



HydroGIS

USER HANDBOOK

Watershed analysis & runoff modelling

From elevation model to rainfall-runoff, flood depth and finished maps
— step-by-step guide with the theory behind every calculation



ROOTPIXIN

Root Level Pixel Information

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Contents

Part 1 — Getting started	2
Welcome to HydroGIS	2
Part 2 — Step-by-step guide	5
Phase A — Set up (sections 1 to 3)	5
Phase B — Explore (sections 4 to 7)	6
Phase C — Hydrology (sections 8 to 11)	8
Phase D — Output (sections 12 to 15)	10
Part 3 — Theory and calculation	12
3.1 From DEM to drainage network	12
3.2 Basin measurements (morphometry)	13
3.3 Rainfall interpolation	14
3.4 From rainfall to runoff — the big picture	16
3.5 The SCS Curve Number method	16
3.6 The runoff coefficient method	19
3.7 Mixed land cover — how HydroGIS applies the equations	19
3.8 Time of concentration and peak discharge	21
3.9 Flood depth with HAND	22
Part 4 — Map composition	23
4.1 Anatomy of a sheet	23
4.2 The six sheet styles	24
4.3 Framing, page size and print quality	25
Part 5 — Reference	26
5.1 Typical curve numbers (AMC II)	26
5.2 Typical runoff coefficients	27
5.3 Typical Manning's n	27
5.4 Input file formats	28
5.5 What you can download (section 15)	28
5.6 Troubleshooting	29
5.7 Formula quick reference	30
5.8 Glossary	31

PART 1

Getting started

What HydroGIS does, what you need, and how the workflow fits together

Welcome to HydroGIS

HydroGIS is a complete watershed-analysis workbench that runs inside your web browser. Starting from nothing more than the outline of your study area, it fetches an elevation model, delineates the drainage network and watersheds, interpolates rainfall from gauges, converts that rainfall into runoff using land-cover information, maps flood extent, and then helps you present all of it as finished cartographic sheets and a written report.

This handbook has two jobs. **Part 1 and Part 2** show you how to use every one of the 15 sections of the tool, in the order you will normally meet them. **Part 3** explains the hydrology and mathematics behind the numbers, so that you can defend your results, and Parts 4 and 5 cover map composition and quick-reference material.



Figure 1. The 15 sections of HydroGIS fall into four phases: set up, explore, hydrology and output.

What you can do with it

- **Terrain analysis** — filled DEM, slope, hillshade, contours, flow direction, flow accumulation, Strahler stream order, drainage density and the Topographic Wetness Index.
- **Catchments** — trace the catchment above any point on a stream, or split the whole area into major basins and sub-watersheds.
- **Rainfall** — load gauge data or pull free historical rainfall automatically, then interpolate it by inverse distance weighting, ordinary kriging or Thiessen polygons.

- **Runoff** — compute direct runoff with the SCS Curve Number method or a runoff coefficient, per land-cover class or cell by cell across the whole map.
- **Flood mapping** — HAND-based flood depth from a chosen stage or from a design storm.
- **Presentation** — six map-sheet styles, an HD PNG or print-ready PDF, a full PDF/Word report, and over forty downloads (KML, GeoTIFF, ESRI ASCII, CSV).

NOTE

HydroGIS is a screening and planning tool. It uses a regular grid, simplified channel hydraulics and event-scale methods. For design of structures or regulatory flood studies, treat the results as a first estimate and confirm them with detailed modelling and field data.

What you need before you start

Item	Details
A modern browser	Chrome, Edge, Firefox or Safari. HydroGIS is a single HTML file — open it and it runs. Analysis is done on your own computer.
Study area	A KML file containing the polygon of your area of interest (WGS 84, latitude/longitude).
Internet connection	Needed for the online DEM tiles, the base map and place labels, and the optional Open-Meteo rainfall fetch.
Rain gauge data (optional)	A CSV with columns <i>name</i> , <i>lon</i> , <i>lat</i> and one column per time period, in millimetres.
Land cover (optional)	A classified LULC KML, with a class name for each polygon. You supply CN, C or Manning values per class inside the tool.
Own DEM (optional)	A GeoTIFF in latitude/longitude (EPSG 4326), if you prefer not to use the online DEM.

The screen at a glance

The left-hand panel holds the 15 numbered sections; the map fills the rest of the window. Each section is a **collapsible card** — click its header to open or close it, or use **Expand all** and **Collapse all** at the top of the panel. Sections 1 and 2 start open; the others start folded so the panel stays short. While the analysis has been run and the pointer is over the study area, a small readout at the bottom-left of the map shows the values under the cursor: elevation, slope, upslope area and wetness index, plus drainage unit, flow direction and rainfall when those layers exist.

TIP

Work top to bottom the first time. Buttons stay unavailable until their inputs exist — for example, *Run analysis* needs a study area and a DEM first — and the status line under each button tells you what is missing.

Quick start in ten moves

1. Open **1. Study area** and upload your study-area KML. The map zooms to it.
2. In **2. Elevation model** wait for the online DEM, or open your own GeoTIFF.
3. In **3. Run analysis** choose the stream threshold and contour interval, then press **Run analysis**.
4. Use **4. Layers and colours** to switch on the layers you want to see and set their colours.
5. Optionally trace a catchment (**5**), delineate drainage units (**6**) and build buffers (**7**).
6. Add rainfall in **8** and interpolate it.

7. Upload a land-cover KML in **10** and give each class a CN or C.
8. Calculate runoff for the classes (**10**) or for the whole map (**11**); run **9. Flood analysis** if you need flood depth.
9. Compose a sheet in **13** and build the report in **14**.
10. Download whatever you need from **15**.

PART 2

Step-by-step guide

Every section of the tool, in working order

Each card below follows the same pattern: what the section is for, how to operate it, and what you get. Control names are printed exactly as they appear in the tool.

Phase A — Set up (sections 1 to 3)

1 Study area

Purpose. Define the area that every later step is clipped to.

HOW TO USE IT

1. Press **Upload study area KML** and choose a KML that contains your area polygon.
2. The map zooms to the area and the status line reports its name and approximate size in km².

Result. The outline is drawn on the map and becomes the analysis boundary. Only this one upload option is offered, so there is nothing else to choose.

TIP

Use one clean, closed polygon in WGS 84. A smaller area means a finer grid and a faster analysis.

2 Elevation model

Purpose. Obtain the terrain surface that all hydrological processing is built on.

HOW TO USE IT

1. After the study area loads, the DEM is fetched automatically from online SRTM/ASTER-based terrain tiles (30 m or finer). The status reads *Waiting for the DEM* until it is ready.
2. If the download fails or you want to retry, press **Fetch online DEM again**.
3. To use your own data instead, choose **Or open a DEM GeoTIFF from this computer**. The file must be in latitude/longitude (EPSG 4326).

Result. A DEM covering the study area, ready for processing.

3 Run analysis

Purpose. Turn the DEM into a hydrologic model in a single pass.

HOW TO USE IT

1. Set **Stream starts above** — the minimum upslope area (default 0.50 km²) a cell needs before it is called a channel.
2. Set the **Contour interval (m)**.
3. Press **Run analysis**.

Result. The tool fills sinks, derives D8 flow direction and accumulation, extracts the drainage network with Strahler order, delineates watersheds and computes slope, wetness index and basin measures. Everything else in the tool depends on this step.

TIP

A smaller stream threshold gives a denser network (more small tributaries); a larger one keeps only the main channels. The theory is in Part 3.

Phase B — Explore (sections 4 to 7)

4 Layers and colours

Purpose. Show or hide any result and choose its colour. Colours carry through to composed maps, the report and the KML exports.

HOW TO USE IT

1. **Reference:** switch the study-area outline and **Place labels** on or off. Place labels use free CARTO tiles — no key or setup.
2. **Terrain:** Elevation, Hillshade, Slope and Contours. Under **Contour levelling** choose *Regular interval from a base level* (interval, base level, bold index line every N lines) or *My own levels* (comma-separated metres), optionally label contours with their height, then press **Apply contour levelling**. Use Show all / Hide all / Index contours only to filter levels.
3. **Drainage network:** Flow accumulation, Flow direction (D8) with arrows, and the Drainage network itself with its label button. Colour or hide each Strahler order individually and choose a line smoothing from *None* to *Very strong*. The **Drainage density surface** uses a window radius (default 1.0 km).
4. **Wetness:** the Topographic Wetness Index (TWI) layer.
5. Adjust **Raster opacity**, or use **Reset colours** to return to defaults.

Result. A map styled exactly the way you want it.

5 Catchment at a point

Purpose. Find everything that drains to a chosen point on a stream.

HOW TO USE IT

1. Press **Pick outlet on map** and click anywhere on a stream. The tool snaps to the nearest channel.
2. The catchment is traced and measured. Use **Catchment layers** to show the delineated catchment, its label and the outlet point.
3. Switch on **Multiple catchments** to keep adding a new catchment with each click — useful for delineating every sub-catchment across the area. **Clear** or **Clear all catchments** starts over.

Result. A catchment polygon with its own measurements, which can also be used as the clip scope in downloads (section 15).

6 Drainage units — watershed analysis

Purpose. Split the whole study area into watershed units.

HOW TO USE IT

1. Choose **Major basins** (units draining to the area edge) or **Sub-watersheds** (basins broken at every stream confluence).
2. Set **Ignore units smaller than** (default 0.25 km²) and press **Delineate drainage units**.
3. Under **Show on the map** switch the units and their labels on; use **Shuffle unit colours**, hide individual units, or rename any unit with the pencil.

Result. A set of labelled, coloured drainage units that appear in the legend, report and exports. Drainage units are separate from Strahler order — renaming or hiding one never changes the other.

7 Buffers

Purpose. Build zones of a chosen distance around hydrological features.

HOW TO USE IT

1. In **Buffer around** pick: whole drainage network, drainage network of selected orders only (set *Only channels of Strahler order N and above*), traced catchment boundary, study area boundary, or outlet points.
2. Choose **Single buffer** (one distance in metres) or **Multiple rings** (comma-separated distances; tick *Draw rings as separate bands* for non-overlapping bands).
3. Press **Build buffers**. Use **Clear buffers** or **Reset colours** as needed.

Result. Buffer polygons, each band with its own area, ready for the map, report, exports and for use as an extra class in land-cover runoff (section 10).

TIP

Distances are measured to the actual lines, so even narrow buffers stay continuous.

Phase C — Hydrology (sections 8 to 11)

8 Rainfall

Purpose. Bring rainfall into the model and spread it over the study area.

HOW TO USE IT

1. **Add gauges.** Press **Open a rain gauge CSV** (header *name,lon,lat* then one column per time period, e.g. *name,lon,lat,Jun,Jul,Aug*; values in mm), click **Add rainfall point on map**, or press **Load a worked example**.
2. **Or fetch automatically.** *Auto rainfall* reads daily rainfall from the free Open-Meteo historical archive (no account, no API key), totals it by month and adds it as a gauge. Choose *Study area centre* or *A coordinate I give*, set **From** and **To**, and press **Fetch rainfall automatically**. The daily CSV can be downloaded. **Auto-detect rainfall + kriging for the whole study area** does the fetch and interpolation together.
3. Pick the **Time period shown** and the **Interpolation method**: *Inverse distance weighting* (distance power, default 2.0), *Ordinary kriging* (variogram model Spherical, Exponential or Gaussian; tick *Fit the variogram automatically* or set Range, Nugget and Sill), or *Thiessen polygons*.
4. Press **Interpolate rainfall** — or **Interpolate every period at once**.

Result. A rainfall surface for each period, summarised per drainage unit, with gauge points and optional labels. The surface feeds the runoff map (section 11).

TIP

See Part 3 for how IDW, kriging and Thiessen differ, and how to choose between them.

9 Flood analysis

Purpose. Map flood depth with the HAND method — a cell floods when it lies lower than the water level above its nearest channel.

HOW TO USE IT

1. **Water level from:** *Flood stage I enter* (metres above channel); *Design storm (SCS-CN + Manning)* with a design rainfall (or the interpolated mean), curve number and Manning n; or *Water level on the DEM* (metres above sea level).
2. **Water reaches the land from:** the drainage network (connected low ground only), a point you pick on the map, or everywhere below that level (no connection test).
3. Set **Height measured above channels of Strahler order** (default 1 and above).
4. Press **Run flood analysis**; use **Show flood layer** and **Clear flood map** to control the display.

Result. A flood-depth raster and a flooded-area summary. The design-storm option derives the stage from runoff, a peak flow and Manning's equation — all explained in Part 3.

TIP

Run the analysis (section 3) first, and choose a Strahler order that matches the channels you consider "the river".

10

Land use / land cover

Purpose. Load land cover and attach the runoff parameters each class needs.

HOW TO USE IT

1. Press **Open a LULC KML**. Each placemark's name, folder or a "class"/"lulc" field is read as its class. Show the layer and set the **LULC fill opacity**.
2. Optionally **Add generated features to LULC**: the drainage network (with a channel width in metres) and/or the drainage buffer bands from section 7 become extra classes drawn over the land cover.
3. In the class table set each class's colour and visibility, and enter its **Curve no. (CN)**, **Runoff coeff. (C)** and **Manning's n**.
4. Under **Runoff calculation** enter a **Design rainfall (mm)** (or use the interpolated mean) and press **Calculate runoff**.

Result. The SCS-CN equation is applied to each class separately and the results are summed — more faithful for a mixed catchment than one averaged CN. The table gives runoff depth and volume per class; **Clear LULC data** resets the section.

TIP

Class values are yours to choose. Part 5 gives typical CN, C and Manning values to start from.

11

Runoff map

Purpose. Turn rainfall into a runoff-depth map, cell by cell.

HOW TO USE IT

1. **Rainfall used**: the interpolated rainfall map (every cell has its own rain) or one design rainfall for the whole area.
2. **Runoff method**: *SCS curve number (CN)* or *Runoff coefficient ($Q = C \times \text{rainfall}$)*.
3. Set the fallback value for cells with no land-cover class (defaults: CN 80, or C 0.5).
4. Press **Calculate runoff map**; show or hide the **Runoff depth** layer.

Result. A runoff-depth raster plus a table: total runoff volume (m³), overall runoff coefficient, and rainfall, area and runoff for each land-cover class.

Phase D — Output (sections 12 to 15)

12 Measurements

Purpose. Read the basin's numbers.

HOW TO USE IT

1. After the analysis, the table fills automatically for the study area, or for the traced catchment when one is active.

Result. Grouped measures: Basin (area, perimeter, longest flow path, shape ratios), Relief, Drainage (channel length, density, frequency, bifurcation, time of concentration), Wetness, Rainfall and Buffers. Formulas are in Part 3 and the table can be downloaded as CSV.

13 Map composition

Purpose. Lay out a finished cartographic sheet with graticule frame, scale bar, north arrow and legend.

HOW TO USE IT

1. Enter the **Map title** and **Subtitle**; choose a **Sheet style** and **Accent colour**. Tick *Use this style for the report figures too* for consistency.
2. Choose a **Base raster** (None, Elevation, Slope, Wetness index, Flow accumulation, Flow direction, Drainage density, Rainfall) and switch the layers you want on the sheet.
3. Set the **Frame the sheet on** option and **Margin**, the **North arrow**, **Scale bar** and **Legend placement**, and the text style for each text element.
4. Choose **Page size** and **Print quality**, press **Preview composition**, then **Save sheet as PDF** or **Save sheet as PNG**.

Result. A print-ready sheet. Part 4 shows the anatomy of a sheet and all six styles.

14 Report

Purpose. Generate a written discussion of your results with composed maps between the sections.

HOW TO USE IT

1. Enter the **Report title**, **Prepared by** and any **Notes to include**.
2. Tick the **Sections to include** and the **Maps to compose into the report**; choose **Map quality** and **Depth of discussion** (Full or Brief).
3. Press **Preview report**, then **Save as PDF** or **Save as Word**.

Result. A PDF or Word report that uses your sheet style, accent colour, north arrow, scale bar and legend placement from section 13. Sections include Introduction and data, Relief and slope, Drainage network, Flow direction and drainage density, Drainage units, Rainfall, Land use and runoff, Buffers, Basin shape and runoff, Practical implications, Method and limitations, and a Measurement table.

15

Downloads

Purpose. Export everything for use in other GIS software.

HOW TO USE IT

1. Choose **Clip downloads to** the Study area or the Delineated catchment.
2. Press any button: Vector (KML), Grids (GeoTIFF and ESRI ASCII .asc), or Tables and maps (CSV, composed PNG, sheet PDF, full report PDF).

Result. Files that open in Google Earth, QGIS and ArcGIS. The full list is in Part 5.

PART 3

Theory and calculation

The hydrology and mathematics behind every number HydroGIS reports

This part explains what the tool computes and why. The rainfall-runoff chapters (3.4 to 3.8) are the heart of it: they derive the SCS Curve Number equation, show how HydroGIS applies it to land-cover classes and to every grid cell, and work through numerical examples you can reproduce by hand.

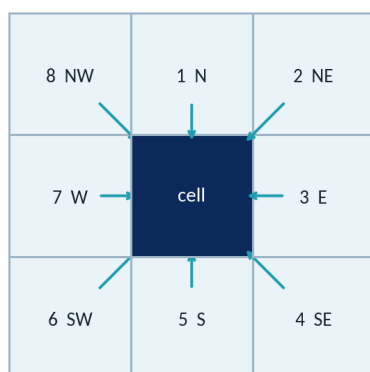
3.1 From DEM to drainage network

A digital elevation model (DEM) is a grid of ground heights. HydroGIS clips it to your study area and then follows the standard raster-hydrology chain.

Filling sinks

Natural terrain has no true pits, but DEMs do — small errors that trap water. HydroGIS removes them with a **priority-flood** fill, which raises each pit just enough that every cell has a downhill route out of the area. The filled DEM is what you can download as *Filled DEM*.

D8 flow direction



In the **D8** (eight-direction) method each cell sends all its water to the one neighbour with the **steepest downhill gradient**:

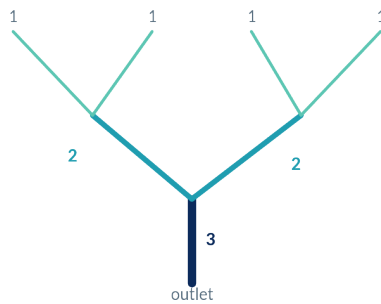
$$\text{slope} = (z_{\text{cell}} - z_{\text{neighbour}}) / \text{distance}$$

The distance is one cell width for the four straight neighbours and $\sqrt{2}$ times that for diagonals. A cell with no lower neighbour inside the area is an **outlet**. In the exported flow-direction grid, 1 = N, 2 = NE, 3 = E, 4 = SE, 5 = S, 6 = SW, 7 = W, 8 = NW and 0 = outlet.

Flow accumulation and the stream threshold

Flow accumulation counts, for each cell, how many cells drain through it. Multiplying by the cell area gives the **upslope (contributing) area**. A cell becomes part of the channel network when its upslope area exceeds the **stream threshold** you set in section 3 (default 0.50 km²). A lower threshold means a denser network.

Strahler stream order



Headwater channels are order 1. When two streams of the **same order** meet, the downstream channel is one order higher; when streams of different orders meet, the higher order continues unchanged. Order is a quick proxy for channel size and is used in HydroGIS to colour channels, select channels for buffers and choose the reference channels for flood analysis.

Slope, watersheds and catchments

Slope uses a 3×3 weighted finite-difference (Horn) kernel on the filled DEM: the east–west and north–south gradients are computed from the eight neighbours, with the nearer ones weighted double, and slope = arctan of the combined gradient, in degrees. Slope classes reported are $<3^\circ$, $3-8^\circ$, $8-15^\circ$, $15-30^\circ$ and $>30^\circ$. **Catchments** are traced upstream along the D8 network from the chosen outlet; **drainage units** are the same idea applied to every outlet or confluence at once.

3.2 Basin measurements (morphometry)

Section 12 reports the standard morphometric parameters. Here, A is basin area (km^2), P perimeter (km), L_b the longest flow path (km), H total relief (m) and ΣL_u the total channel length (km).

Measure	Formula	What it tells you
Drainage density	$D_d = \frac{\Sigma L_u}{A}$ (km/km^2)	Channel length per unit area. High values: fast, flashy response, impermeable or weakly vegetated ground.
Stream frequency	$F_s = \frac{N_u}{A}$	Number of reaches per km^2 .
Bifurcation ratio	$R_b = \frac{N_u}{N_{u+1}}$	Branching between successive orders (mean is reported); typically 3–5 in undisturbed basins.
Form factor	$R_f = \frac{A}{L_b^2}$	Low values mean an elongated basin with flatter, longer flood peaks.
Circularity ratio	$R_c = \frac{4\pi A}{P^2}$	Closer to 1 = more circular; water from all parts arrives together.
Elongation ratio	$R_e = \frac{2\sqrt{A/\pi}}{L_b}$	Near 1 = circular; 0.6–0.8 is typical of moderate relief.
Relief ratio	$R_h = \frac{H}{L_b}$	Overall steepness along the main flow path.
Ruggedness number	$R_n = H \cdot D_d$	Combines relief and drainage density; high = steep, dissected terrain.
Length of overland flow	$L_g = \frac{1}{2D_d}$	Average distance rain travels over the ground before reaching a channel.
Hypsometric integral	$HI = \frac{Z_{\text{mean}} - Z_{\text{min}}}{Z_{\text{max}} - Z_{\text{min}}}$	Share of the basin's volume remaining above its lowest point; indicates erosional maturity.

Topographic Wetness Index. For each cell, TWI compares how much water arrives from upslope with how quickly it can drain away:

$$TWI = \ln\left(\frac{a}{\tan \beta}\right), \quad a = \frac{A_{up}}{\Delta x}$$

Here A_{up} is the upslope area and Δx the cell width, so a is the contributing area per unit contour length; β is the local slope (floored at a small value so flat cells stay finite). High TWI marks valley bottoms and flat, converging ground where saturation and flooding start. The Measurements table reports the mean TWI and the percentage of the area with $TWI \geq 10$.

3.3 Rainfall interpolation

Gauges give rainfall at points; runoff needs it everywhere. HydroGIS offers three ways to fill the gaps.

Inverse distance weighting (IDW)

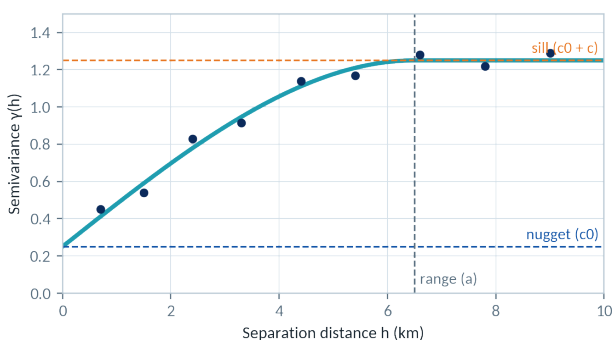
$$\hat{Z}(x_0) = \frac{\sum_i w_i Z_i}{\sum_i w_i}, \quad w_i = \frac{1}{d_i^p}$$

Nearby gauges count more than distant ones. The **distance power** p (default 2.0) controls how quickly influence fades: a larger p gives a more local, spottier surface; a smaller p gives a smoother one. IDW never predicts values outside the range of the gauges.

Ordinary kriging

Kriging weights the gauges using a model of how rainfall similarity decays with distance — the **variogram**. The weights λ_i sum to 1 and are chosen to minimise the estimation variance. You pick the model shape and either fit its three parameters automatically or enter them.

$$\hat{Z}(x_0) = \sum_i \lambda_i Z_i, \quad \sum_i \lambda_i = 1, \quad \Gamma \lambda + \mu \mathbf{1} = \gamma_0$$



Nugget (c_0) — variation at zero distance: measurement error and very short-scale variability.

Sill ($c_0 + c$) — the level at which the variogram flattens: gauges farther apart than the range are uncorrelated.

Range (a) — the distance beyond which gauges stop influencing each other.

Model shapes — Spherical, Exponential and Gaussian — differ in how the curve approaches the sill; Gaussian is smoothest near the origin.

$$\gamma(h) = c_0 + c \left[\frac{3h}{2a} - \frac{h^3}{2a^3} \right] \quad (h \leq a); \quad \gamma(h) = c_0 + c \quad (h > a)$$

Thiessen polygons

Every cell takes the value of its **nearest gauge**, producing a patchwork of polygons. It is the simplest method, it preserves actual gauge values, and it is a good choice for very sparse networks or when you want an explicitly gauge-based areal average.

TIP

Choosing a method. With 3 or fewer gauges use Thiessen or IDW; kriging needs enough points to say something about the variogram. With a dense network and a clear spatial trend, kriging usually gives the most defensible surface.

Automatic rainfall. The Open-Meteo option fetches daily totals for one point (the study area centre or coordinates you give), sums them by month and adds the point as a gauge. A single point cannot show spatial variation, so the “auto-detect + kriging” shortcut is best read as an areal-rainfall estimate, not a spatial pattern.

3.4 From rainfall to runoff – the big picture

Not all rain becomes streamflow. Part is intercepted by leaves, part fills surface depressions, part soaks into the soil and part evaporates. What remains and flows over the surface or just beneath it to the channels is **direct runoff**. Two families of methods estimate it, and HydroGIS provides both: the **SCS Curve Number** method, which models losses explicitly, and the **runoff coefficient** method, which simply applies a fraction.

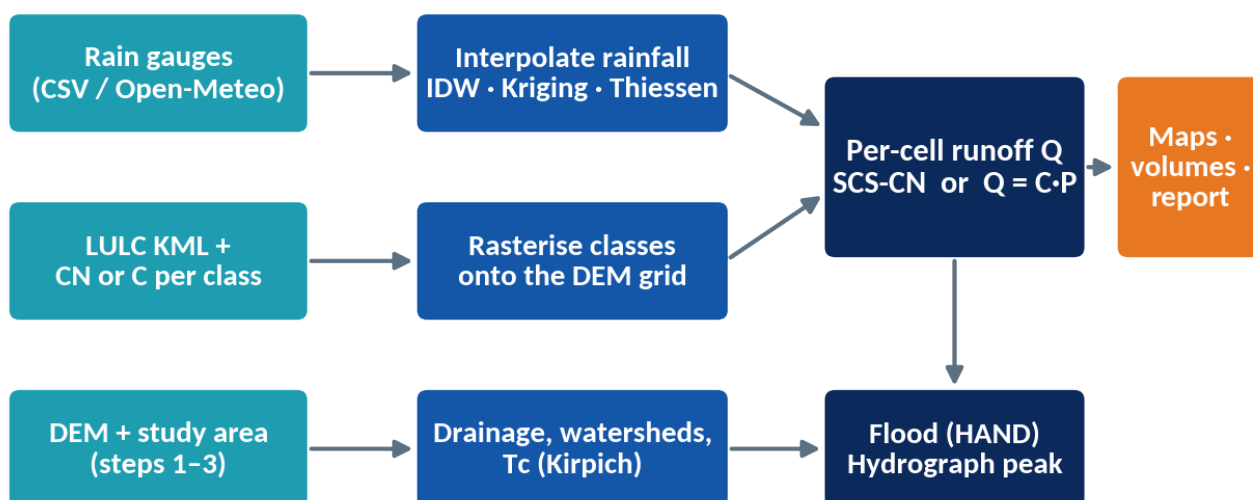


Figure 2. How HydroGIS turns inputs into runoff. Land-cover classes are rasterised onto the DEM grid so that every cell gets its own CN or C.

3.5 The SCS Curve Number method

Developed by the U.S. Soil Conservation Service (now NRCS), the method relates direct runoff Q to storm rainfall P through a single parameter, the **Curve Number (CN)**, which reflects land cover, soil type and moisture. All depths are in millimetres.

Step 1 – potential maximum retention S

S is the most water the ground could hold after runoff begins. It is tied to CN:

$$S = \frac{25400}{CN} - 254$$

CN = 100 means a perfectly impervious surface ($S = 0$: all rain runs off); CN = 30 means very permeable ground ($S \approx 593$ mm). Typical values range from about 40 (forest on sandy soil) to 98 (pavement and roofs).

Step 2 – initial abstraction I_a

Before any runoff starts, rain must first satisfy interception, depression storage and early infiltration. This initial abstraction is taken as a fixed fraction of S :

$$I_a = 0.2 S$$

Step 3 – the runoff equation

$$Q = \frac{(P - I_a)^2}{P - I_a + S} = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (P > I_a), \quad Q = 0 \quad (P \leq I_a)$$

The reasoning is a proportion: the fraction of the water available after the initial abstraction ($P - I_a$) that becomes runoff, $Q / (P - I_a)$, equals the fraction of potential retention that has actually been used, F / S . Substituting $F = (P - I_a) - Q$ and solving for Q gives the equation above. Rain below I_a produces no runoff at all.

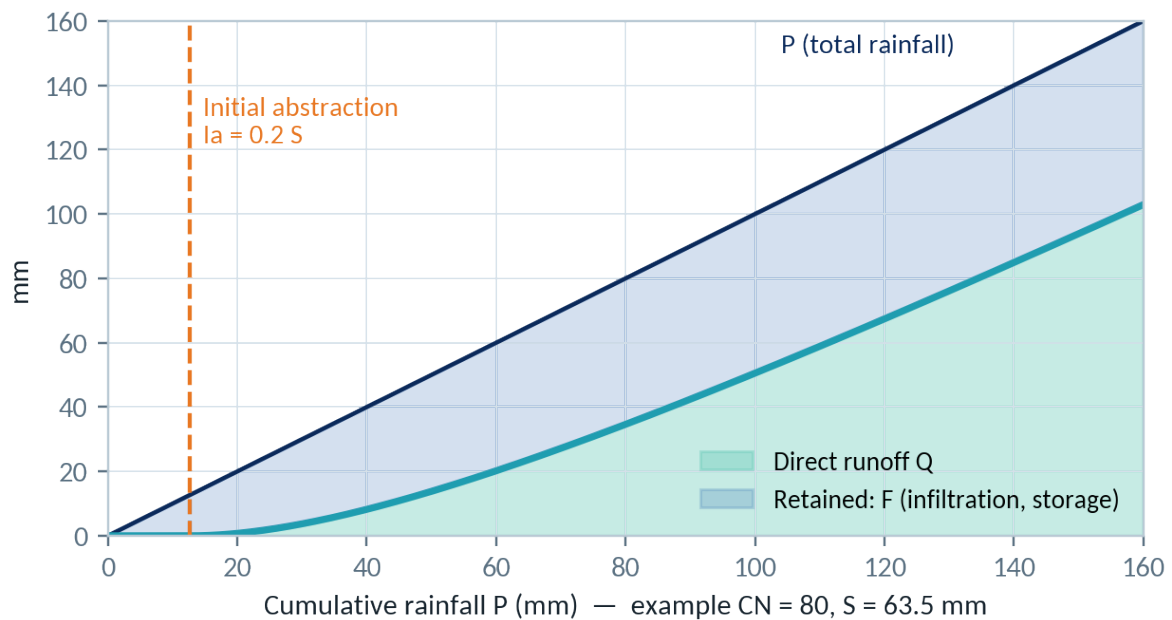


Figure 3. Cumulative rainfall ($CN = 80$): runoff starts only after I_a is satisfied, then rises towards the P line as the soil fills.

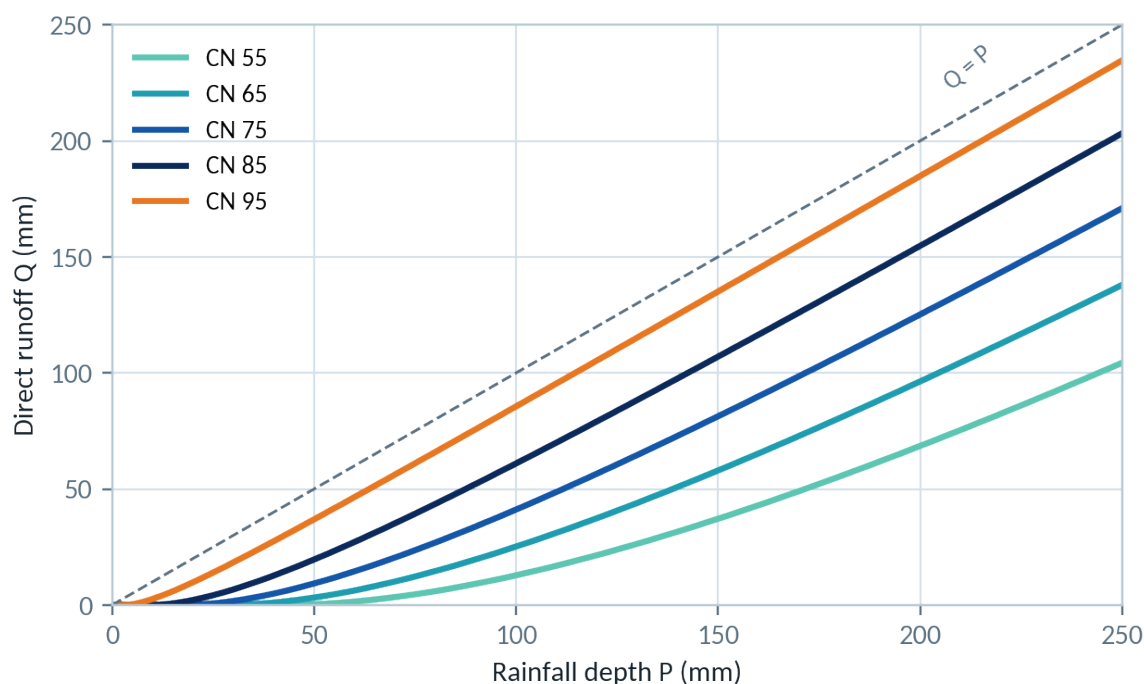


Figure 4. Runoff depth Q versus rainfall P for five curve numbers. Higher CN gives more runoff and an earlier start.

Where do curve numbers come from?

CN depends on four things: **land cover** and treatment, **hydrologic soil group** (A: sands and gravels, high infiltration; B: moderate; C: slow; D: clays and shallow soils, very slow), **hydrologic condition** (good, fair or poor cover) and **antecedent moisture**. HydroGIS does not guess these for you — you enter the CN for each class in section 10, so that you can follow your local guidance. Part 5 lists typical TR-55 values to start from.

Antecedent moisture condition (AMC)

Published CN tables assume **average** moisture (AMC II). If the catchment is unusually dry (AMC I) or wet (AMC III), adjust CN before entering it:

$$CN_I = \frac{4.2 CN_{II}}{10 - 0.058 CN_{II}}$$

$$CN_{III} = \frac{23 CN_{II}}{10 + 0.13 CN_{II}}$$

For example $CN_{II} = 80$ becomes about 63 for dry conditions and about 90 for wet ones.

Worked example 1 — a single curve number

A storm of $P = 100$ mm falls on ground with $CN = 80$:

$$S = \frac{25400}{80} - 254 = 63.5 \text{ mm}, \quad I_a = 12.7 \text{ mm}, \quad Q = \frac{(100 - 12.7)^2}{100 + 0.8 \times 63.5} = 50.5 \text{ mm}$$

So about half of the rain (50.5 mm) becomes direct runoff. Over a 9 km^2 area that is $0.0505 \text{ m} \times 9\,000\,000 \text{ m}^2 \approx 454\,900 \text{ m}^3$.

3.6 The runoff coefficient method

The simpler alternative multiplies rainfall by a dimensionless coefficient C between 0 and 1 — the fraction of rain that runs off:

$$Q = C \times P$$

Roofs and pavement have C near 0.9; forests and sandy lawns, 0.05–0.25. Because it has no initial abstraction, the method makes runoff proportional to rainfall for any storm size, which suits quick estimates or long-period totals but is less realistic for small storms. In HydroGIS you enter C per class (section 10) and choose “Runoff coefficient” in section 11.

3.7 Mixed land cover — how HydroGIS applies the equations

Real catchments are never a single CN. There are two ways to handle a mixture, and HydroGIS reports both so you can see the difference.

(a) Area-weighted average

$$CN_w = \frac{\sum_i CN_i A_i}{\sum_i A_i}$$

The classes are averaged into one CN (or one C) and the equation is applied once. HydroGIS shows this as the “area-weighted CN” in the LULC summary. It is quick but can understate runoff, because Q is a *non-linear* function of CN.

(b) Class by class (composite runoff)

$$V = \sum_i \frac{Q_i}{1000} A_i$$

The **Calculate runoff** button in section 10 applies the SCS equation to *each class separately*, using that class’s CN, and sums the volumes. Classes with no CN are left out and their area is reported. The mean runoff depth over the rated area is then V / A .

(c) Cell by cell (the runoff map)

Section 11 goes one step further. The classes are rasterised onto the DEM grid and, **for every cell k inside the study area**:

- the rainfall P_k is read from the interpolated rainfall surface (or the single design rainfall);
- the cell’s land-cover class gives CN_k (or C_k); where no class covers the cell, the fallback value you set is used (default CN 80 or C 0.5);

- SCS-CN: $S_k = 25400 / CN_k - 254$, $I_a = 0.2 S_k$, and $Q_k = (P_k - I_a)^2 / (P_k + 0.8 S_k)$ if $P_k > I_a$, else 0; or, for the coefficient method, $Q_k = C_k P_k$;
- the cell's runoff volume is $Q_k \times \text{cell area}$.

Summing over all cells gives the total runoff volume, and the ratio of runoff volume to rainfall volume is the **overall runoff coefficient**:

$$C_{\text{overall}} = \frac{V_{\text{runoff}}}{V_{\text{rain}}} = \frac{\sum Q_k A_k}{\sum P_k A_k}$$

Because rainfall and land cover both vary across the grid, this is the most spatially faithful of the three approaches. It also yields per-class averages for the results table.

Worked example 2 — three land-cover classes

A 9 km² catchment receives **P = 100 mm**. The land-cover table gives:

Class	CN	Area (km ²)	S (mm)	I _a (mm)	Q (mm)	Volume (m ³)
Forest	70	4.0	108.9	21.8	32.7	130,843
Cropland	80	3.5	63.5	12.7	50.5	176,887
Built-up	92	1.5	22.1	4.4	77.6	116,462
Total		9.0			47.1	424,192

Class by class: total volume = **424,192 m³**, a mean depth of **47.1 mm** and an overall coefficient of 0.47.

Area-weighted CN: $CN_w = (70 \times 4.0 + 80 \times 3.5 + 92 \times 1.5) / 9 = 77.6$, giving $Q = 45.8$ mm and $V = 412,344$ m³.

Averaging the CN first would have **under-estimated the runoff by about 3 %**, because the built-up class (CN 92) produces disproportionately more runoff than the forest (CN 70) saves. This is why HydroGIS applies the equation per class.

CAUTION

Use storm rainfall, not monthly totals. The Curve Number equation was calibrated on single storm events. If you feed it a monthly or seasonal total it will produce a number, but that number is not storm runoff. Use a design storm or a measured event depth for CN work; keep monthly totals for rainfall mapping and the coefficient method.

Assumptions and limitations

- CN is an empirical index. The result is only as good as the CN you assign — document your source and soil group.
- The initial-abstraction ratio is fixed at 0.2, the original standard. Some regions have found 0.05 fits better.
- The equation gives a *depth* for a whole storm; it contains no timing and no rainfall intensity.
- It is least reliable for very small storms (P close to I_a), in snow-affected areas and on very flat or very large catchments.
- The grid resolution limits how small a land-cover feature can be represented; narrow channels added as LULC classes are drawn at the width you give.

3.8 Time of concentration and peak discharge

Runoff *depth* says how much water; flood work also needs *how fast*. The **time of concentration** t_c is the time for water from the most remote point to reach the outlet. After t_c the whole catchment is contributing, so rain that lasts at least that long produces the catchment's peak flow.

Kirpich formula

$$t_c = 0.0195 L^{0.77} S_o^{-0.385} \quad S_o = \frac{H}{L}$$

Here L is the longest flow path in metres, H the relief in metres, S_o the average slope along the path (m/m), and t_c comes out in **minutes**. HydroGIS takes L from the longest flow path in the flow-length grid and H from the elevation range of the area.

Example. $L = 8\,000$ m and $H = 200$ m give $S_o = 0.025$, so $t_c = 0.0195 \times 8000^{0.77} \times 0.025^{-0.385} \approx \mathbf{82 \text{ minutes}}$ (about 1.4 hours).

SCS triangular unit hydrograph

The design-storm flood option converts runoff depth into a peak discharge with the SCS triangular hydrograph. The peak occurs at the time to peak T_p , taken as $0.667 t_c$:

$$Q_p = \frac{0.208 A Q}{T_p}, \quad T_p = 0.667 t_c$$

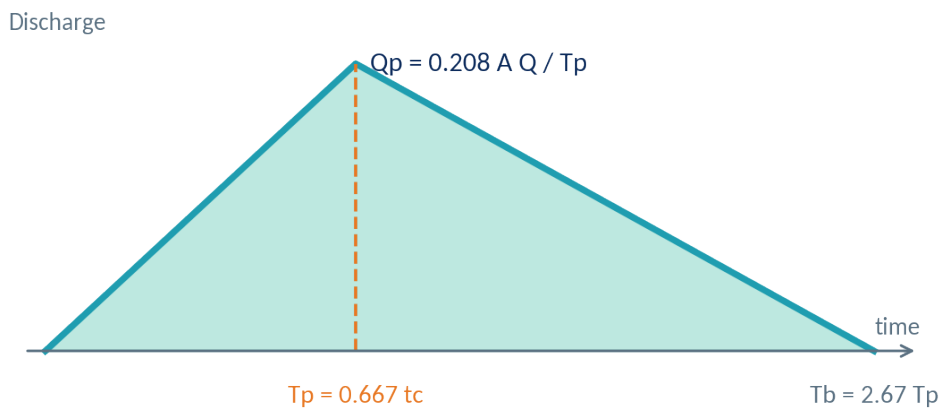


Figure 5. Triangular hydrograph: the peak Q_p (m^3/s) follows from the catchment area A (km^2), runoff depth Q (mm) and T_p (hours).

The constant 0.208 absorbs the unit conversions, so A is in km^2 , Q in mm and T_p in hours. In the flood routine the area is the upslope area of each channel cell and L is the flow length to that cell, so the peak is computed *cell by cell along the river*, increasing downstream.

3.9 Flood depth with HAND

HAND — Height Above the Nearest Drainage — measures how far each cell sits above the channel it drains to. If the river rises to a stage y , every connected cell with HAND below y is under water.

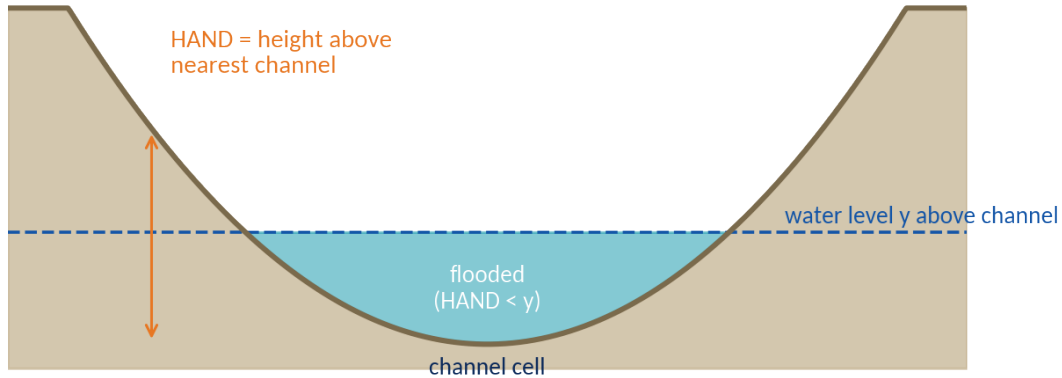


Figure 6. HAND: cells whose height above the nearest channel is less than the water level are flooded.

$$\text{HAND}(x) = z(x) - z(\text{nearest channel cell it drains to})$$

$$\text{depth}(x) = \max[0, y - \text{HAND}(x)]$$

You can give the stage directly (metres above the channel), give a water level above sea level on the DEM, or let HydroGIS derive the stage from a design storm:

1. Compute direct runoff Q from the design rainfall and curve number (section 3.5).
2. For each channel cell, compute the peak discharge Q_p from the upslope area, Q and the Kirpich time of concentration (section 3.8).
3. Take the channel slope S_o from the filled DEM over a short distance downstream (never less than 0.0005 m/m).
4. Assume a rectangular channel whose width follows a regime relationship, then solve Manning's equation for the flow depth y that carries Q_p .

$$W = 3.5 \sqrt{Q_p}$$

$$Q = \frac{1}{n} A_r R^{2/3} S_o^{1/2}, \quad R = \frac{A_r}{W + 2y}, \quad A_r = Wy$$

The depth y is found numerically by bisection until Manning's discharge matches Q_p . The Manning roughness n is the value you enter (default 0.035, typical of a natural, fairly clean channel). The result is a stage for each channel cell, and flood depth over the land follows from the HAND relation above.

NOTE

Connectivity matters. With *The drainage network (connected low ground only)*, a low-lying hollow that is not connected to a channel is not flooded; with *Everywhere below that level* it is. Choose the one that matches your question — river flooding or ponding.

PART 4

Map composition

Anatomy of a sheet, six styles, and print settings

Section 13 builds a complete cartographic sheet around whatever you have drawn. It follows the conventions of survey maps: a ticked neatline with latitude and longitude, a scale bar, a north arrow and a legend that lists only what is actually shown.

4.1 Anatomy of a sheet

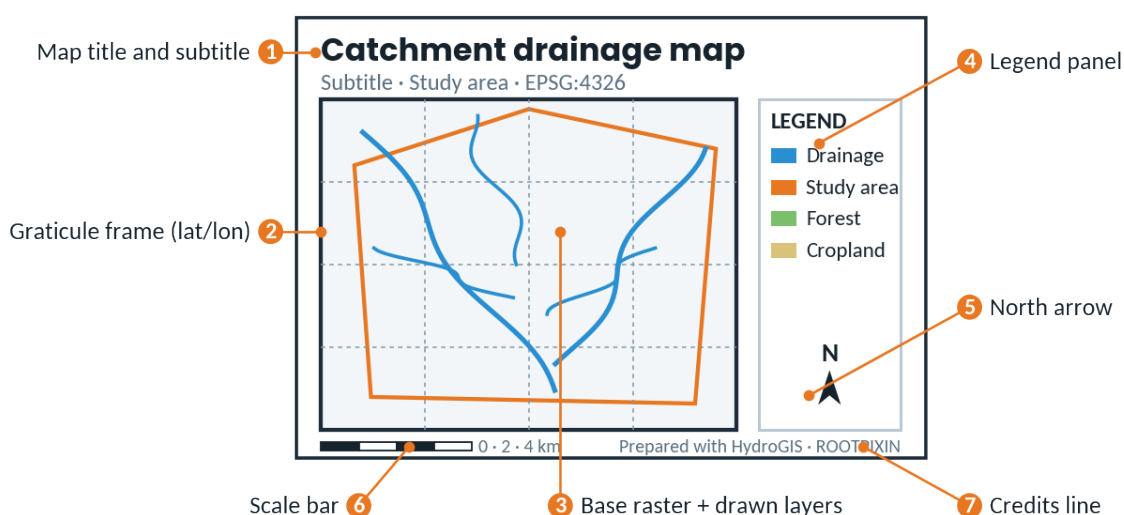
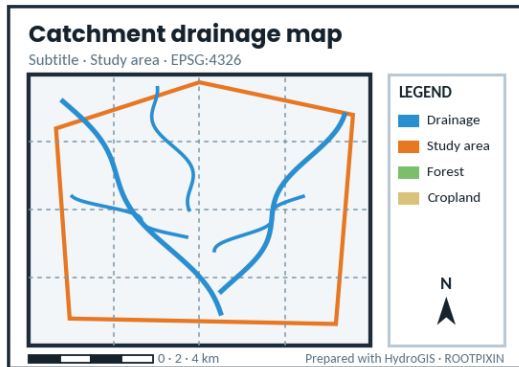


Figure 7. The parts of a composed sheet (Classic survey style shown). Every part can be switched, styled or repositioned in section 13.

#	Element	Controls in section 13
1	Title and subtitle	Map title, Subtitle; font size and colour in <i>Text style</i>
2	Graticule frame	Graticule and ticked neatline layer; coordinate-label text style; accent colour
3	Base raster + layers	Base raster; the layer switches (terrain, drainage, rainfall, flood, LULC, catchments, reference)
4	Legend	Legend placement: right-hand panel, strip beneath, inside the frame or none
5	North arrow	Solid arrow, Split needle, Compass rose, Plain N with line, or None
6	Scale bar	Chequered bar, Stepped bar, Line with ticks, or None
7	Credits line	Text style: Credits line

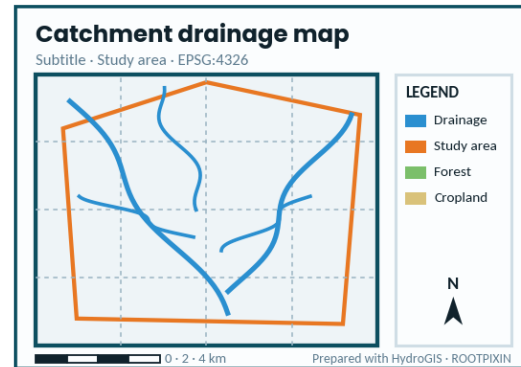
4.2 The six sheet styles

Choose a style with **Sheet style**; the accent colour tints the frame, titles and rules. Tick *Use this style for the report figures too* and every figure in the PDF or Word report matches.



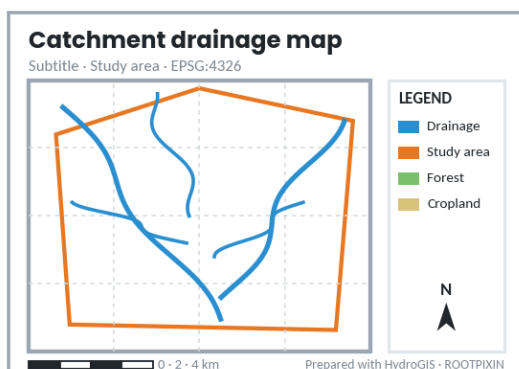
Classic survey sheet

White paper, dark neatline: the traditional topographic look. Best for printed deliverables.



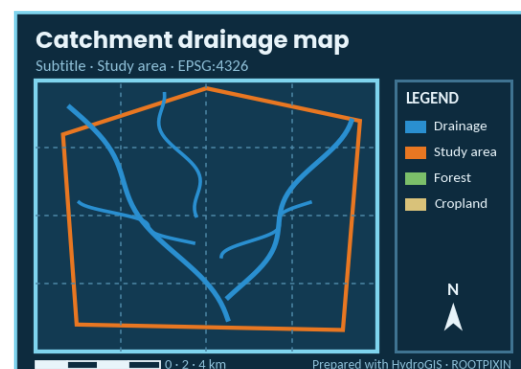
Modern light

Cool white with a teal frame. Clean for presentations and reports.



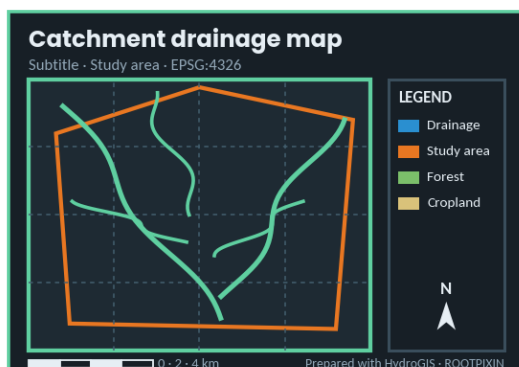
Minimal white

Pale grey frame and graticule so the data dominates. Best for figures inside documents.



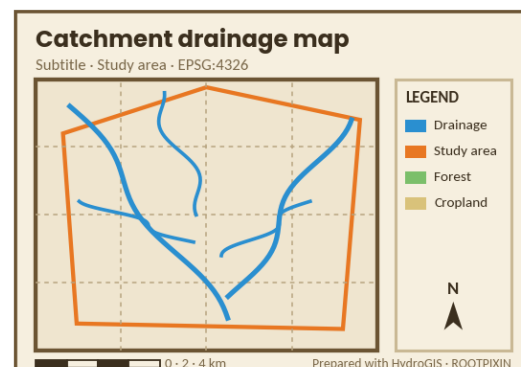
Blueprint

Deep blue paper with cyan linework. Striking on screen and for technical posters.



Slate dark

Charcoal paper with a green frame. Suits dark-mode slides and night-time displays.



Sepia atlas

Warm parchment tones with brown linework for an atlas or archival feel.

Figure 8. The six built-in styles shown on the same sample map.

4.3 Framing, page size and print quality

Frame the sheet on chooses what the map is zoomed to: what is drawn (the tightest sensible frame), the study area, the traced catchment, all traced catchments, the drainage units shown, or the buffers. **Margin around the feature** adds breathing space as a percentage. Page sizes and the pixel size of a PNG at each print quality are:

Page (portrait)	Size (mm)	150 dpi	300 dpi	450 dpi	600 dpi
A5	148 × 210	874 × 1240	1748 × 2480	2622 × 3720	3496 × 4961
A4	210 × 297	1240 × 1754	2480 × 3508	3720 × 5262	4961 × 7016
A3	297 × 420	1754 × 2480	3508 × 4961	5262 × 7441	7016 × 9921
A2	420 × 594	2480 × 3508	4961 × 7016	7441 × 10524	9921 × 14031
A1	594 × 841	3508 × 4967	7016 × 9933	10524 × 14900	14031 × 19866
Legal	216 × 356	1276 × 2102	2551 × 4205	3827 × 6307	5102 × 8409
Letter	216 × 279	1276 × 1648	2551 × 3295	3827 × 4943	5102 × 6591

Landscape is the same size with width and height swapped. Higher dpi gives crisper lines and text but much larger files; 300 dpi is the usual choice for print, 150 dpi for screens. Use **Preview composition** before saving.

TIP

For a figure that will be shrunk into a report, choose the Minimal white style, a legend strip beneath the map, and the A4 landscape page. For a wall poster, use A1 or A2 at 150–300 dpi.

PART 5

Reference

Typical parameter values, file formats, downloads and troubleshooting

5.1 Typical curve numbers (AMC II)

Values below are representative NRCS TR-55 curve numbers for the four hydrologic soil groups. They are starting points: always confirm against the guidance used in your country or project.

Land cover (condition)	A	B	C	D
Row crops, straight row (good)	67	78	85	89
Small grains, straight row (good)	63	75	83	87
Pasture / grassland (good)	39	61	74	80
Pasture / grassland (fair)	49	69	79	84
Pasture / grassland (poor)	68	79	86	89
Meadow (good)	30	58	71	78
Woods (good)	30	55	70	77
Woods (fair)	36	60	73	79
Woods (poor)	45	66	77	83
Open space, lawns, parks (good, >75 % grass)	39	61	74	80
Residential, ¼ acre lots (38 % impervious)	61	75	83	87
Residential, ½ acre lots (65 % impervious)	77	85	90	92
Commercial and business (85 % impervious)	89	92	94	95
Industrial (72 % impervious)	81	88	91	93
Paved areas, roofs (impervious)	98	98	98	98
Gravel roads	76	85	89	91
Dirt roads	72	82	87	89

Water bodies and the drainage channels added in section 10 are usually given CN 98–100 (all rain becomes runoff).

5.2 Typical runoff coefficients

Surface	C range
Asphalt and concrete pavement	0.70 – 0.95
Roofs	0.75 – 0.95
Business and commercial areas	0.50 – 0.95
Industrial areas	0.50 – 0.90
Residential — single-family	0.30 – 0.50
Residential — multi-unit, attached	0.60 – 0.75
Suburban	0.25 – 0.40
Parks, cemeteries	0.10 – 0.25
Playgrounds	0.20 – 0.35
Unimproved / bare land	0.10 – 0.30
Lawns on sandy soil (flat to steep)	0.05 – 0.20
Lawns on heavy soil (flat to steep)	0.13 – 0.35
Forest and woodland	0.05 – 0.25
Cultivated land	0.15 – 0.40

Within each range, use the lower value for flat, permeable ground and light rainfall and the upper value for steep, compacted ground and heavy storms.

5.3 Typical Manning's n

Channel type	n
Concrete-lined, smooth	0.012 – 0.015
Excavated earth channel, clean	0.018 – 0.025
Natural stream, clean and straight	0.025 – 0.033
Natural stream, winding with pools and shoals	0.033 – 0.045
Natural stream, weedy or stony	0.045 – 0.07
Floodplain with light brush and trees	0.05 – 0.10

HydroGIS uses 0.035 for the design-storm flood analysis if you leave the field empty.

5.4 Input file formats

Input	Format
Study area	KML with one or more closed polygons (WGS 84).
DEM (optional)	GeoTIFF in latitude/longitude, EPSG 4326.
Rain gauges	CSV. Header name, lon, lat, Period1, Period2, One row per gauge; rainfall in mm. Example: Gauge A, 85.14, 25.60, 120, 310, 280.
Land use / land cover	KML polygons. The class is read from the placemark name, its folder, or a field called "class" or "lulc". CN, C and n are entered in the tool, not in the file.

5.5 What you can download (section 15)

Group	Files
Vector (KML)	Drainage, Contours, Boundary, Drainage units, Buffers, Rain gauges, LULC classes, Traced catchment, All catchments, Everything
Grids (GeoTIFF and .asc)	Filled DEM, Slope, Flow accumulation, Flow direction, Drainage density, Rainfall, Distance to network, Buffer bands, Wetness index, Drainage units, Flood depth
Tables (CSV)	Measurements, Drainage unit areas, Rainfall summary, Buffer areas, LULC and runoff data
Maps and report	Composed map PNG, Composed sheet PDF (HD), Full report PDF (and Word from section 14)

All downloads can be clipped to the Study area or to the Delineated catchment. GeoTIFF and ESRI ASCII grids open directly as raster layers in QGIS and ArcGIS.

5.6 Troubleshooting

Message or symptom	What to do
"Load a study area and a DEM first."	Complete sections 1 and 2 before pressing Run analysis.
DEM does not arrive	Check your internet connection and press Fetch online DEM again, or open your own GeoTIFF (EPSG 4326).
Place labels or base map blank	They need an internet connection. Place labels are free and need no key.
"Give at least one class a curve number (CN)..."	Enter a CN for at least one class in the section 10 table.
"...no cell has a rainfall value — check the rainfall surface covers the study area."	Interpolate rainfall (section 8) and make sure your gauges and study area overlap; gauges far away give poor surfaces.
"...give a design rainfall and a curve number between 30 and 100."	Enter positive rainfall and a CN in that range in section 9.
"This rainfall gives no direct runoff at this curve number."	Rainfall is below the initial abstraction I_a . Use a larger storm or a higher CN.
Runoff volume looks too high or low	Check the units (mm), whether monthly totals were used for CN, the AMC of your CN, and the fallback value for unclassified cells.
Network too dense or too sparse	Change <i>Stream starts above</i> in section 3 and run the analysis again.
Analysis is slow	Use a smaller study area and avoid 600 dpi previews until the layout is final.

5.7 Formula quick reference

Quantity	Formula	Units
Retention S	$S = 25400 / CN - 254$	mm
Initial abstraction	$I_a = 0.2 S$	mm
SCS runoff depth	$Q = (P - I_a)^2 / (P + 0.8 S), P > I_a$	mm
Coefficient runoff	$Q = C \times P$	mm
Runoff volume	$V = Q / 1000 \times A$	m ³ (A in m ²)
Weighted CN	$\Sigma(CN_i \cdot A_i) / \Sigma A_i$	-
Overall coefficient	$\Sigma(Q_k \cdot A_k) / \Sigma(P_k \cdot A_k)$	-
Kirpich Tc	$T_c = 0.0195 L^{0.77} S_o^{-0.385}$	min (L in m)
Time to peak	$T_p = 0.667 T_c$	same unit as Tc
Triangular peak	$Q_p = 0.208 A Q / T_p$	m ³ /s (A km ² , Q mm, T _p h)
Manning discharge	$Q = (1/n) A R^{(2/3)} S_o^{(1/2)}$	m ³ /s
Regime width	$W = 3.5 \sqrt{Q_p}$	m
HAND flood depth	$\max(0, y - HAND)$	m
TWI	$\ln(a / \tan \beta)$	-
IDW weight	$w_i = 1 / d_i^p$	-
Drainage density	$\Sigma L_u / A$	km/km ²
Form factor	A / L_b^2	-
Circularity	$4\pi A / P^2$	-
Elongation	$2\sqrt{(A/\pi)} / L_b$	-

5.8 Glossary

Term	Meaning
AMC	Antecedent moisture condition: how wet the catchment was before the storm (I dry, II average, III wet).
CN	Curve Number: an index (about 30–100) of a surface's tendency to produce runoff.
D8	Eight-direction flow model: each cell drains to its single steepest downhill neighbour.
DEM	Digital elevation model: a grid of ground heights.
HAND	Height above the nearest drainage: elevation relative to the closest channel the cell drains to.
Hydrologic soil group	Soil classification A to D by infiltration capacity (A high, D very low).
Ia	Initial abstraction: rain absorbed before runoff begins.
Strahler order	A ranking of channels by branching hierarchy.
TWI	Topographic wetness index: a measure of where water tends to accumulate.
Tc	Time of concentration: travel time from the most remote point to the outlet.
Variogram	A model of how rainfall similarity decreases with distance, used in kriging.

NOTE

Keep learning. Standard references for the methods in this handbook include NRCS National Engineering Handbook Part 630 (Hydrology) and TR-55 for the Curve Number method, Chow, Maidment and Mays *Applied Hydrology* for rainfall-runoff and routing, and Rennó et al. (2008) for HAND.



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Pixel-level hydrology, in your browser.