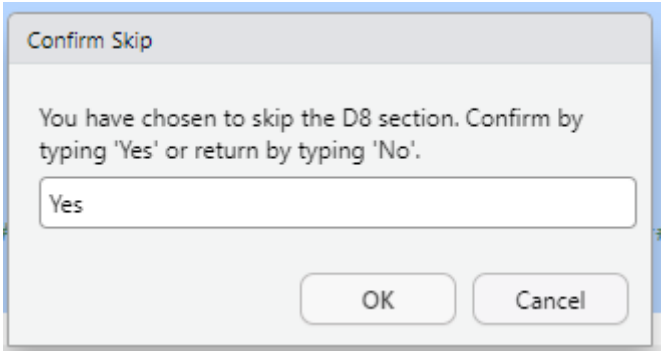


11.3. Skip D8 watershed generation

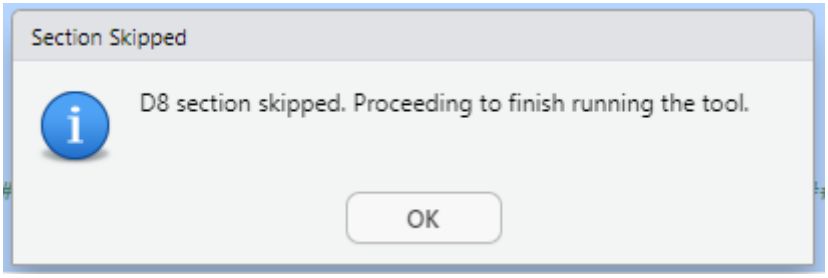
If the user wants to skip the D8 flow method for generating potential areas draining to the combined sewer, type 'Yes' in the provided box, then click 'ok' to move to the next window.



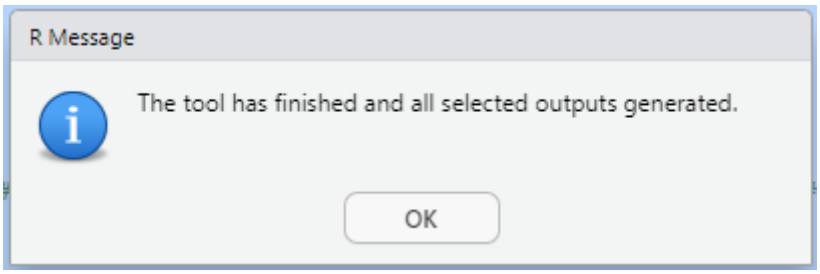
Next another window will appear to confirm the user is happy to skip this section. If the user is happy to skip this section type 'Yes'. If the user does not want to skip this section type 'No' to return to the previous window and select again. Once the user has selected, they must click 'ok' to move on.



The window below will appear to inform the user they have successfully skipped this section and will be moved to the next step. Click ‘ok’ to proceed.

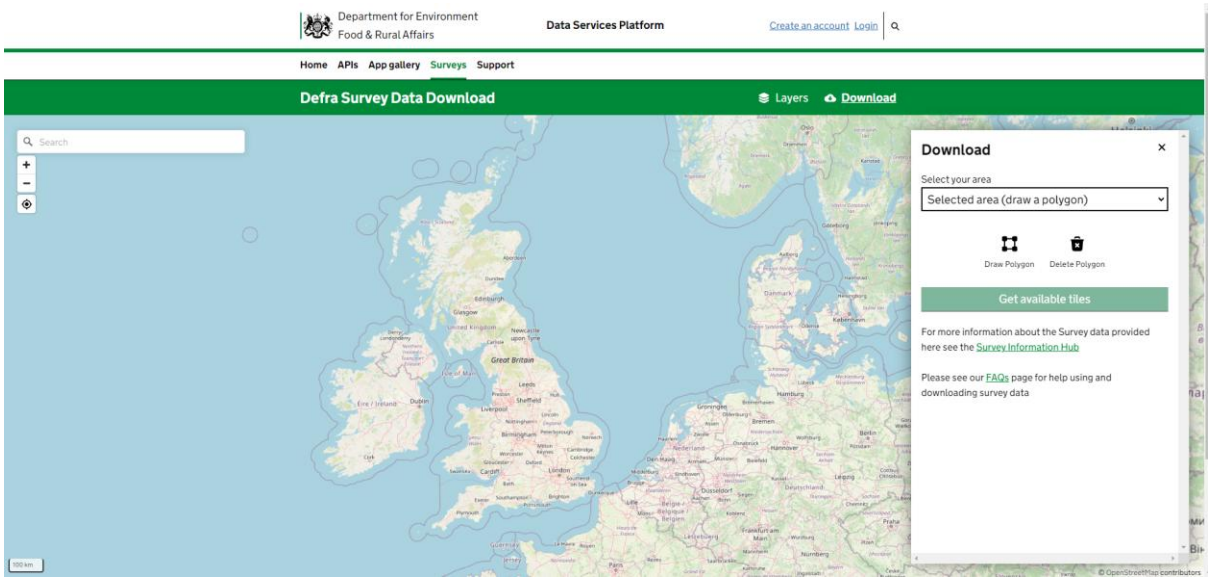


The final window to appear will inform the user the tool has finished running and all selected outputs have been generated and saved. Click ‘ok’ to close the tool.

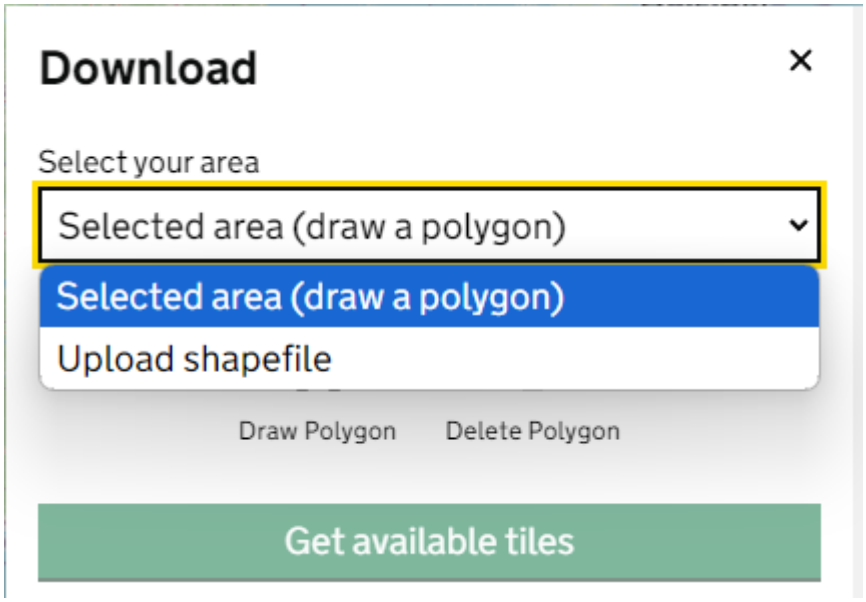


12. How to download Lidar data from the EA

DSM/DTM data can be downloaded from here if required. The link will open the following page.

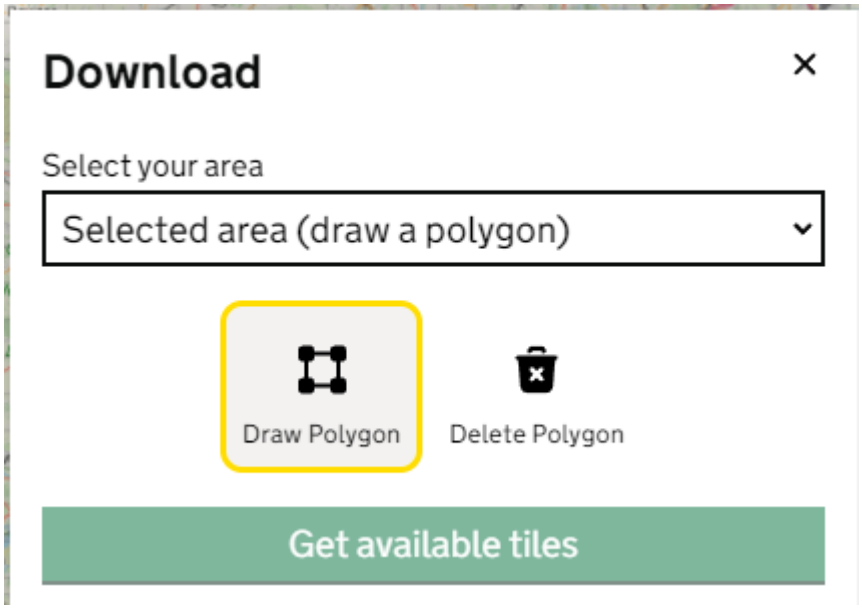


There are two options for selecting the data for the area of interest. These options are selected from the drop-down menu.

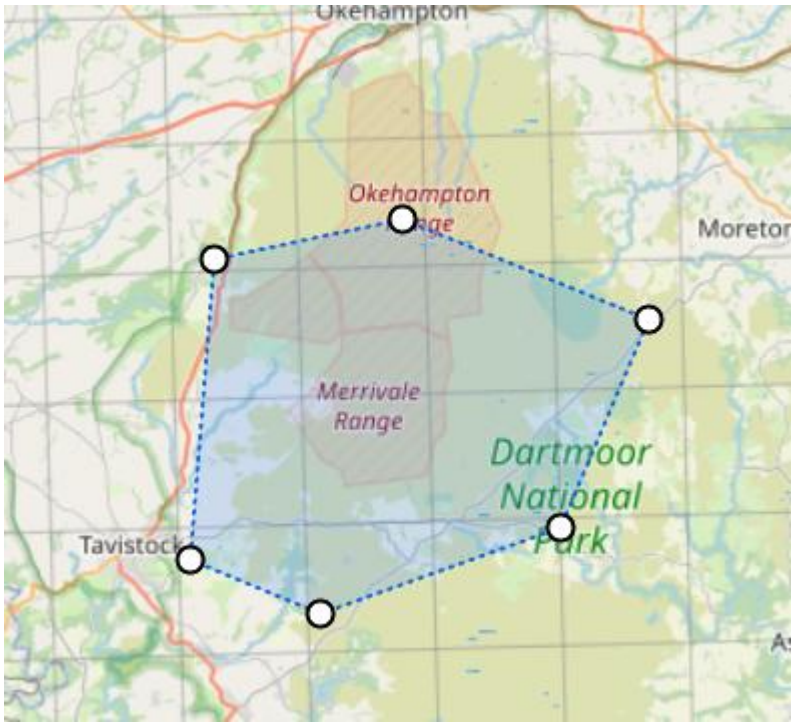


12.1. Select Area by Polygon

If you want to draw a polygon select the 'Selected area (draw a polygon)' from the drop-down menu, then click on the draw polygon icon.



This will allow you to draw a polygon for the area of interest. To draw the polygon, click on the map, each click will create a point, and these will form the shape of the polygon. When placing the last point to complete the polygon you will need to double click rather than just click once, this will indicate that this is the last point and no more will be drawn. An example is below.



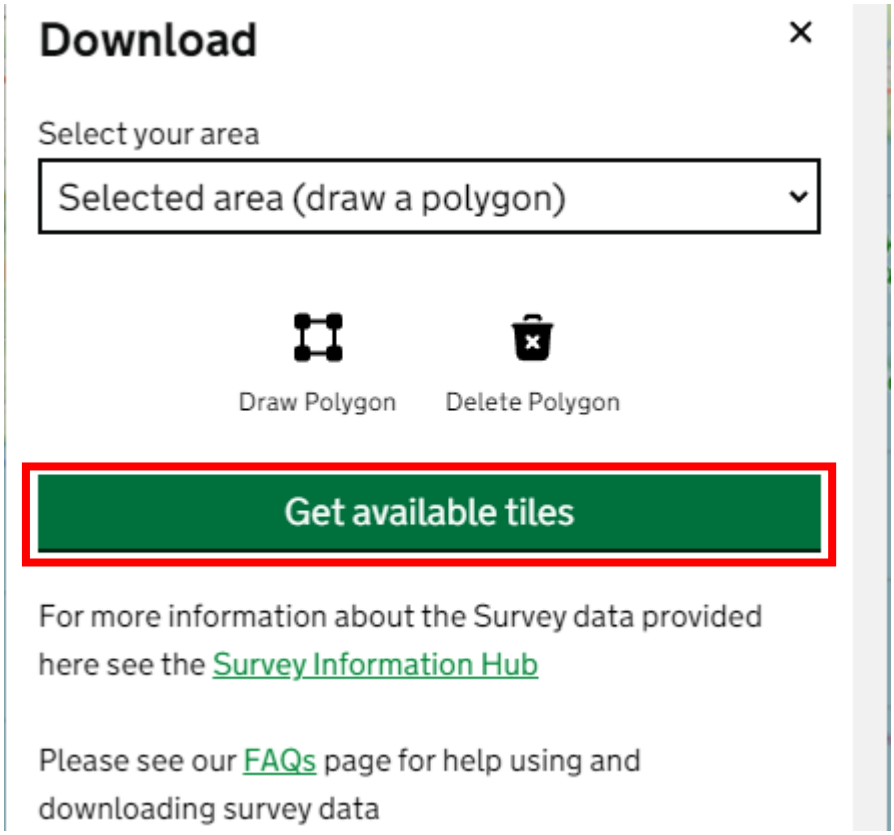
12.2. Select download data area using a shapefile

The second drop down option is 'Upload shapefile'. For this the shapefile you want to use must be put into a zip file. The zip file must contain the .shp, .sbx, .sbn, .prj, . dbf,

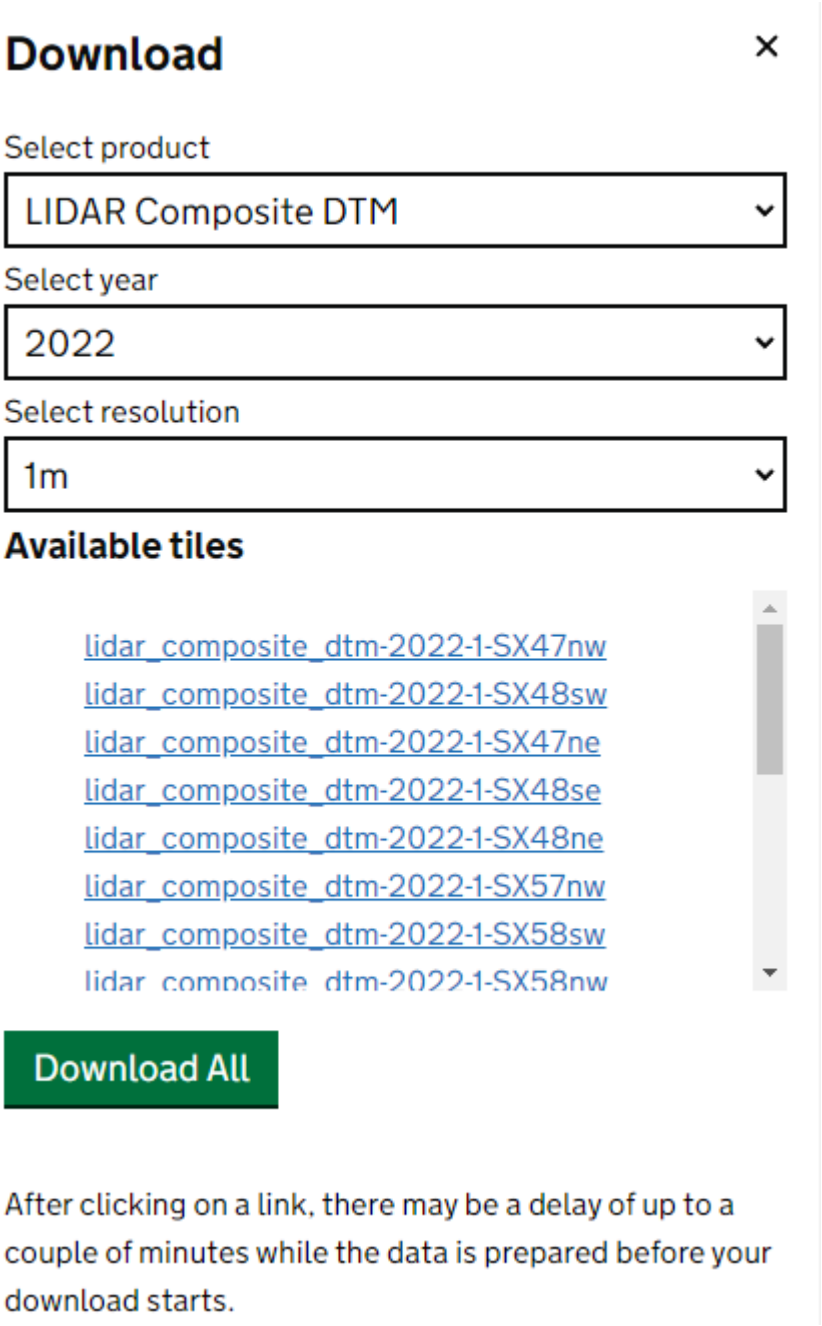
.cpg layers associated with the shapefile layer. This shapefile can then be selected using the ‘choose file’ option or dragged and dropped from the folder in file explorer. Once the shapefile has been added, click the ‘Get available tiles’ option to show the relevant data layers.

Downloading the relevant data

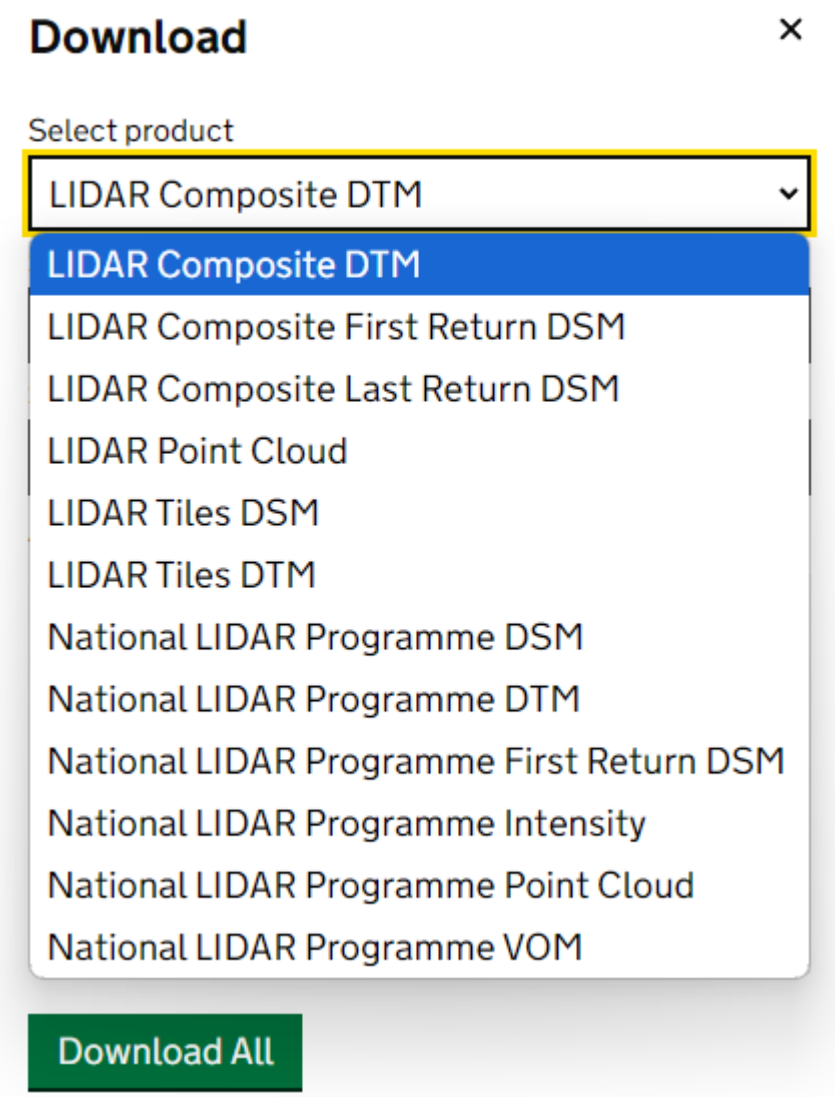
Once the polygon has been drawn, select the ‘Get available tiles’ option



Once this is selected a new option window will open

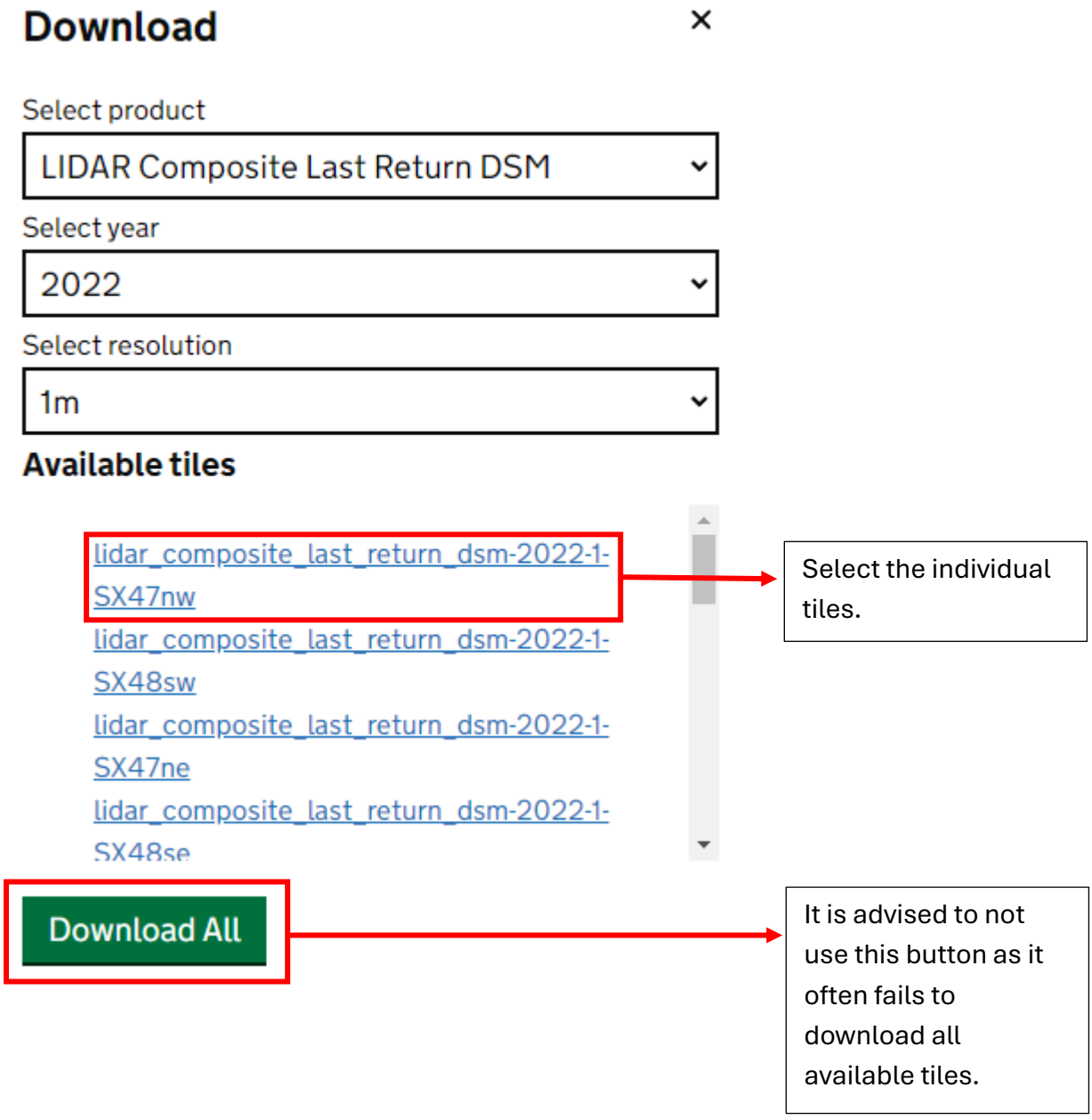


The default option will be 'LIDAR Composite DTM', however there are many options in the drop-down menu.



For the tool, it is recommended that the 'LIDAR Composite Last Return DSM' is selected. The year can also be selected and the most recent year is recommended. You can also select the resolution and for the DSM the option is 1m or 2m. It is recommended that a resolution of 1m is used.

The tiles that fall within the area of interest are listed. This tiles can be downloaded individually by selecting each option. Download all is an option, however this does not always work and sometimes only provides the first DEM tile, therefore it is recommended to download each tile individually.


Download
Select product
LIDAR Composite Last Return DSM
Select year
2022
Select resolution
1m
Available tiles
lidar_composite_last_return_dsm-2022-1-SX47nw
lidar_composite_last_return_dsm-2022-1-SX48sw
lidar_composite_last_return_dsm-2022-1-SX47ne
lidar_composite_last_return_dsm-2022-1-SX48se
Download All
Select the individual tiles.
It is advised to not use this button as it often fails to download all available tiles.

12.3. Create one DSM from multiple tiles

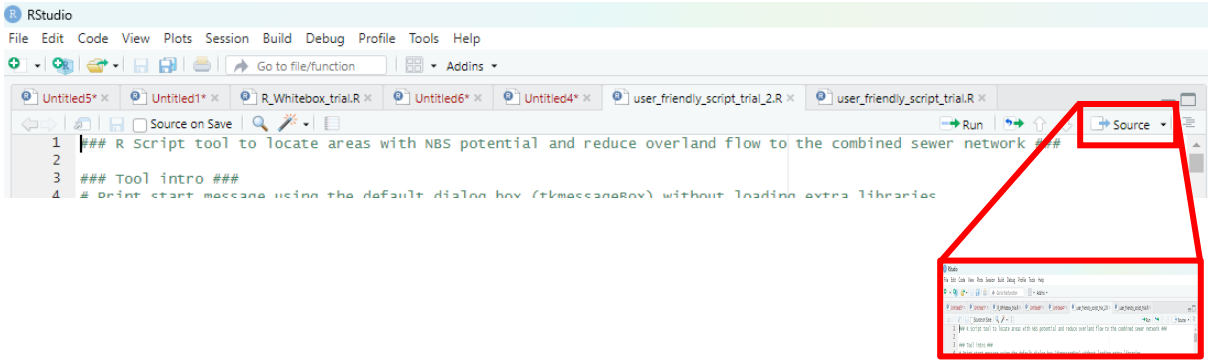
If multiple tiles are downloaded, they will need to be mosaiced together to create one DSM to be used with the tools. To do this open RStudio and used the following code.

```
library(terra)

# User: copy-paste your folder path here

setwd("C:/Users/YourName/Documents/Rasters")

# User: just list file names (no folder path needed)

files <- c("raster1.tif", "raster2.tif", "raster3.tif")

# Load rasters (R will look in working directory automatically)

rasters <- lapply(files, rast)

# Mosaic

mosaic_raster <- do.call(mosaic, c(rasters, fun = mean))

# Save result in the same folder

writeRaster(mosaic_raster, "mosaic_output.tif", overwrite = TRUE)

# Provides pop-up message to inform the user the file has saved

cat("☑ Mosaic saved in:", getwd(), "\n")
```

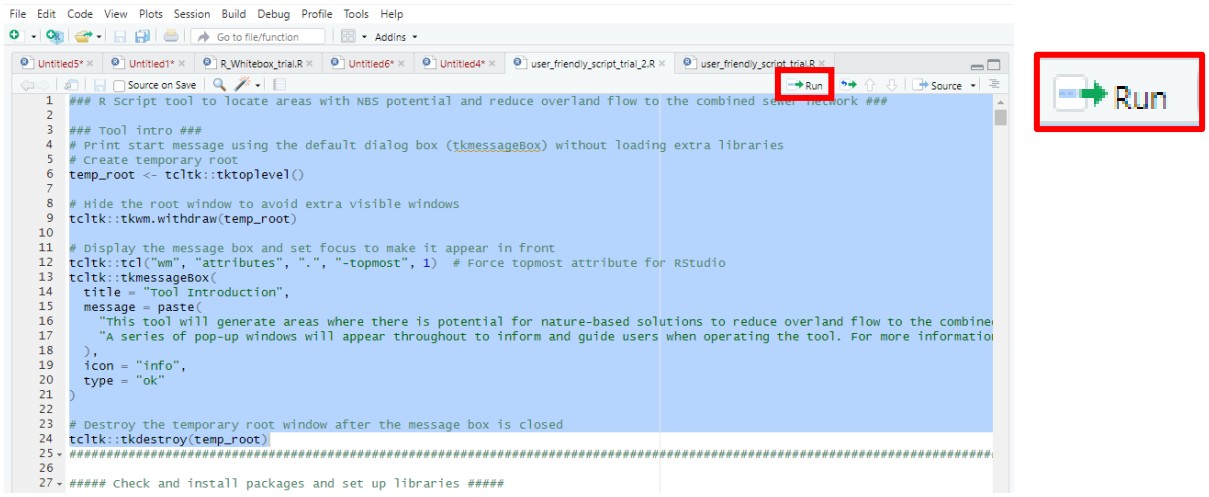
To set the working directory type in the file pathway in place of C:/Users/YourName/Documents/Rasters make sure the file pathway sits with quotation marks, and the forward slash is used, not a backslash.

To provide the individual DSM layers type the file name of the layer in place of raster1. Make sure each file name is in quotation marks and ends with the file extension '.tif'.

To run the entire script, click the source button.



Alternatively, if only a portion of the script is required to run, then just click and highlight the text needed and click run.



To stop the script, click the  icon

13. Interpreting the Results

13.1. D8 vs DInf

Field data has not been collected to verify which flow direction method produces a more realistic and/or robust result for the sub-catchment areas. Therefore, information in the manual regarding the differences between the flow direction methods have been outlined and the option to choose between the two has been provided. Firstly, it's important to note that flow pathway outputs from the DInf method represent fractional cells, which means that only a fraction of flow will transfer between one cell and another, as it moves it multiple directions. This means that the total sub-catchment area will not always equal the surface area of the draining sub-catchment.

Trials have shown that the DInf flow direction method can sometimes provide a sub-catchment in an area the D8 flow direction method did not. Therefore, it may be beneficial to use the DInf flow method as it could provide more potential areas for NbS. However, the DInf method could overestimate sub-catchment areas. It may be better to overestimate the number of potential areas to assess then to miss potential areas and opportunities for NbS. It may be beneficial to run the analysis with both D8 and DInf and compare or combine the results to ensure all potential areas have been produced.

13.2. Extracting permeable potential opportunity areas

If the tool is being used to assess permeable opportunity areas for NbS, then after the geospatial analysis conducted with the SCORe tool, the user must extract only permeable areas draining to the combined sewer network, from the sewer sub-catchment layer. The user could use a GIS layer of impermeable areas and erase those from the sub-catchments produced by the tool. Datasets such as OS MasterMap have this data available, although it is not open source.

13.3. Catchment suitability

Some of the catchments produced by both DInf and D8 flow direction methods may be small in size and therefore, unsuitable for NbS. A screening may be required with a suitable size threshold; this would remove any unsuitable results. Furthermore, the DInf flow direction method can provide very large catchment areas (the D8 does not do this) and these catchments areas may need to be refined to be of better use, the flow pathways from the flow accumulation output can be helpful for this.

It is important to emphasise that the topographic catchments generated using the SCORe methodology will not all be suitable for green solutions to storm overflows. For example, there may be barriers to flow that were not represented in the DEM, which means that flow generated in an area of interest is not actually directed towards the

expected area of PF. Furthermore, many areas may not produce enough runoff to be worth intervening on, for example due to a combination of the soil conditions (well-draining), gradient, land cover (e.g. forested areas tend to produce less runoff than grassland) and upslope contributing area (an area at the bottom of a larger contributing area is more likely to produce runoff). This is why further desk-based analysis and in-field surveys are required to provide further screening of potential opportunity areas (see Section 14~~13~~).

14. Next Steps

The following steps should be conducted after the geospatial analysis; this includes conducting a desktop survey using street view software (e.g. Google Street View) to assess the potential contributing areas for barriers to flow. Due to the 1m resolution of the DSM (recommended) used, some barriers may not be included. Barriers to flow can include walls and hedgebanks, and these can be located using street view software. Wet weather surveys are also highly recommended to be conducted after conducting a desk-based survey. The wet weather surveys should be conducted during heavy rainfall events, and ideally when the ground has been left saturated after a period of wet weather. These conditions will enable overland flow to be visible during a site visit. The flow accumulation output from the tool can be used to help with identifying flow pathways and where water may be exiting an area and entering the combined sewer network. These steps combined will further refine the areas with potential for NbS.

The use of hydraulic modelling is also recommended to assess the potential for NbS at a selected site, as well as compare different NbS. Hydraulic modelling will enable a better understanding of the potential for NbS to reduce overland flow entering the combined sewer network. A variety of software can be used, such as InfoWorks. Furthermore, natural capital accounting can be used to compare NbS to grey infrastructure. This step will assist with understanding the costs and benefits of each solution and inform decisions regarding which solution to deploy.