

UNIT 5

GIS Data Modeling & Creating Maps

Surface Modeling · Hydrology Modeling · Map Design & Printing — Geographic Information Systems (GIS)

This unit covers three closely related aspects of practical GIS work: building continuous surface models from sampled elevation data, deriving hydrological information such as flow paths and watersheds from those surfaces, and finally composing the results into a well-designed, print-ready map layout.

5.1 Surface Modeling

A surface model represents a continuously varying phenomenon — most commonly terrain elevation — as a data structure that lets a GIS estimate a value (height, temperature, concentration, etc.) at any location, not just at the points that were actually measured. Surface models are the foundation for contouring, slope and aspect analysis, hydrological modeling, visibility analysis, and 3-D terrain visualization.

5.1.1 Data Structures for Surfaces

GIS software represents continuous surfaces using two fundamentally different data structures: the raster (grid) DEM and the TIN. Both are built from sampled elevation points, contour lines, or breaklines, but they organize that data very differently.

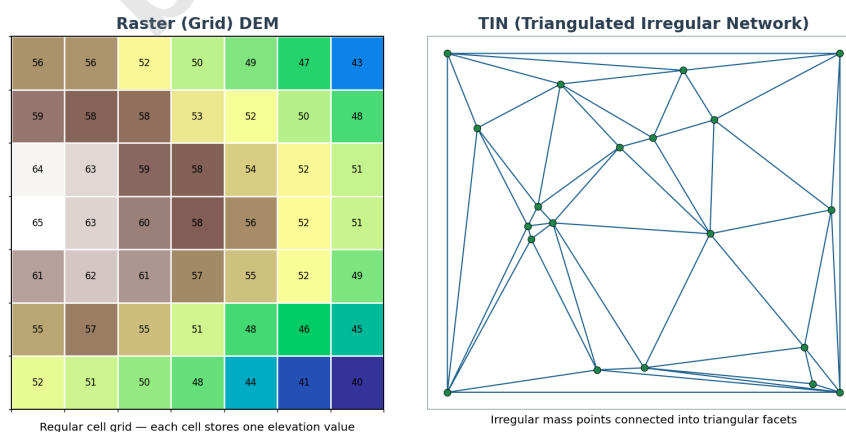


Figure 5.1 — Raster DEM (regular grid of elevation cells) versus TIN (irregular network of triangular facets built from mass points).

Property	Raster DEM (Grid)	TIN
Structure	Regular array of square cells	Irregular network of triangles

Property	Raster DEM (Grid)	TIN
Elevation storage	One value per cell (cell center)	Elevation stored only at nodes (vertices)
Resolution	Fixed, uniform everywhere	Varies — denser where terrain is complex
Best suited for	Continuous raster analysis, large areas	Areas with sharp breaklines (ridges, streams, roads)
Storage size	Can be large for high resolution	Compact — adapts point density to terrain
Common source	Interpolation, satellite DEMs (SRTM, ASTER)	Survey points, LiDAR mass points, contour vertices

Note: A TIN is generally more accurate for representing sharp terrain features because triangle edges can be forced to follow breaklines such as ridgelines and stream channels, whereas a raster grid smooths across them unless resolution is very fine.

5.1.2 Interpolation Methods

When only scattered sample points (survey points, boreholes, weather stations) are available, spatial interpolation is used to estimate values across the entire study area and build a continuous raster surface. The three interpolation methods most commonly taught and used in GIS are:

- Inverse Distance Weighting (IDW) — estimates each unknown cell as a weighted average of nearby sample points, where weight decreases with distance (commonly $1/d^2$). Simple and fast, but produces a surface that never exceeds the range of the input values and creates "bullseye" patterns around clustered points.
- Kriging — a geostatistical method that models the spatial autocorrelation of the data (via a variogram) before interpolating. It produces statistically optimal estimates and can also report a prediction-error surface, but requires more data and computation than IDW.
- Spline — fits a smooth, minimum-curvature mathematical surface through the sample points. It can estimate values outside the input value range (useful for smooth phenomena like water-table height) but can overshoot in areas with abrupt changes.

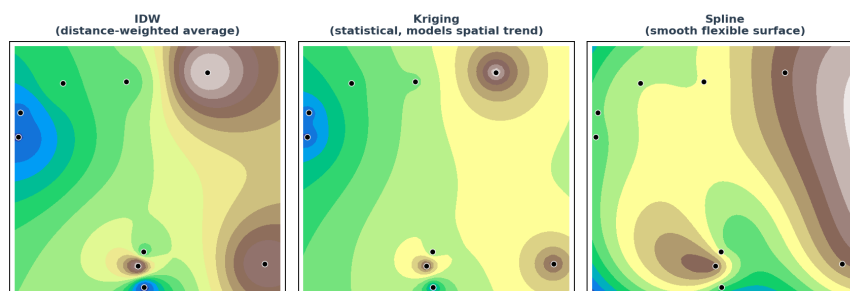


Figure 5.2 — The same nine sample points interpolated with IDW, Kriging, and Spline. Notice how each method produces a visibly different surface from identical input data.

Example 5.1

Nine borehole elevation readings are collected across a construction site and a continuous elevation surface is needed to plan earthwork cut-and-fill volumes.

Which interpolation method is most appropriate, and why?

Solution

IDW is a reasonable quick choice, but because earthwork volume calculations are sensitive to small elevation errors, Kriging is usually preferred: it uses the spatial autocorrelation structure of the terrain to produce a more statistically robust estimate and, importantly, also outputs a standard-error surface that tells the engineer where the surface is least reliable (e.g., far from any borehole).

5.1.3 Terrain Derivatives — Slope, Aspect, Hillshade, Contours

Once a DEM exists, several important secondary surfaces (terrain derivatives) can be computed automatically from it:

- Slope — the rate of elevation change per unit horizontal distance, expressed in degrees or percent. Computed from the local gradient (rate of change in the X and Y directions) at each cell.
- Aspect — the compass direction that the steepest downhill slope faces at each cell (0° – 360° , measured clockwise from north). Used in solar radiation, snowmelt, and habitat modeling.
- Hillshade — a simulated illumination of the terrain from a given sun azimuth and altitude, producing a shaded-relief image that makes terrain features visually intuitive.
- Contour lines — lines of equal elevation, generated by "slicing" the DEM at regular elevation intervals; still the most widely used way to communicate terrain shape on a printed map.

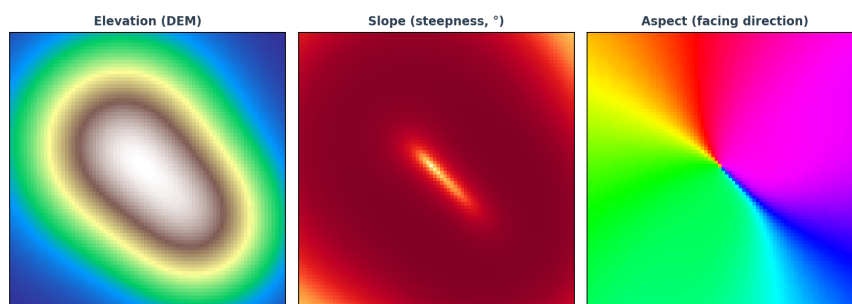


Figure 5.3 — A DEM (left) and its slope (center) and aspect (right) derivatives. Steeper areas appear darker in the slope map; aspect is coded by compass direction.

Note: Slope and aspect are both computed from the same local 3×3 neighborhood gradient — this is the same neighborhood-window concept used later for flow direction in hydrology modeling (Section 5.2).

Key Takeaways — Surface Modeling

- ✓ A surface model lets a GIS estimate a continuous value anywhere in the study area from sampled or measured data.
- ✓ Raster DEMs use a uniform grid of cells; TINs use an irregular network of triangles anchored at mass points and breaklines.
- ✓ IDW, Kriging, and Spline are the three standard interpolation methods, each with different assumptions and trade-offs.
- ✓ Slope, aspect, hillshade, and contours are terrain derivatives computed directly from a DEM.

5.2 Hydrology Modeling

Hydrological (watershed) modeling uses a DEM to simulate how water moves across a landscape — where it flows, where it accumulates, and which area of land drains into a given outlet point. This is central to flood-risk mapping, watershed management, and stream-network extraction.

5.2.1 Sink Filling

Real-world DEMs almost always contain spurious depressions ("sinks") caused by interpolation error or data resolution — single cells or small clusters that are lower than every neighboring cell, with no downhill outlet. Before flow can be traced across the whole surface, these sinks must be filled by raising their elevation to match the lowest point on their surrounding rim, so that water is never mathematically trapped.

5.2.2 Flow Direction — the D8 Algorithm

The most widely used flow-direction method is D8 ("deterministic eight-neighbor"). For every cell, the algorithm examines its eight surrounding neighbors and assigns flow entirely to whichever single neighbor represents the steepest downhill drop. Each of the eight possible directions is given a standard power-of-two code so that the direction can be stored as one integer per cell.

D8 Flow-Direction Coding (3×3 window)

78 code 32	72 code 64	69 code 128
74 code 16	66 	60 code 1
71 code 8	64 code 4	58 code 2

Figure 5.4 — D8 flow-direction coding. The center cell (elevation 66) flows to its steepest downhill neighbor — here, the SE cell at elevation 58 (code 2).

Example 5.2

For the 3×3 neighborhood in Figure 5.4, the center cell has elevation 66. Its eight neighbors are 78, 72, 69, 74, 60, 71, 64, 58 (going clockwise from NW). Which direction does the center cell flow, and what D8 code is assigned?

Solution

The steepest drop is toward the lowest neighboring elevation, 58 (southeast), giving a drop of $66 - 58 = 8$ over the diagonal distance. No other neighbor produces a steeper downhill gradient, so flow is assigned to the SE cell, which carries D8 code 2.

5.2.3 Flow Accumulation and Stream Network Extraction

Once every cell has a flow direction, flow accumulation is computed: for each cell, the GIS counts how many upstream cells drain through it (assuming one unit of runoff per cell). Cells with very high accumulation values lie on natural drainage paths. Applying a threshold to the flow-accumulation raster (e.g., "keep only cells with more than 500 contributing upstream cells") extracts a stream network that closely matches real channels visible on the ground.

5.2.4 Watershed Delineation

A watershed (or drainage basin/catchment) is the entire upslope area that drains to a chosen outlet point. Given a filled DEM, its flow-direction raster, and a pour point, GIS software traces backward through the flow-direction raster to identify every cell whose flow eventually passes through that outlet — delineating the watershed boundary automatically.

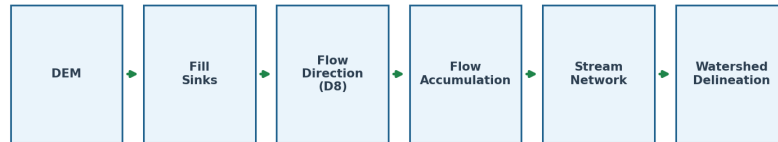


Figure 5.5 — The standard hydrological modeling workflow: from a raw DEM to a delineated watershed boundary.

Step	Input	Output	Purpose
Fill Sinks	Raw DEM	Depressionless DEM	Removes false low points that trap flow
Flow Direction	Filled DEM	D8 direction raster	Assigns each cell a single downhill flow path
Flow Accumulation	Direction raster	Accumulation raster	Counts upstream contributing cells per cell
Stream Network	Accumulation raster	Stream vector/raster	Extracts channels above a threshold
Watershed	Direction raster + pour point	Watershed polygon	Delineates the contributing drainage area

Note: The order of these steps matters: running flow direction on an unfilled DEM produces broken, incomplete flow paths wherever a sink interrupts the drainage.

Key Takeaways — Hydrology Modeling

- ✓ Sink filling removes spurious depressions so flow can be traced across the entire DEM.
- ✓ D8 assigns each cell's flow to its single steepest downhill neighbor, coded as a power of two.
- ✓ Flow accumulation counts upstream contributing cells and is used to extract stream networks.
- ✓ Watershed delineation traces the full upslope contributing area to a chosen outlet (pour point).

5.3 Designing and Printing the Map

Analysis results are only useful if they can be communicated clearly. Cartographic design is the process of arranging map elements — the data itself plus supporting context — into a layout that is accurate, readable, and visually balanced before printing or exporting.

5.3.1 Essential Map Elements

- Title — states clearly what the map shows; should be the most visually prominent text element.
- Map body / data frame — the actual geographic data display, normally the largest element on the page.
- Legend — explains every symbol, color, and pattern used to represent data in the map body.
- North arrow — indicates map orientation (essential unless the map is conventionally north-up and this is stated).
- Scale bar — allows the reader to measure real-world distance directly from the printed page; preferred over a text-only representative fraction because it remains correct even if the map is resized.
- Data source / metadata — author, date, coordinate system/projection, and source of the underlying data, usually placed in small text near the map border.
- Neatline / border — a frame around the whole composition that gives the layout a clean, finished edge.

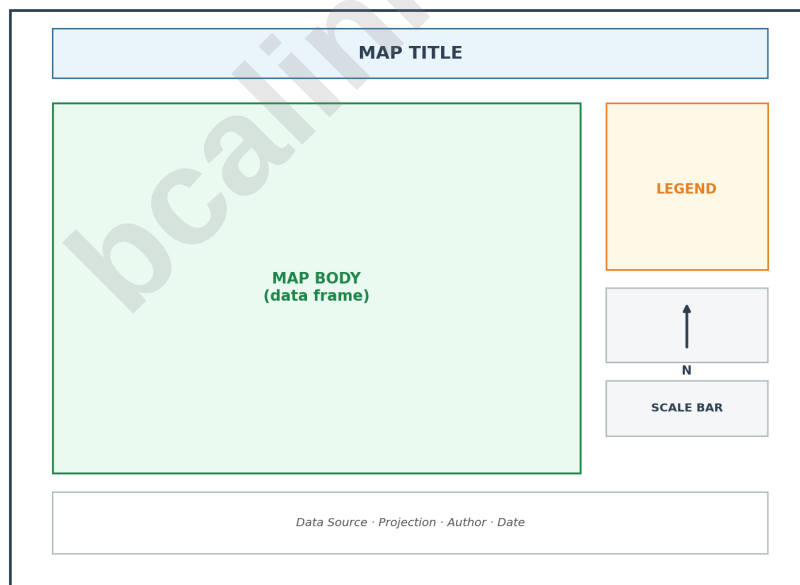


Figure 5.6 — Standard cartographic layout: title block, map body, legend, north arrow, scale bar, and metadata, all inside a neatline.

5.3.2 Design Principles

- Visual hierarchy — the most important information (title, then map body) should draw the eye first; supporting elements (legend, scale bar) should be smaller and less prominent.

- **Balance** — elements should be distributed so the page does not feel heavier on one side; white space is used deliberately, not left over by accident.
- **Consistency** — one color scheme and one symbol style should be used throughout so the legend applies unambiguously to everything in the map body.
- **Appropriate generalization** — the level of coordinate and label detail should match the intended print/output scale; overly dense labeling at small scale produces clutter.
- **Projection choice** — the map's coordinate reference system should suit its purpose (e.g., an equal-area projection for thematic/statistical maps where area comparison matters, versus a conformal projection where shape and angle preservation matter more).

Example 5.3

A watershed delineation map (from Section 5.2) needs to be prepared as a final printed handout for a public meeting on flood risk. List the map elements that are essential for this specific audience and purpose.

Solution

Title identifying the watershed and its purpose (e.g., "Flood Risk — XYZ Watershed Boundary"); a legend distinguishing the watershed boundary, stream network, and any flood zones; a scale bar and north arrow so residents can orient themselves relative to known landmarks; and a data-source/date line for credibility. Because the audience is the general public rather than technical staff, coordinate grid lines and projection details can be minimized or omitted in favor of a simpler, uncluttered layout.

5.3.3 Preparing for Print / Export

- Set the output page size and orientation (e.g., A4 portrait vs. landscape) to match the shape of the study area before finalizing element placement.
- Choose an export resolution (DPI) appropriate to the medium — around 300 DPI for print, lower for on-screen/PDF-only distribution — to balance clarity against file size.
- Export to a format matching the intended use: PDF for sharing and printing (preserves vector sharpness and text searchability), PNG/JPEG for embedding in documents or presentations, and georeferenced formats (GeoPDF, GeoTIFF) when the map itself needs to remain spatially usable in other software.
- Proofread text and check the legend against the map body one final time — printing reveals size and readability issues that are easy to miss on screen.

Note: A common mistake is finalizing colors and label sizes on a large monitor and then discovering, only after printing, that fine details or thin lines are no longer legible at actual print size — always preview at (or as close as possible to) true output size before sending the final job to print.

Key Takeaways — Designing and Printing the Map

- ✓ A complete map layout includes a title, map body, legend, north arrow, scale bar, and source/metadata, inside a neatline.
- ✓ Good cartographic design balances visual hierarchy, balance, consistency, and appropriate generalization for the intended scale.
- ✓ Projection choice should match the map's purpose — equal-area for thematic comparison, conformal where shape/angle accuracy matters.
- ✓ Export settings (page size, DPI, file format) should be chosen to match how the final map will be used and distributed.

— *End of Unit 5* —

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