Model user manual and tutorials

DATASET

"GrounDwater sAlinizaTion and pollution AsseSsmEnt Tool"

This project is part of the Water4All program supported by the European Union

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Author(s): Eleni Anna Nanou, Gianluigi Busico

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Reviewer: All Consortium's Partners

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V0.2	**26/04/2026**	BUSICO G.	**Revision 1**
-	-	-	
-	-	-	-

EXECUTIVE SUMMARY:

The guidelines present the methodology for the assessment of ADI – SP and ADI – AGL vulnerability indices in ArcGIS Pro.

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PREFACE

This manual provides step-by-step guidelines for reproducing the Salinization (SP) and Agricultural Leaching (AGL) Vulnerability Index (ADI) using ArcGIS Pro. Developed as part of the DATASET project within the framework of the Water4All program supported by the European Union, this guide is intended for GIS practitioners and environmental scientists engaged in groundwater vulnerability assessments. The document covers the full processing workflow, from setting up the coordinate reference system and loading input datasets, through the extraction and reclassification of global raster layers, to the final computation of both vulnerability indices using weighted overlay analysis in ArcGIS Pro. Each section is structured to guide the user through a standardized procedure, ensuring consistency in spatial resolution and parameter treatment across all input layers. Where deviations from the standard workflow are required, such as alternative extraction methods for specific datasets, these are clearly flagged with dedicated notes.
Users are advised to follow each step in sequence and to refer to the provided classification tables when assigning parameter ratings and weights. Section 4 addresses the Salinization Vulnerability Index (ADI_SP), covering parameters including the Digital Elevation Model, groundwater head, recharge, aquifer and soil hydraulic conductivity, and distance from saline and freshwater sources. Section 5 addresses the Agricultural Leaching Vulnerability Index (ADI_AGL), incorporating clay content, depth to water, slope, recharge, and aquifer hydraulic conductivity.
Together, these indices offer a spatially explicit assessment of groundwater vulnerability to both salinization and agricultural pollution, supporting evidence-based water resource management decisions. The delivery of the M2 Model User Manual and Tutorials represents a significant methodological milestone within the DATASET project. By grounding the entire workflow in openly available global datasets and standard GIS tools, the manual operationalizes the project's five founding principles: Easy, Open, Reliable, Flexible, and Dynamic, ensuring that the methodology can be deployed across diverse coastal and data-scarce regions without dependence on costly local surveys or proprietary software. The document is structured to serve:

- GIS practitioners and environmental scientists as the primary users, guiding them through a standardized end-to-end procedure that spans coordinate system configuration, global database extraction, multi-parameter reclassification, and weighted overlay computation of the final vulnerability maps.
- At the same time, its transparent index formulation and clearly documented parameter weighting tables make it a valuable reference for academic researchers seeking to adapt or benchmark the ADI methodology in their own study contexts.
- Water resource managers and regional planners can draw on the manual to understand the scientific basis and scenario-modelling potential of the indices, including the integration of climate projections, in support of evidence-based groundwater governance.

As such, this deliverable consolidates the project's analytical core and establishes the technical foundation upon which subsequent validation activities, stakeholder engagement, and policy-oriented outputs will be built.

1. PROJECT INTRODUCTION

Groundwater is an essential freshwater resource, particularly in coastal areas where approximately 2.15 billion people reside within 100 km of the coastline. These regions face dual threats: saltwater intrusion (SWI) driven by over-extraction and sea-level rise, and agricultural leaching (AGL) of pesticides and fertilizers into shallow aquifers. Both processes frequently co-occur, degrading groundwater quality and posing serious risks to ecosystems and human health.

The DATASET project addresses this challenge by developing a Groundwater Vulnerability Assessment (GVA) methodology built on five strategic pillars:

EASY	Retains a GIS overlay index structure with parameters, ratings, and weights directly applicable without specialized software beyond standard GIS tools.
OPEN	Built entirely on openly available continental and global datasets, reducing reliance on costly local surveys and ensuring applicability in data-scarce regions.
RELIABLE	Employ systematic reviews and statistical procedures to optimize weight and rating classifications and minimize subjectivity.
FLEXIBLE	Allows operators to toggle parameters on/off to produce SP-only or AGL-only vulnerability maps, or a combined assessment.
DYNAMIC	Integrates freely available climate projections (precipitation, temperature, evapotranspiration) enabling scenario modelling for climate change and land-use change impacts.

The methodology is grounded in two well-established vulnerability indices: DRASTIC (Aller et al., 1987) for AGL assessment and GALDIT (Lobo-Ferreira et al., 2005; Chachadi & Lobo-Ferreira, 2007) for SP/SWI assessment. Both use a GIS overlay-index framework following five steps: (1) data collection and preparation, (2) GIS processing of thematic maps, (3) classification of each map, (4) assignment of ratings and weights, and (5) computation of the final vulnerability index.

Building on the outputs of D1.2, Deliverable D1.3 establishes the conceptual and mathematical framework of the DATASET index. The central design principle is parameter selection based strictly on two mandatory criteria:

- Global Data Availability: all factors must be retrievable from open databases with worldwide coverage.
- Ease of Use: the methodology must be straightforward to implement without sacrificing scientific rigor.

A key innovation is the explicit distinction between numerical and qualitative parameters. The systematic reviews revealed that standard vulnerability methods mix objective, measurable quantities (depth to water, recharge, hydraulic conductivity) with categorical classifications (aquifer media, soil texture, vadose impact) that introduce operator subjectivity. The DATASET index prioritizes numerical parameters and eliminates or replaces the most subjective qualitative factors, particularly those with low spatial variability or high uncertainty.

2. INDEX STUCTURE

The DATASET index is structured as two complementary sub-indices, allowing users to choose between a fully automated global screening tool and a more precise, locally calibrated assessment:

Automated DATASET Index (ADI)	**Improved DATASET Index (IDI)**
Intrinsic specific vulnerability assessment for AGL and SLZ Use only globally available open-source datasets. No manual data collection required. Deployable for any coastal area worldwide with minimal effort. Provides a robust first-level screening.	Risk assessment (Probability × Exposure × Vulnerability) Integrates locally sourced field data with open datasets. Requires water quality monitoring data (minimum 40 samples). Introduces probabilistic refinement and salinity origin classification.

Four parameters appear in both the AGL and SP ADI formulations, though with different weights and rating classifications adapted to each process:

- Recharge — Vertical/Lateral (R): The primary transport mechanism for contaminants (AGL) and the principal force maintaining freshwater pressure against saltwater intrusion (SP). Includes both vertical meteoric recharge and lateral recharge from adjacent high-relief areas.
- Slope / Ground Elevation (E): Governs the balance between infiltration and runoff (AGL context) and determines the spatial distribution of salt/freshwater source areas and subsidence zones (SP context). Acts as a conditioning factor for lateral recharge identification.
- Hydraulic Conductivity (C): Controls pollutant dispersion in the saturated zone (AGL) and seawater migration speed through the aquifer (SP). High conductivity is the primary pathway for contamination in both processes.

- Soil Properties (S): Regulates near-surface infiltration rates. Fine-textured soils (clay, silt) reduce vulnerability by limiting contaminant migration (AGL) and restricting saline water infiltration (SP). Expressed as clay/silt/sand fractions from global datasets.

2.1. Specific parameters for ADI - AGL

- Depth to Water Table (D): Represents the thickness of the unsaturated zone. Shallower water tables provide less protection against surface-applied agrichemicals, as pollutants have less distance to travel before reaching groundwater.

ADI-AGL Formula

ADIAGL = D(rating) × D(weight) + R(rating) × R(weight) + E(rating) × E(weight) + C(rating) × C(weight) + S(rating) × S(weight)

2.2. Specific parameters for ADI - SL

- Distance from Salt/Freshwater Sources (L): Encodes proximity to both saltwater sources (coastline, tidal lagoons, depressed surface water bodies) and freshwater sources (rivers, lakes, lateral recharge zones in elevated terrain). A spatial query using the elevation layer classifies surface water bodies as salt or freshwater sources based on their topographic position.
- Groundwater Head (G): The elevation of the water table relative to sea level. Groundwater levels below sea level increase vulnerability to SWI; levels above sea level provide a hydraulic barrier. Calculated as: $G = E - D$.

ADI-SP Formula

ADISP = L(rating) × L(weight) + G(rating) × G(weight) + R(rating) × R(weight) + E(rating) × E(weight) + C(rating) × C(weight) + S(rating) × S(weight)

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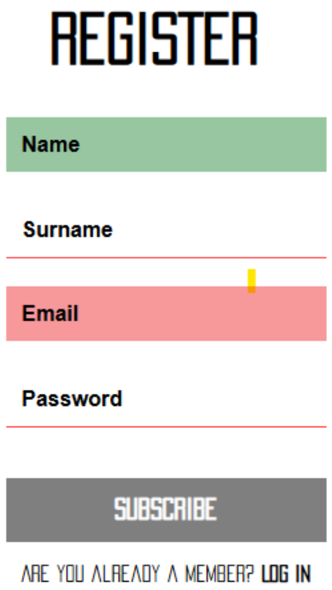
3. GUIDELINES TO REPRODUCE ADI INDICES

3.1. Download the Global Database

To access and download the Global Database, visit: https://www.datasetw4all.info/

The DATASET website, accessible at https://www.datasetw4all.info/, serves as the primary platform for presenting the project and its outcomes to the community. It supports dissemination by showcasing results and functions as an internal network hub, enabling the exchange of documents and materials related. The website allows free navigation across all its sections however, downloading the DATASET Database requires free registration. The users can subscribe inserting name, surname and a working email address. The possibility to directly log in with google account is available



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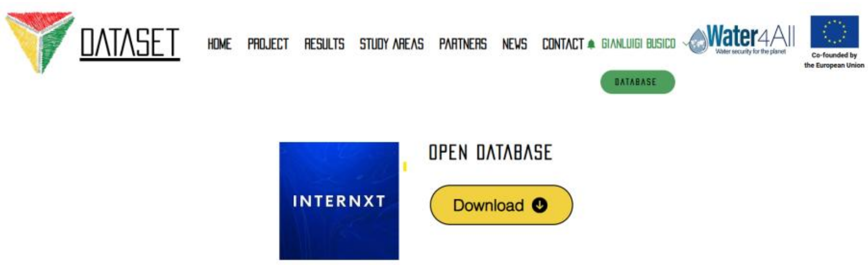
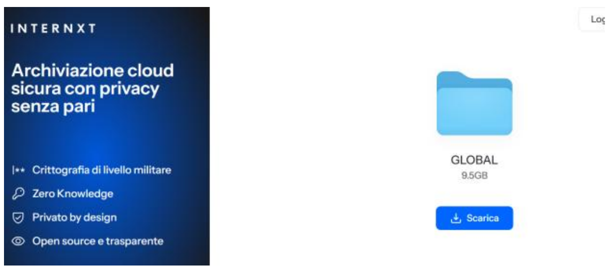
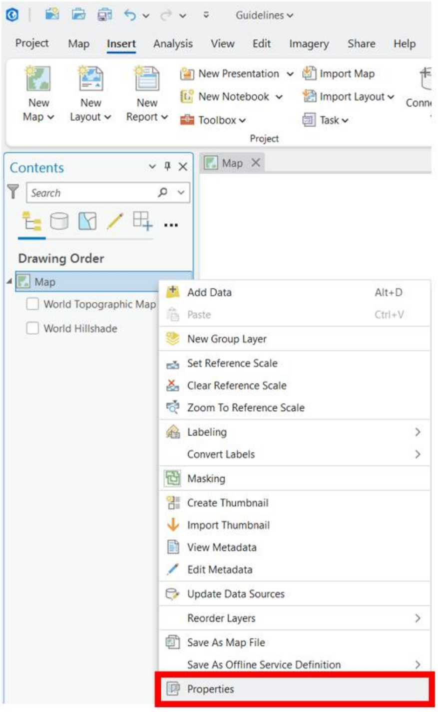
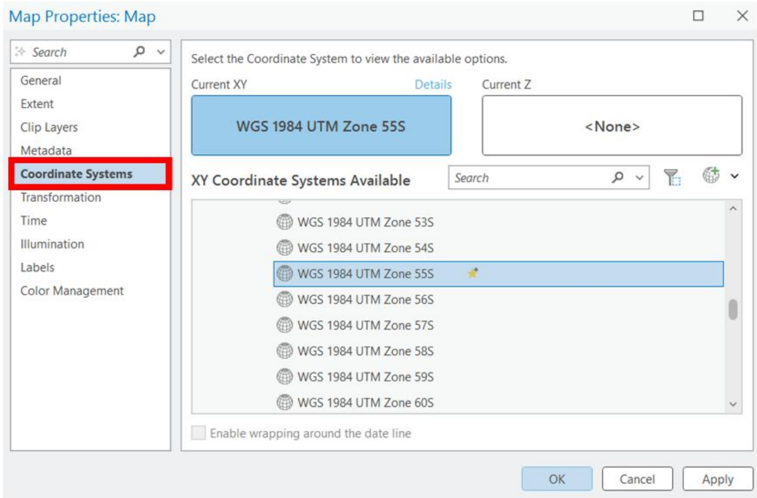




3.2. Set the Coordinate System

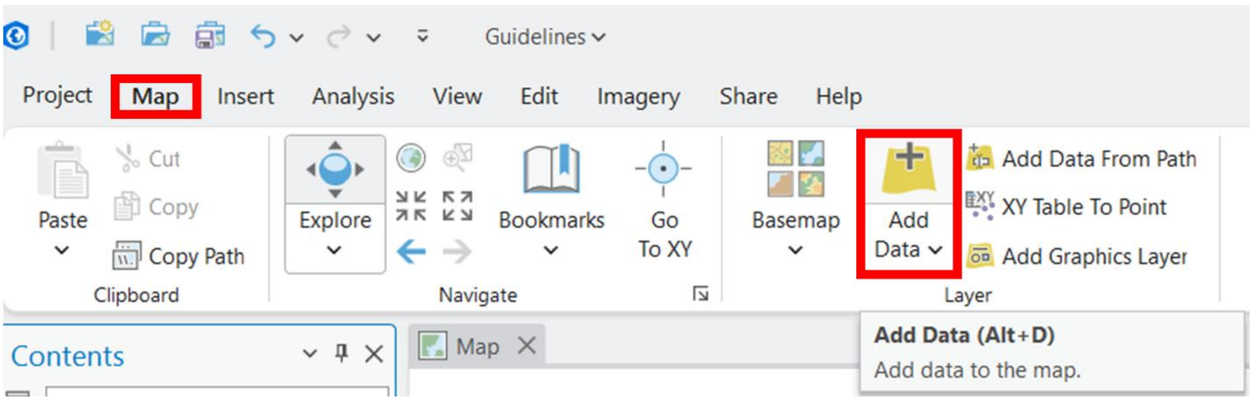
Open a new Map in ArcGIS Pro. In the content table right click on Map and go to: ***Properties*** → ***Coordinate Systems.*** Select the coordinate system that matches the study area and click **OK**.





3.3. Load Files

To load vector and raster files in ArcGIS Pro, go to the **Map** tab on the toolbar and click **Add Data**. Then browse to the location of your files and select the dataset you want to add. Load the **study area polygon**.



3.4. Refine the Resolution

All the raster layers required for the vulnerability index assessment (both for SP and AGL) must have the same spatial resolution. To ensure consistency, values from the global raster datasets should be extracted by a point grid with a predefined resolution.

<u>In this example the selected resolution is 100 m × 100 m.</u>

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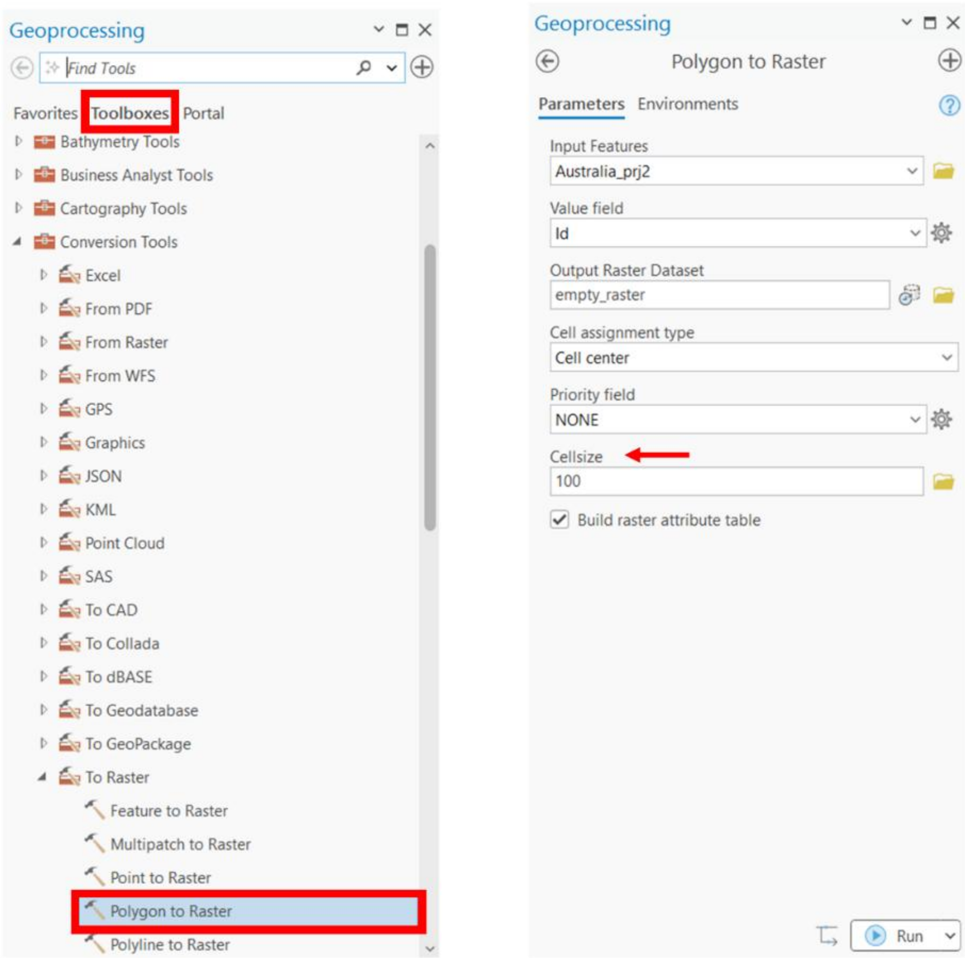
The procedure described below is a general standard workflow that should be used as a reference for processing all the global raster datasets. **Steps (a)** and **(b)** are only applied once, while **Steps (c)** and **(d)** are repeated for each parameter to develop the corresponding raster layers.

Step (a). Create an Empty Raster

In the main menu, go to: ***Analysis → Tools → Toolboxes → Conversion Tools → To Raster → Polygon to Raster.*** In the dialog box, set:

- **Input Features:** Study area polygon
- **Value Field:** Id
- **Output Raster Dataset:** Select the location and name of the raster file
- **Cell size:** Required resolution (e.g., 100 m)

Click **Run.**



Step (b). Create a point grid

Go to: ***Analysis → Tools → Toolboxes → Conversion Tools → From Raster → Raster to Point.*** In the dialog box, set:

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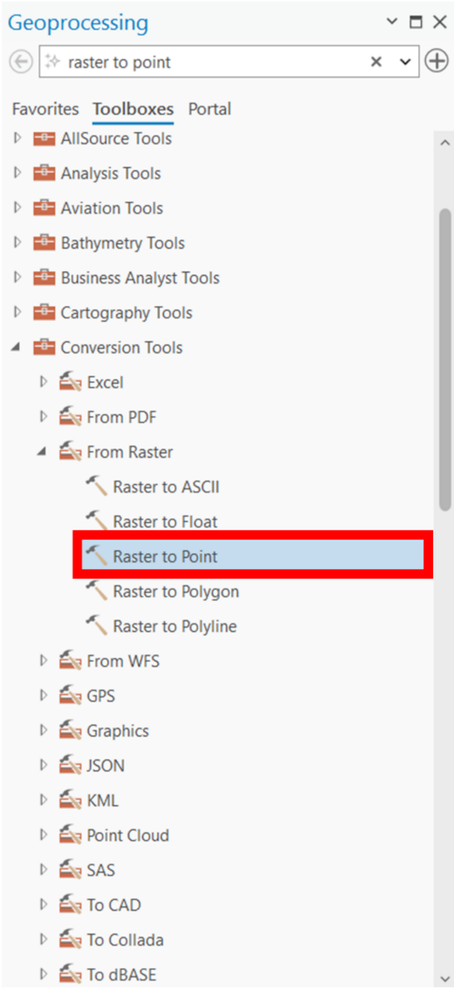
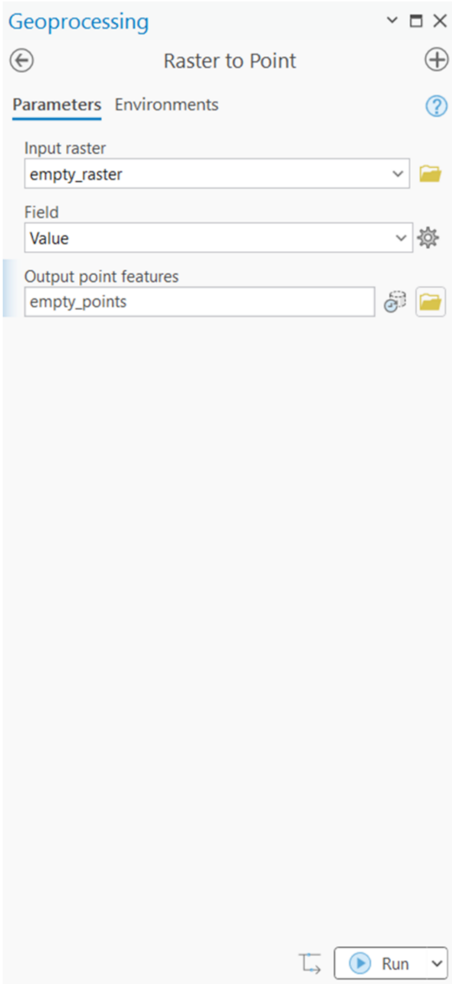
- **Input Raster:** Empty raster created in Step (a)
- **Field:** Value
- **Output point features:** Select the location and name of the point shapefile

Click **Run.**





Step (c). Extract values from the global dataset

Go to: ***Analysis → Tools → Toolboxes → Spatial Analyst Tools → Extraction → Extract Values to Points.*** In the dialog box, set:

- **Input point features:** Point shapefile created in Step (b)
- **Input raster:** Selected global raster dataset
- **Output point features:** Select the location and name of the new point shapefile that contains the extracted values

Click **Run.**

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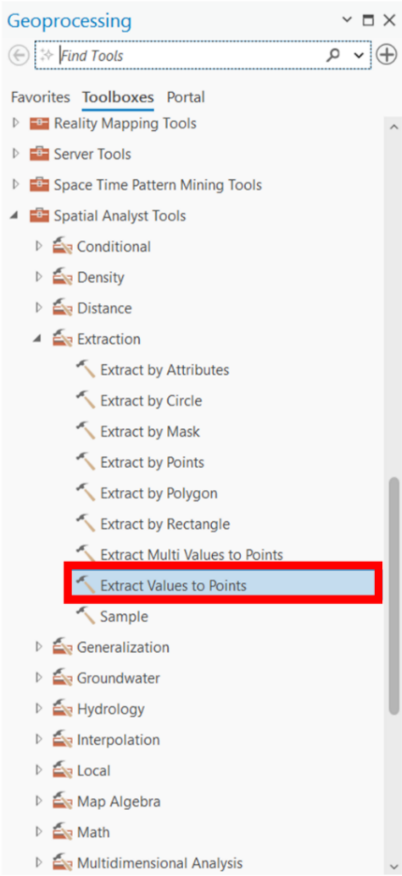
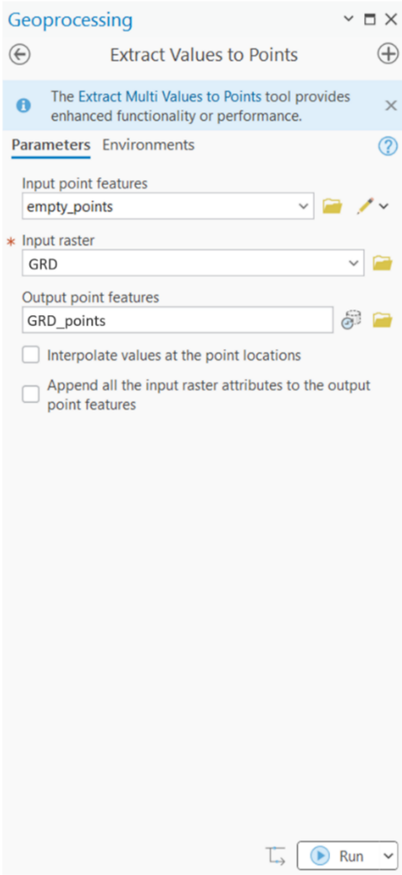
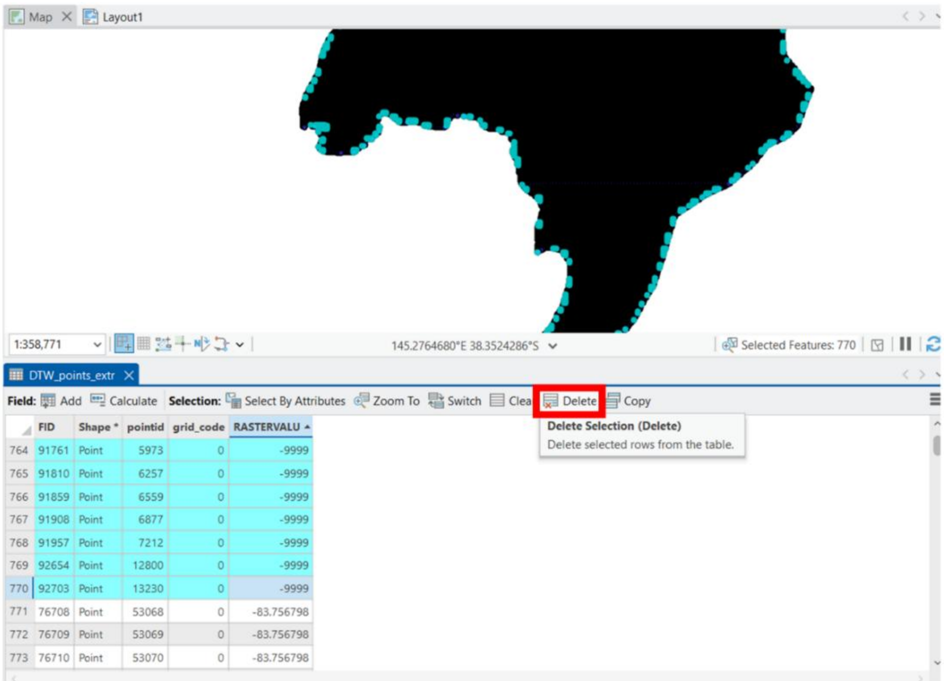




Review the attribute table of the point shapefile with the extracted values. If present, select and remove points with a value of –9999, which represent No Data values in the raster dataset.

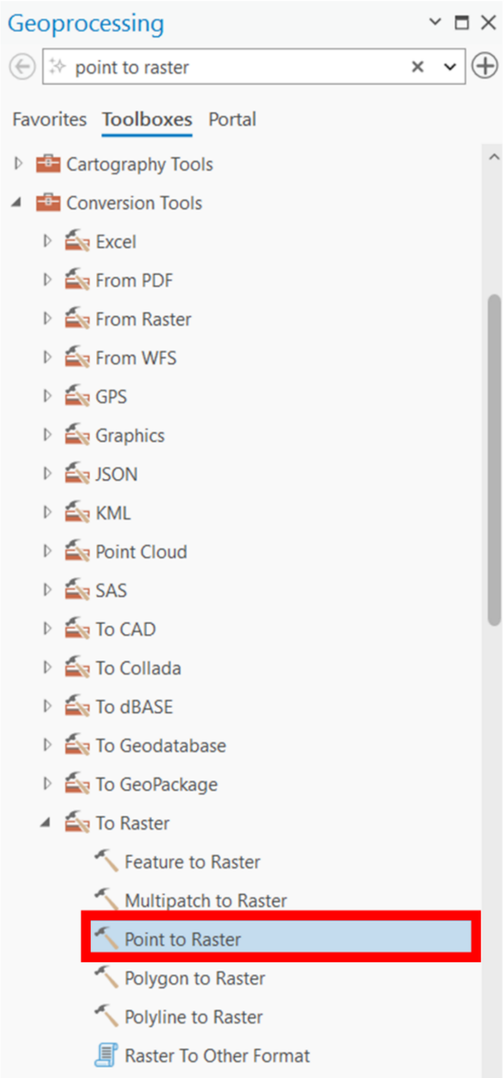


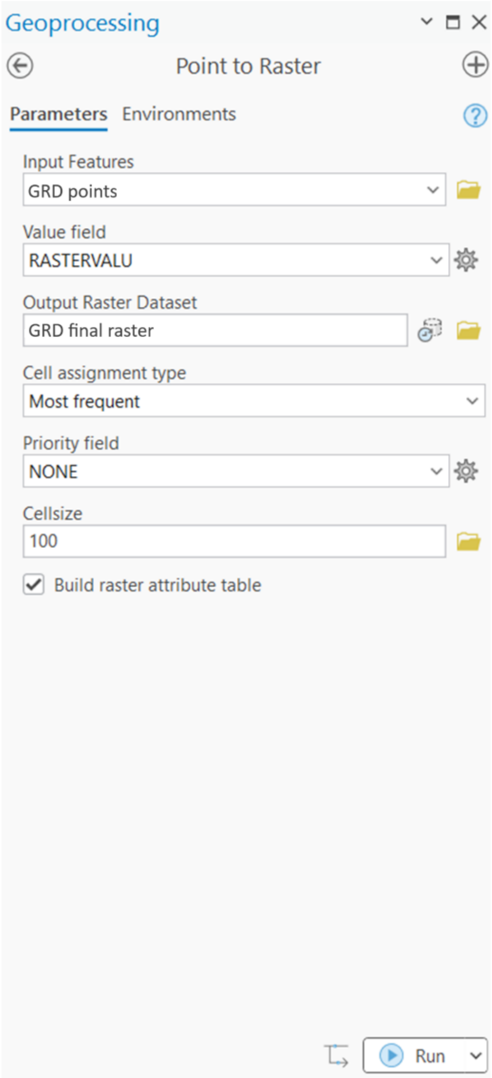
Step (d). Create the final raster layer

Go to: ***Analysis → Tools → Toolboxes → Conversion Tools → To Raster → Point to Raster.*** In the dialog box, set:

- **Input point features:** Revised point shapefile with the extracted raster values from Step (c)
- **Value field:** Rastervalue
- **Output raster dataset:** Select the location and name of the final raster layer
- **Cell size:** Required resolution (e.g., 100 m)

Click **Run.**





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4. ESTIMATION OF THE SALINIZATION (SP) VULNERABILITY INDEX (ADI)

4.1. Digital Elevation Model (DEM)

To download the DEM go to: https://download.geoservice.dlr.de/TDM30_EDEM/

Use the interactive map to locate the area of interest and download the appropriate file(s).

Finally, follow **Steps (c)** and **(d)** of the standard procedure described above to extract the values to the point grid, and develop the final raster layer.

To reclassify the DEM open: ***Analysis*** → ***Tools*** → ***Toolboxes*** → ***Spatial Analyst Tools*** → ***Reclass*** → ***Reclassify.*** In the Reclassify dialog box, set:

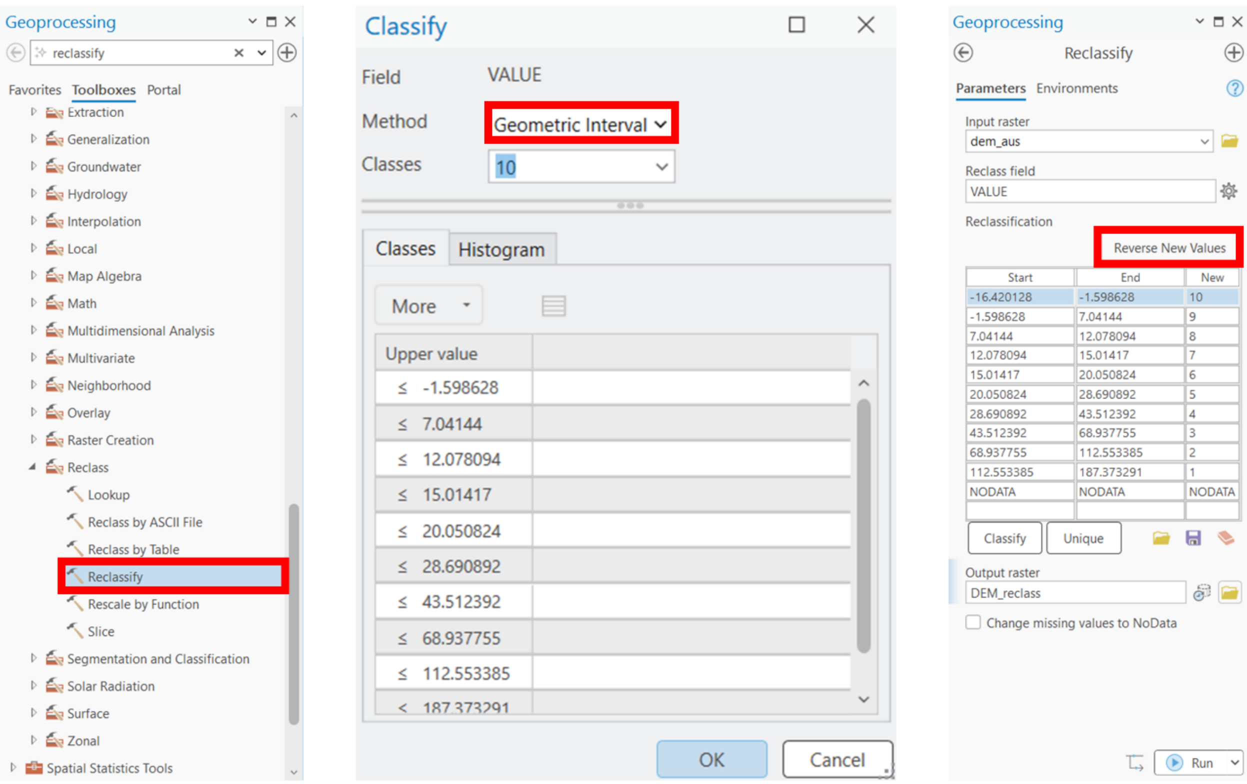
- **Input raster:** DEM of the study area
- **Reclass field:** Value

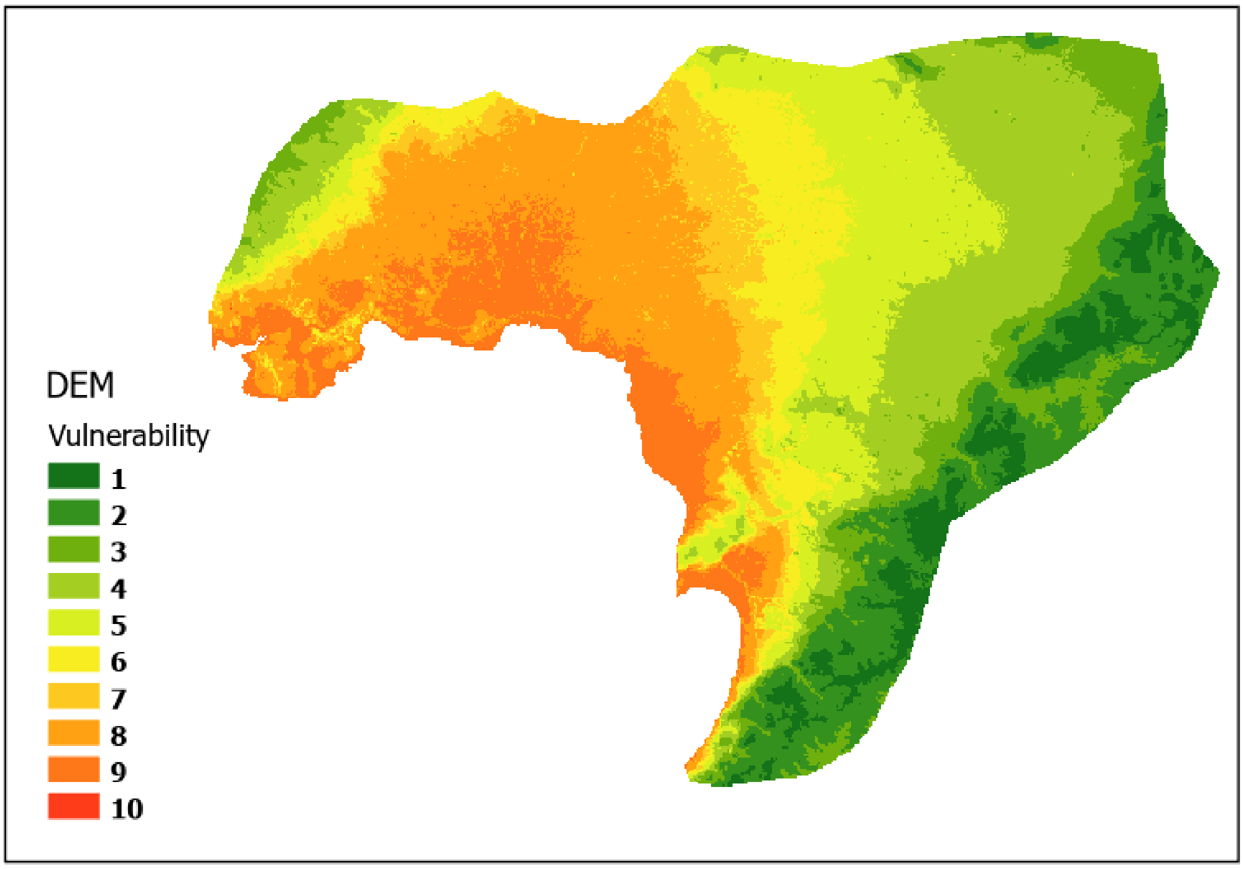
Click **Classify** to open the classification window and set the following:

- **Method:** Geometric Interval
- **Classes:** 10

Click **OK** to apply the classification.

Returning to the main Reclassify dialog box, select **Reverse New Values,** and specify the output name and location. Click **Run** to develop the final reclassified DEM layer.





4.2. Groundwater Head

For the development of the groundwater head layer, two raster files are required: the DEM layer (unclassified), and the Depth to Water layer.

Depth to Water

To select the appropriate raster file from the dataset, go to: ***Global → Raster files → Depth to water***. From this folder, select the continental raster that corresponds to the location of the study area.

Follow **Steps (c)** and **(d)** of the standard procedure to develop the final raster layer.

NOTE:

*In some cases, **Steps (c)** and **(d)** of the standard raster processing procedure cannot be applied directly to develop the Depth to Water raster layer. If there are difficulties with **Step (c)**, an alternative approach should be used.*

Alternative Procedure – Extract by Mask

To extract the raster within the study area boundary, open: ***Analysis → Tools → Toolboxes → Spatial Analyst Tools → Extraction → Extract by mask.***

In the *Parameters* tab, set:

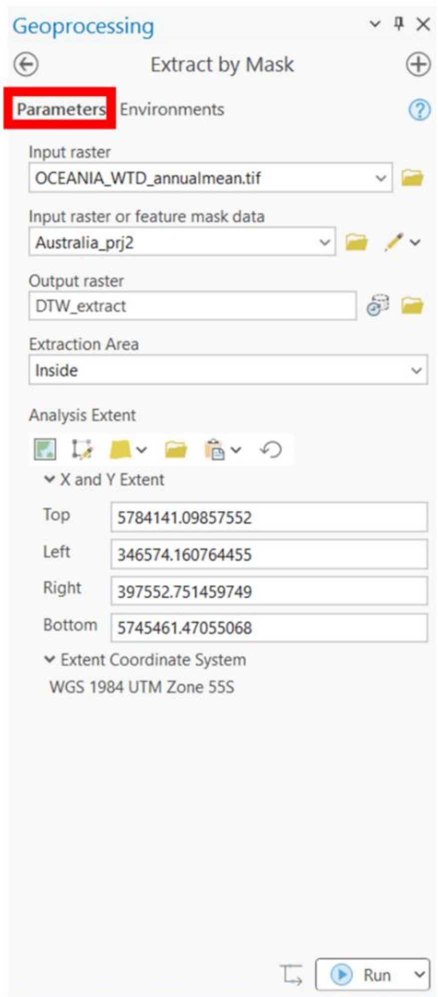
- **Input raster:** Selected continental raster
- **Input raster or feature mask data:** Study area polygon
- **Output raster:** Define the name and location of the file

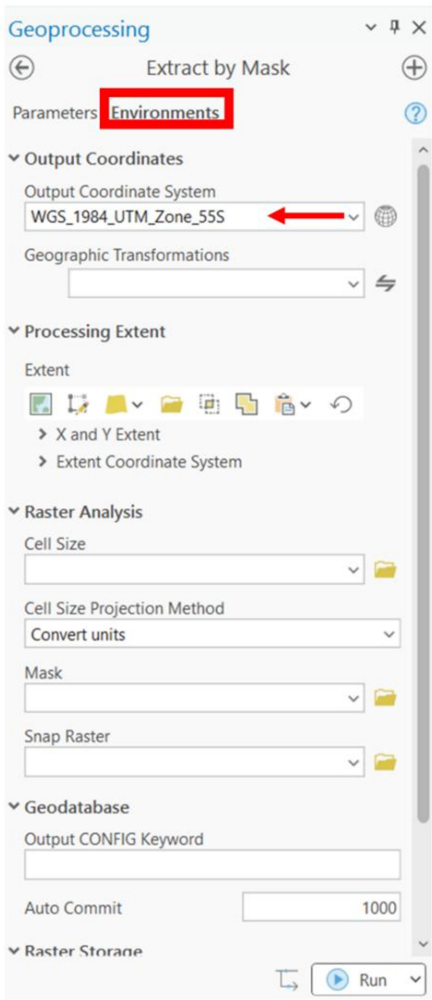
In the *Environments* tab, set:

- **Output coordinate system:** Coordinate reference system of the study area

Click **Run** to develop the raster file for the study area.

Then apply **Steps (c)** and **(d)** of the standard procedure to the developed raster layer to downscale it to the required resolution.

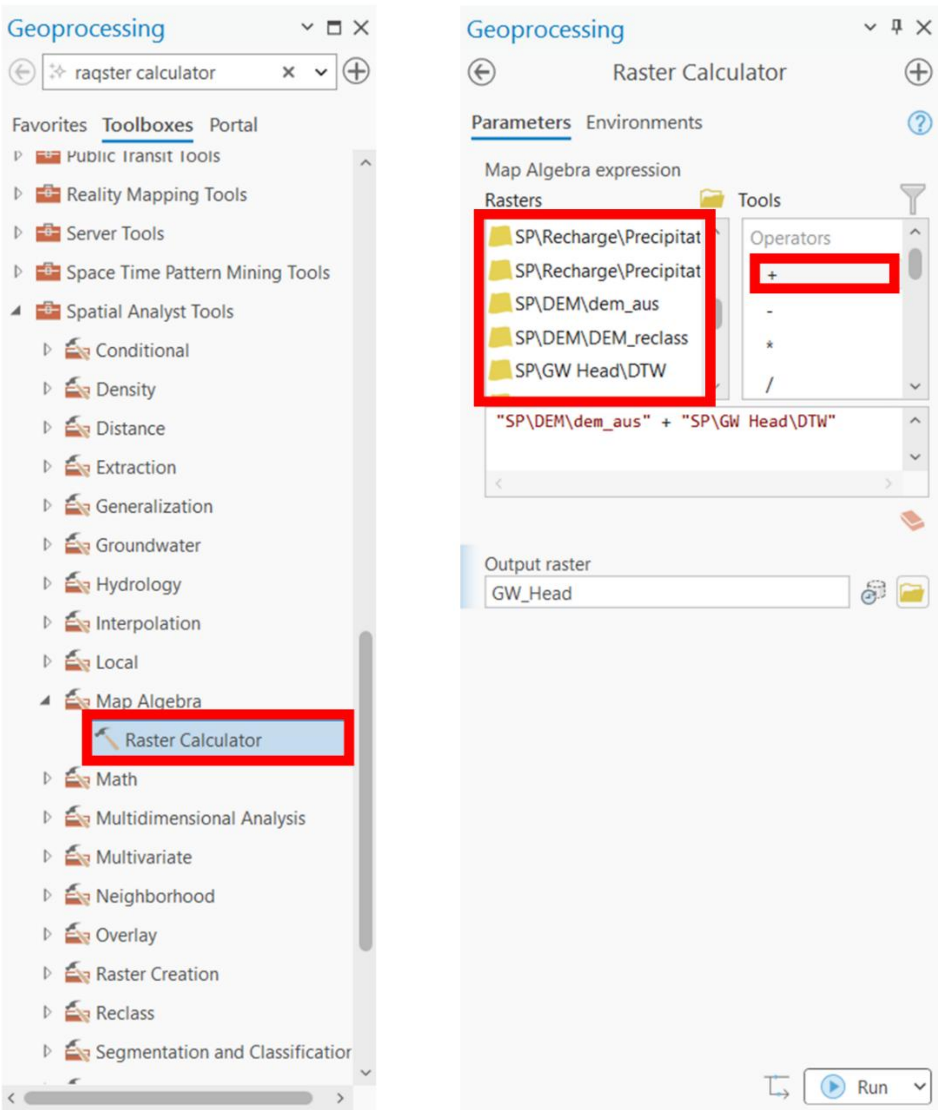




To develop the Groundwater Head raster layer, go to: ***Analysis → Tools → Toolboxes → Spatial Analyst Tools → Map Algebra → Raster Calculator.*** Groundwater Head is calculated using the expression:

Groundwater Head = DEM + Depth to Water

In the **Raster Calculator** window, double-click to choose the two raster layers, and the plus sign (+) between them. In the **Output** define the name and location of the Groundwater Head raster layer.



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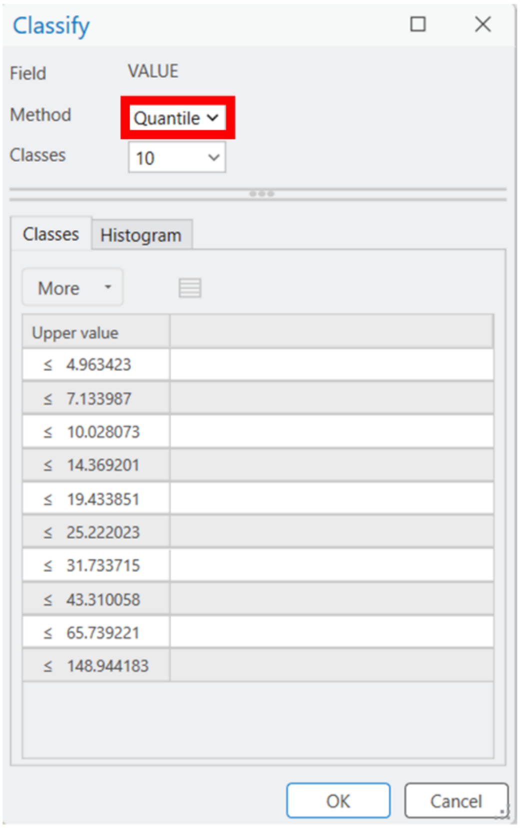
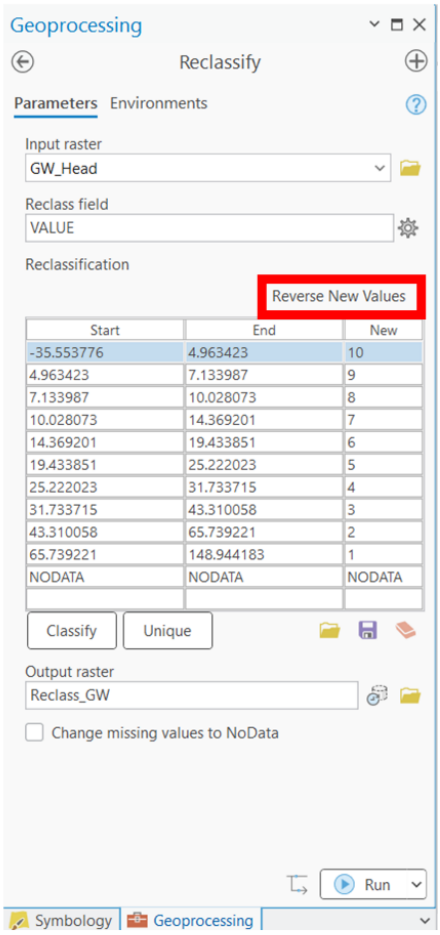
To reclassify the Groundwater Head raster layer open: ***Analysis → Tools → Toolboxes → Spatial Analyst Tools → Reclass → Reclassify.*** In the Reclassify dialog box, click **Classify** to open the classification window and set the following:

- **Method:** Quantile
- **Classes:** 10

Click **OK** to apply the classification.

Returning to the main Reclassify dialog box, select **Reverse New Values,** and specify the output name and location. Click **Run** to develop the final reclassified Groundwater Head layer.





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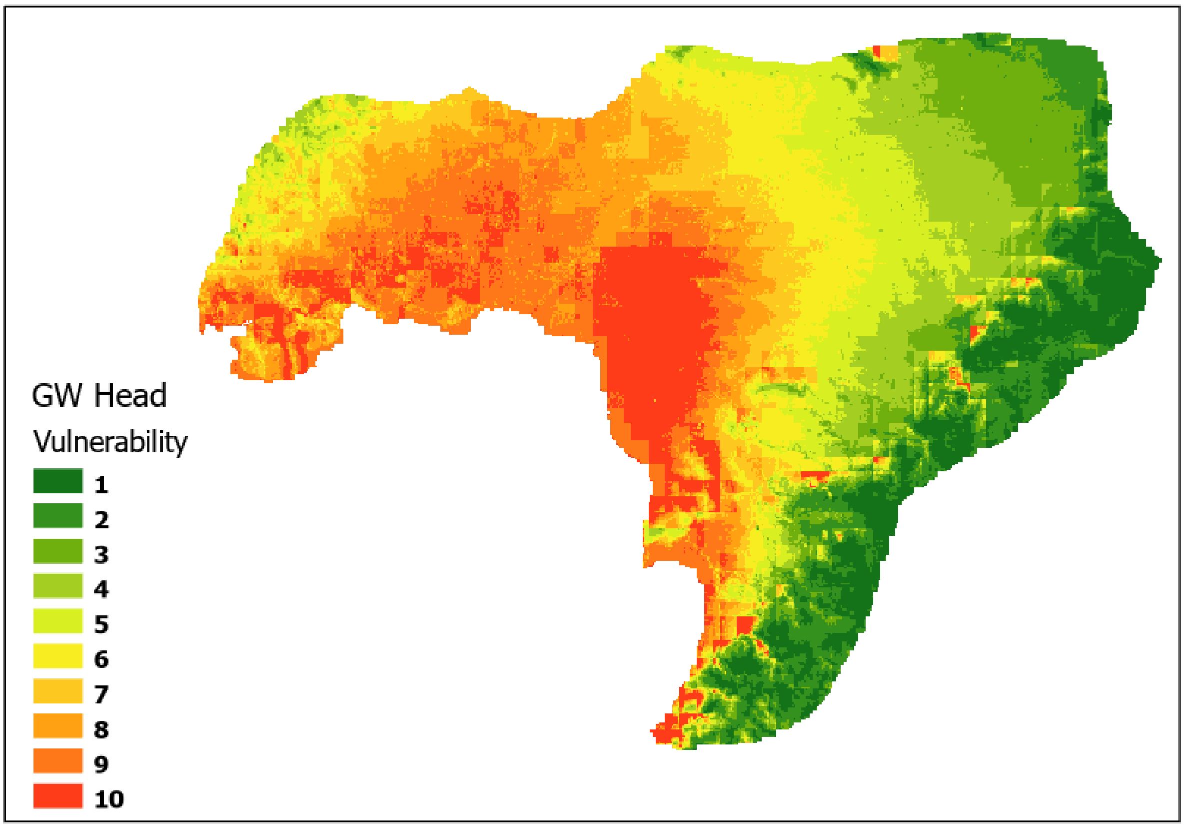


4.3. Recharge

If the study site is located in Europe, go to: ***Global → Raster files → Groundwater recharge PAN EU*** and open the corresponding raster layer. Subsequently, follow **Steps (c)** and **(d)** of the raster processing procedure to develop the recharge layer.

NOTE: For study areas located outside Europe, groundwater recharge is estimated with precipitation and soil texture data. Even for study areas within Europe, users may optionally follow the procedure below to calculate recharge.

- *Precipitation*

Navigate to: ***Global → Raster files → Precipitation*** and open the file named **PCP_AVERAGE.tif.** Then follow **Steps (c)** and **(d)** of the standard procedure to develop the precipitation raster layer for the study area.

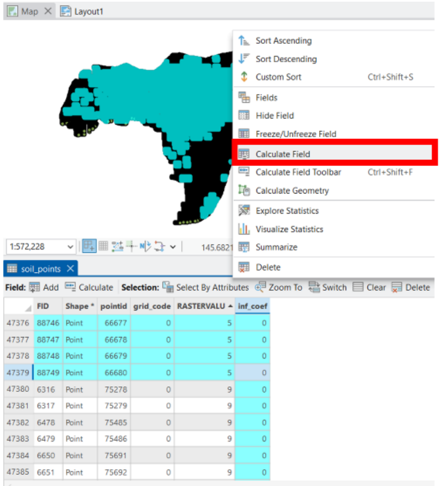
- *Coefficient of Infiltration*

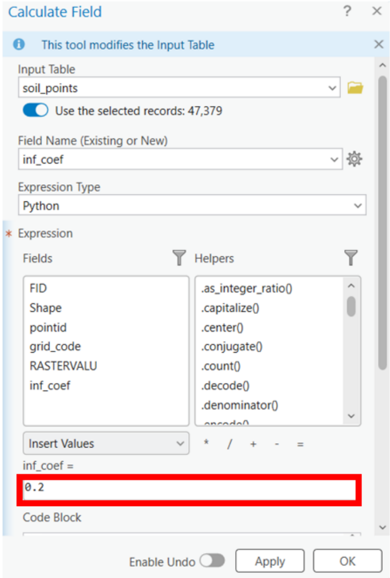
To load the soil texture dataset go to: ***Global → Raster files → Soil characteristics → Soil properties → Soil_texture_USDA.tif.*** Then follow **Step (c)** of the standard procedure to generate the point shapefile with the soil texture values for the study area.

Open the attribute table of the point shapefile and create a new field with the following properties:

- **Field name:** Infiltration coefficient (Inf_coef)
- **Data type:** Double

Use the **Calculate Field** and the provided classification table to assign the appropriate infiltration coefficient values based on the soil texture classes present in the study area.





ID	Raster legend texture	Coefficient of Infiltration
1	clay	0.025
2	silt Clay	0.03
3	silty Clay Loam	0.075
4	sandy clay	0.3
5	sandy clay loam	0.2
6	clay loam	0.03
7	silt	0.05
8	silt loam	0.1
9	loam	0.17
10	sand	0.5
11	loamy sand	0.35
12	sandy loam	0.25

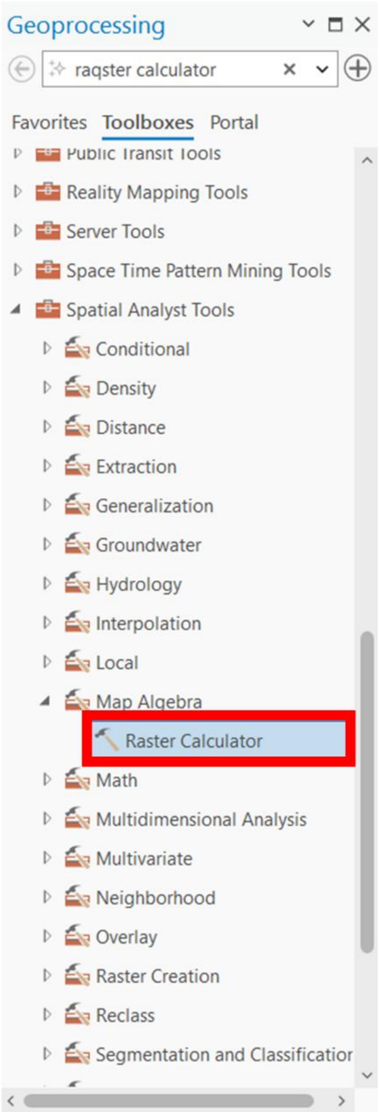
Finally, follow **Step (d)** of the standard procedure to develop the raster layer using the **infiltration coefficient as the value field**.

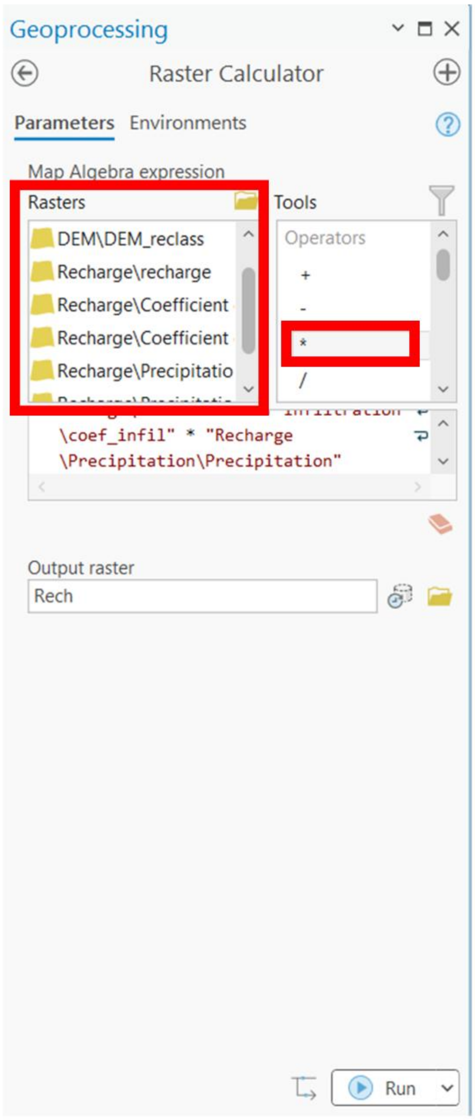
- *Recharge Calculation*

To calculate recharge go to: ***Analysis → Tools → Toolboxes → Spatial Analyst Tools → Map Algebra → Raster Calculator.*** Recharge is calculated with the expression:

$$\text{Recharge} = \text{Precipitation} \times \text{Coefficient of infiltration}$$

In the **Raster Calculator** window, double-click to insert the two raster layers, and the multiplication operator (*) between them. In the **Output** define the name and location of the recharge raster layer.



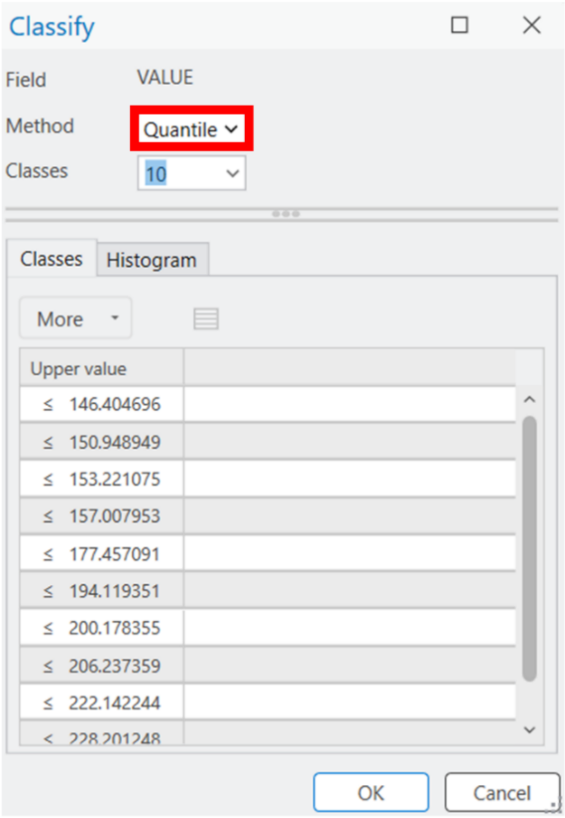


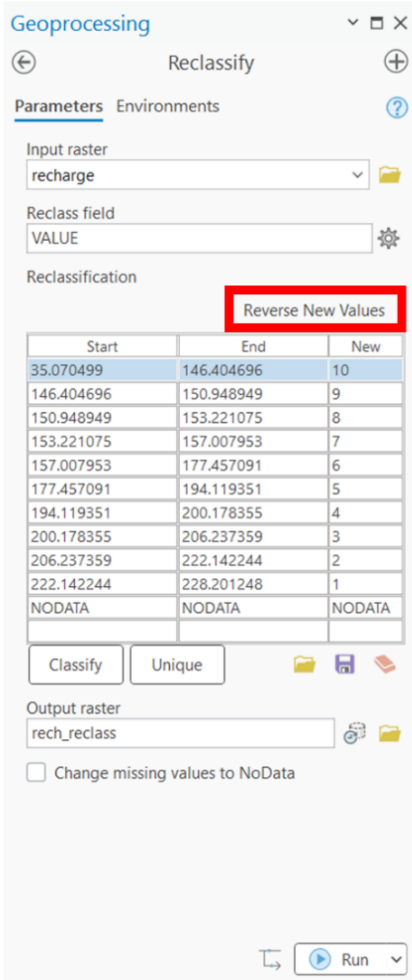
To reclassify the recharge layer open: ***Analysis*** → ***Tools*** → ***Toolboxes*** → ***Spatial Analyst Tools*** → ***Reclass*** → ***Reclassify.*** In the Reclassify dialog box, click **Classify** to open the classification window and set the following:

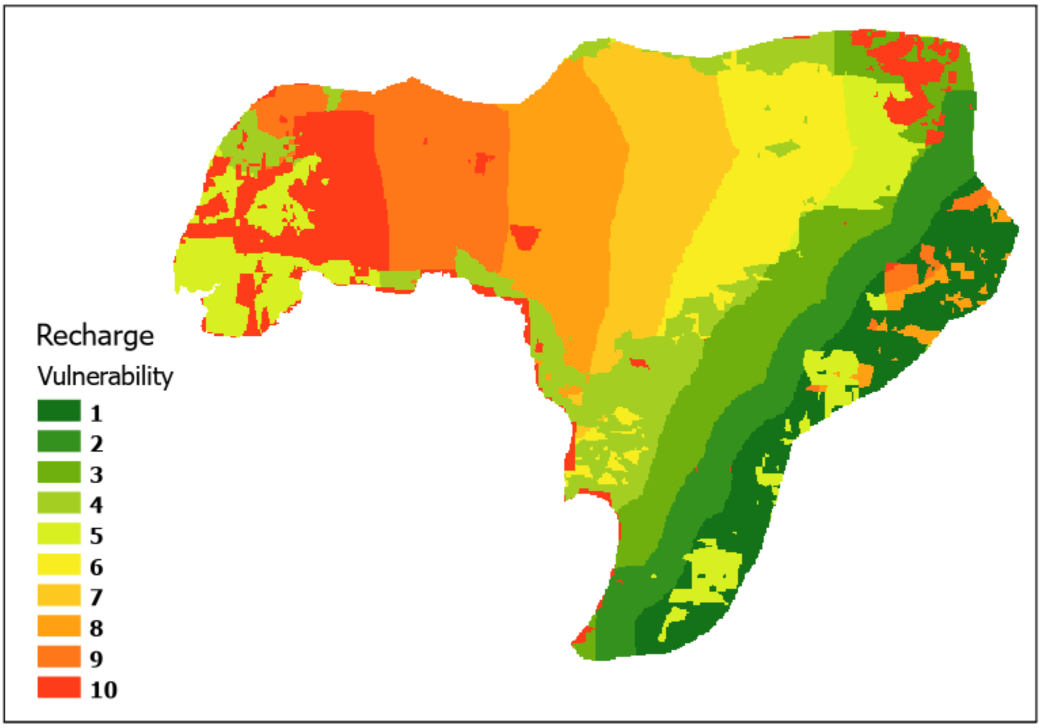
- **Method:** Quantile
- **Classes:** 10

Click **OK** to apply the classification.

Returning to the main Reclassify dialog box, select **Reverse New Values,** and specify the output name and location. Click **Run** to develop the final reclassified recharge layer.


Classify
Field
VALUE
Method
Quantile
Classes
10
Classes
Histogram
More
Upper value
≤ 146.404696
≤ 150.948949
≤ 153.221075
≤ 157.007953
≤ 177.457091
≤ 194.119351
≤ 200.178355
≤ 206.237359
≤ 222.142244
≤ 228.201248
OK
Cancel


Geoprocessing
Reclassify
Parameters
Environments
Input raster
recharge
Reclass field
VALUE
Reclassification
Reverse New Values
Start | End | New
35.070499 | 146.404696 | 10
146.404696 | 150.948949 | 9
150.948949 | 153.221075 | 8
153.221075 | 157.007953 | 7
157.007953 | 177.457091 | 6
177.457091 | 194.119351 | 5
194.119351 | 200.178355 | 4
200.178355 | 206.237359 | 3
206.237359 | 222.142244 | 2
222.142244 | 228.201248 | 1
NODATA | NODATA | NODATA
Classify
Unique
Output raster
rech_reclass
Change missing values to NoData
Run


Recharge
Vulnerability
1
2
3
4
5
6
7
8
9
10

4.4. Aquifer Hydraulic Conductivity

To load the required dataset go to: ***Global* → *Raster files* → *Rock permeability* → *GLHYMPS_250_RASTER.tif.***

Subsequently, apply **Step (c)** of the standard procedure to extract logK values to a point shapefile.

Open the attribute table of the shapefile, which now contains the extracted logK values (rastervalue). Create a new field in the attribute table with the following:

- **Field name:** *HC_m_s*
- **Data type:** Double

Right-click on the new attribute table field and select **Calculate Field**.

Calculate the hydraulic conductivity using the following expression:

$$HC = 10 ** (K/100) \times 10{,}000{,}000$$

Where K corresponds to the **rastervalue** field.

Click **Apply**, and then **OK**.

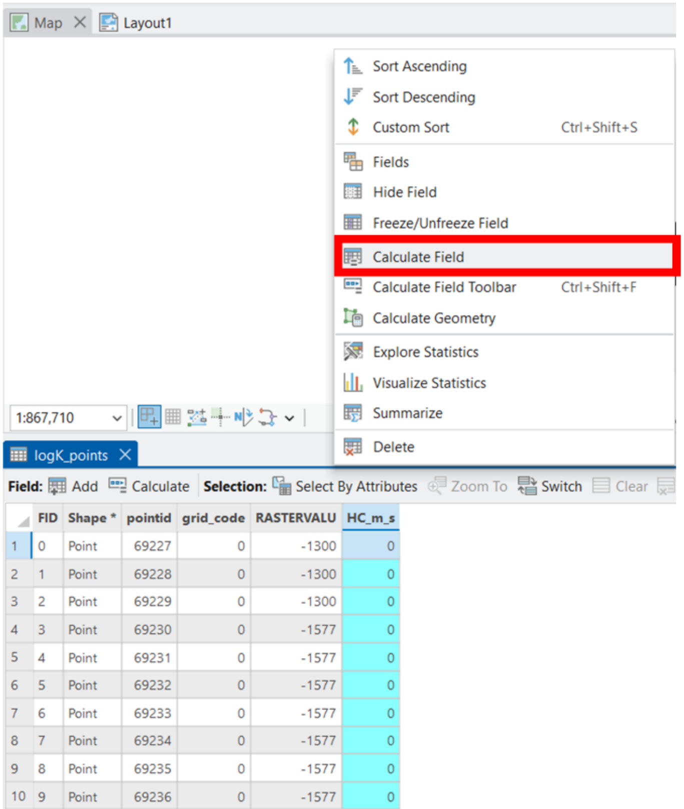
Create another field in the attribute table:

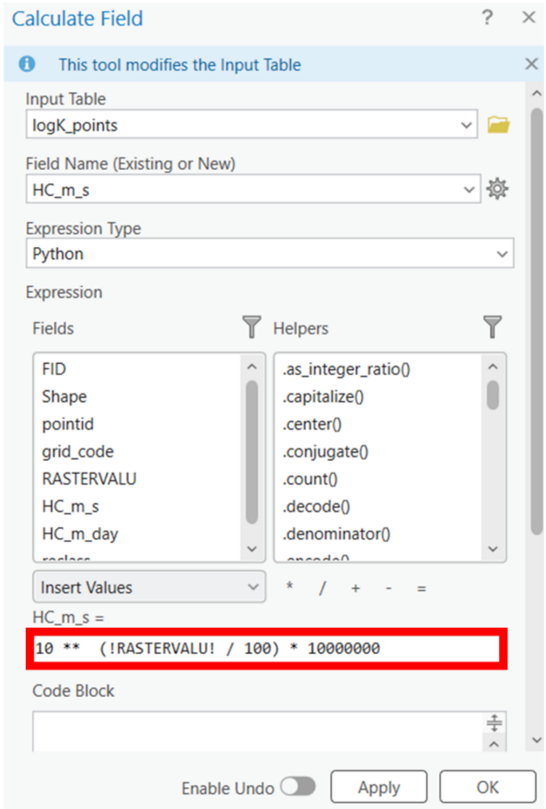
- **Field name:** *HC_m_day*
- **Data type:** Double.

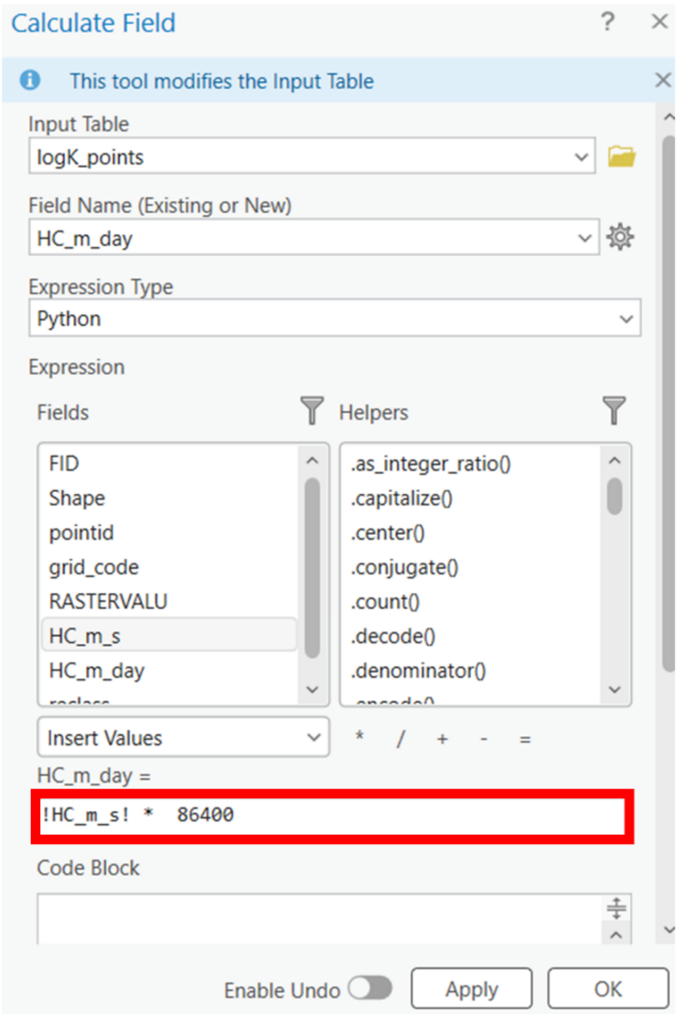
Use **Calculate field** again and multiply the hydraulic conductivity in m/s by 86400 to convert it in m/day.

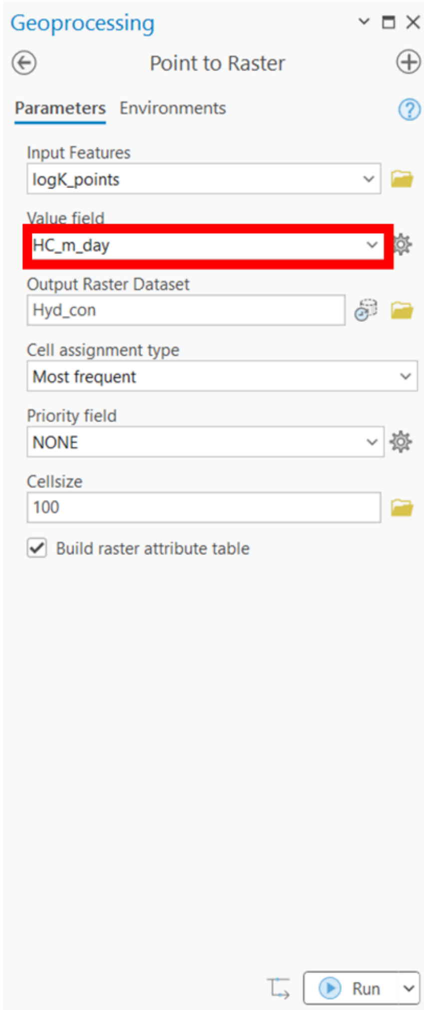
Click **Apply**, and then **OK**.

Then, follow **Step (d)** of the standard procedure with HC_m_day as the value field.









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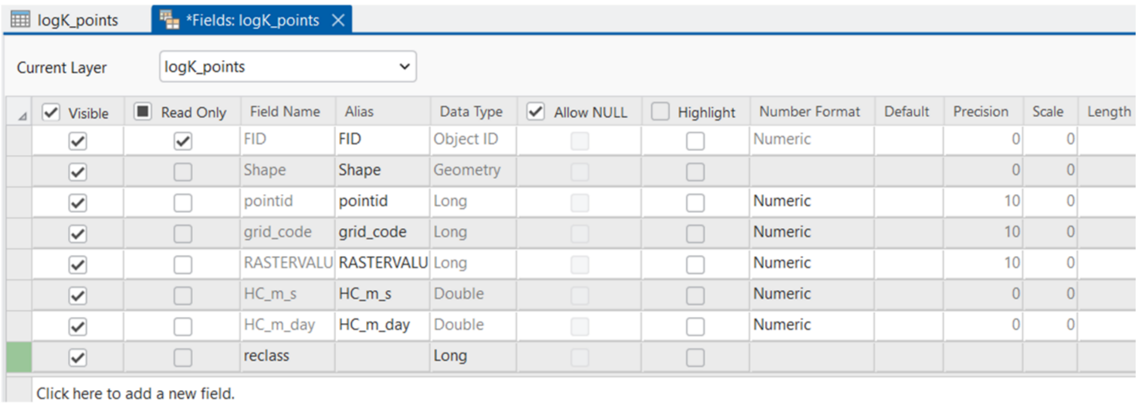
To reclassify the aquifer hydraulic conductivity layer, open: ***Analysis* → *Tools* → *Toolboxes* → *Spatial Analyst Tools* → *Reclass* → *Reclassify.*** In the Reclassify dialog box, click **Classify** to open the classification window and set the following:

- **Method:** Equal interval
- **Classes:** 10

Click **Run** to develop the reclassified hydraulic conductivity raster.

NOTE: If fewer than 10 hydraulic conductivity classes are present within the study area, an alternative classification approach should be applied.

1. Create a new field in the point shapefile attribute table and set:
    - **Field Name:** Reclass
    - **Data Type:** Long
2. Use **Select by Attributes** or manually select points within the hydraulic conductivity ranges (m/day) defined in the classification table below.
3. Use **Calculate Field** to assign the corresponding ratings to the selected points.
4. Repeat this process for all defined conductivity ranges.

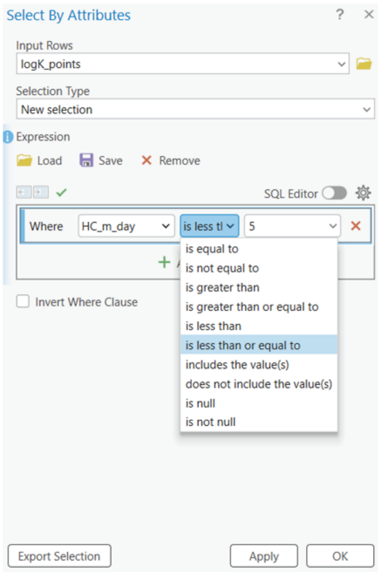

logK_points | *Fields: logK_points

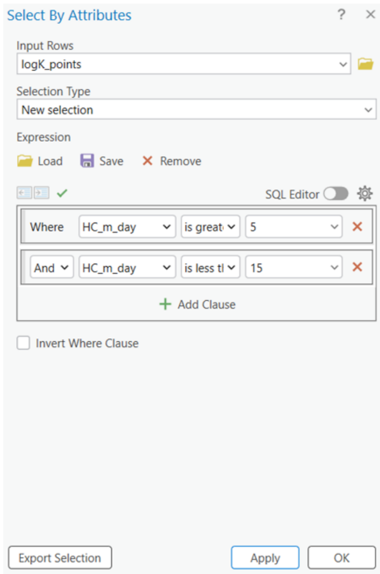
Current Layer: logK_points

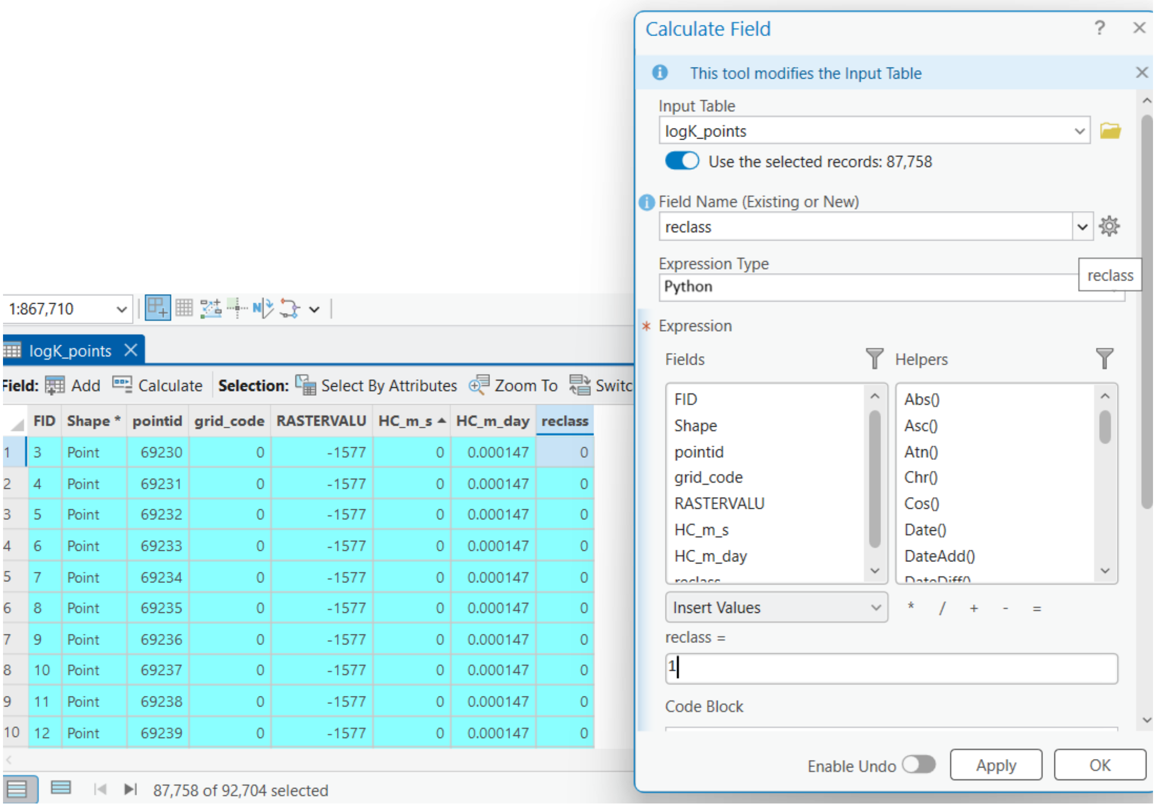
Visible	Read Only	Field Name	Alias	Data Type	Allow NULL	Highlight	Number Format	Default	Precision	Scale	Length
✓	✓	FID	FID	Object ID			Numeric		0	0	
✓		Shape	Shape	Geometry					0	0	
✓		pointid	pointid	Long			Numeric		10	0	
✓		grid_code	grid_code	Long			Numeric		10	0	
✓		RASTERVALU	RASTERVALU	Long			Numeric		10	0	
✓		HC_m_s	HC_m_s	Double			Numeric		0	0	
✓		HC_m_day	HC_m_day	Double			Numeric		0	0	
✓		reclass		Long							

Click here to add a new field.

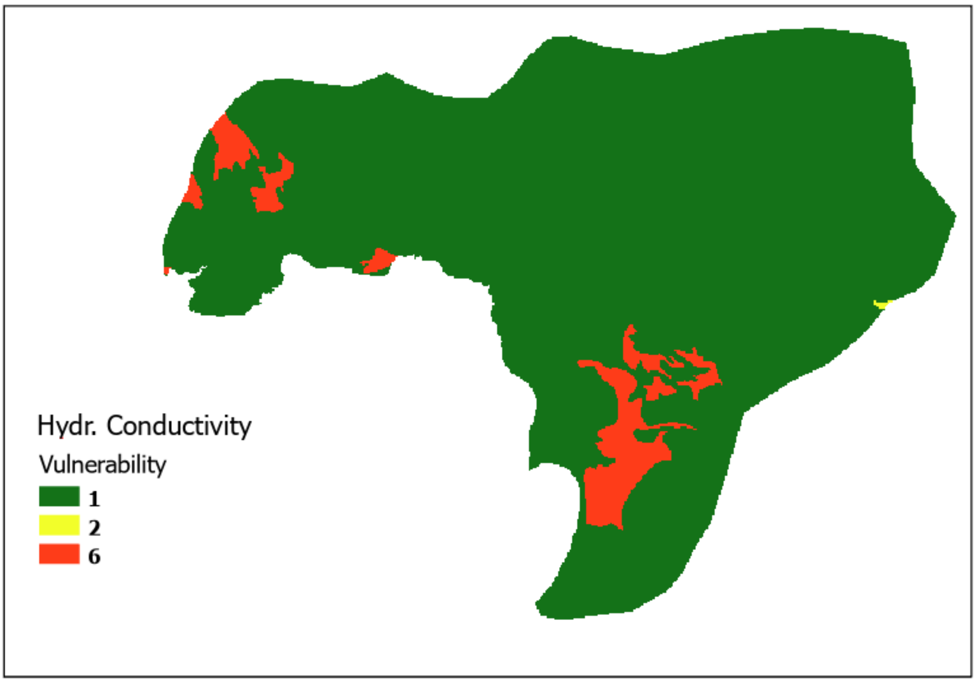
Conductivity [m/day]	
Range	Rating
0.05 – 5	1
5 – 15	2
15 – 25	4
25 – 50	6
50 – 100	8
>100	10
C Weight: 3	







Finally follow **Step (d)** of the standard procedure and use the reclassified values (ratings) as the value field to develop the final raster layer of aquifer hydraulic conductivity.



4.5. Soil Hydraulic Conductivity

To calculate the soil hydraulic conductivity, the soil texture is required. Open the attribute table of the soil texture point shapefile (See Subchapter 2.3 - Coefficient of infiltration) and make a new field with the following properties:

- **Field name:** Soil Hydraulic Conductivity (soil_HC)
- **Data type:** Double

Use **Calculate Field** and the provided classification table below to assign the appropriate soil hydraulic conductivity values *in m/day* based on the **soil texture classes** present in the study area.

ID	Soil texture	HC_m/day
1	clay	7.6
2	silt Clay	7.1
3	silty Clay Loam	11.0
4	sandy clay	2.9
5	sandy clay loam	5.8
6	clay loam	4.2
7	silt	20.6
8	silt loam	9.5
9	loam	4.7
10	sand	92.2
11	loamy sand	26.1
12	sandy loam	12.6

Then, follow **Step (d)** of the standard procedure to develop the raster layer using the soil hydraulic conductivity as the value field.

To reclassify the soil hydraulic conductivity layer open: ***Analysis* → *Tools* → *Toolboxes* → *Spatial Analyst Tools* → *Reclass* → *Reclassify.*** In the Reclassify dialog box, click **Classify** to open the classification window and set the following:

- **Method:** Geometric interval
- **Classes:** 10

Click **Run** to develop the reclassified soil hydraulic conductivity raster.

NOTE: If fewer than 10 soil hydraulic conductivity classes are present within the study area, an alternative classification approach should be applied.

1. Create a new field in the soil texture point shapefile attribute table and set:
    - **Field name:** Reclass
    - **Data Type:** Long
2. Use **Select by Attributes or** manually select points within the soil hydraulic conductivity ranges defined in the classification table below.
3. Use **Calculate Field** to assign the corresponding ratings to the selected points.
4. Repeat this process for all defined soil conductivity ranges.

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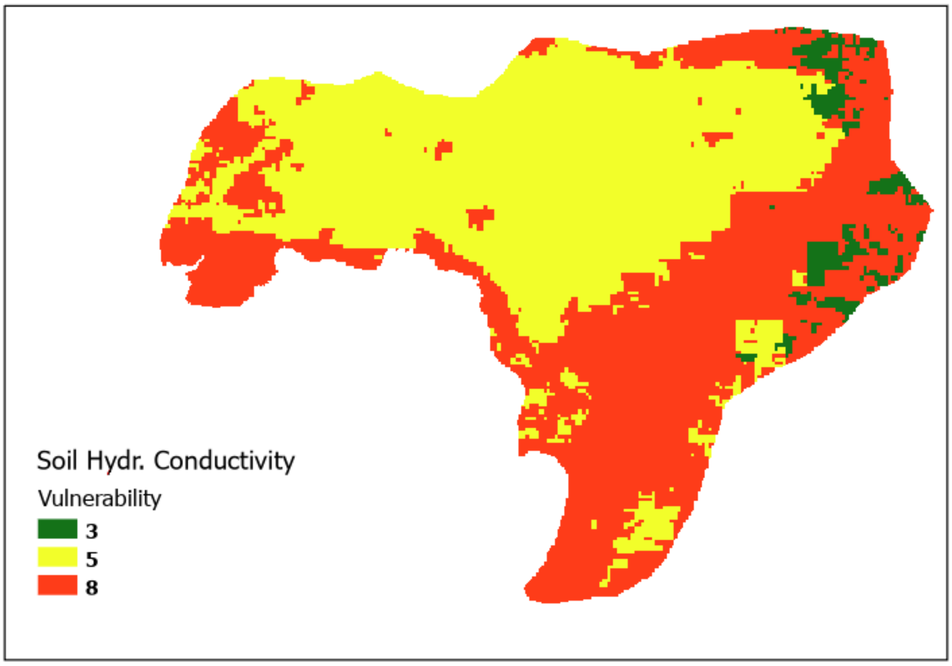
Soil K	
m/day	Rate
>40	10
10 - 40	8
5 - 10	5
2.5 - 5	3
>2.5	1

Finally, follow **Step (d)** of the standard procedure and use the reclassified values (ratings) as the value field to develop the final raster layer of soil hydraulic conductivity.

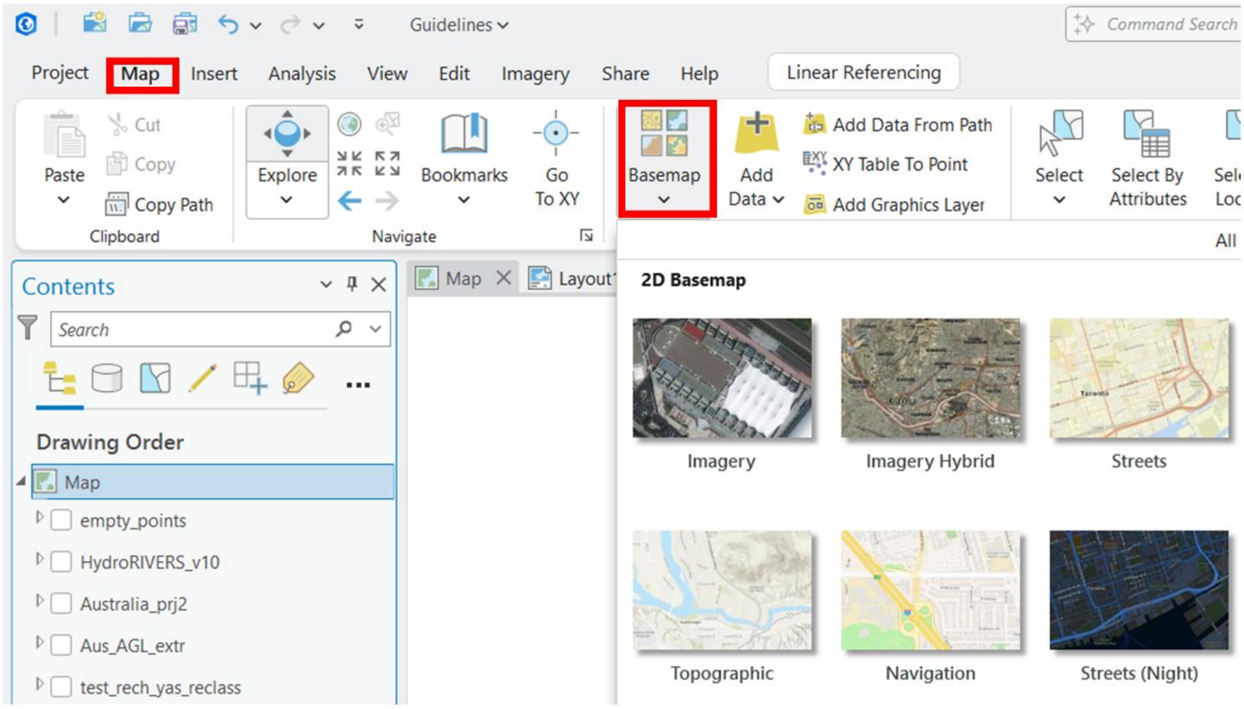


4.6. Distance from Saline and Fresh Water Sources

To develop the distance layers, surface water sources must be identified. They include rivers, lakes, lagoons, wetlands, and the coastline.

To load the global river dataset, go to: ***Global → Shapefiles → Rivers → HydroRIVERS_v10 → HydroRIVERS_v10.shp.***

<u>**NOTE:**</u> Since there is no comprehensive global dataset for lakes/lagoons, and the available river dataset may not provide sufficient detail for all study areas, it is recommended that water bodies should be digitized manually where necessary. This can be carried out in the ArcGIS Pro environment with Esri basemaps. To load a basemap go to ***Map → Basemap,*** and select an appropriate option, like Topographic or Streets. Continue with the digitization of the coastline, rivers, and lakes.



The coastline is always considered a saline source, while the rest of the surface water bodies may function as saline, fresh, or both, depending on their elevation. Their categorization is performed with the Digital Elevation Model (DEM). Water bodies located at an elevation equal to or lower than 2 m are classified as saline sources, while those located at elevations greater than 2 m are categorized as freshwater sources.

To achieve this, right-click on the DEM layer and select Symbology. In the Symbology tab, select **Classify**, and manually adjust the class break so that the first class corresponds to values ≤ 2 m.

After the categorization into saline and freshwater sources based on elevation, the datasets must be separated into individual shapefiles according to the type of source they represent.

If a water body shapefile contains both saline and freshwater sections, it must be divided accordingly. For example, rivers that are saline near the coast and freshwater further inland must

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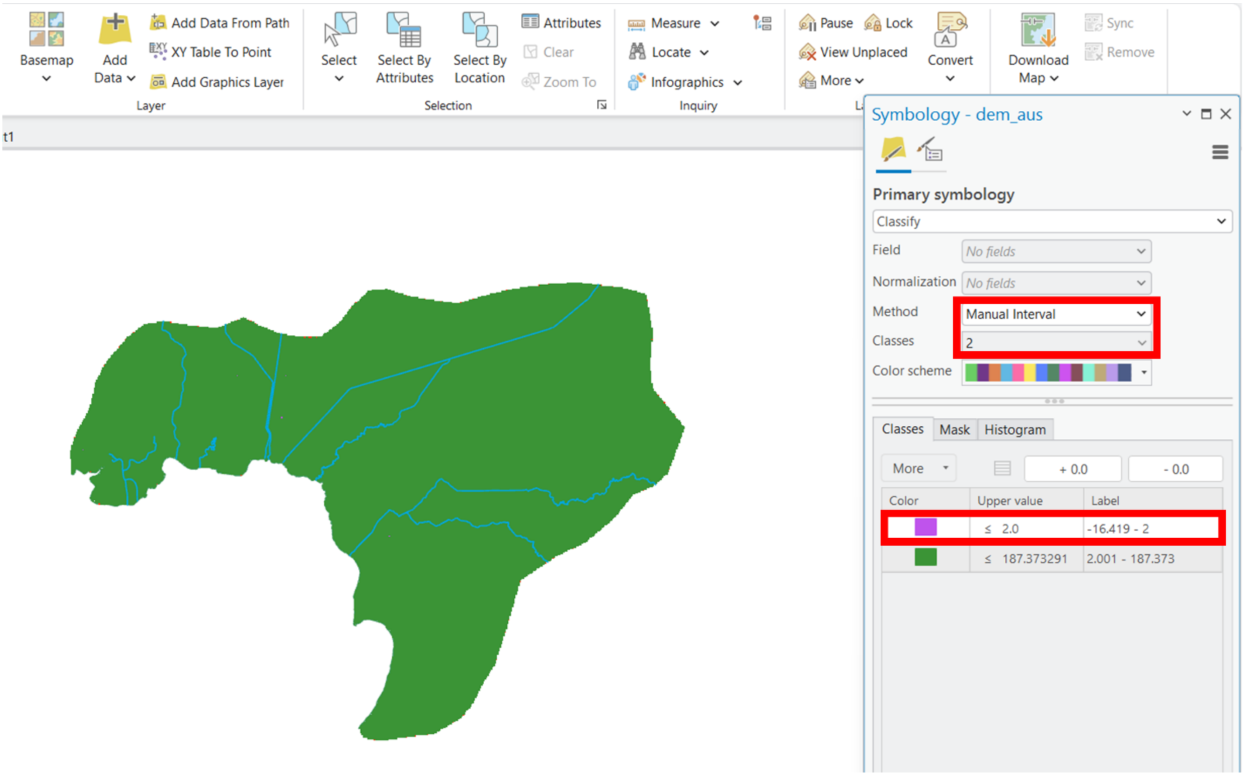
be split into two shapefiles: one containing the saline sections of the rivers, and the other containing the freshwater sections. The same applies to lagoons, lakes, and wetlands.

In the present example, the elevation in the study area is > 2 m, so all the surface water bodies are considered freshwater.



To calculate the distance go to: ***Analysis* → *Tools* → *Toolboxes* → *Spatial Analyst Tools* → *Distance* → *Distance Accumulation.*** In the distance accumulation window, set under *Parameters*:

- **Input raster or feature sources:** Water body shapefile (coastline, river, lake etc.)
- **Output distance accumulation raster:** Define the name and location of the distance layer

Then go to *Environments* and set:

- **Output coordinate system:** Select the coordinate system of the study area
- **Processing Extent:** Select *Extent of a Layer* and choose the study area polygon
- **Cell size:** Required resolution (e.g., 100 m)
- **Mask:** Study area polygon

Click **Run** to develop the distance raster layer.

Repeat this process for every water body shapefile (saline and fresh).

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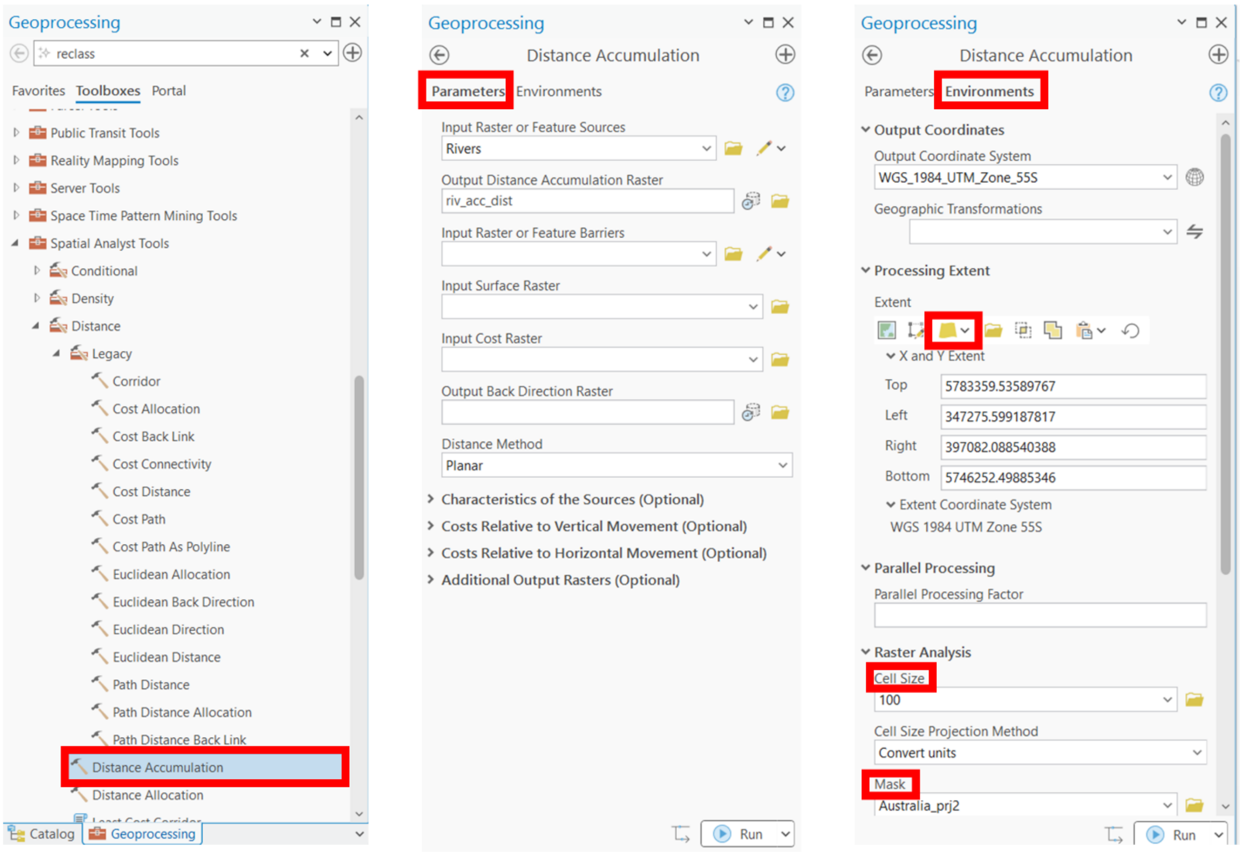


To reclassify the distance raster layers, go to: ***Analysis → Tools → Toolboxes → Spatial Analyst Tools → Reclass → Reclassify.*** In the Reclassify dialog box, click **Classify** to open the classification window and set the following:

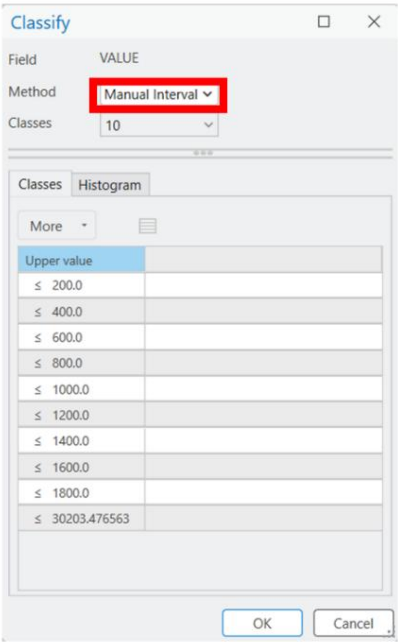
- **Method:** Manual interval
- **Classes:** 10

Adjust the class break values manually with **200 m intervals** for all classes and leave the final (maximum) class limit unchanged.

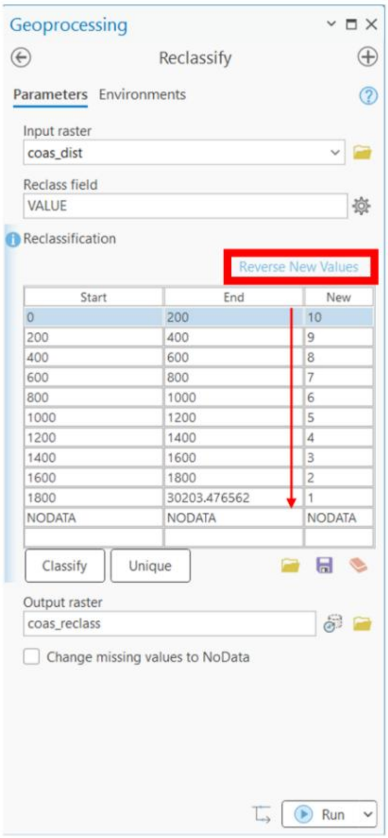
Click **OK** to apply the classification.

Returning to the main Reclassify dialog box:

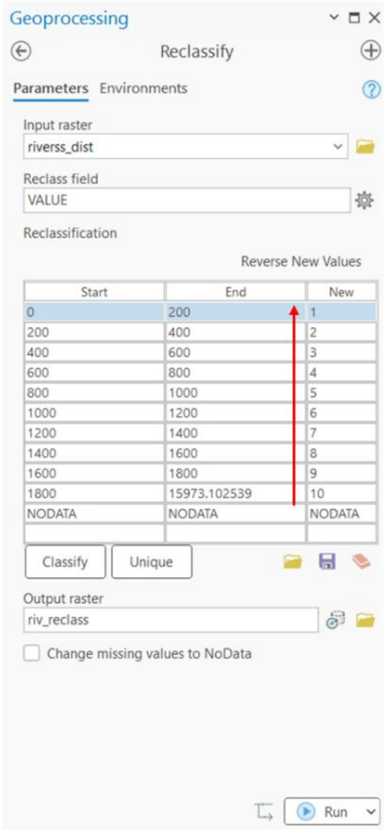
1. **Saline sources**: Select **Reverse New Values and** specify the output name and location. Click **Run** to develop the final reclassified raster layer.
2. **Freshwater sources**: Leave the classification as is and specify the output name and location. Click **Run** to develop the final reclassified raster layer.



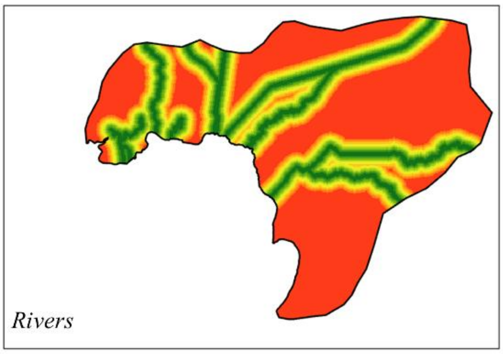
Saline sources

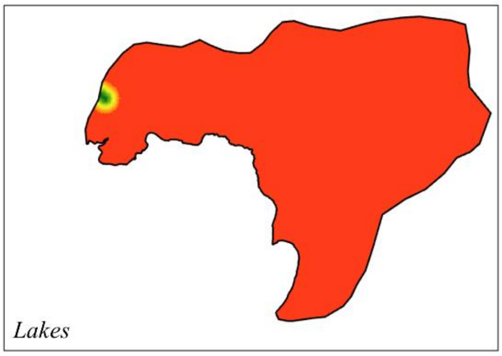


Freshwater sources

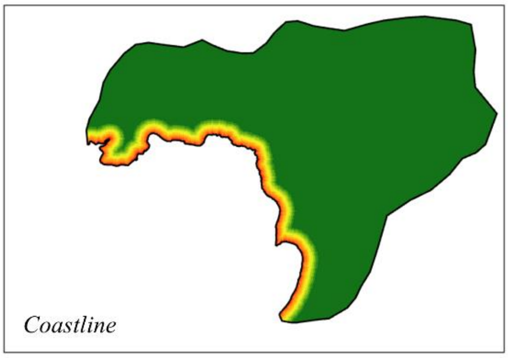


Freshwater sources





Saline sources



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4.7. Calculation of the Salinization Vulnerability Index (ADI)

To calculate the final vulnerability index, assign weights to each parameter based on the provided weighting table.

Concerning the weights of distance rasters:

Rivers

- If they act exclusively as either freshwater or saline sources: **0.02 (total weight)**
- If they act as both freshwater and saline sources: **0.01 assigned to each category**

Lagoons and lakes

- If they act exclusively as either freshwater or saline sources: **0.05 (total weight)**
- If they act as both freshwater and saline sources: **0.025 assigned to each category**

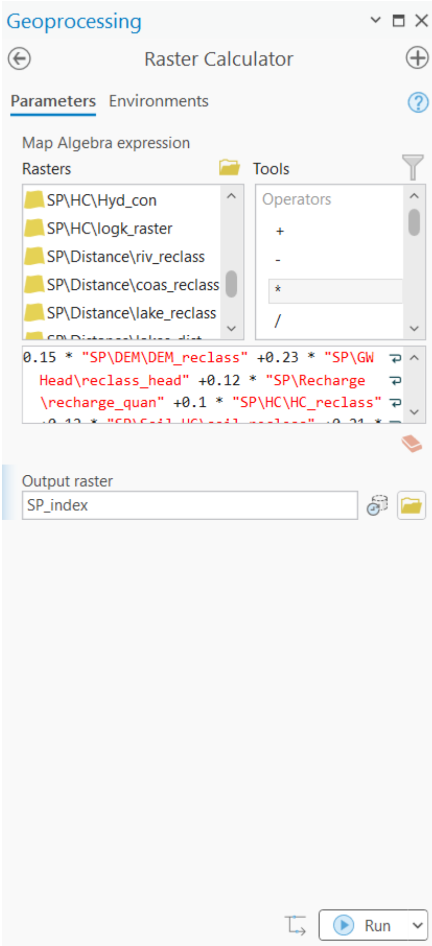
PARAMETERS	**WEIGHT**
DEM	0.15
Groundwater Head	0.23
Recharge	0.12
Aquifer Conductivity	0.10
Soil Conductivity	0.12
Coastline	0.21
Rivers *saline*	0.01
Rivers *fresh*	0.01
Lagoons/Lakes *fresh*	0.025
Lagoons/Lakes *saline*	0.025

To compute the final Salinization Vulnerability Index, go to: **Analysis → Tools → Toolboxes → Spatial Analyst Tools → Map Algebra → Raster Calculator**.

In the Raster Calculator, use the following expression, and apply distance weight adjustments to the **reclassified raster layers**, specific to the study area. Here:

0.15 × DEM + 0.23 × GW Head + 0.12 × Recharge + 0.10 × Aquifer Hydraulic Conductivity + 0.12 × Soil Hydraulic Conductivity + 0.21 × Coastline + 0.02 × Rivers + 0.05 × Lakes

Specify the output file name and location, then click **Run**.

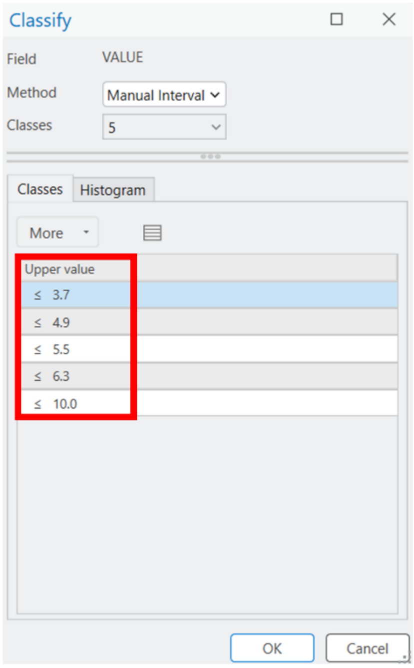


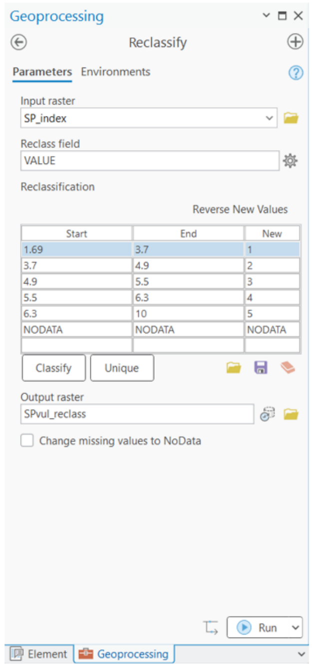
To reclassify the vulnerability raster go to: ***Analysis → Tools → Toolboxes → Spatial Analyst Tools → Reclass → Reclassify.*** In the Reclassify dialogue box, click **Classify** to open the classification window and set the following:

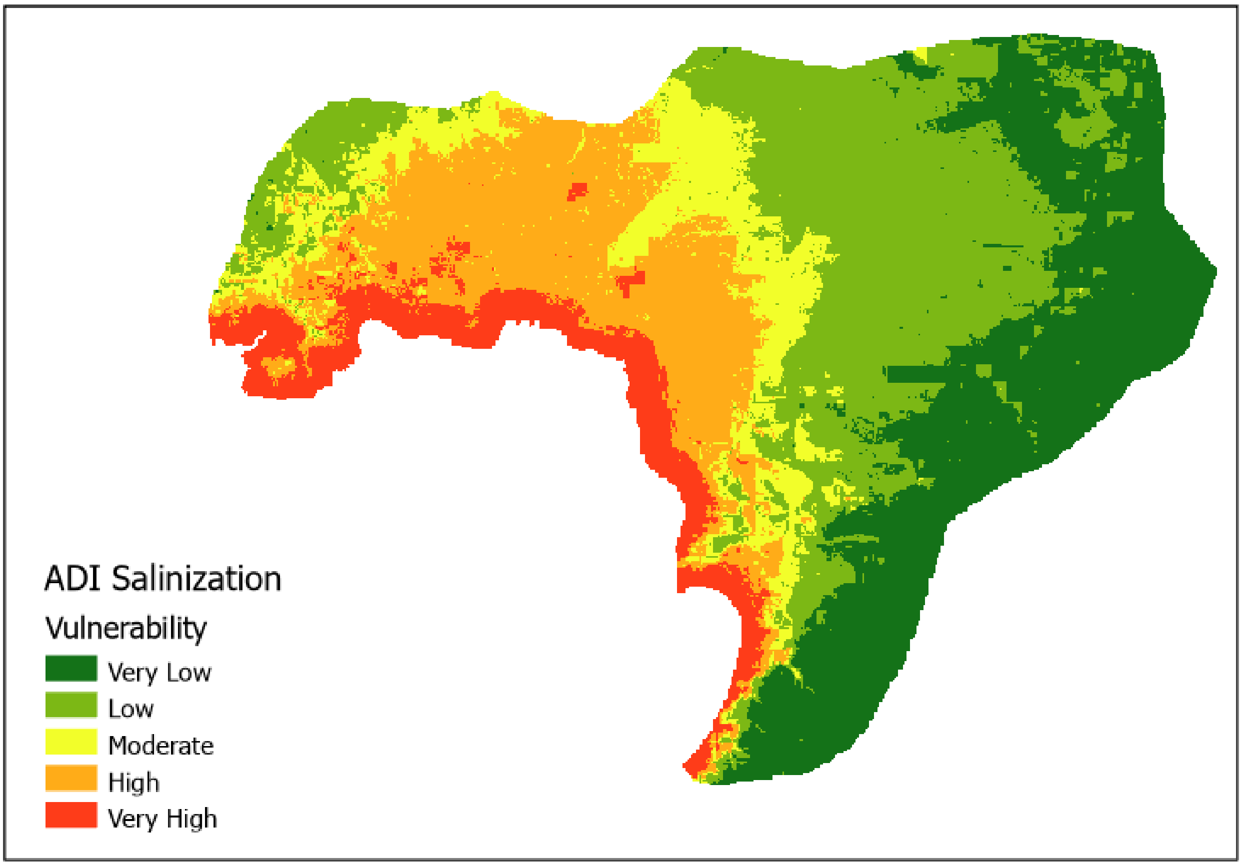
- **Method:** Manual interval
- **Classes:** 5

Adjust the class break values manually according to the provided classification table. Then specify the output file name and location and click **Run** to generate the final salinization vulnerability map.

VULNERABILITY		
CLASSIFICATION	RANGE	VALUE
Very Low	1.0 - 3.7	1
Low	3.7 - 4.9	2
Moderate	4.9 - 5.5	3
High	5.5 - 6.3	4
Very High	6.3 - 10.0	5







5. ESTIMATION OF THE AGL VULNERABILITY INDEX (ADI)

5.5. Clay Content (%)

To select the raster file from the dataset, navigate to ***Global → Raster files → Soil characteristics → Soil properties,*** and open **clay_0.5cm_ mean_1000.tif**.

Follow **Steps (c)** and **(d)** of the standard procedure to develop the clay content raster layer that corresponds to the study area.

To reclassify the raster layer go to: ***Analysis → Tools → Toolboxes → Spatial Analyst Tools → Reclass → Reclassify.*** In the Reclassify dialog box, set:

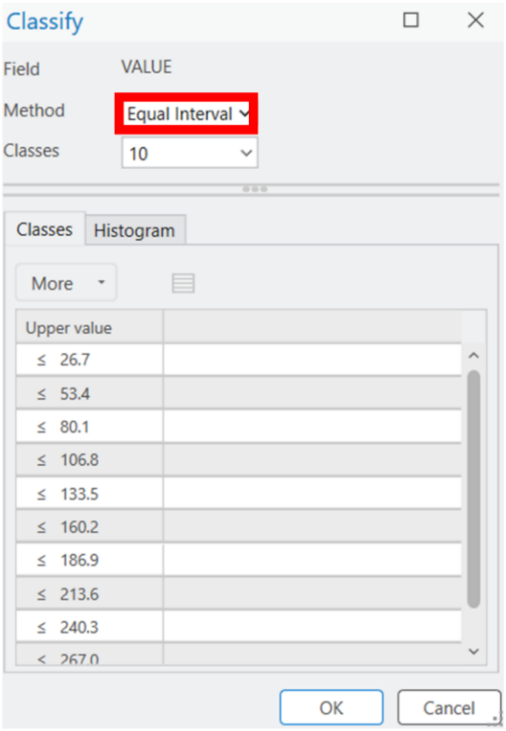
- **Input raster:** Clay content
- **Reclass field:** Value

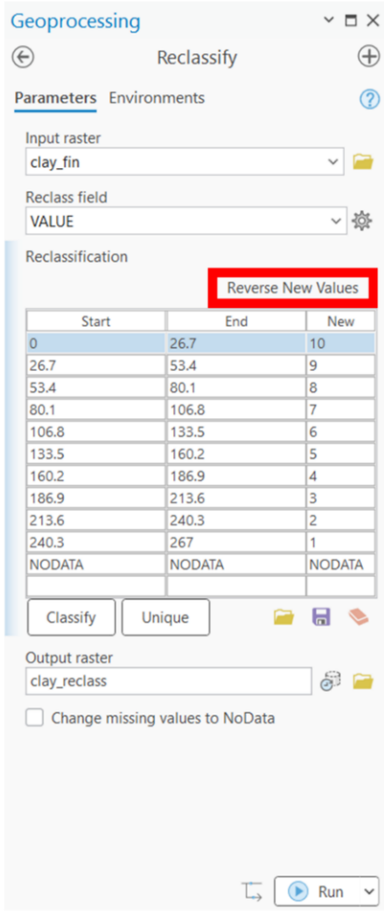
Click **Classify** to open the classification window and set the following:

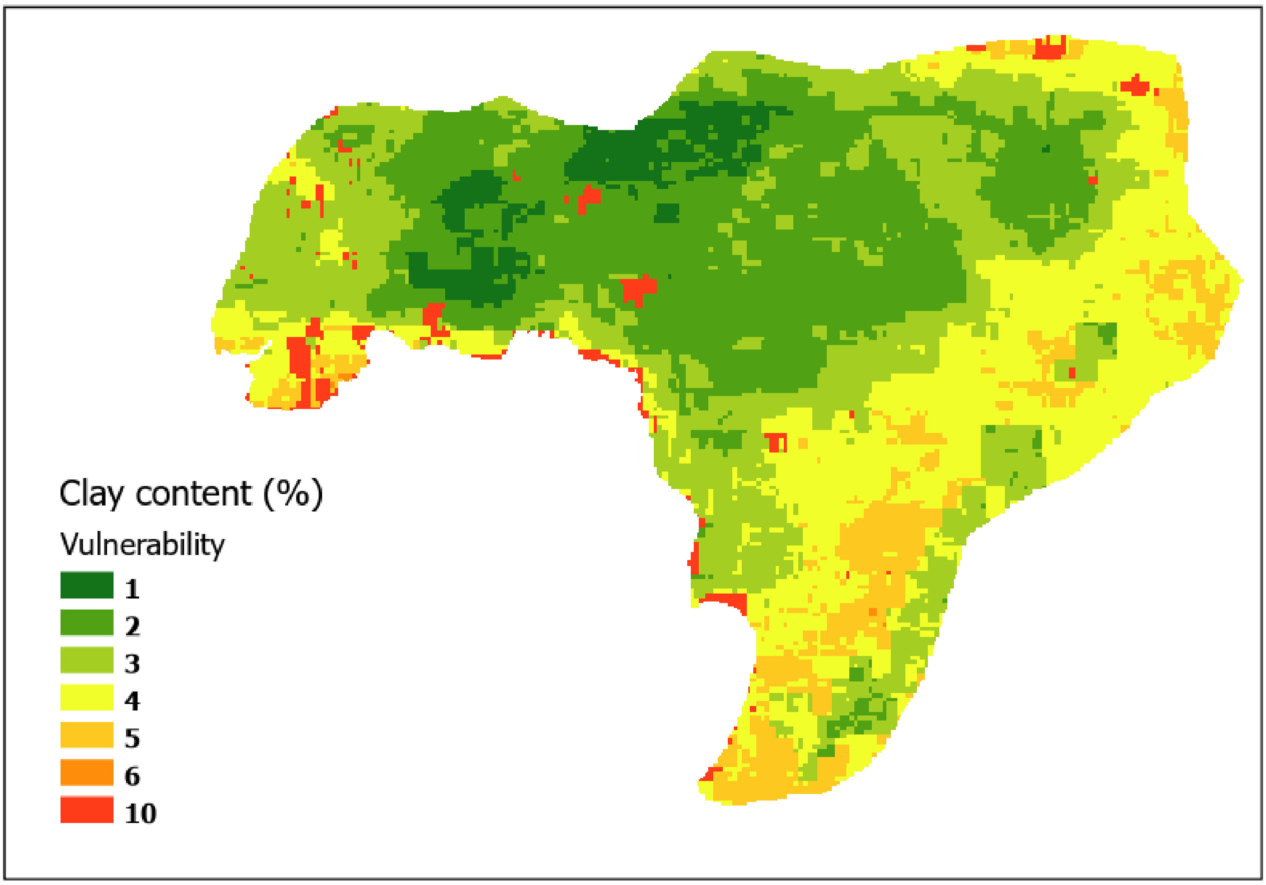
- **Method:** Equal interval
- **Classes:** 10

Click **OK** to apply the classification.

Returning to the main Reclassify dialog box, select **Reverse New Values,** and specify the output name and location. Click **Run** to develop the final reclassified raster layer.


Classify
Field VALUE
Method Equal Interval
Classes 10
Classes Histogram
More
Upper value
≤ 26.7
≤ 53.4
≤ 80.1
≤ 106.8
≤ 133.5
≤ 160.2
≤ 186.9
≤ 213.6
≤ 240.3
≤ 267.0
OK Cancel


Geoprocessing
Reclassify
Parameters Environments
Input raster
clay_fin
Reclass field
VALUE
Reclassification
Reverse New Values
Start End New
0 26.7 10
26.7 53.4 9
53.4 80.1 8
80.1 106.8 7
106.8 133.5 6
133.5 160.2 5
160.2 186.9 4
186.9 213.6 3
213.6 240.3 2
240.3 267 1
NODATA NODATA NODATA
Classify Unique
Output raster
clay_reclass
Change missing values to NoData
Run


Clay content (%)
Vulnerability
1
2
3
4
5
6
10

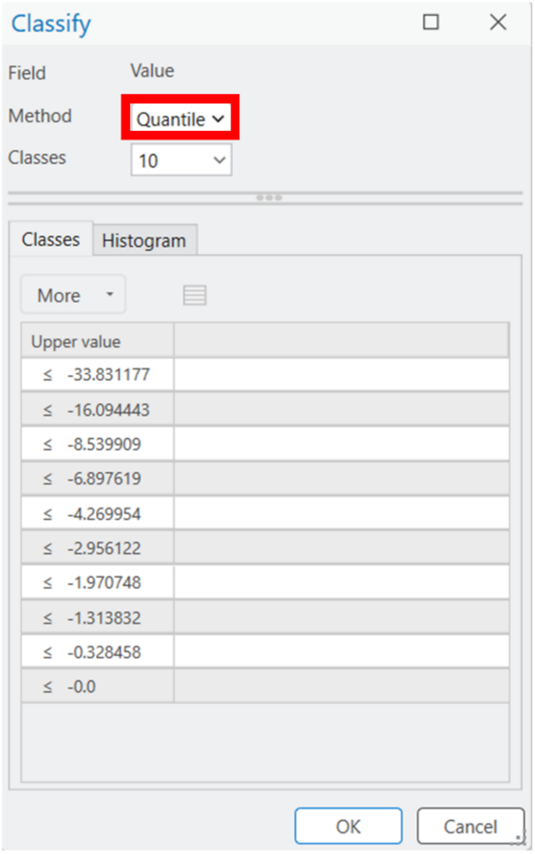
5.6. Depth to Water

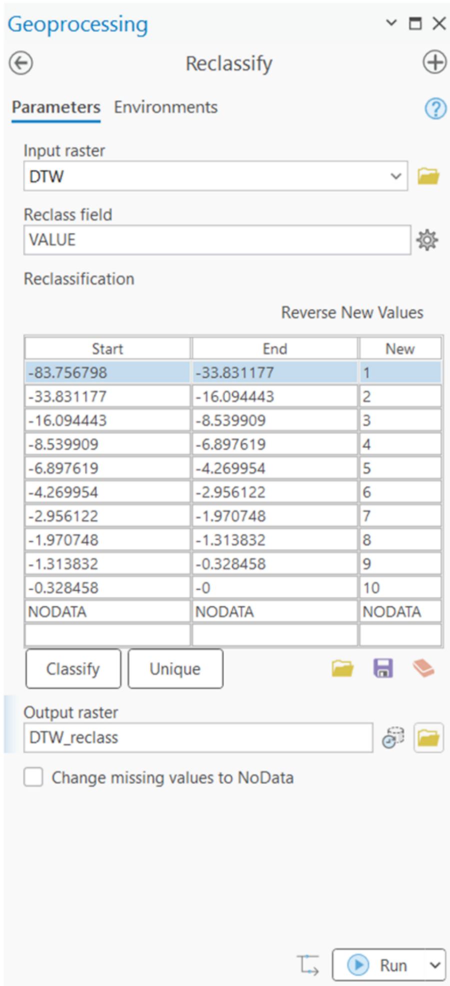
The creation of the depth to water raster file is described in Subchapter 2.2.

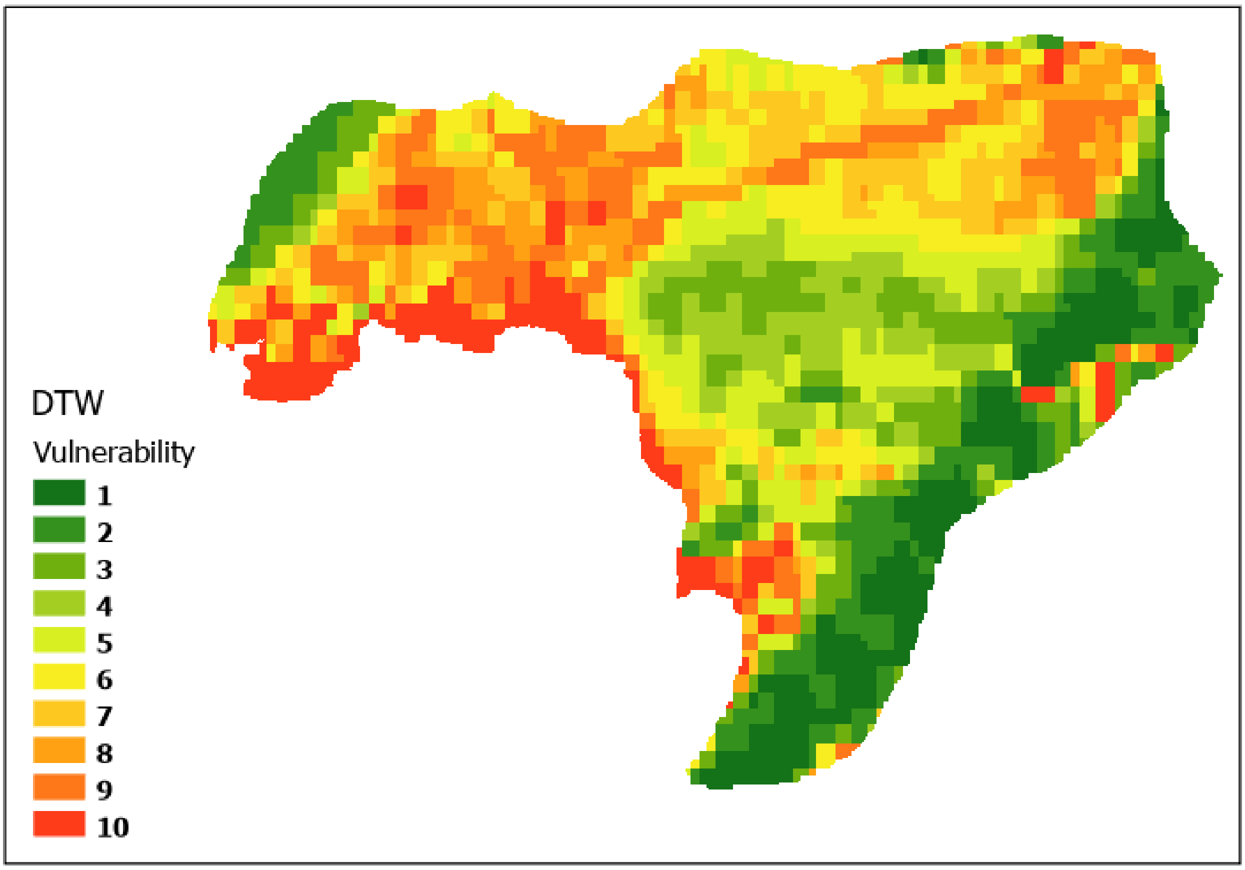
To reclassify the depth to water layer open: ***Analysis* → *Tools* → *Toolboxes* → *Spatial Analyst Tools* → *Reclass* → *Reclassify.*** In the Reclassify dialog box, click **Classify** to open the classification window and set the following:

- **Method:** Quantile
- **Classes:** 10

Click **Run** to develop the reclassified depth to water layer.





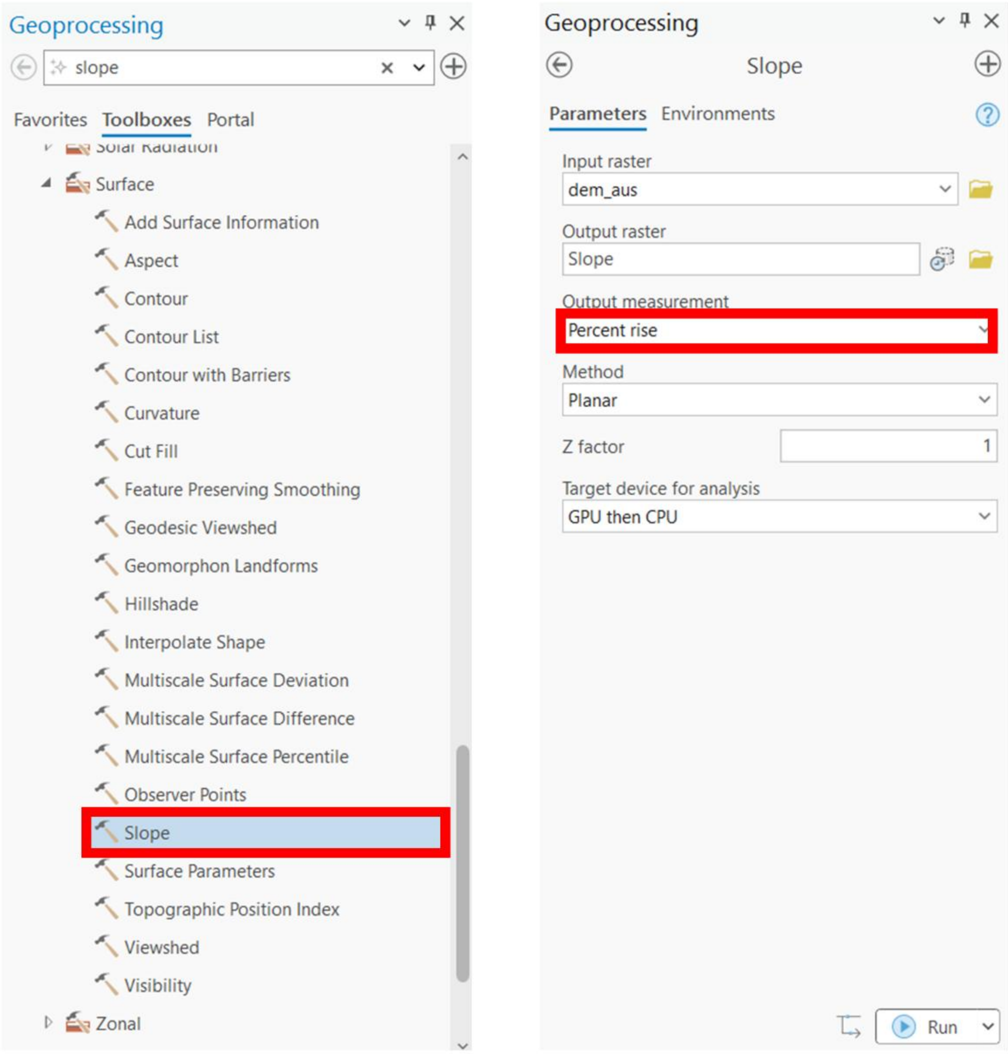


5.7. Slope

To develop the slope raster layer, go to: ***Analysis → Tools → Toolboxes → Spatial Analyst Tools → Surface → Slope.*** In the dialog box, set:

- **Input raster:** Digital Elevation Model (DEM)
- **Output raster:** Define the name and location of the slope raster
- **Output measurement:** Percent rise

Click **Run** to develop the slope raster layer.

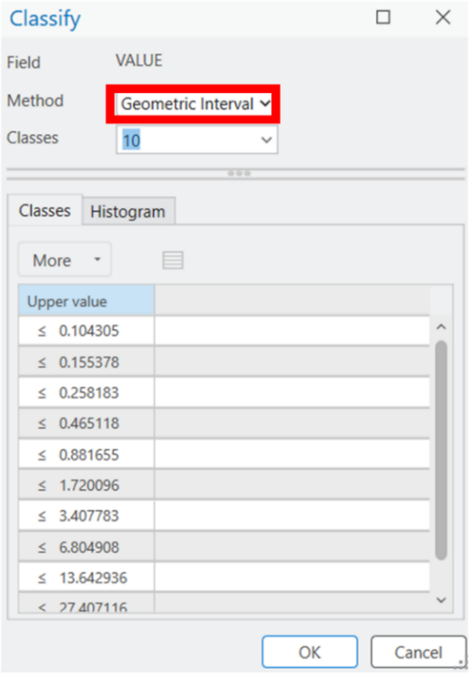


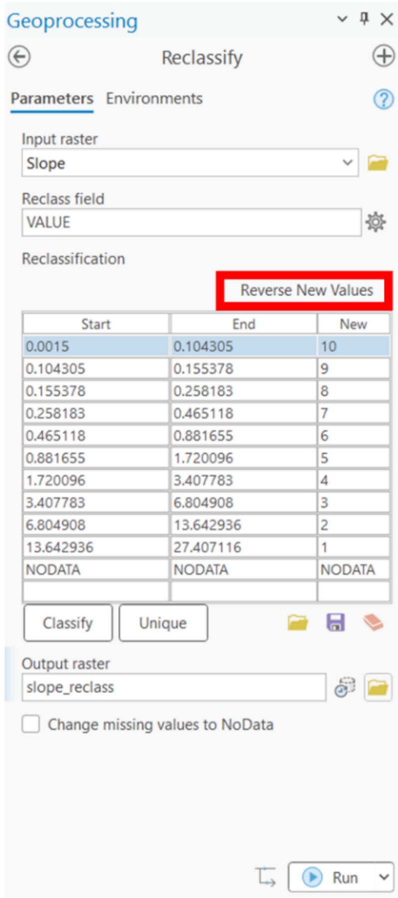
To reclassify the slope layer go to: ***Analysis* → *Tools* → *Toolboxes* → *Spatial Analyst Tools* → *Reclass* → *Reclassify.*** In the Reclassify dialog box, click **Classify** to open the classification window and set the following:

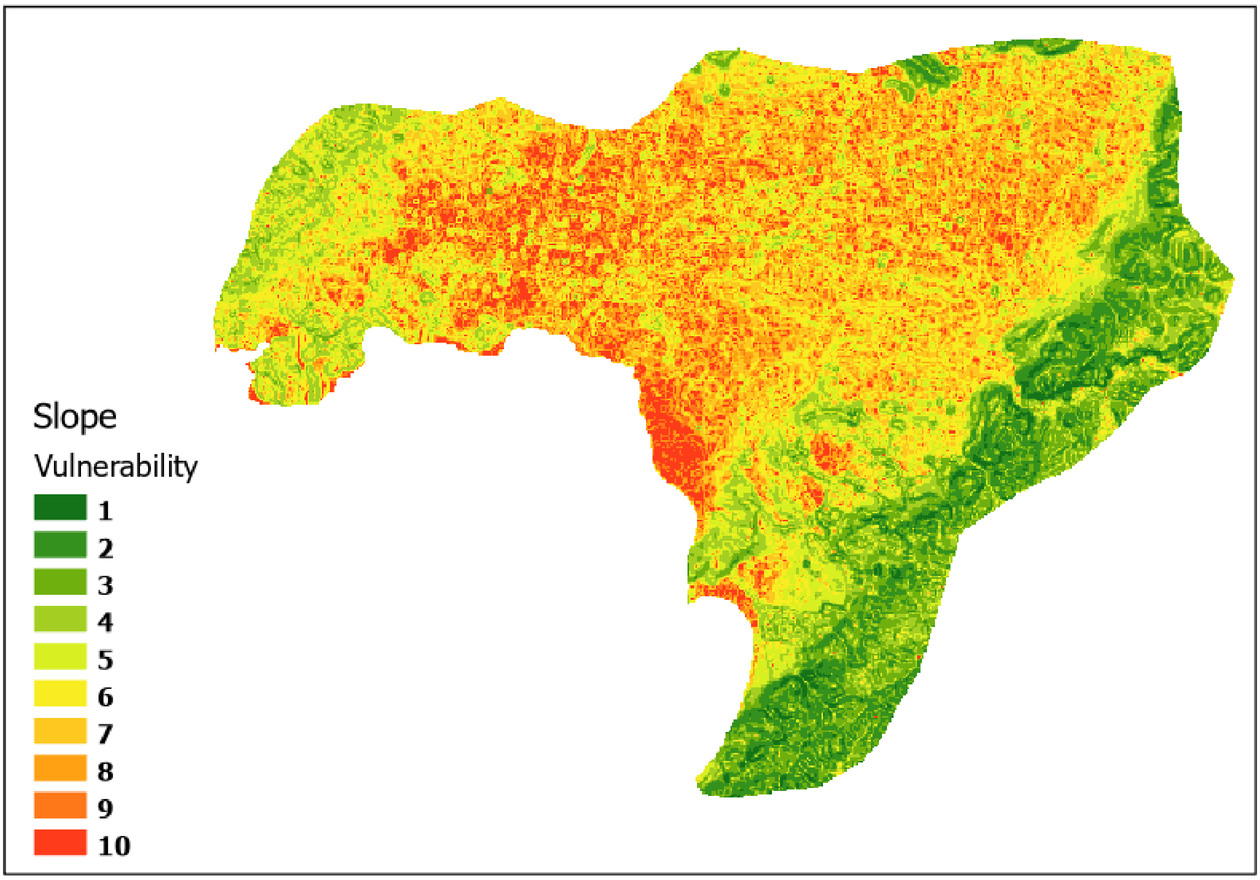
- **Method:** Geometric interval
- **Classes:** 10

Click **OK** to apply the classification.

Returning to the main Reclassify dialog box, select **Reverse New Values,** and specify the output name and location. Click **Run** to develop the final reclassified slope layer.







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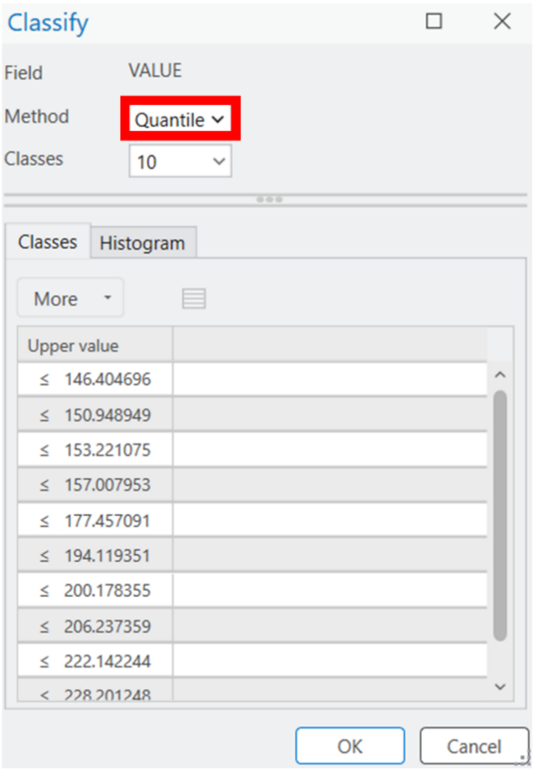
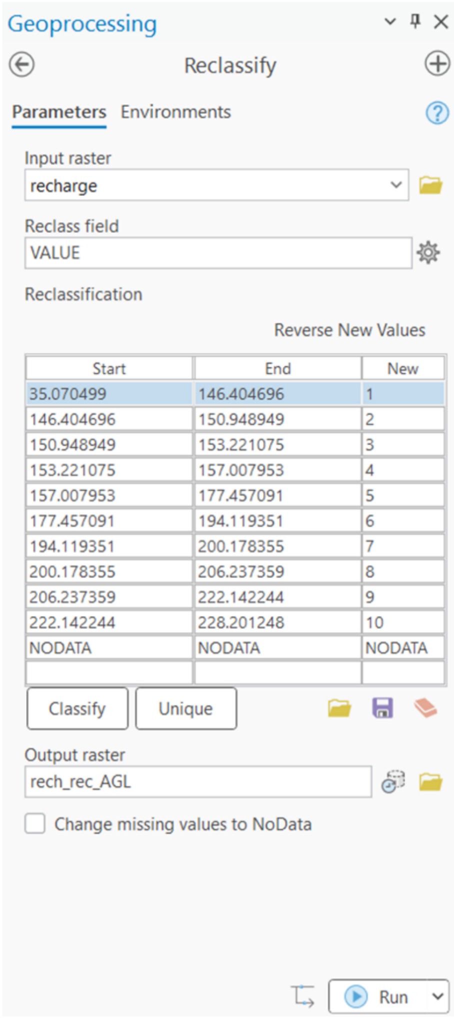
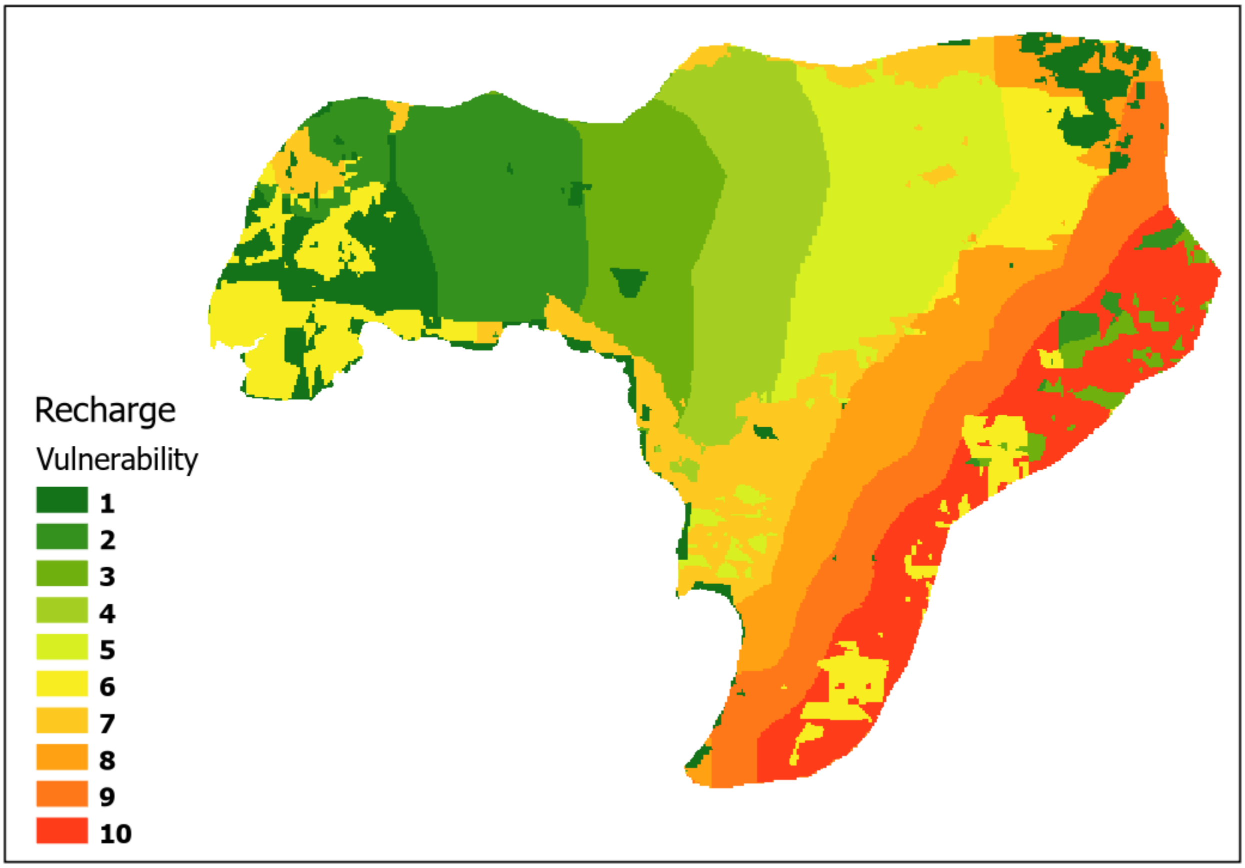
5.8. Recharge

The development of the recharge raster layer in ArcGIS Pro has been described previously (see Subchapter 2.3).

The reclassification of the recharge layer follows the same procedure described earlier. However, for the development of the reclassified recharge layer used in the AGL vulnerability index, the class values are **NOT reversed**.







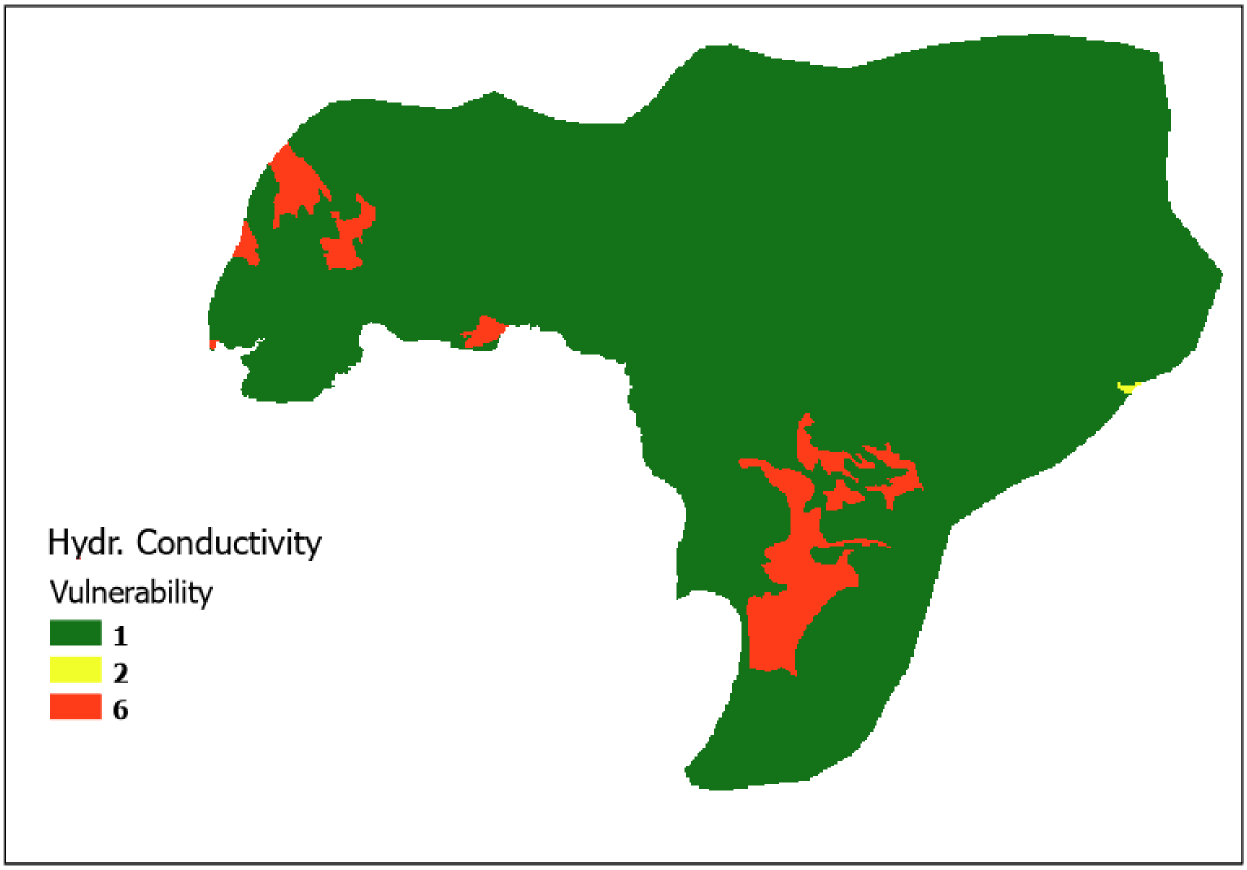
5.9. Aquifer Hydraulic Conductivity

The development of the aquifer hydraulic conductivity raster layer in ArcGIS Pro has been described previously (see Subchapter 2.4).

The reclassification of the aquifer hydraulic conductivity layer follows the same procedure described earlier. However, for the development of the reclassified raster layer used in the AGL vulnerability index, the classification method is **Quantile**.

NOTE: If fewer than 10 hydraulic conductivity classes are present within the study area, the alternative classification approach should be applied using the same table (see Subchapter 2.4).

Conductivity [m/day]	
Range	Rating
0.05 – 5	1
5 – 15	2
15 – 25	4
25 – 50	6
50 – 100	8
>100	10
C Weight: 3	



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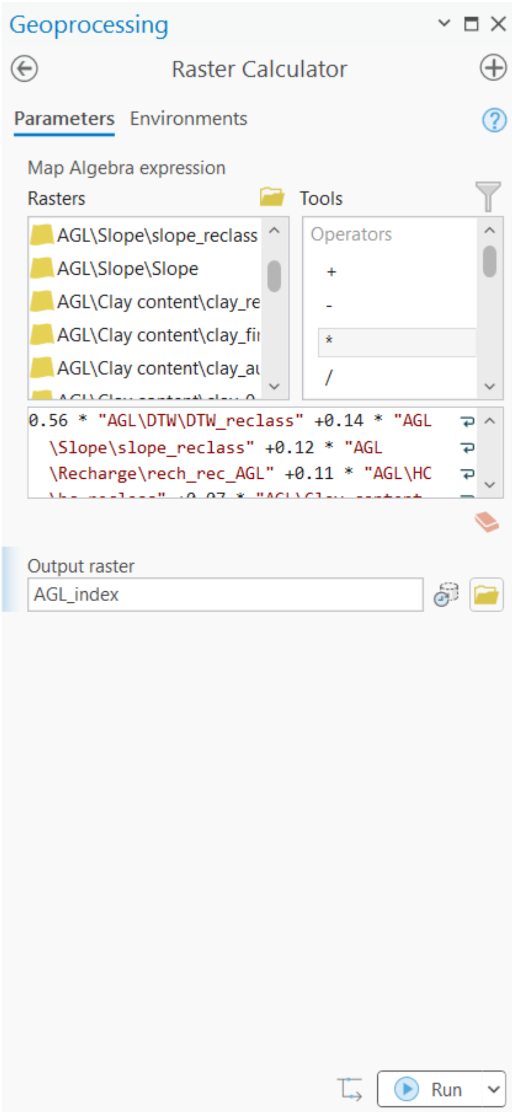
5.10. Calculation of the Agricultural Leaching (AGL) Vulnerability Index (ADI)

To compute the final Agricultural Leaching (AGL) Vulnerability Index, go to: **Analysis → Tools → Toolboxes → Spatial Analyst Tools → Map Algebra → Raster Calculator**.

In the **Raster Calculator** window, insert the **reclassified raster layers** using the following expression:

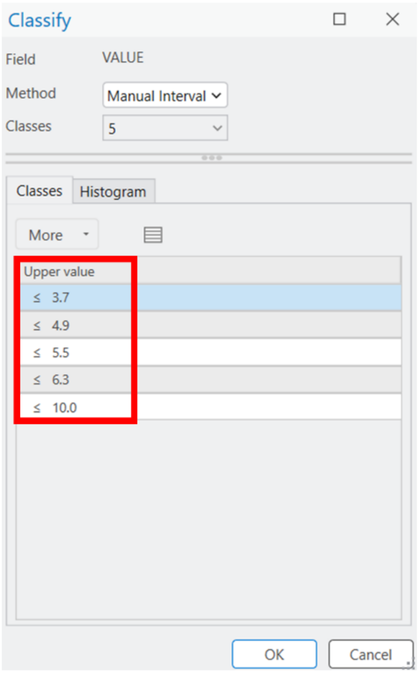
0.56 × Depth to Water + 0.14 × Slope + 0.12 × Recharge + 0.11 × Aquifer Hydraulic Conductivity + 0.07 × Clay (%)

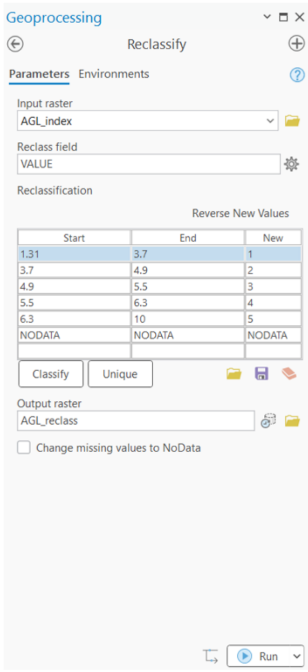
Specify the output file name and location, then click **Run**.

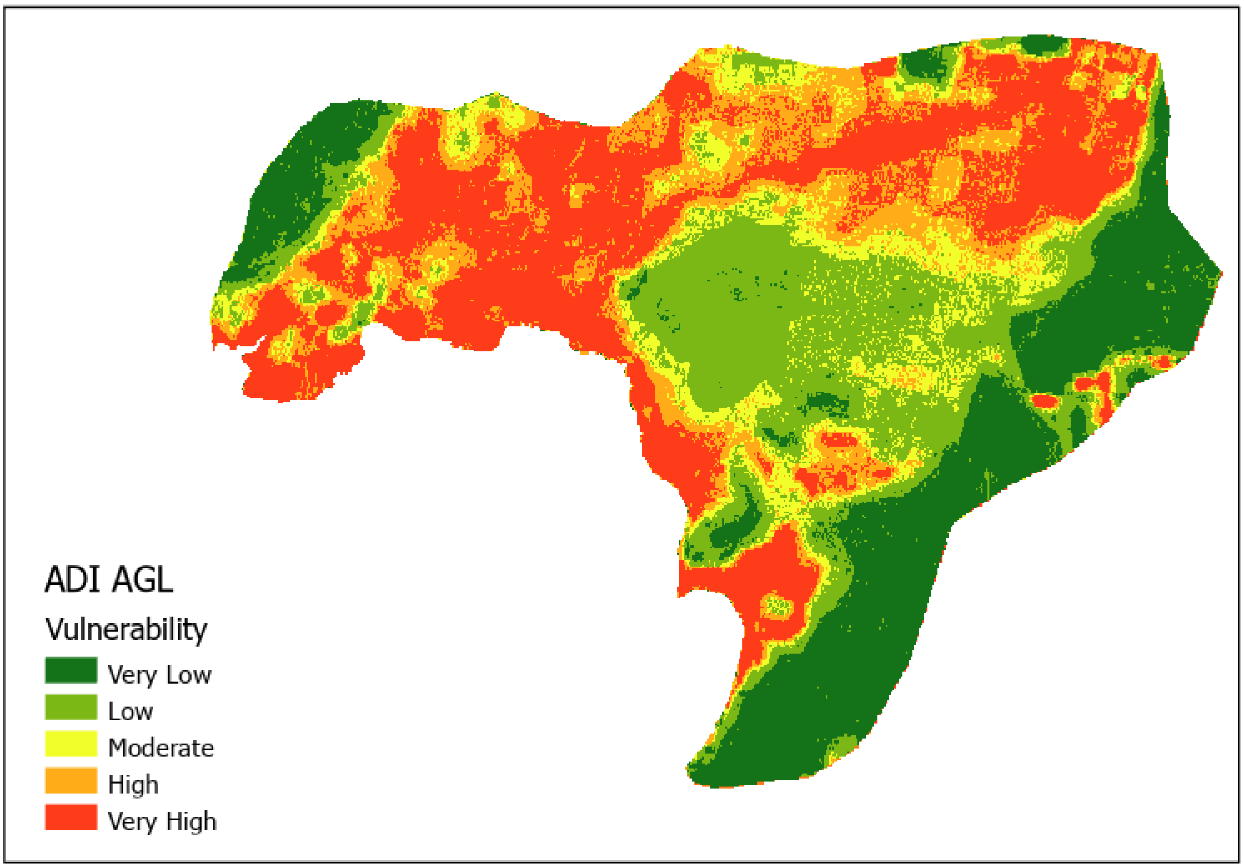


The reclassification of the AGL vulnerability index raster layer follows the same procedure described in Subchapter 2.7.

VULNERABILITY		
CLASSIFICATION	RANGE	VALUE
Very Low	1.0 - 3.7	1
Low	3.7 - 4.9	2
Moderate	4.9 - 5.5	3
High	5.5 - 6.3	4
Very High	6.3 - 10.0	5







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The manual could end with some contact details for support, reference to other deliverables, limitations for use, disclaimer, if you think that is appropriate.