



# Monitoring Pistachio Orchards

## ADVANCED GIS

### About

### Syllabus

#### *Introduction to Spatial Analysis (3 hours lecture)*

- *Common spatial analysis techniques*
- *Introduction to spatial analysis tools in QGIS/WebGIS*

#### *Advanced Spatial Analysis Techniques (3 hours lecture, 3 hours exercises)*

- *Spatial statistics and analyses*
- *Practical exercises in QGIS*

#### *GIS Toolboxes and Plugins (1 hour lecture, 3 hours exercises)*

- *Overview of GIS toolboxes and plugins*
- *Processing Toolbox in QGIS*
- *Practical exercises with GIS toolboxes and plugins*

#### *Building GIS Models I (3 hours exercises)*

- *Introduction to model building in GIS*
- *Model Designer in QGIS*
- *Creating basic models*

#### *Building GIS Models II (4 hours exercises)*

- *Advanced model building techniques*
- *Introduction to Python scripting for GIS*
- *Integrating scripts in models*
- *Practical model building exercises*

#### *Precision Farming with GIS (1 hour lecture, 1 hour exercises)*

- *Introduction to precision farming concepts*
- *Role of GIS in precision farming*

#### *Computing Management Zones (1 hour lecture, 2 hours exercises)*

- *Methods for computing management zones*
- *Practical exercises in computing management zones using FieldCalc/QGIS*

#### *Using Apps to Display and Analyze Sensor Data (3 hours lecture, 2 hour exercises)*

- *Collecting and integrating sensor data in GIS*
- *Case studies using apps for data display and analysis*
- *Practical exercises with sensor data*

*Case Studies and Practical Applications (10 hours lab sessions)*

- *Detailed case studies in precision farming*
- *Project planning and implementation*
- *Real-world applications and success stories*
- *Student-led case study presentations*

*The homework will include: 20 hrs literature analysis, GIS terminology, and individual study.*

## Objectives and Competences

*Course objectives:*

- *To advance students' knowledge in spatial analysis and GIS toolboxes.*
- *To provide skills in building GIS models for complex spatial problems.*
- *To explore real-world applications of GIS, with a focus on precision farming.*
- *To integrate digital tools and apps for data collection, display, and analysis in GIS projects.*

*Competences:*

- *Proficiency in advanced spatial analysis techniques.*
- *Ability to use and customize GIS toolboxes.*
- *Skills in building and implementing GIS models.*
- *Practical experience in applying GIS to precision farming and analyzing sensor data.*

## Intended Learning Outcomes

*Students that will successfully attend the course will be able to:*

- *Conduct advanced spatial analysis using GIS.*
- *Utilize and customize various GIS toolboxes for specific tasks.*
- *Build and apply GIS models to solve spatial problems.*
- *Implement digital tools and apps in precision farming projects.*
- *Analyze and interpret sensor data for agricultural applications.*

## Course Content

### Introduction to Spatial Analysis

Let's first recapitulate some basic terms crucial for this course:

**Geographic information system (GIS)** is a computer-based system to analyse and present spatial data.

**Spatial data** refers to data which cover more than one spatial dimension (2D, 3D, ...).

**Geographic data** (shortly **geodata**) are data representing features or phenomena related to the Earth.

**Analysis** is the process of breaking a complex topic into smaller parts in order to gain a better understanding of it.

**Spatial Analysis** is the quantitative analysis of phenomena, considering the geometric, geographical or topological properties of their elements.

## Spatial Analysis in a Nutshell

Spatial analysis is a component of Geographic Information Systems (GIS), which allows users to examine spatial relationships, patterns and trends in geographic data. Analysis generates new data, and that data can be in the form of new layers, tables or simple values. The result of an analysis might express the same variable as the original data (for instance, computing the average value), or a different one (for instance, if we compute a slope layer from an elevation layer).

Spatial analysis can answer questions like:

- *"Where should a new warehouse be built to minimize delivery times?"*
- *"Which agricultural lands fall within flood-prone zones?"*
- *"How has urban sprawl expanded over the past decade?"*
- *"What is the shortest route for emergency vehicles to reach an accident site?"*

Common spatial analysis techniques include **buffering**, **overlay analysis**, **spatial interpolation**, **network analysis** and **spatial clustering**. Each technique serves a specific purpose and is used across various disciplines to solve real-world problems.

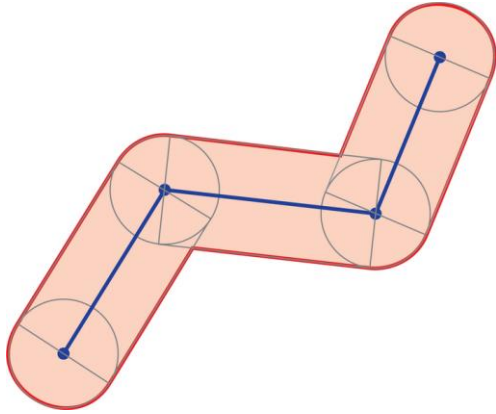
For instance, **buffering** is used to create zones around features, such as a 500-meter buffer around rivers to assess areas at risk of flooding. In urban planning, this technique helps determine the coverage of public facilities, like schools or hospitals, and identify underserved areas. **Overlay analysis** combines multiple layers of data to derive new insights, such as identifying suitable locations for renewable energy projects by overlaying layers of solar radiation, land use and proximity to infrastructure.

**Network analysis** focuses on routing and logistics, commonly used in transportation and emergency services. For example, it helps determine the shortest path for ambulances to reach patients or optimize delivery routes for logistics companies. **Spatial interpolation** is valuable in environmental sciences, where data from weather stations can be interpolated to predict temperature or rainfall across unsampled areas. Similarly, **spatial clustering** methods like hotspot analysis are applied in public health to identify areas with high concentrations of disease outbreaks, enabling targeted interventions.

By employing these techniques, spatial analysis transforms raw geospatial data into actionable insights, supporting decision-making in fields ranging from environmental management and urban development to public health and disaster response.

## Buffer Analysis

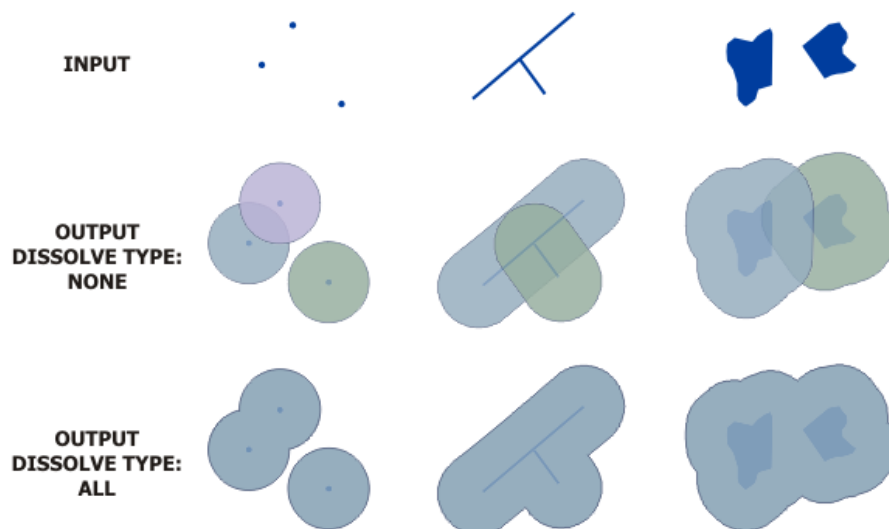
A **buffer** is a zone created around a geographic feature (point, line or polygon) at a specified distance. This zone represents the area of influence or proximity around that feature. Buffer analysis is widely used in GIS for proximity studies and is a foundational spatial analysis tool. Buffer analysis is versatile, forming the foundation for many spatial queries and decision-making processes across fields like environmental science, urban planning, public safety and more.



The principle of creating a buffer of a vector feature. Blue is the original (poly)line, gray are the buffers of individual segments and red is the resulting buffer area of the whole line. Source: Bplewe / CC BY-SA 4.0

### How It Works:

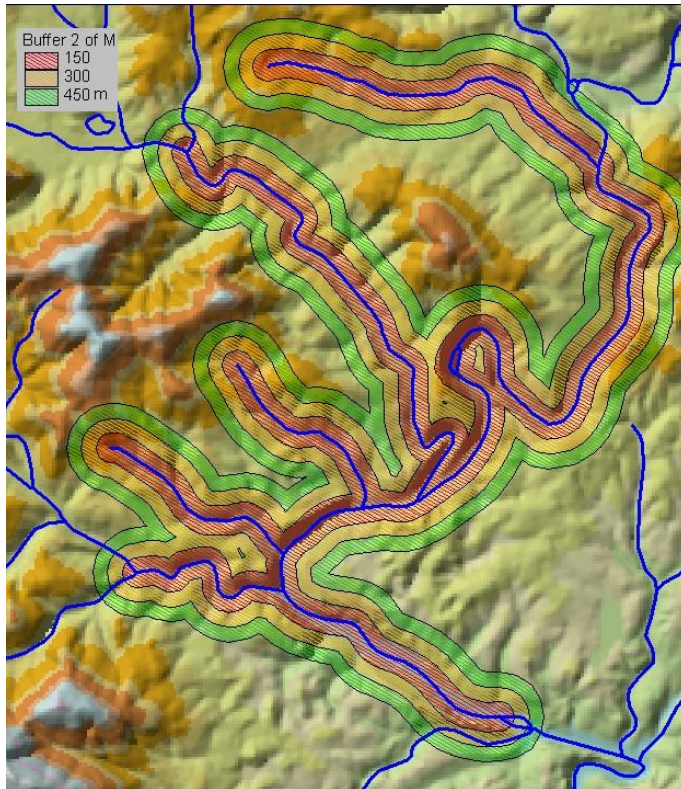
1. **Input Features:** Buffers can be created around points (e.g. a school), lines (e.g. a road) or polygons (e.g. a lake).
2. **Buffer Distance:** A user defines the distance from the feature to determine the extent of the buffer zone. This distance can be uniform (e.g. 1 km buffer for all features) or variable, based on an attribute of the feature (e.g. pollution spread varying with factory size).
3. **Buffer Shape:** Buffers are typically circular around points, elongated along lines or follow the boundary shape for polygons. Advanced GIS tools also allow creating **dissolved buffers**, where overlapping buffer zones merge into one, or **multi-ring buffers**, with multiple zones at increasing distances.
4. **Output:** The result is a new polygon layer representing the buffer zone(s). This can then be overlaid with other data layers for analysis.



*Creating a buffer zone around different types of vector features. From left to right: point features, line features and polygon features. If the resulting buffer zones are dissolved, only one polygon is created in places where the individual buffer zones would overlap (bottom line). Source: ArcGIS Resource Center*

### Examples of Buffer Analysis:

- **Environmental Management:**
  - **Use Case:** Identifying areas at risk of flooding by creating a buffer around rivers.
  - **Workflow:** A buffer of 500 meters around all rivers is overlaid with land-use data to highlight critical zones like residential areas or farmlands.
- **Urban Planning:**
  - **Use Case:** Analyzing public service coverage, such as ensuring schools are within walking distance for communities.
  - **Workflow:** A 1 km buffer is created around schools and overlaid with population density data to identify underserved neighborhoods.
- **Transportation and Safety:**
  - **Use Case:** Evaluating the impact of road construction on nearby habitats.
  - **Workflow:** Buffers of varying widths are created along proposed road alignments to identify zones where construction might disrupt wildlife or sensitive ecosystems.
- **Public Health:**
  - **Use Case:** Assessing the spread of pollutants from industrial facilities.
  - **Workflow:** A buffer zone (e.g. 2 km) is created around factories, and population data is analysed to identify at-risk communities.
- **Emergency Services:**
  - **Use Case:** Optimizing fire station placement to ensure coverage within a specific response time.
  - **Workflow:** Buffers are drawn around existing fire stations based on their average response radius, highlighting gaps in coverage.



*Multi-ring buffer around selected rivers. Rings are created at distances of 150, 300 and 450 metres. The resulting polygons are dissolved. Source: Ticald622 / CC BY-SA 3.0*

Key Considerations:

- **Real-World Accuracy:** Buffer distance should reflect real-world scenarios, such as the actual spread of pollutants or realistic walking distances.
- **Scale and Units:** Ensure consistency in map units (meters, kilometers, etc.) to avoid inaccuracies.
- **Edge Effects:** Buffers near map edges may lead to incomplete zones unless corrected.

## Overlay Analysis

**Overlay analysis** is a fundamental GIS technique used to combine **two or more** spatial datasets to create a new layer that identifies relationships or patterns between them. By stacking spatial data layers (e.g. land use, elevation and soil types), overlay analysis helps in answering complex spatial questions and supports decision-making across various domains. Overlay analysis can be performed with both vector and raster data. Operations of **map algebra** are used for raster data.

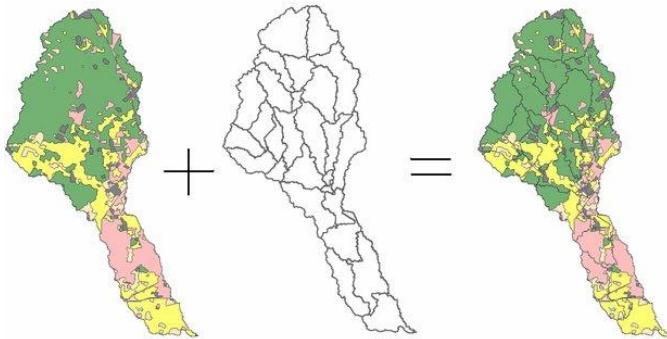
The process involves:

1. **Input Data:** Multiple spatial datasets are needed, typically as vector or raster layers.
2. **Alignment and Projection:** Ensure all layers share the same spatial reference system and alignment.

3. **Overlay Operation:** Layers are combined through mathematical, logical, or spatial operations to produce a new dataset. The result retains attributes and geometry from the input layers, revealing interactions or overlaps.
4. **Analysis:** The derived layer is analyzed to extract insights, identify patterns, or make decisions.

Types of vector overlay analysis:

- **Union:** Combines all input features, retaining all attributes and geometries from both datasets.
  - **Example:** Analyzing land use and administrative boundaries to evaluate how land use patterns align with jurisdictional areas.
- **Intersect:** Retains only the overlapping areas between input datasets, combining attributes where they overlap.
  - **Example:** Identifying regions suitable for agriculture by intersecting layers of fertile soil and areas with sufficient rainfall.
- **Erase:** Removes the overlapping portion of one dataset from another.
  - **Example:** Excluding protected areas from a potential development zone layer.
- **Clip:** Trims one dataset to fit within the boundary of another, maintaining the original data attributes of the clipped features.
  - **Example:** Extracting city-specific road networks by clipping the road layer to city boundaries.



*Intersect overlay combines attributes from both input layers in the smallest common regions. Source: Johnson, Nathan & Maidment, David & Katz, Lynn. (2005). ArcGIS and HSPF model development.*

Types of raster overlay analysis:

- Combines cell values from multiple raster layers using mathematical or logical operations (e.g. addition, subtraction, or Boolean logic).
  - **Example:** Adding rainfall and elevation layers to identify areas prone to landslides.
- Weighted overlay is a common raster analysis where layers are assigned weights based on their importance to the analysis goal.
  - **Example:** Prioritizing conservation areas by combining layers of biodiversity, proximity to water, and human impact, each weighted by its significance.

Examples of Overlay Analysis:

- **Environmental Management:** Identifying flood-prone areas by overlaying layers of elevation, proximity to rivers, and rainfall intensity. This helps in disaster preparedness and land-use planning.
- **Urban Planning:** Selecting the best location for a new park by overlaying population density, land availability, and proximity to existing green spaces.
- **Public Health:** Mapping areas at high risk for mosquito-borne diseases by overlaying layers of stagnant water locations, population density, and temperature suitability for mosquito breeding.
- **Infrastructure Development:** Planning a highway by overlaying layers of land ownership, soil type, and protected environmental areas to minimize conflicts and impacts.
- **Wildlife Conservation:** Determining critical habitats for conservation by overlaying species distribution, vegetation type, and human activity layers.

## Buffer and Overlay Analysis Exercise: Noise Pollution Analysis

**Problem to Solve:** Assess noise pollution impact zones around major roads or highways to guide urban planning.

**Data Needed:**

- **Vector data:** Road network (polylines).
- **Vector data:** Population density or residential areas (polygons).

**Tools in QGIS:**

- **Buffer:** Create noise impact zones around the roads.
- **Intersection or Spatial Join:** Identify residential areas within the noise zones.

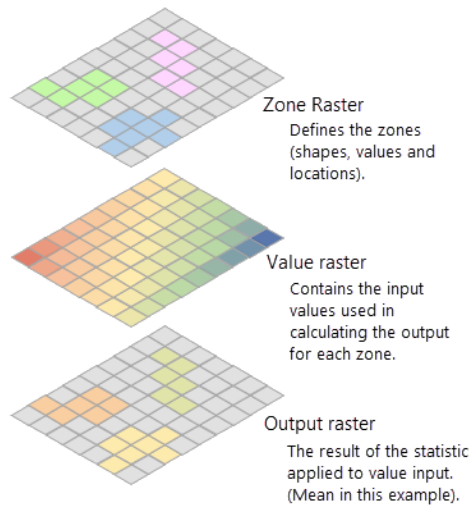
**Workflow:**

1. Load the road network data into QGIS.
2. Use the **Buffer** tool to generate buffer zones around roads (e.g. 100 meters for high traffic roads).
3. Overlay the buffer with residential area polygons using the **Intersection** tool.
4. Visually analyse the output to estimate the population affected by noise pollution.

## Advanced Spatial Analysis Techniques

### Zonal Statistics

Zonal statistics is a spatial analysis technique used in GIS to **summarize the values of a raster dataset within the boundaries** of defined zones. The zones are typically defined by a vector dataset, such as polygons (e.g. administrative boundaries, watersheds) or raster cells with identical values. The goal of zonal statistics is to calculate statistical measures (e.g. mean, sum, minimum, maximum) for the raster values that fall within each zone.



*The principle of zonal statistics with zones defined by raster data. Source: <https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-zonal-statistics-works.htm>*

## Zonal Statistics Exercise: Assessing Vegetation Health

**Problem to Solve:** Assess vegetation health in different regions using vegetation index data (e.g. NDVI).

**Data Needed:**

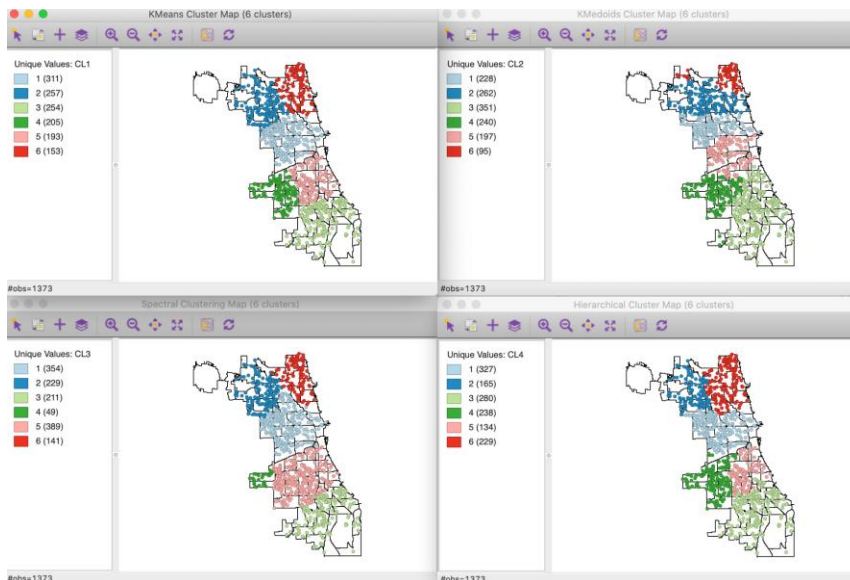
- **Vector data:** Regions or land use zones (e.g. protected areas, farming regions).
- **Raster data:** NDVI (Normalized Difference Vegetation Index) or other vegetation indices.

**Tools in QGIS:**

- **Zonal Statistics:** Use the "Zonal Statistics" tool to calculate the average NDVI value within each region or land use zone.
- **Symbology:** Color-code the regions based on NDVI to highlight healthy vegetation areas and those that may require attention.

## Cluster Analysis

Cluster analysis is a statistical and spatial analysis technique used to **group a set of objects** or observations into clusters or groups based on their similarity or proximity. In GIS, it is often employed to identify patterns, trends, or concentrations in spatial data by analyzing the locations or attributes of features. Cluster analysis can reveal natural groupings, such as crime hotspots, disease outbreaks, or customer demographics. Methods include hierarchical clustering, k-means clustering, and density-based clustering (e.g. DBSCAN). These techniques can be applied to points, polygons, or attributes and are widely used in fields like urban planning, public health, market analysis and environmental studies.



Points divided into 6 clusters by the k-means clusters method. Each result reflects different input parameters of the k-means method. Source: [https://geodacenter.github.io/workbook/9a\\_spatial1/lab9a.html](https://geodacenter.github.io/workbook/9a_spatial1/lab9a.html)

## Cluster Analysis Exercise: Temperature Anomalies and Heat Islands

**Problem to Solve:** Detect urban heat islands or areas experiencing unusual temperature anomalies, which can be used to plan urban cooling strategies.

**Data Needed:**

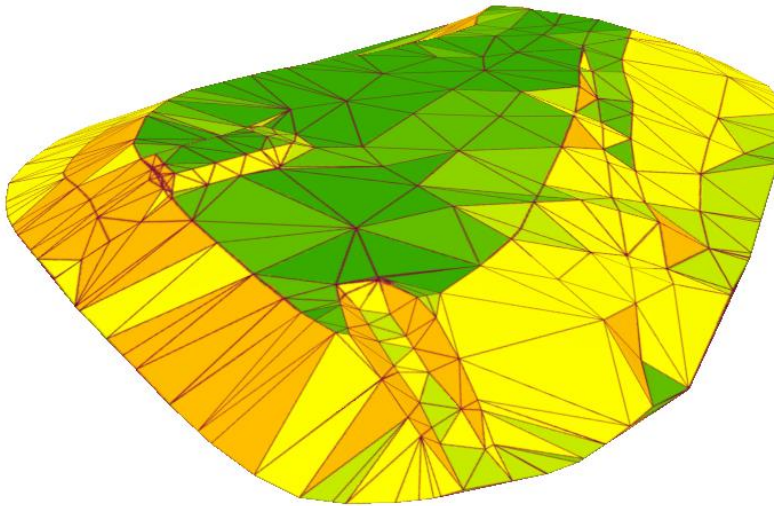
- Temperature data (either from ground stations or remotely sensed data like MODIS or Landsat).
- Urban land cover or population data for context.

**Tools in QGIS:**

- **K-Means Clustering:** Identify clusters of areas with higher-than-average temperature anomalies.
- **DBSCAN:** Use for detecting areas with high-density temperature anomalies.
- **Raster Calculator:** Combine temperature data with urban land cover data to identify temperature hotspots.
- **Symbology:** Style the clusters to highlight areas with the most significant temperature differences.

## Surface Analysis

Surface analysis is a spatial analysis technique used to study and interpret continuous data represented as a surface, typically through raster datasets. It involves analyzing variations across the surface to understand trends, patterns or relationships within the data. Common surface analysis operations include calculating slope and aspect (to study terrain), identifying high and low points (peaks and depressions) and performing viewshed or visibility analysis. These techniques are widely applied in fields like environmental modeling, urban planning, and hydrology. For example, surface analysis can help predict water flow across a landscape, model solar radiation exposure or assess the visibility of landmarks from specific vantage points.



*Surface created by triangulated irregular network (TIN) symbolised by its slope.*

## Surface Analysis Exercise: Identifying Suitable Areas for Solar Panel Installation

**Problem to solve:** Identify areas suitable for solar panel installation based on terrain characteristics such as slope and aspect. Locations with an optimal slope and south-facing aspect are preferred for maximum solar energy capture.

### Data needed:

- **Raster Data:** Digital Elevation Model (DEM) of the study area.
- **Vector Data (optional):** Boundary shapefile for the area of interest (e.g. municipality boundary).

### Tools in QGIS:

- **Slope:** To calculate terrain slope from the DEM.
- **Aspect:** To determine terrain orientation.
- **Raster Calculator:** To apply suitability criteria.
- **Reclassify by Table:** To categorise slopes and aspects into suitability classes.

## GIS Toolboxes and Plugins

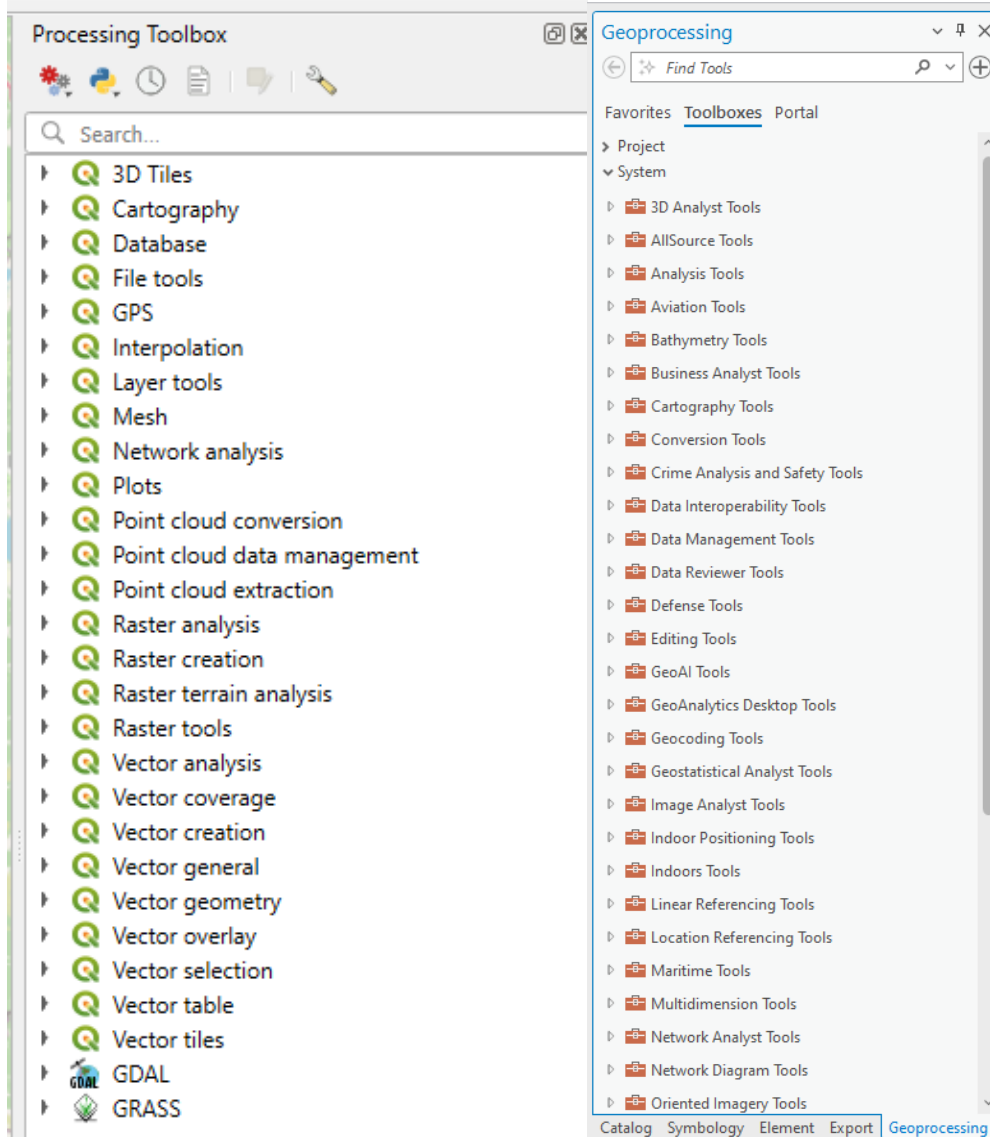
Standard GIS tools provide powerful capabilities for managing, visualising and analyzing spatial data; however, they can sometimes fall short when faced with highly specialized tasks, unique workflows or emerging analytical needs. This limitation arises because built-in tools are designed to cater to general use cases, leaving users seeking solutions for niche or advanced problems. Toolboxes address this challenge by offering a structured set of additional geoprocessing tools, enabling users to perform more complex operations, like spatial statistics, raster modeling or 3D analysis, all within the native environment of the GIS software. For tasks that go beyond even these enhanced functionalities, plugins serve as an invaluable resource. These user-developed add-ons integrate seamlessly into the software,

providing specialized features, connections to external data sources, or entirely new analytical frameworks, allowing users to customise their GIS experience to meet specific project demands. Together, toolboxes and plugins expand the horizons of what GIS can achieve, empowering users to tackle diverse and intricate spatial problems effectively.

A **toolbox** in GIS is a collection of pre-built tools or geoprocessing functions designed to perform specific spatial analysis or data manipulation tasks. It provides a structured way to access built-in capabilities of the GIS software. In **QGIS**: The "Processing Toolbox" includes tools for vector analysis, raster processing and integration with external libraries like GRASS and SAGA. In **ArcGIS**: The "ArcToolbox" provides tools for geostatistical analysis, 3D analysis and network analysis.

A **plugin** in GIS is an add-on or extension that provides additional features, tools or integrations not available in the standard installation of the software. Plugins are often user-developed and community-contributed. Plugins add functionality beyond the built-in capabilities of the GIS software. They require installation, typically through a plugin manager or an online repository. Plugins can be customised or built using programming languages like Python. In ArcGIS: "Spatial Analyst" or "3D Analyst" are plugins (called *extensions* in ArcGIS) which need to be installed separately. In QGIS: "QuickOSM" plugin is often used to download data from OpenStreetMap or "Layman" plugin can be used to communicate with a Layman data catalogue, connecting desktop GIS and WebGIS.

The **Processing Toolbox** in QGIS is a centralized interface for accessing a wide array of geoprocessing tools. It acts as a gateway to native QGIS tools, as well as functionalities from integrated external libraries like **GRASS GIS**, **SAGA GIS**, **GDAL**, and **Orfeo Toolbox**. These tools enable users to perform spatial analysis, data transformation, raster processing, and more.



*The Processing Toolbox in QGIS and Geoprocessing panel in ArcGIS Pro both provide a set of spatial analysis tools divided into groups by their purpose.*

## Using the Processing Toolbox in QGIS

1. **Accessing the Toolbox:**
  - Open QGIS.
  - Go to **Processing > Toolbox** to enable it. It appears as a panel on the side of the QGIS interface.
2. **Searching for Tools:**
  - Use the search bar to quickly locate a specific tool by its name (e.g. "Buffer").
  - Browse through categories to explore available tools.
3. **Workflow for Using Tools:**
  - Input Selection:** Select the input dataset (vector or raster) for the tool. This can be done by browsing through the file system or selecting a layer already loaded in QGIS.
  - Parameter Configuration:** Set the required parameters for the tool. For example:

- For a buffer operation: Define the buffer distance and output layer format.
    - For raster calculations: Enter the algebraic expression and specify the output resolution.
  - **Output Specification:** Choose where to save the output (temporary or permanent layer) and define its format (e.g. GeoPackage, Shapefile, TIFF).
  - **Execution:** Click "Run" to execute the tool. Progress is shown in a log window.
  - **Result Review:** The output layer is automatically added to the Layers panel for visualisation and further analysis.
4. **Batch Processing:**
    - Many tools in the Processing Toolbox support batch processing, allowing users to apply the same operation to multiple datasets simultaneously.
  5. **Model Building:**
    - The Processing Toolbox integrates with the **Model Designer** for creating workflows that chain multiple tools together into automated processes.

## Exercise: Interpolating Temperature Values Across a Study Area

*This exercise demonstrates how to derive meaningful spatial insights from sparse point data, a foundational skill in GIS analysis. Even if you don't have real-world temperature data, a synthetic dataset with a few points can be created to simulate weather station data.*

**Problem to Solve:** Use weather station data to create a temperature surface for a region. Visualise spatial temperature trends and identify areas of high or low temperature by interpolating temperature values. This is useful for applications such as climate analysis, agriculture planning or environmental monitoring.

### Data Needed:

- A set of weather station points (can be a sample dataset or generated synthetically). Each station should have attributes for location (latitude/longitude) and temperature readings (e.g. in °C). Example: CSV file with columns for station name, coordinates and temperature values.

### Tools in QGIS Processing Toolbox:

- **IDW Interpolation** (native QGIS tool) – interpolation algorithm

### Workflow

1. **Prepare the Data**
  - Import the weather station point data (e.g. CSV or shapefile) into QGIS.
  - Ensure the attribute table contains a column for temperature values.
2. **Perform IDW Interpolation**
  - Open the IDW Interpolation tool from the Processing Toolbox.
  - Select the weather station points as the input layer.
  - Choose the temperature attribute for interpolation.
  - Define the extent and resolution of the output raster based on the study area's boundary.
  - Run the tool and save the resulting raster layer (e.g. "Temperature\_IDW").

3. **Visualize the Results**
  - Add the raster layer to the QGIS project.
  - Apply a colour gradient to the layer.
4. **Analyse the Results**
  - Interpret the temperature trends, such as identifying hotspots or areas with cooler temperatures.

## Exercise: Cost Distance Analysis for Optimal Route Planning

**Problem to Solve:** Identify the least-cost path between two locations based on a cost surface, such as terrain slope or land use. Cost distance analysis is often used in transportation planning, ecological studies (e.g. wildlife corridors) and infrastructure development.

### Data Needed:

1. **Raster Data:**
  - Digital Elevation Model (DEM) or land use raster.
2. **Vector Data:**
  - Start and end points (locations) as point layers.

### Tools in QGIS Processing Toolbox:

- **GDAL Tools:**
  - Proximity (Raster Distance):** To compute distance rasters.
- **Raster Calculator:** To create a cost surface.
- **Shortest Path (Point to Layer):** To calculate the least-cost path.

### Workflow

1. **Load the Data**
  - Import the DEM or land use raster and the start/end point vector layers into QGIS.
2. **Create a Cost Surface**
  - If using a DEM: Calculate the slope using the **Slope** tool from the Processing Toolbox.
  - Combine slope and other cost factors (e.g. land use, forested areas) using the **Raster Calculator**. For example, assign higher costs to steeper slopes or restricted areas:  
"slope\_raster" \* 2 + "land\_use\_raster"
  - Save the resulting cost surface as a new raster layer.
3. **Calculate the Cost Distance**
  - Use the **Proximity (Raster Distance)** tool to generate a distance raster from the start point based on the cost surface.
4. **Find the Least-Cost Path**
  - Use the **Shortest Path** tool with the start and end points, referencing the cost surface raster.
  - Save the output as a vector line layer representing the optimal path.
5. **Analyse the Results**
  - Overlay the path with the original cost surface and DEM to visualize the terrain and path efficiency.
  - Optionally, calculate path length or cost using the **Field Calculator**.

## Exercise: Analysing Watershed Delineation

*Standard tools in QGIS do not support hydrological operations like flow direction, accumulation, and watershed delineation, which require specialized algorithms. Tools from GRASS and SAGA GIS integrate seamlessly into the QGIS Processing Toolbox, enabling users to perform these advanced spatial analyses.*

**Problem to Solve:** Identify areas where water accumulates and delineate watersheds to aid in water resource management.

**Data Needed:**

- A Digital Elevation Model (DEM) of the study area.
- River or stream network data (optional, for validation).

**Tools in QGIS:**

**GRASS Tools:**

- **r.watershed:** To compute flow direction, accumulation, and watershed boundaries.

**SAGA Tools:**

- **Catchment Area (Flow Accumulation):** To calculate flow accumulation.
- **Channel Network and Drainage Basins:** To generate stream networks.

**Workflow:**

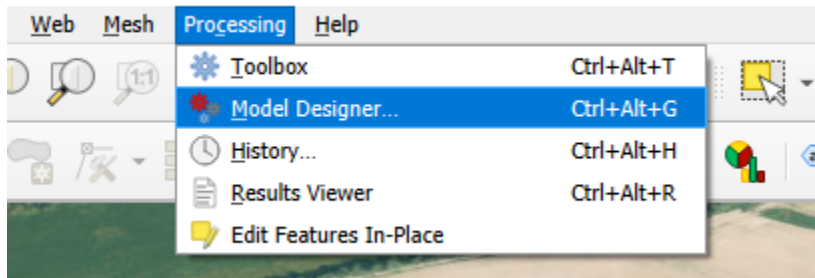
1. **Install SAGA GIS**
  - Download SAGA GIS binaries
  - Install SAGA GIS plugin
  - Enable SAGA tools in the "Processing toolbox"
2. **Load the Data**
  - Import the DEM raster into QGIS.
  - (Optional) Load vector points to define specific outlets or areas of interest.
3. **Preprocessing the DEM**
  - Use the **Fill Sinks (Wang & Liu)** tool from the Processing Toolbox to remove depressions and ensure proper flow direction. Save the output as a new DEM.
4. **Calculate Flow Direction and Accumulation**
  - Use the **r.watershed** tool from GRASS GIS.
  - Input the preprocessed DEM and set thresholds for flow accumulation.
  - Generate output layers for flow direction, accumulation, and streams.
5. **Delineate Watersheds**
  - Use the **Catchment Area (Flow Accumulation)** tool or the **Channel Network and Drainage Basins** tool from SAGA GIS.
  - Define watershed boundaries based on the flow direction and accumulation results.
6. **Analyze the Results**
  - Overlay the watershed boundaries with land use or soil data to assess the impact of water flow.
  - Visualise stream networks to identify potential sites for water management structures like dams or retention basins.

## Expected Outcome:

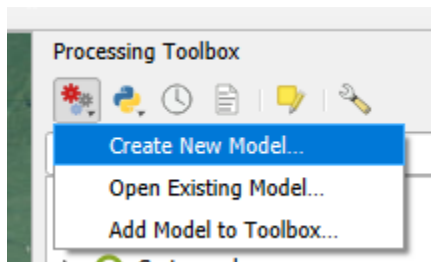
- A map showing delineated watershed boundaries and stream networks.
- Identification of flow accumulation patterns and key drainage basins.
- Insights into water flow dynamics to inform environmental or engineering decisions.

## Building GIS Models I

In GIS, a **model** is a workflow that automates a sequence of geoprocessing tasks to solve a spatial problem or analyze geographic data. Models are typically created using visual interfaces, like the **Model Designer** in QGIS or **Model Builder** in ArcGIS, where users drag and connect geoprocessing tools and input/output data layers. To build a model, you define the input datasets, select the tools for analysis (e.g. buffer, overlay, raster calculation) and configure their parameters, linking them in a logical sequence. Models are invaluable for streamlining repetitive tasks, ensuring consistency in analysis and enabling non-technical users to run complex workflows without manual intervention. They also make workflows more transparent, easy to share and reproducible.



*Model Designer in QGIS is located under the “Processing” menu.*



*Alternatively, a new or existing model can be also opened from the “Processing Toolbox” panel.*

Every new model starts with an empty canvas. You start creating a model by adding items into the canvas and connecting them together into a workflow. There are two types of items which form a model: **inputs** and **algorithms**.

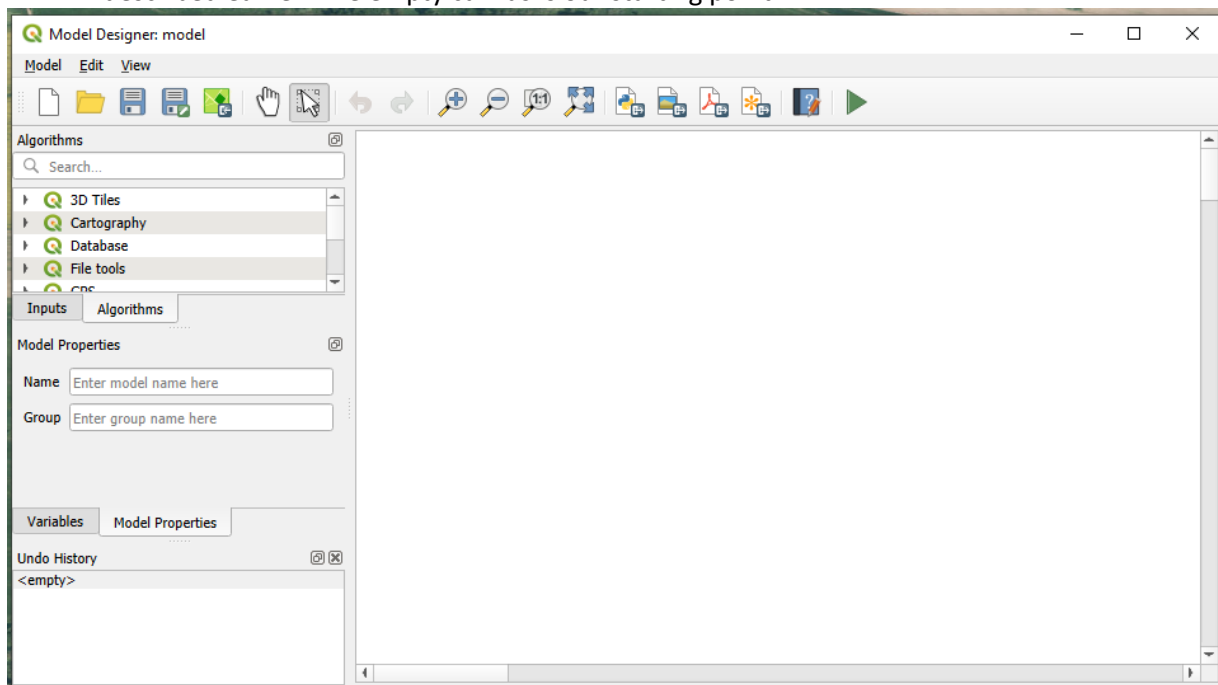
- **Inputs** are the layers, values and properties which can be changed with every run of the model. Inputs are exposed via the user interface of the model when executed and any user running the model can select inputs of the model suited to their needs. Inputs can be mandatory (e.g. a layer to be used for processing) or optional.
- **Algorithms** are the processing tools used to perform the desired workflow. They are the business logic. Algorithms depend on the inputs defined for the model. In contrast to inputs, algorithms cannot be changed when running the model – to make a change in the algorithms in the model, one has to *edit* the model (hence creating a different version of the model).

Inputs and algorithms are connected into a sequence of tasks like a chain. The result of a model is called an **output** and is usually in the form of a new layer or layers, although it can also be just a selection or change of existing layer(s).

## Tutorial: Cost Distance Analysis for Optimal Route Planning, the Model Approach

In one of the previous examples, the task was to perform a cost distance analysis for optimal route planning. We will now reuse that example and create a model capable of performing some of the sub-tasks in one step, thus simplifying the process.

1. Let's create a new model by opening the "Model designer" from the "Processing" menu, as described earlier. The empty canvas is our starting point.

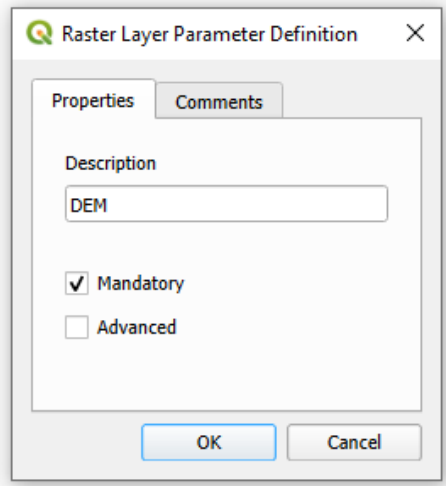


*A new and empty model in QGIS's Model Designer.*

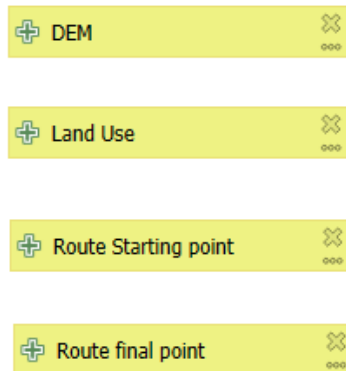
2. We will be creating our model in the order from inputs to the outputs. So first, define the inputs of the model. In our case, these are:
  - a. digital elevation model ("DEM"),
  - b. land use raster,
  - c. route starting point and
  - d. route final point.

Inputs can be added to the model from the list on the side of the Model Designer. Every input must be defined by the type of data it provides. So we will add our inputs as these types:

- a. digital elevation model ("DEM") – Raster Layer,
- b. land use raster – Raster Layer,
- c. route starting point – Point
- d. route final point – Point.

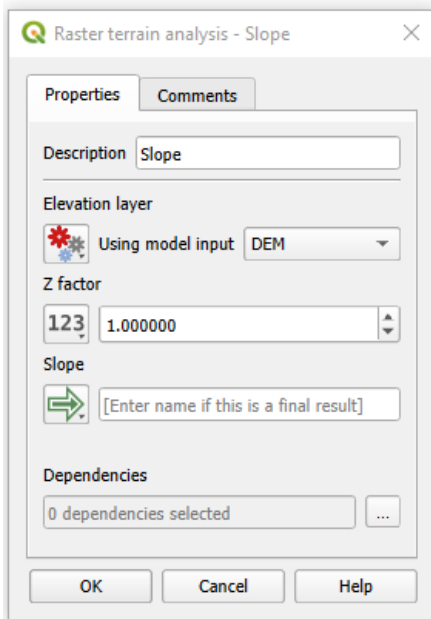


*Defining a DEM input as a raster layer, which is mandatory to run the model.*



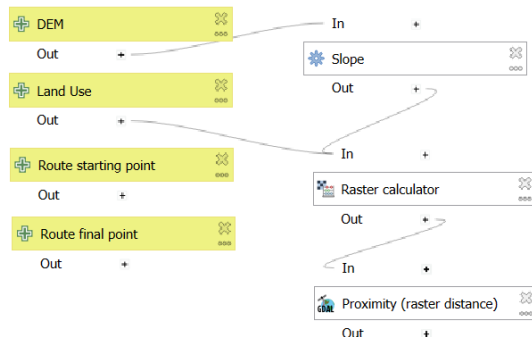
*Four model inputs. For now without any mutual connection.*

3. As a next step, add the necessary algorithms in the model. They can be dragged and dropped from the “Algorithms” list on the side of the Model Designer or added with a double-click. In our task, we need algorithms:
  - a. “Slope”,
  - b. “Raster Calculator”,
  - c. “Proximity (Raster Distance)” and
  - d. “Shortest Path”.
4. Every time an algorithm is added to the model, its parameters must be filled. This connects the algorithms with the inputs.



*Defining a Slope algorithm with the “DEM” model input as the elevation layer to use for calculating the slope.*

- When an input is connected to an algorithm and then to another algorithm, the individual parts are connected with lines.



*A ready-to-use model with interconnected inputs and algorithms.*

## Building GIS Models II

The possibilities with Model Designer go far beyond simple automation. You can create **custom GIS tools** by designing a model that combines multiple algorithms into a single, reusable process. These models can include branching logic, allowing for different processing paths depending on user-defined parameters. They can also integrate both raster and vector processing in the same workflow, making them useful for tasks such as suitability analysis, environmental monitoring, urban planning, and terrain analysis. Once built, a model can be saved and run like any other tool in the Processing Toolbox, or even shared with colleagues as a file. This means that Model Designer is not just a time-saver, but also a bridge between routine GIS operations and advanced, repeatable workflows that can be integrated into larger projects, ensuring accuracy and efficiency in spatial analysis.

## Python scripting in QGIS

In QGIS, the Model Designer and Python programming language work hand in hand through the Processing Framework, which means a workflow you create visually can be transformed into a **Python script** — and a Python script can be turned back into a model — with very little extra work.

When you finish building a model in the Model Designer, you can save it as a `.model3` file (the native QGIS model format) and then export it as a Python script directly from the Model Designer interface using the “**Export as Python script**” option. This generates a `.py` file containing a self-contained Python function that calls the same algorithms and uses the same parameters as your model. This is useful when you want to extend the model’s capabilities, integrate it into larger Python-based workflows, run it headlessly (e.g., in batch mode without opening QGIS), or deploy it as part of a plugin.

The reverse is also possible, though slightly less direct. If you have a Python script that uses the `processing.run()` or `processing.runAndLoadResults()` commands to execute a series of algorithms, you can **recreate the same logic in the Model Designer** by adding the equivalent tools and connecting them in the same sequence. While QGIS does not have an “import Python as model” button, you can follow the script step by step, adding each tool, input, and output into the Model Designer. This approach is particularly helpful when converting scripts created by others into an easy-to-use visual workflow for non-programmers.

By moving between models and Python scripts, you can take advantage of the strengths of both worlds: the clarity and accessibility of the visual Model Designer, and the flexibility and automation power of Python. This makes it possible to adapt workflows for different audiences — from technical GIS analysts to casual users who just want to click “Run” on a well-prepared tool.

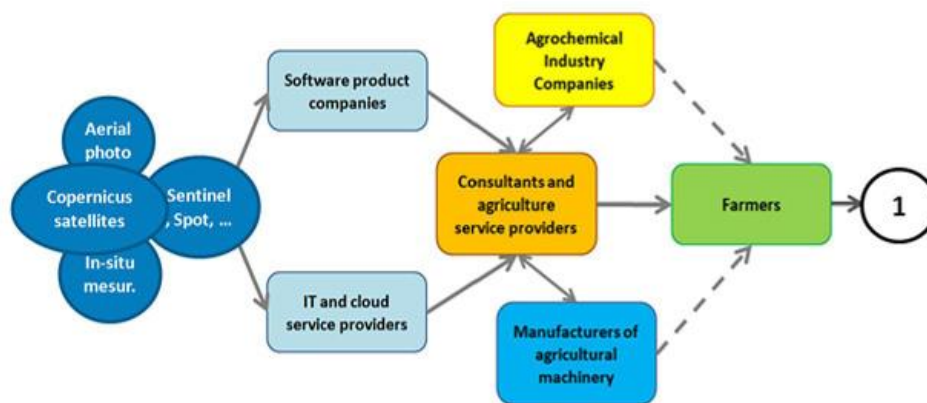
In QGIS, you can integrate your own **Python scripts** directly into a model built with the Model Designer by treating the script as a **custom processing algorithm**. The process works like this: first, you need to create your Python script in the **Processing Script Editor** (found in **Processing Toolbox** → **Create New Script**). Your script must follow the QGIS Processing Framework syntax, meaning it should define a class derived from `QgsProcessingAlgorithm` and implement methods such as `initAlgorithm()`, `processAlgorithm()`, and `name()`. In the script, you can define **input parameters** (e.g., layers, numbers, strings) and **outputs** just like any built-in QGIS tool. Once the script is saved in your QGIS profile’s `processing/scripts` folder, it will automatically appear in the **Processing Toolbox** under the “Scripts” group.

When building your model in the Model Designer, you can now drag your Python script from the **Scripts** section of the Processing Toolbox into the model canvas, just like any other algorithm. You can connect it to preceding steps by linking its inputs to the outputs of earlier tools in the model, and you can pass its outputs to later tools in the chain. This way, the Python code becomes just one step in a larger automated workflow, allowing you to handle special calculations, custom logic, or integrations with external systems that standard QGIS tools can’t easily provide.

This approach is particularly powerful when you have **specialized code** — for example, a custom statistical calculation or data transformation — and you want it to be reusable, parameterized, and accessible within a no-code model interface. It bridges the flexibility of Python with the visual logic of the Model Designer, making your workflows both **programmable** and **user-friendly**.

## Precision Farming with GIS

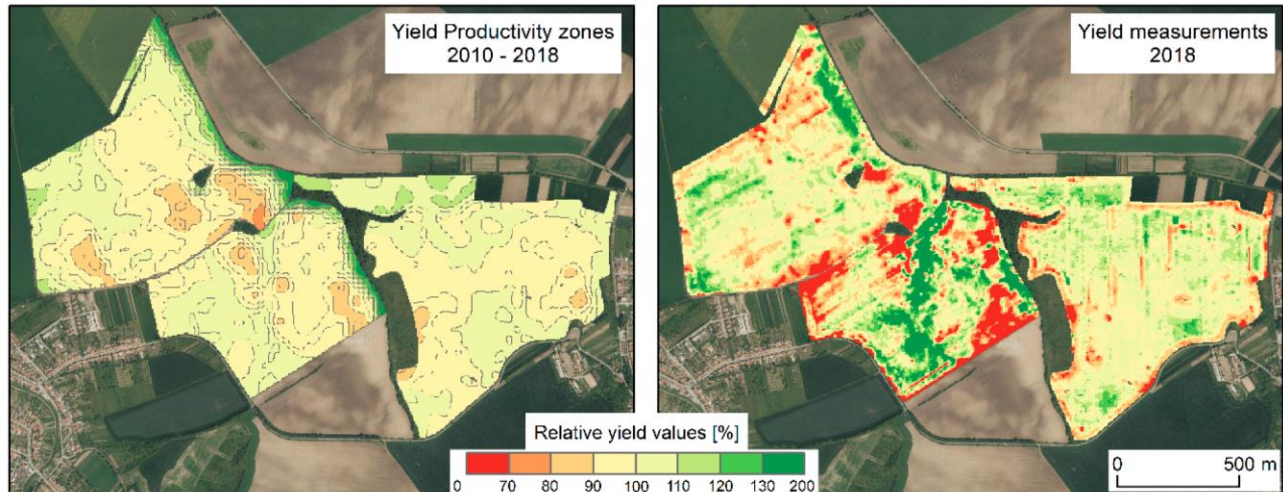
Precision farming, also known as **site-specific crop management** or **precision agriculture**, represents a cutting-edge approach to modern agriculture. It integrates **advanced technologies to optimise the use of resources, improve crop yields and minimise environmental impacts**. Definitions of precision farming vary, but they converge on its core principles of **efficiency and sustainability**. Some define it as a management practice focused on utilising precise information to increase profitability. Others emphasize its environmental dimension, describing it as the application of technologies and principles to manage spatial and temporal variability for better crop performance and ecological benefits. From a technological perspective, it involves **monitoring, analysing and controlling plant production to balance cost and ecological impact**. Precision farming enhances resource efficiency by minimizing waste and reduces the environmental footprint of farming practices. An integrated view highlights the use of high-precision positioning systems, geospatial mapping and variable rate technologies.



*Actors in the field of precision farming. From data providers to farmers. Source: Šafář, V. et al. (2022). The Role of Remote Sensing in Agriculture and Future Vision. Agris On-line Papers in Economics and Informatics. XIV. 107-124. 10.7160/aol.2022.140109.*

Precision farming relies on several key methods. Site-specific crop management tailors agricultural interventions to the unique characteristics of different zones within a field, using tools like **GIS and remote sensing to map spatial variability**. Variable rate technology enables the **precise application** of inputs such as fertilizers and pesticides, adjusted to the specific needs of various field areas. Remote sensing, through satellite and drone imagery, provides real-time insights into crop health, soil moisture and vegetation indices, enabling the early detection of stress factors such as nutrient deficiencies or diseases.

Another critical method is **yield mapping**, which combines GNSS with yield monitors on harvesting equipment to document spatial variations in productivity. This data informs future management strategies to enhance underperforming zones. Soil and crop sensing technologies measure vital parameters like soil moisture, nutrient content and pH levels, while advanced sensors assess crop nutrient levels and recommend suitable interventions.

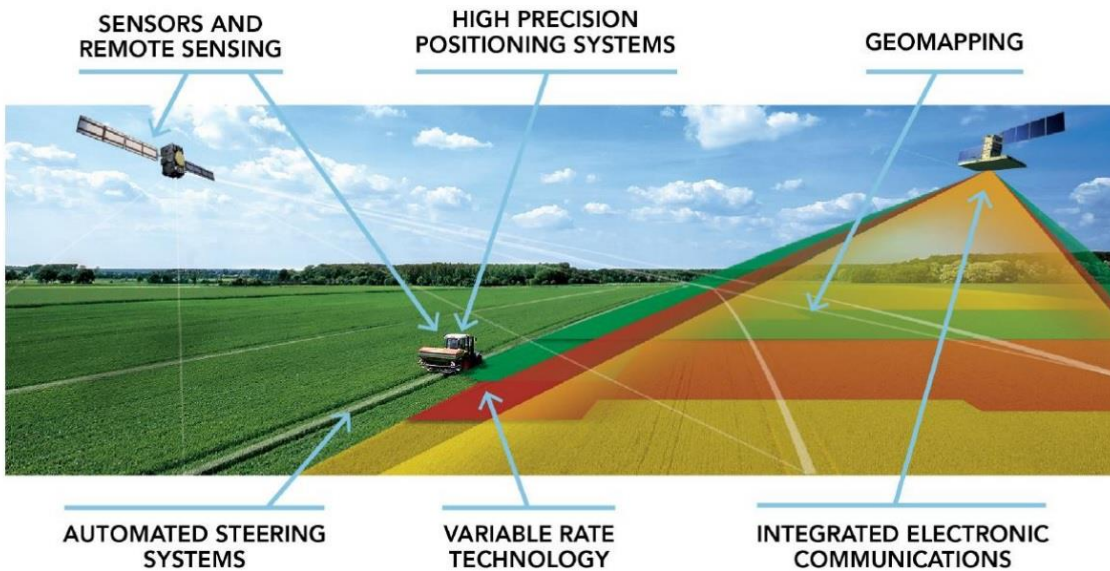


*The analysis of yield productivity zones: yield productivity zone prediction derived from satellite images (left) and the map of yield measurements as computed by a harvester (right). Source: Řezník, T. et al. (2020). Prediction of Yield Productivity Zones from Landsat 8 and Sentinel-2A/B and Their Evaluation Using Farm Machinery Measurements. Remote Sensing, 12(12), 1917. <https://doi.org/10.3390/rs12121917>*

**Decision support systems** play a central role in precision farming by integrating field data, weather forecasts and historical trends to optimize decisions on planting, irrigation and fertilisation. Geospatial analysis and mapping further enhance precision by providing detailed spatial layers, including soil types, elevation and water availability. The integration of Internet of Things (IoT) and big data analytics allows continuous data collection from the field, offering actionable insights that improve precision in resource allocation and intervention timing.

## Methods of Precision Farming

Precision farming employs a variety of advanced methods designed to optimise agricultural practices, increase efficiency and minimize environmental impacts.



*Technologies of precision farming. Source: <https://kas32.com/en/post/view/332>*

One of the fundamental methods is **site-specific crop management (SSCM)**, which involves tailoring agricultural practices to the unique conditions of specific zones within a field. This method is enabled by detailed mapping of spatial variability using geospatial technologies like GIS and remote sensing. By understanding differences in soil composition, moisture levels and nutrient availability, SSCM allows for customized interventions in each zone.

**Variable Rate Technology (VRT)** is another cornerstone of precision farming. It adjusts the application of inputs such as seeds, fertilisers and pesticides according to the precise requirements of different areas within a field. This technique reduces input waste, enhances crop productivity, and minimises the risk of overapplication, which can harm the environment.

**Remote sensing** plays a critical role in providing real-time data about crop health, soil moisture and vegetation status. Through satellite, aerial or drone imagery, remote sensing technologies enable farmers to monitor large areas quickly and detect potential problems such as nutrient deficiencies, pest infestations or water stress early. This timely information supports better decision-making and targeted interventions.

**Yield mapping** involves the use of GNSS-enabled yield monitors on harvesting equipment to record the spatial variations in crop output across a field. These maps help identify high- and low-performing areas, providing insights for optimizing future farming practices and addressing specific issues that limit productivity.

**Soil and crop sensing** technologies are crucial for understanding the precise conditions of the field. Sensors measure critical parameters such as soil pH, moisture levels, organic matter content and nutrient availability. Crop sensors assess the health and nutrient needs of plants, guiding variable-rate application of inputs.



*An integrated soil sensor measuring soil pH, moisture, temperature and conductivity.*

**Decision support systems (DSS)** integrate data from various sources, such as weather forecasts, soil analysis and crop growth models, to provide actionable recommendations. These systems use advanced algorithms to help farmers make informed decisions about planting schedules, irrigation strategies and pest control measures.

**Geospatial analysis and mapping** enhance the precision of farming practices by generating detailed spatial layers of field attributes, such as elevation, soil type and water retention capacity. These layers inform planning and implementation, ensuring that resources are allocated optimally across the field.

The integration of **Internet of Things (IoT)** devices and **big data analytics** has revolutionised precision farming. IoT devices, such as soil moisture probes and climate stations, continuously collect field data. This data is processed using big data technologies to identify patterns and trends, improving the timing and accuracy of agricultural interventions.

**Automation and robotics** are increasingly utilized in precision farming, enabling tasks such as planting, spraying and harvesting to be performed with high accuracy. Automated machinery often operates using GNSS guidance, ensuring consistent performance and reducing human error.

Lastly, **on-farm experimentation and adaptive management** are integral to precision farming. Farmers use data to test and refine strategies, ensuring that practices remain responsive to changing conditions and field-specific dynamics.

Through these methods, precision farming achieves its goals of enhancing productivity, reducing costs and promoting environmental sustainability. By addressing the variability within fields and applying resources only where needed, these techniques ensure that modern agriculture meets the growing demands of a changing world.

## Role of GIS in Precision Farming

Geographic Information Systems (GIS) are central to precision farming, enabling the efficient integration, analysis and visualization of spatial data to optimise agricultural practices. When combined with **remote sensing**, **Internet of Things (IoT) data analysis**, **cloud computing** and **emerging GeoAI technologies**, GIS transforms agricultural management into a data-driven, sustainable and future-ready domain.

GIS supports **spatial mapping and analysis**, creating detailed maps that reveal variability within fields, such as soil properties, moisture levels and crop health. These maps guide site-specific management, enabling precise interventions. Remote sensing enhances GIS by providing high-resolution imagery from satellites and Unmanned Aerial Vehicles (UAVs) to monitor vegetation health, detect diseases and assess water stress. For example, vegetation indices such as NDVI derived from remote sensing are processed in GIS to identify underperforming zones and direct resources where they are most needed.

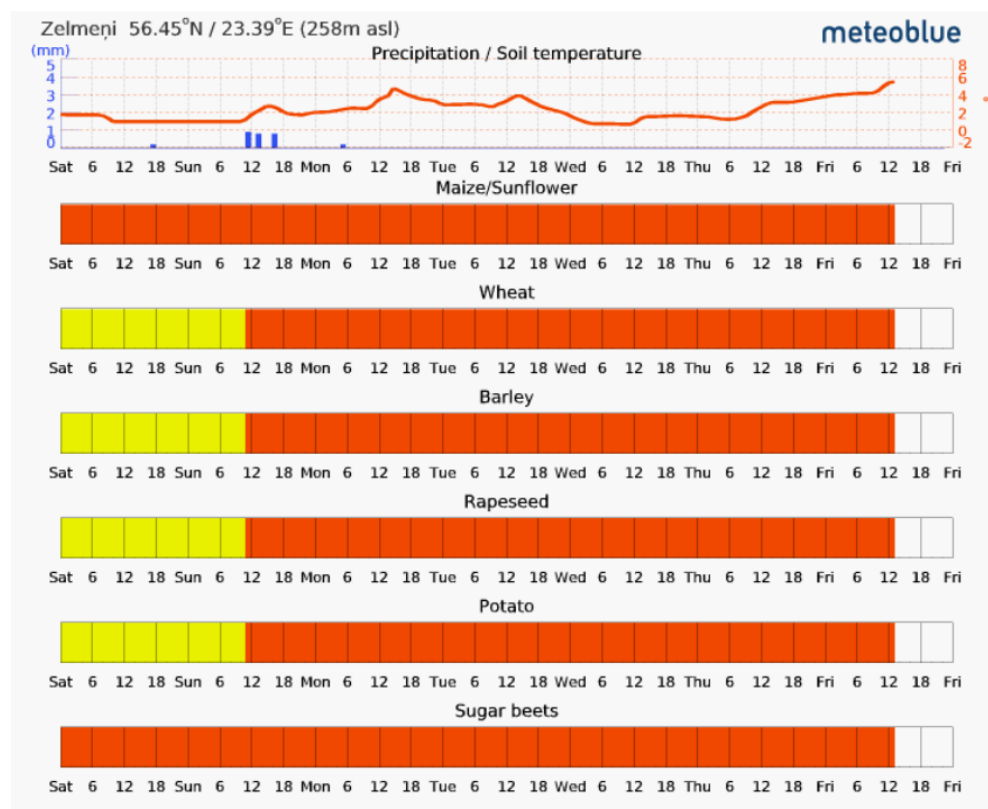
The integration of **IoT data analysis** into GIS further expands its capabilities. IoT devices, including soil moisture sensors, weather stations and crop health monitors, generate vast quantities of real-time data. GIS serves as a platform to process and analyse this data spatially and temporally, transforming raw inputs into actionable insights. For example:

- **Soil and Weather Monitoring:** IoT data on soil moisture and weather conditions is overlaid in GIS to optimise irrigation schedules.
- **Predictive Maintenance:** Data from farm machinery is analysed to predict maintenance needs and prevent downtime.
- **Dynamic Decision-Making:** Real-time IoT data feeds into GIS-driven models to adjust field operations dynamically in response to changing conditions.

**Data integration and cloud computing** enhance the scalability and accessibility of GIS in precision farming. By storing and processing vast datasets on the cloud, GIS platforms support collaborative decision-making and enable stakeholders to access critical insights remotely. Cloud computing also powers advanced analytics, such as big data processing and predictive modeling.

GIS aids in **decision-making and resource optimisation** by combining spatial data with advanced predictive models. This ensures the precise application of inputs such as fertilisers and pesticides, reducing waste and costs. Variable rate technology, guided by GIS insights, applies resources only where needed, enhancing efficiency. Scenario analysis tools within GIS allow farmers to simulate various strategies, assessing their potential outcomes before implementation.

## Sowing window



*Based on a development of soil temperature and precipitation, the sowing window shows how suitable are time intervals in the upcoming 7 days for sowing different corn species in the area of interest. The scale goes from suitable (green) to unsuitable (red). Source: <https://groundwater.smartagro.lv>*

Through **continuous monitoring and feedback**, GIS integrated with IoT and remote sensing data provides a dynamic view of field conditions. Real-time insights enable early detection of issues such as pest outbreaks or nutrient deficiencies. Additionally, GIS evaluates the effectiveness of applied practices, facilitating ongoing refinement and improvement.

GIS drives **environmental and economic sustainability** by reducing chemical usage, conserving water and maximising productivity. Targeted interventions minimize environmental impacts, while efficient resource use enhances profitability by lowering costs and improving yields.

Looking ahead, **GeoAI (Geospatial Artificial Intelligence)** is revolutionising GIS in precision farming. By leveraging machine learning and AI, GeoAI enables advanced analytics of geospatial and IoT data to identify patterns, predict trends and support real-time decision-making. For instance:

- **Predictive Analytics:** GeoAI forecasts crop yields, pest outbreaks and weather impacts with high precision.

- **Automated Data Processing:** AI algorithms process remote sensing and IoT data rapidly, providing actionable insights without manual intervention.
- **Climate Resilience:** GeoAI predicts the long-term impacts of climate change on agriculture, helping farmers adapt proactively.

The fusion of GIS, remote sensing, IoT data analysis, cloud computing and GeoAI is reshaping precision farming. These technologies enable modern agriculture to be more efficient, sustainable and resilient, addressing current challenges while preparing for future demands.

## Exercise: Analysis of NDVI in QGIS

**Problem to Solve:** Create variable rate application zones for precision farming by analyzing crop health variability using the Normalized Difference Vegetation Index (NDVI) derived from remote sensing data. Identify areas of low, medium, and high vegetation health.

### Data Needed:

- **Remote Sensing Data** – Multispectral imagery with at least two bands: red (R) and near-infrared (NIR). Data can come from satellites (e.g. Sentinel-2) or drones.

### Tools in QGIS Processing Toolbox:

- Raster Calculator: To calculate NDVI.
- Reclassify by Table: To classify NDVI values into zones.

### Workflow:

- 1. Load the Data**
  - Import the multispectral imagery (R and NIR bands) into QGIS.
  - Load the field boundary layer if available to limit the analysis to the area of interest.
- 2. Calculate NDVI**
  - Use the Raster Calculator to compute the NDVI using the formula:  $(NIR - Red) / (NIR + Red)$
  - Save the output as a new raster layer (e.g. "NDVI").
- 3. Classify NDVI into Zones**
  - Use the Reclassify by Table tool to classify NDVI values into three or more categories (e.g., low, medium, high vegetation health).
  - Define thresholds based on the NDVI range (e.g. low: 0-0.3, medium: 0.3-0.6, high: 0.6-1.0).
  - Save the output as a new raster layer (e.g. "NDVI\_Zones").
- 4. Create a Prescription Map**
  - Convert the classified NDVI raster into vector polygons using the **Raster to Polygon** tool.
- 5. Export Results**
  - Export the prescription map as a shapefile or GeoJSON for use in variable rate application equipment.

# Computing Management Zones

**Management zones** are spatially defined areas within an agricultural field that exhibit relatively homogeneous characteristics in terms of soil properties, vegetation health, and yield potential. These zones are delineated based on the natural variability of the field, which arises from differences in factors such as soil composition, topography, moisture availability, and historical crop performance. By identifying and managing these zones, farmers can optimize the application of inputs, such as fertilizers, water, and pesticides, to meet the specific needs of each area, leading to improved productivity, cost savings, and environmental sustainability.

The concept of management zones is central to precision agriculture, as it addresses the inherent heterogeneity of fields that traditional farming methods often overlook. Instead of treating the entire field uniformly, management zones allow for site-specific interventions, ensuring that resources are allocated where they are most needed. This targeted approach not only enhances crop growth and yield but also minimizes the wastage of inputs and reduces environmental impacts, such as nutrient runoff or overuse of chemicals.

The delineation of management zones relies on various data sources and analytical techniques. **Yield maps** generated from harvesters equipped with GPS and yield sensors provide a historical perspective of crop productivity across the field. These maps help identify areas that consistently perform above or below average. Remote sensing data, such as satellite imagery, is used to calculate vegetation indices like NDVI and EVI, which reflect plant health and biomass. These indices are particularly useful for detecting spatial variability in vegetation during the growing season.

In addition to yield and vegetation data, soil sampling plays a crucial role in defining management zones. Soil analyses provide detailed information on nutrient levels, pH, organic matter content, and other physical and chemical properties that influence crop growth. Digital Elevation Models (DEMs) add another layer of insight by revealing topographic features such as slope and aspect, which affect water distribution and erosion patterns.

Management zones are typically categorized into areas of high, medium, and low productivity potential. For instance, high-productivity zones may receive higher doses of fertilizers and water to maximize yields, while low-productivity zones may be managed differently to address underlying limitations, such as nutrient deficiencies or poor drainage. This approach can also involve choosing different crops or crop varieties better suited to the specific conditions of each zone.

The delineation and management of these zones are further enhanced by advanced technologies such as Geographic Information Systems and machine learning algorithms. GIS integrates and analyzes multiple layers of spatial data to create precise management zone maps. Machine learning models can identify patterns and cluster similar areas into zones with high accuracy, even in large and complex datasets.

In practice, management zones serve as the foundation for **Variable Rate Application (VRA)** strategies, where the application of inputs is tailored to the requirements of each zone. For example, in nitrogen fertilization, zones with high yield potential may receive higher rates of nitrogen, while low-potential zones are given lower rates to avoid waste and environmental harm.

Overall, management zones provide a systematic way to address field variability, enabling farmers to make data-driven decisions that enhance agricultural efficiency and sustainability. By focusing on the

specific needs of each part of the field, this approach aligns with the goals of modern precision agriculture, offering both economic and ecological benefits.

FieldCalc is a specialized software tool designed to support precision agriculture by enabling the calculation, visualization, and application of management zones. It provides a platform for integrating diverse agricultural data, analyzing spatial variability, and creating actionable outputs, such as Variable Rate Application (VRA) maps, that are directly compatible with modern agricultural machinery.

## Key Functionalities of FieldCalc

1. **Integration of Diverse Data Sources:** FieldCalc supports the integration of various datasets, including satellite imagery (e.g., Sentinel-2, Landsat), soil analysis data, yield maps, and terrain data like Digital Elevation Models (DEMs). These datasets are essential for understanding field variability and defining zones with homogeneous characteristics.
2. **Computation of Vegetation Indices:** FieldCalc enables the calculation of vegetation indices such as NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) from satellite imagery. These indices provide insights into plant health, biomass, and stress levels, which are critical for identifying areas with different productivity potentials.
3. **Clustering and Delineation of Management Zones:** Using clustering algorithms like K-Means, FieldCalc groups areas within a field that exhibit similar characteristics into management zones. These zones are refined through user-defined parameters and agronomic knowledge to ensure practical and effective implementation.
4. **Creation of Variable Rate Application (VRA) Maps:** FieldCalc translates management zones into VRA maps, which assign specific input recommendations (e.g., fertilizer rates, irrigation schedules) to each zone. These maps are formatted for use with variable rate agricultural machinery, ensuring accurate and efficient application of resources.
5. **Support for Decision-Making:** By analyzing spatial data and providing visual outputs, FieldCalc assists farmers and agronomists in making informed decisions. This includes planning interventions tailored to the unique characteristics of each management zone.
6. **Real-Time and Historical Data Analysis:** FieldCalc allows the incorporation of real-time data from IoT devices, such as soil moisture sensors or weather stations, to adjust zones dynamically. Additionally, it supports historical analysis, such as multi-year yield variability studies, to inform long-term field management strategies.
7. **User-Friendly Interface:** The software is designed with a focus on usability, providing intuitive tools for data visualization, map customization, and export functionality. It ensures accessibility for users with varying levels of technical expertise.
8. **Cloud and API Integration:** FieldCalc can connect with cloud-based platforms and APIs to access remote sensing data or share results. This feature enhances collaboration among stakeholders, such as agronomists, farmers, and advisors.

## Applications of FieldCalc:

- **Precision Fertilisation:** Creating maps to guide site-specific fertiliser application based on nutrient needs.
- **Irrigation Management:** Optimising water use by delineating zones with different moisture requirements.

- **Yield Optimisation:** Identifying and managing high- and low-yield zones to maximize overall productivity.
- **Sustainability Practices:** Minimizing environmental impact by reducing excess input applications in sensitive areas.

FieldCalc is an essential tool for precision farming, enabling data-driven management of agricultural fields. Its functionalities streamline the process of analysing spatial variability and translating insights into practical actions, helping farmers optimize resource use, enhance yields and achieve sustainability goals.

## Using Apps to Display and Analyze Sensor Data

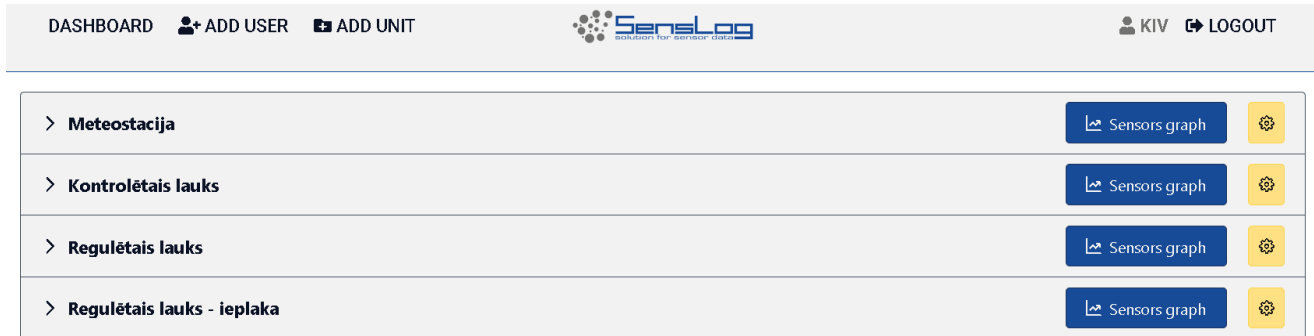
Sensor data provides critical real-time and historical insights into environmental and crop conditions. Common sensor sources include soil moisture probes, weather stations, multispectral cameras on drones, and GPS-enabled yield monitors. These sensors often store data in formats such as CSV, GeoJSON, or shapefiles, which can be easily imported into QGIS. Integration starts with ensuring that each dataset is georeferenced — either directly from the sensor's GPS or by manually assigning coordinates. Once imported, the data can be joined to existing spatial layers (such as field boundaries or forest management compartments) for further analysis. For example, soil moisture readings collected at multiple points can be interpolated using QGIS's **IDW Interpolation** tool to create continuous moisture maps that inform irrigation decisions. Similarly, canopy height data from LiDAR sensors can be processed in QGIS to identify areas of poor growth in forest stands.

Practical workflows increasingly involve mobile data collection apps that link directly with QGIS. Tools like **QField** allow field operators to collect sensor readings, photos, and GPS points directly on-site, and sync them to a central GIS project. In precision agriculture, a farmer might use QField to walk through a wheat field, recording leaf color readings from a chlorophyll meter at geotagged locations. Back in QGIS, this data can be symbolized with graduated colors to quickly highlight nitrogen deficiencies, and combined with satellite NDVI layers to plan targeted fertilizer application.

These app-based workflows are not limited to simple display; they enable real-time decision-making. For example, integrating weather station data streams via APIs into QGIS allows a forester to visualize microclimate patterns across a plantation, correlate them with pest outbreak records, and design targeted treatment zones. Similarly, connecting drone-derived NDVI maps with in-field sensor data enables farmers to validate aerial imagery, refine management zones, and adjust harvest plans. By combining mobile data collection, sensor integration, and GIS analysis, QGIS serves as the central hub for transforming raw sensor readings into actionable maps for precision agriculture and forestry operations.

## SensLog dashboard

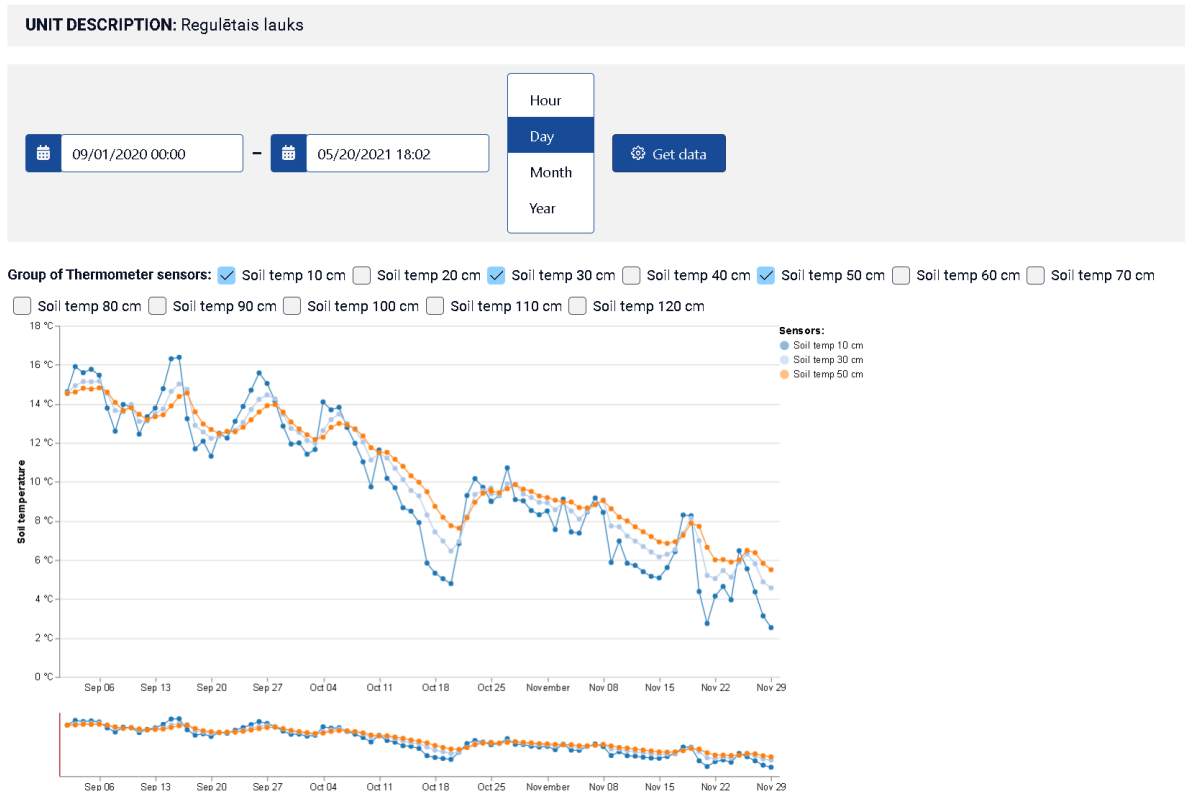
SensLog is a web application for displaying data using graphs. A graph can display a single sensor or a unit containing multiple sensors. Data is obtained from measurements taken by various types of sensors. The web application does not require the user to install any additional programs. All that is needed to run the web application is a web browser with cookies and JavaScript enabled.



The main dashboard page of SensLog dashboard.

After successfully logging in, the dashboard itself will be displayed. Ordinary users cannot add new users. If the logged-in user has admin privileges, a button for adding a new user will also be displayed in the left corner.

For logged-in users, the units assigned to that user are displayed. The “Sensors graph button” displays a graph for a specific unit. Each unit can contain multiple sensors. The unit contains multiple sensors. When the unit is pressed, a list of sensors belonging to that unit is displayed. The sensor can be displayed using the View graph button after expanding the specific unit. The sensor can be edited using the Edit sensor button and deleted using the Delete sensor button.



Graph of thermometer sensors in SensLog dashboard.

# Case Studies and Practical Applications

## Exercise: Environmental and Economic Impact Assessment

**Objective:** Calculate the benefits of precision fertiliser application using the created zones.

### Steps:

- **Calculate Area of Each Zone:**
  - Open the attribute table of the fertiliser zones layer.
  - Add a new column for the area:
    - Click **Field Calculator** and use the expression `$area` to calculate each zone's area in square metres.
  - Convert to hectares if needed by dividing by 10,000.
- **Estimate Fertiliser Use:**
  - Multiply the area of each zone by the recommended fertiliser rate for that nutrient level.
  - Add a column in the attribute table for **Fertiliser Needed** and calculate using a manual formula.
- **Compare Costs:**
  - Calculate total fertiliser costs for precision application vs. uniform application across the entire field.
  - Add notes to your calculations for reference.
- **Assess Environmental Impact:**
  - Discuss the potential reduction in nutrient runoff based on reduced fertiliser use in high-nutrient areas.
  - Highlight long-term benefits such as improved soil health and water quality.
- **Write a Summary:**
  - Include the economic and environmental benefits in a brief report (1–2 paragraphs).
  - Submit the report alongside your map layouts.

## Course Final Quiz

1. Which description explains the best what a **spatial analysis** is?
  - a. data representing features or phenomena related to the Earth
  - b. quantitative analysis of phenomena, considering the geometric, geographical or topological properties of their elements
  - c. computer-based system to analyse and present spatial data
2. Which of the following are types of **overlay analysis**?
  - a. intersect
  - b. union
  - c. select
  - d. buffer
3. Which spatial analysis technique would you use to **calculate the average NDVI value within each region or land use zone**?
  - a. cluster analysis
  - b. buffer

- c. clip
  - d. zonal statistics
4. What option does a user have to **extend QGIS with additional features, tools or integrations** not available in the standard installation of the software?
- a. install plugins
  - b. buy a Pro version
  - c. perform an overlay analysis
  - d. build a model with Model Designer
5. Which precision farming concept can be described as “**spatially defined areas within an agricultural field that exhibit relatively homogeneous characteristics in terms of soil properties, vegetation health, and yield potential**”?
- a. decision support systems
  - b. management zones
  - c. Internet of Things
  - d. yield mapping