

Terrain Baseline Assessment

Lake Toba Pumped Storage Hydropower Project

Report prepared by bglSpatial for Lake Toba Pumped Storage Hydropower Project

Date: January 2026

Version: 1.0

Project Location

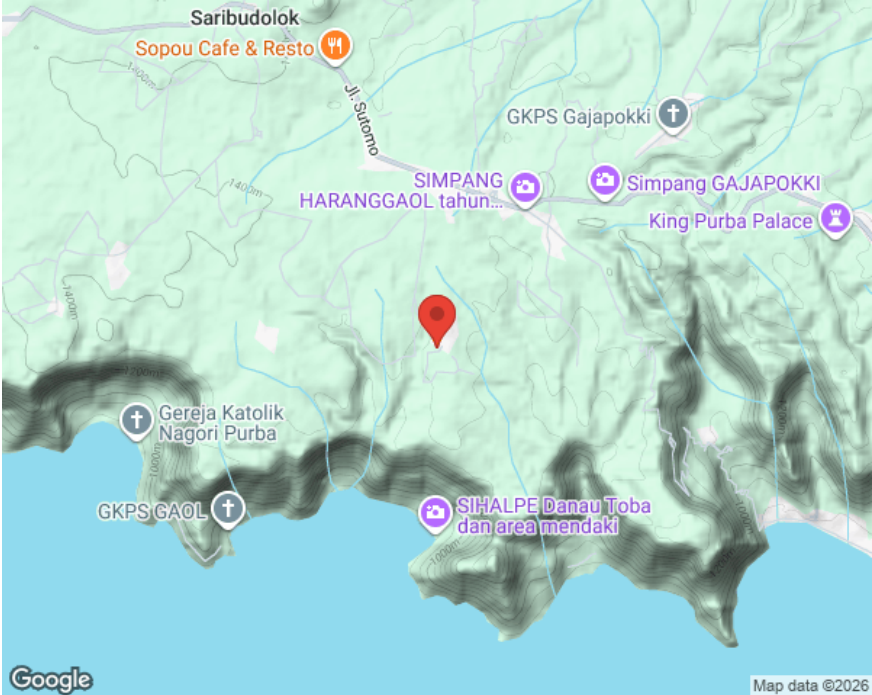


Figure 1: Lake Toba Pumped Storage Hydropower Project Area of Interest (Terrain Map)

1.0 Terrain Baseline Assessment

Project: Lake Toba Pumped Storage Hydropower Project **Location:** Lake Toba **Project Type:** Pumped Storage Hydropower **Client:** Greencorpllc **Prepared by:** bglSpatial **Date:** January 27, 2026 **Version:** 1.0

1.1 Data Resolution and Scope

Important: This terrain baseline assessment uses **ASF 12-meter resolution** digital elevation data. The analysis characterizes regional-scale terrain patterns suitable for preliminary site assessment and constraint mapping. **Intended Use:** Results guide the scope and location of detailed site investigations, including LiDAR surveys, geotechnical studies, and field reconnaissance. This assessment does not replace site-specific engineering surveys required for detailed design. **Resolution Limitations:** Terrain features smaller than ~36 meters (3x pixel size) may not be reliably captured. Derived metrics (slope, curvature, HAND) inherit these limitations.

1.0 Executive Summary

Executive Summary: Terrain Baseline

The terrain within the Lake Toba Pumped Storage Hydropower Project study area is predominantly characterized by flat to gently sloping landforms. A significant 46.2% of the area is classified as flat terrain, while gentle slopes (averaging 27.96%) constitute the dominant slope class. The topography is primarily composed of elevated ridge tops, with a relatively uniform aspect distribution; north-facing slopes are most common, representing 16.4% of the area. The hypsometric integral of 0.73 indicates a landscape in a mature stage of geomorphic development, with a significant proportion of the landmass remaining at higher elevations relative to the local relief.

These characteristics present both opportunities and constraints for project development. The extensive areas of flat and gentle terrain offer favorable conditions for the siting of surface infrastructure, including access roads, construction laydown areas, and ancillary facilities, potentially minimizing initial earthworks. However, the presence of steep terrain, which comprises 21.5% of the study area, will require careful alignment of penstock routes, transmission corridors, and any upper reservoir infrastructure to avoid geotechnical instability. The dominant low erosion risk across most of the site is a positive factor for construction-phase sediment control.

Key areas requiring further detailed assessment and targeted mitigation focus on terrain-related geohazards. Although overall erosion risk is low, the 8.3% of the area classified as high erosion risk necessitates site-specific erosion and sediment control plans, particularly

for cut slopes and disturbed areas within these zones. The interface between proposed infrastructure and the identified steep slopes demands a comprehensive geotechnical investigation to assess slope stability, foundation conditions, and the need for engineered retaining structures. Mitigation measures must be designed to address potential impacts from earthworks, including landslide risk and increased sediment yield to Lake Toba during both construction and operation.

2.0 Study Area Description

The study area encompasses approximately **35.19 km²** located at coordinates 2.8979°N, 98.6339°E.

2.1 Study Area Extent

Parameter	Value
Total Area	35.19 km ²
Bounding Box (West)	98.6046°
Bounding Box (South)	2.8629°
Bounding Box (East)	98.6667°
Bounding Box (North)	2.9340°
Coordinate System	EPSG:32647

3.0 Data Sources and Methods

3.1 Digital Elevation Model

This assessment utilizes the **ALOS PALSAR Radiometric Terrain Corrected (ASF)** with a spatial resolution of 12 meters.

Parameter	Value
DEM Source	ASF
Resolution	12 m
Provider	ASF DAAC / NASA Earthdata
NoData Coverage	35.47%

3.2 Analysis Methods

Terrain derivatives were calculated using standard algorithms:

- **Slope:** Maximum Downhill Slope method (O'Callaghan & Mark, 1984) — maximum gradient to any of 8 neighbors
- **Aspect:** Derived from slope direction, reported as compass bearing
- **TPI:** Topographic Position Index at local and regional scales (Weiss, 2001)
- **Curvature:** Profile and planform curvature using Zevenbergen & Thorne (1987)

4.0 Elevation Analysis

Based on the 12m resolution digital elevation model (DEM) data, the Lake Toba Pumped Storage Hydropower Project area exhibits a significant altitudinal range of approximately 532 meters, from a minimum of 880 meters to a maximum of 1,412 meters above sea level. This substantial relief indicates a landscape characterized by moderate to steep topographic complexity, typical of volcanic highland terrain. The mean elevation of approximately 1,266 meters, coupled with a high standard deviation of ~167 meters, confirms considerable local variability in terrain. The hypsometric integral of 0.73 suggests a landscape in a mature stage of geomorphic development, where erosional processes have dissected the terrain but a significant proportion of the original elevated landmass remains, implying generally stable, well-drained slopes at a regional scale.

The distribution of land area across the five defined elevation zones is notably bimodal, with concentrations in both the lowest (Zone 1: 19.96%) and highest (Zone 5: 21.95%) bands. The three intermediate zones (Zones 2-4) collectively account for 58.08% of the area, with Zone 3 (1,336-1,359m) being the most extensive single mid-elevation band. This distribution has direct implications for project design. The extensive area in the highest zone (above 1,370m) may offer suitable locations for an upper reservoir, provided geotechnical conditions are favorable. The broad mid-elevation plateau, evidenced by the 25th to 75th percentile range (1,274m to 1,368m) containing 50% of the terrain, suggests the potential for routing penstocks and access infrastructure across relatively uniform slopes, minimizing extreme gradients. However, the substantial area in the lowest zone necessitates careful planning for the lower reservoir, intake/outlet structures, and power station to accommodate the base-level topography and associated drainage patterns.

Notable features derived from the statistics include the pronounced elevation difference between the median (1,350m) and the mean (1,266m), which indicates a negatively skewed distribution; a larger land area exists at elevations above the median, forming an elevated plateau or ridge complex. The narrow interquartile range (IQR) of 94 meters (1,274m to 1,368m) relative to the total range further emphasizes this concentration of terrain across a central elevation band. The close proximity of the 75th percentile (1,368m), 95th percentile

(1,380m), and maximum (1,412m) elevation suggests the upper reaches of the site comprise a relatively confined summit area. For drainage implications, the reliable detection of features wider than 36m indicates that major watershed divides, ridges, and primary stream channels will be well-characterized, informing catchment analysis and flood risk assessment. However, fine-scale erosion features, such as narrow gullies or small landslide scars below this detection threshold, may not be captured, requiring ground-truthing for detailed engineering design.

4.1 Elevation Statistics

Statistic	Value
Min	880.0 m
Max	1412.0 m
Mean	1265.8 m
Std	166.6 m
Median	1350.0 m
Range	532.0 m
P5	887.0 m
P25	1274.0 m
P75	1368.0 m
P95	1380.0 m

4.2 Elevation Zone Distribution

Zone	Elevation Range	Area (km ²)	Percentage
Zone 1 (880-1132m)	880 - 1132 m	7.02	20.0%
Zone 2 (1132-1336m)	1132 - 1336 m	6.97	19.8%
Zone 3 (1336-1359m)	1336 - 1359 m	6.89	19.6%
Zone 4 (1359-1370m)	1359 - 1370 m	6.58	18.7%
Zone 5 (1370-1412m)	1370 - 1412 m	7.72	22.0%

5.0 Slope Analysis

Based on the 12m resolution data, the terrain within the Lake Toba project area is predominantly characterized by gentle to moderate slopes. The dominant slope class is **Gentle (2-5°)**, covering 28.0% of the area, closely followed by **Moderate (5-10°)**, which covers 25.8%. Combined with the **Flat (0-2°)** class at 18.2%, these three categories constitute over 71% of the total terrain. This indicates a regional morphology of rolling hills and moderate inclines, with a median slope of 6.5°. However, the presence of a maximum slope of 77° and a 95th percentile (p95) of 36.3° confirms that the landscape is interspersed with significant, localized areas of very steep to extreme terrain, which are detectable as regional-scale features in this dataset.

From an engineering perspective, the high proportion of gentle to moderate slopes is favorable for project infrastructure development, such as access roads, transmission corridors, and ancillary facilities, as it implies a reduced need for extensive, deep-cut grading. However, the **Moderate (5-10°)** and **Moderately Steep (10-15°)** classes, which together cover over 32% of the area, will require planned grading and robust erosion control measures, as indicated by the class descriptions. The **Steep (15-30°)** and **Very Steep (30-45°)** classes, comprising a combined 20% of the area, represent zones of major geotechnical constraint. Development here would necessitate significant engineered earthworks, comprehensive slope stability assessments, and potentially specialized foundation designs. It is critical to note that the 12m resolution averages gradients over a pixel; localized, sharp features like small gullies or cut slopes with an extent of less than ~36m may be underrepresented, meaning steeper conditions could be encountered during detailed design.

Areas of primary concern are those classified as **Steep, Very Steep, and Extreme (>15°)**, which total approximately 21.5% of the project area. Per IFC Performance Standard 1 and 4 guidelines, these zones require a precautionary approach. Recommended mitigation includes: **1) Avoidance and Minimization:** Siting critical infrastructure and laydown areas within the Flat to Moderate slope zones where feasible, using the slope class map for preliminary corridor planning. **2) Detailed Site Investigation:** Conducting high-resolution topographic surveys (e.g., LiDAR) and geotechnical investigations in all proposed development footprints, especially where the 12m data indicates slopes >10°, to identify fine-scale hazards not captured in this analysis. **3) Engineered Controls:** For unavoidable work on steeper slopes, implementing designs per international geotechnical standards, including engineered retaining structures, reinforced slopes, and comprehensive surface water management and sediment control plans to prevent erosion and instability. **4) Exclusion:** Formally designating areas in the **Extreme (>45°)** class, such as cliff faces, as no-go exclusion zones for any project activity.

5.1 Slope Statistics

Statistic	Value
Min	0.0°
Max	77.0°
Mean	10.4°
Std	11.4°
Median	6.5°
P90	29.2°
P95	36.3°

5.2 Slope Class Distribution

Class	Range	Area (km ²)	Percentage	Description
Flat	0° - 2°	6.42	18.2%	Suitable for most development with minimal grading
Gentle	2° - 5°	9.84	28.0%	Minor grading may be required; suitable for solar arrays
Moderate	5° - 10°	9.07	25.8%	Grading required; erosion control measures needed
Moderately Steep	10° - 15°	2.28	6.5%	Significant earthworks required; stability assessment needed
Steep	15° - 30°	4.61	13.1%	Major engineering constraints; geotechnical assessment essential
Very Steep	30° - 45°	2.43	6.9%	Severe constraints; avoidance recommended where possible
Extreme	45° - 90°	0.54	1.5%	Development not feasible; exclusion zone

6.0 Aspect Analysis

Based on 12m resolution data, the dominant detectable slope orientation for the Lake Toba project area is North (N), which comprises 16.4% of the terrain and is the modal direction. However, the aspect distribution is relatively dispersed, with significant areas also facing Northeast (15.8%), West (13.5%), and Northwest (15.7%). The low concentration parameter (0.39) and high circular standard deviation (~105°) confirm that slopes face many directions, indicating a complex, non-uniform topography at a regional scale.

For a solar project, this aspect distribution is suboptimal, as a large proportion of slopes face away from the equator (North, Northwest, Northeast), reducing direct solar irradiance. The significant area of East and West-facing slopes would receive strong morning or afternoon sun but limited midday exposure. For general projects, the varied aspects will create a mosaic

of microclimates, influencing local temperature, moisture, and wind patterns. North-facing slopes are typically cooler and more humid, potentially supporting different vegetation, while South-facing slopes are warmer and drier. This heterogeneity also affects erosion potential, as slope stability and runoff patterns vary with orientation. The prevalence of northerly aspects may influence site-specific planning for drainage, foundation design, and vegetation management.

6.1 Aspect Statistics

Statistic	Value
Modal Direction	North (N)
Circular Mean	4.0°
Concentration	0.39
Flat Area	18.1%

6.2 Aspect Class Distribution

Direction	Area (km ²)	Percentage
North (N)	4.69	16.4%
Northeast (NE)	4.51	15.8%
East (E)	3.75	13.1%
Southeast (SE)	2.87	10.0%
South (S)	2.15	7.5%
Southwest (SW)	2.27	7.9%
West (W)	3.87	13.5%
Northwest (NW)	4.50	15.7%

7.0 Topographic Position

Based on the Weiss (2001) Topographic Position Index (TPI) analysis of the 12m-resolution ASF DEM data, the study area exhibits a remarkably balanced distribution of elevated and depressed landforms. The dominant class is "Ridge Top" (26.3%), closely followed by "Valley Bottom" (25.1%), indicating a landscape of pronounced relief where elevated and low-lying positions are nearly equally prevalent. The remaining half of the area is composed of transitional slopes, with "Mid-Slope" being the most common (23.0%). This pattern suggests a

dissected, high-relief terrain where ridge lines and valley networks are both extensive features of the landscape.

The dominance of "Ridge Top" positions indicates a landscape character defined by significant local and regional topographic highs. This is consistent with the youthful, high-relief terrain suggested by the complementary Hypsometric Integral (HI=0.725), which points to a landscape in an early stage of geomorphic evolution with high erosion potential. From an engineering perspective, this topographic configuration presents both challenges and opportunities. The prevalence of ridges may offer favorable, stable alignment corridors for access roads and penstock routes, avoiding major valley flooding. However, the extensive, steep mid-slopes and deeply incised valleys imply significant excavation requirements, complex drainage management to handle concentrated runoff, and potential geotechnical stability concerns on cut slopes. The near-equal abundance of ridges and valleys also suggests that reservoir siting and water conveyance will need to navigate a complex, high-relief topography, where the regional-scale TPI patterns are critical for identifying major, stable divides versus localized knolls within larger valleys.

7.1 TPI Statistics

Statistic	Local Scale	Regional Scale
Window Size	5 pixels (150 m)	19 pixels (570 m)
Minimum	-26.5	-66.6
Maximum	30.1	103.6
Mean	-0.00	-0.02
Std Dev	1.27	6.66
Median	0.00	0.00

7.2 Landform Classification

Landform	Percentage	Description
Ridge Top	26.3%	Elevated positions on both local and regional scales
Upper Slope	12.5%	Local ridges within regional mid-slopes
Mid-Slope	23.0%	Transitional slopes and flat areas
Lower Slope	13.1%	Local valleys within regional mid-slopes
Valley Bottom	25.1%	Depressed positions on both local and regional scales

Dominant Landform: Ridge Top

8.0 Curvature Analysis

Based on the 12m resolution data, the detectable terrain features at the Lake Toba site indicate a landscape with a slight predominance of concave forms (34.6%) over convex (34.0%) and planar (31.5%) forms. This suggests a relatively balanced but dissected terrain where concave valleys and hollows are marginally more common than convex ridges and spurs, with a significant portion of the area consisting of planar or near-planar slopes.

Hydrologically, the prevalence of concave forms promotes localized runoff convergence, potentially increasing surface water flow and sediment transport into drainage networks. This pattern, combined with the presence of convex slopes, indicates an active erosion and deposition system where material is shed from ridges and accumulated in valleys. For construction, the curvature patterns highlight the need for careful geotechnical assessment. Concave areas may require enhanced drainage and foundation measures to manage subsurface water, while cut-and-fill operations on convex slopes must account for potential instability. The significant planar areas may offer more stable platforms for infrastructure, though their interfaces with steeper, curved slopes warrant attention. These interpretations reflect regional-scale patterns derived from the 12m data; site-specific investigations are required to address finer-scale terrain features not captured in this analysis.

8.1 Curvature Statistics

Parameter	Profile	Planform
Minimum	-0.0604	-0.0906
Maximum	0.0623	0.0760
Mean	0.0000	0.0000
Std Dev	0.0056	0.0058

8.2 Landform Distribution

- Convex (ridges/hilltops): 34.0%
- Concave (valleys/depressions): 34.6%
- Planar (uniform slopes): 31.5%

9.0 Erosion Susceptibility

1. Overall Distribution of Erosion-Prone Terrain

The terrain-based erosion susceptibility analysis for the project area indicates that the majority of the landscape is classified as having a low susceptibility to erosion, covering 27.7 km² or 78.6% of the assessed area. Terrain with moderate susceptibility comprises 4.6 km² (13.1%), while high-susceptibility terrain is the least extensive at 2.9 km² (8.3%). This distribution suggests that, from a topographic perspective, the most erosion-prone conditions are spatially limited. It is critical to frame this as a susceptibility index based solely on terrain characteristics—specifically slope gradient (70% weighting), profile curvature (20%), and the Hypsometric Integral (10%). This model identifies areas with geomorphological predisposition to erosion but does not quantify actual erosion rates, which are a function of additional factors not included in this analysis.

2. Spatial Concentration of High-Risk Areas

The high and moderate erosion susceptibility classes exhibit a strong and exclusive association with the steepest slope categories. All moderate-risk terrain (4.6 km²) is concentrated on 'Steep' (98.6%) and 'Very Steep' (1.4%) slopes. Similarly, all high-risk terrain (2.9 km²) is found on 'Very Steep' (81.3%) and 'Extreme' (18.7%) slopes. This indicates that the spatially discrete zones of highest erosion susceptibility are exclusively located on the steepest valley sidewalls and escarpments within the project landscape. The Hypsometric Integral value of 0.725 suggests a generally youthful, disequilibrium landscape with high relief, which is consistent with the presence of such steep, potentially unstable slopes. This terrain-focused analysis does not incorporate rainfall erosivity, soil properties, or land cover, which are necessary to identify specific convergent flow pathways or actively eroding sites.

3. Relationship Between Slope Class and Erosion Risk

The cross-tabulation data reveals a deterministic relationship between slope gradient and the assigned erosion susceptibility class within this model. Low-susceptibility terrain is distributed across a spectrum of slope classes, predominantly 'Gentle' (35.6%) and 'Moderate' (32.8%). In contrast, the model assigns no moderate or high susceptibility to slopes gentler than 'Steep'. Consequently, 100% of the combined moderate and high-susceptibility area (7.5 km²) occurs on slopes classified as 'Steep', 'Very Steep', or 'Extreme'. This underscores that slope gradient is the dominant controlling factor in this terrain-based index. The inclusion of profile curvature and the basin-scale Hypsometric Integral provides secondary refinement, differentiating risk on these steep slopes, but the model's output remains an indicator of topographic potential rather than a prediction of geomorphic process rates.

9.1 Erosion Risk Distribution

Risk Category	Area (km ²)	Percentage	Description
Low	27.70	78.6%	Terrain conditions generally favorable for development; standard erosion controls sufficient
Moderate	4.60	13.1%	Moderate terrain susceptibility; enhanced erosion controls and monitoring recommended
High	2.90	8.3%	Steep and/or concave terrain with high runoff potential; comprehensive erosion management required

Dominant Risk Category: Low

9.2 Erosion Risk by Slope Class

Distribution of erosion risk categories across slope classes (percentage of each risk category):

Slope Class	Low	Moderate	High
Flat	23.2%	0.0%	0.0%
Gentle	35.6%	0.0%	0.0%
Moderate	32.8%	0.0%	0.0%
Moderately Steep	8.2%	0.0%	0.0%
Steep	0.2%	98.6%	0.0%
Very Steep	0.0%	1.4%	81.3%
Extreme	0.0%	0.0%	18.7%

9.3 Application Guidance

This terrain-based erosion susceptibility mapping provides a foundation for site planning and informs subsequent investigations:

- **Prioritize field investigation:** High-susceptibility areas warrant priority geotechnical reconnaissance to verify conditions
- **Guide facility layout:** Locate permanent infrastructure away from high-susceptibility terrain where feasible
- **Inform drainage design:** Concentrate stormwater management measures in areas of high runoff potential
- **Scope detailed studies:** Target site-specific erosion modeling (RUSLE/USLE) to high-risk zones identified here

Supplementary studies for detailed design: soil erodibility testing, rainfall intensity analysis, and vegetation cover mapping.

Note: This assessment uses terrain parameters only (slope, curvature, landscape maturity) at 12m resolution.

9.4 Engineering Assumptions

Based on the hypsometric analysis (HI = 0.725), this landscape exhibits characteristics of a **youthful (actively eroding)** erosional environment:

Implications for Engineering Design:

- **Penstock alignments** must assume active downcutting and lateral erosion in stream channels
- **Reservoir siting** should account for high sediment yield from youthful watersheds
- **Foundation design** must consider ongoing slope adjustment processes
- **Drainage infrastructure** should be sized for high sediment loads

Recommendation: Geotechnical investigations should characterize erosion rates and active geomorphic processes along proposed infrastructure corridors.

10.0 Flood Susceptibility (HAND)

The HAND (Height Above Nearest Drainage) analysis for the Lake Toba Pumped Storage Hydropower Project area indicates a significant proportion of terrain with topography conducive to flood susceptibility. The analysis classifies 43.8% of the assessed area (15.42 km²) as "Flood-Prone," representing the lowest-lying land. A further 25.9% (9.11 km²) is classified as "Low Susceptibility," 12.7% (4.47 km²) as "Moderate Susceptibility," and 17.6% (6.19 km²) as "High Elevation." The mean HAND value of 23.48 meters suggests the overall terrain is moderately elevated relative to drainage channels, though the presence of a minimum value near zero confirms the existence of areas at or very near the drainage network base level.

The low-lying, flood-prone terrain is concentrated in topographic depressions and along the riparian corridors of the drainage network, where the HAND value approaches zero. These areas correspond to valley bottoms and the immediate floodplains of streams and rivers, which form the natural pathways for surface water flow and accumulation. For project siting and infrastructure placement, this distribution necessitates careful avoidance of these identified low-lying corridors for permanent structures, access roads, and ancillary facilities to minimize exposure to topographically-driven surface water accumulation. It is critical to note that HAND is a static topographic indicator of relative elevation above drainage channels; it identifies areas with flood-prone topography but does not constitute a flood hazard or risk assessment. This analysis does not incorporate precipitation, hydrological modeling, return period events, or hydraulic characteristics. A full evaluation of flood risk in accordance with IFC Performance Standard 3 would require subsequent, detailed hydrological and hydraulic studies.

10.1 HAND Class Distribution

Susceptibility Class	Area (km ²)	Percentage
Flood-Prone	15.42	43.8%
Low Susceptibility	9.11	25.9%
Moderate Susceptibility	4.47	12.7%
High Elevation	6.19	17.6%

Flood-Prone Area (HAND < 5m): 15.42 km² (43.8%)

10.2 HAND Statistics

Statistic	Value (m)
Minimum	-0.00
Maximum	460.00
Mean	23.48
Median	6.00
Std Dev	48.77

10.3 Methodology

- **Method:** Height Above Nearest Drainage (HAND) derived from D8 flow direction
- **Drainage Threshold:** 100 cells (~0.09 km² contributing area)
- **Classification:** Flood-Prone (<5m), Low (5-15m), Moderate (15-30m), High (≥30m)

10.4 Limitations

This HAND-based flood susceptibility assessment has the following limitations:

- **Topographic indicator only:** HAND measures relative elevation above drainage, not actual flood risk
- **No precipitation data:** Does not include rainfall patterns, intensity, or return periods
- **No hydraulic modeling:** Does not simulate water flow, velocity, or depth
- **No channel capacity:** Assumes all drainage channels can overflow (conservative assumption)
- **Static analysis:** Does not account for seasonal water level variations or dam operations
- **Resolution constraint:** Based on 12m ASF DEM; localized drainage features may not be captured

HAND identifies topographic flood susceptibility only. Does not include precipitation analysis, return periods, or hydraulic modeling.

11.0 Hydrological Landscape Classification

The study area has been classified into hydrological landscape units based on the combination of Height Above Nearest Drainage (HAND) and slope gradient, following the conceptual framework of Nobre et al. (2011). This classification provides a functional zonation of terrain based on hydrological position and geomorphic activity.

11.1 Classification Criteria

Classification thresholds: **HAND = 10.0 m, Slope = 5.0°**

Landscape Unit	HAND	Slope	Hydrological Interpretation
Wetland	< 10.0m	< 5.0°	Valley bottoms, floodplains, riparian zones
Hillslope	≥ 10.0m	≥ 5.0°	Active erosional slopes, valley sides
Plateau	≥ 10.0m	< 5.0°	Flat uplands, terraces, interfluves
Transitional	< 10.0m	≥ 5.0°	Escarments, bluffs, incised valley walls

11.2 Landscape Unit Distribution

Landscape Unit	Area (km ²)	Percentage	Description
Wetland	13.91	39.5%	Low-lying areas near drainage channels; flood-prone valley bottoms and floodplains
Hillslope	11.73	33.3%	Sloping terrain elevated above drainage; actively eroding slopes and valley sides
Plateau	2.35	6.7%	Flat terrain elevated above drainage; upland plateaus, terraces, and interfluves
Transitional	7.20	20.5%	Steep terrain near drainage; escarpments, bluffs, and incised valley walls

Dominant Landscape Unit: Wetland (39.5%)

11.3 Interpretation

- **Significant wetland/floodplain presence (39.5%):** Areas near drainage channels with low slopes indicate flood-prone terrain
- **Active hillslope terrain (33.3%):** Elevated, sloping areas where erosion processes are active

This classification integrates flood susceptibility (HAND) and erosion susceptibility (slope) into a unified terrain zonation for land use planning.

12.0 Terrain Suitability Summary

Based on the provided terrain analysis, the proposed Lake Toba Pumped Storage Hydropower (PSH) project site presents a **moderately suitable to suitable** terrain profile with clear advantages and manageable constraints. The dominant gentle slopes (28%) and high proportion of flat terrain (46.2%) are highly favorable for the construction of the lower reservoir, ancillary infrastructure (switchyards, access roads), and potential powerhouse locations. The elevated ridge top landform is advantageous for siting the upper reservoir, as it can provide natural topographic containment, potentially reducing earthworks. The overall low dominant erosion risk further supports construction feasibility and long-term slope stability for embankments and excavations.

Key constraints requiring specific mitigation measures are primarily related to slope stability and erosion. While steep terrain (>30% slope) is present, it is confined to a manageable **21.5%** of the study area. This terrain will require careful geotechnical investigation, engineered slope stabilization (e.g., terracing, retaining structures, soil nailing), and controlled blasting for any necessary excavations. Furthermore, areas classified as having a **high erosion risk (8.3%)** must be identified and protected through immediate implementation of erosion and sediment control plans (ESCPs), including silt fences, sediment basins, and rapid revegetation, to prevent sedimentation in the reservoirs and downstream waterways.

For project layout optimization, it is recommended to **concentrate major infrastructure on the identified gentle and flat zones** to minimize earthworks and environmental disturbance. The uniform aspect distribution suggests no significant solar exposure constraints for vegetation or construction. **Further critical studies must include:** 1) Detailed geotechnical investigations, including boreholes and shear strength testing, particularly within the steep terrain zones and proposed reservoir footprints; 2) A high-resolution seismic hazard assessment given the region's tectonic setting; and 3) A refined hydrological model to confirm water availability and optimize the hydraulic circuit between reservoirs, leveraging the high hypsometric integral (0.73) which indicates a mature, dissected landscape with good head potential.

Conclusion on Terrain Feasibility: The terrain characteristics of the site are **feasible** for a pumped storage hydropower project per IFC Performance Standards. The dominant suitable slopes, containment potential, and low erosion risk provide a solid foundation. The identified constraints (steep slopes, localized high erosion) are quantifiable and can be effectively mitigated through standard engineering practices and robust environmental management plans, as part of an integrated design and risk management approach.

12.1 Summary Statistics

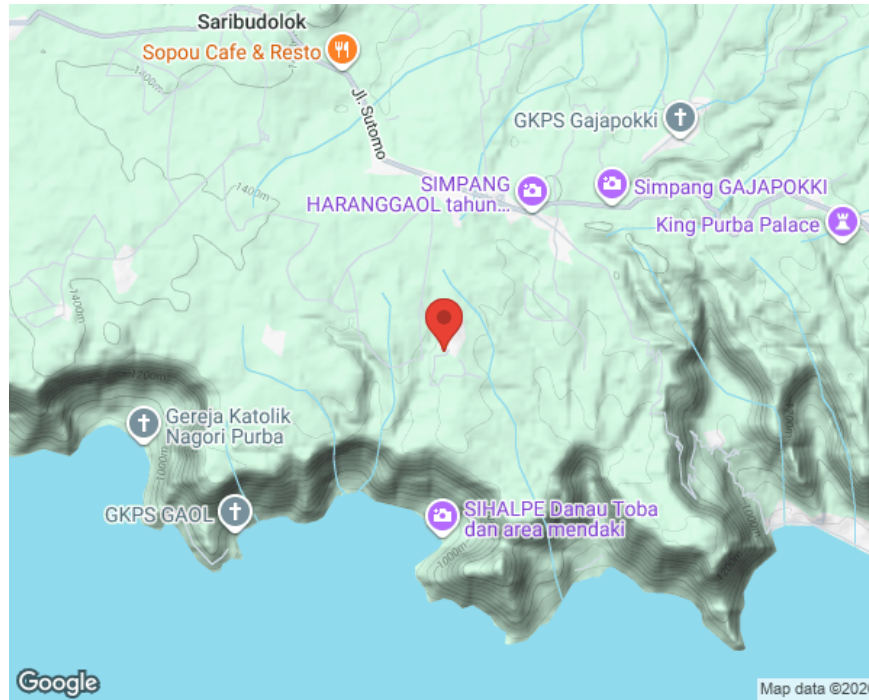
Parameter	Value
Dominant Slope Class	Gentle (28.0%)
Dominant Aspect	North
Dominant Landform	Ridge Top
Flat Terrain (<5°)	46.2%
Steep Terrain (>15°)	21.5%
Hypsometric Integral	0.725

13.0 References

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14.0 Appendix: Figures and Maps

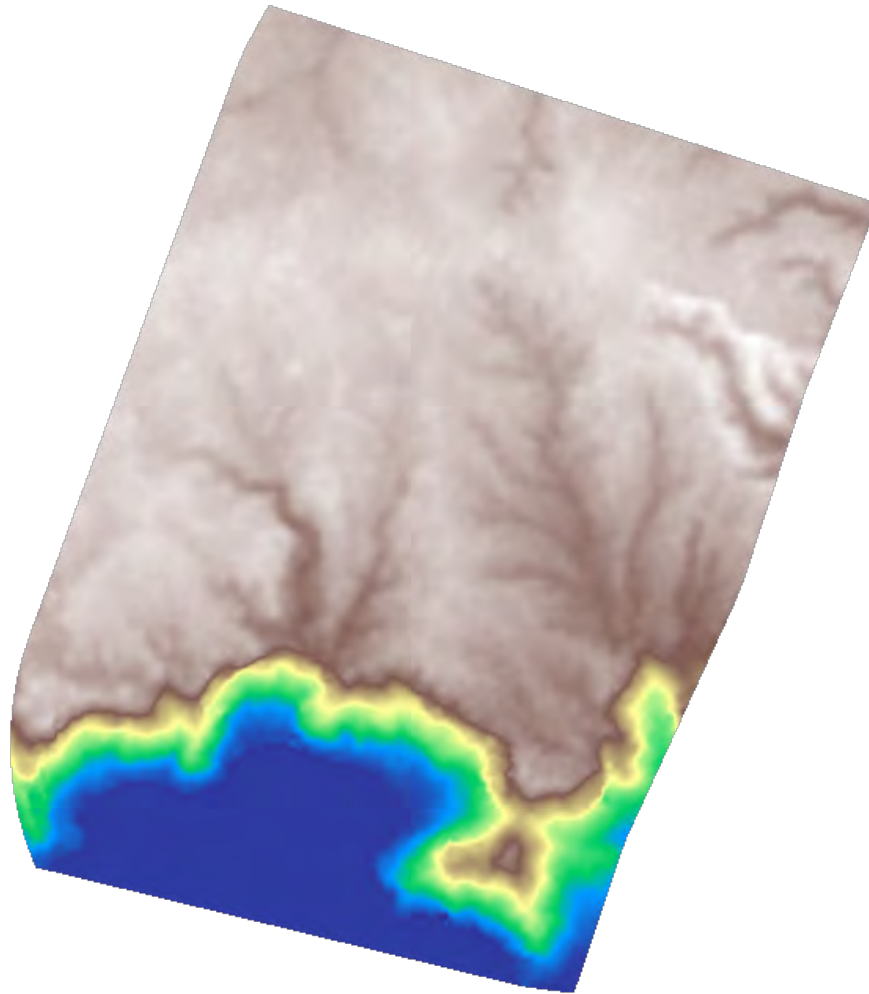
14.1 Figure 1: Project Location Map



Project Location Map

Overview map showing the study area location and regional context.

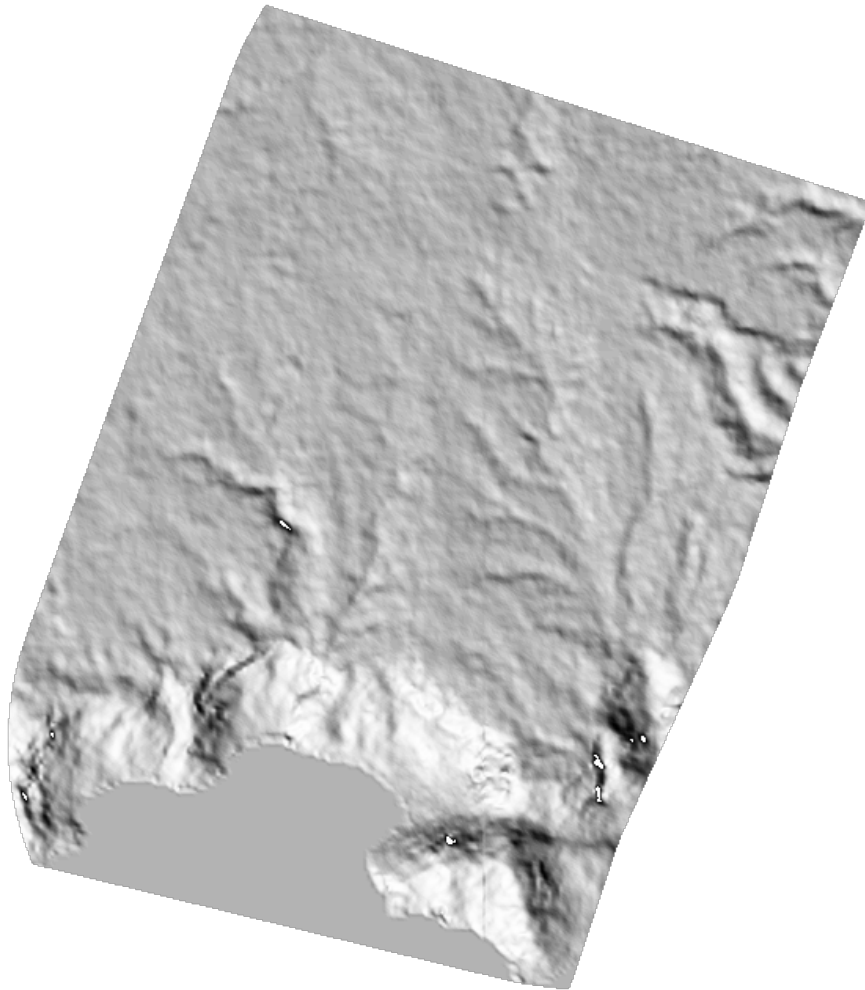
14.2 Figure 2: Digital Elevation Model



Digital Elevation Model

Elevation surface showing terrain relief across the study area.

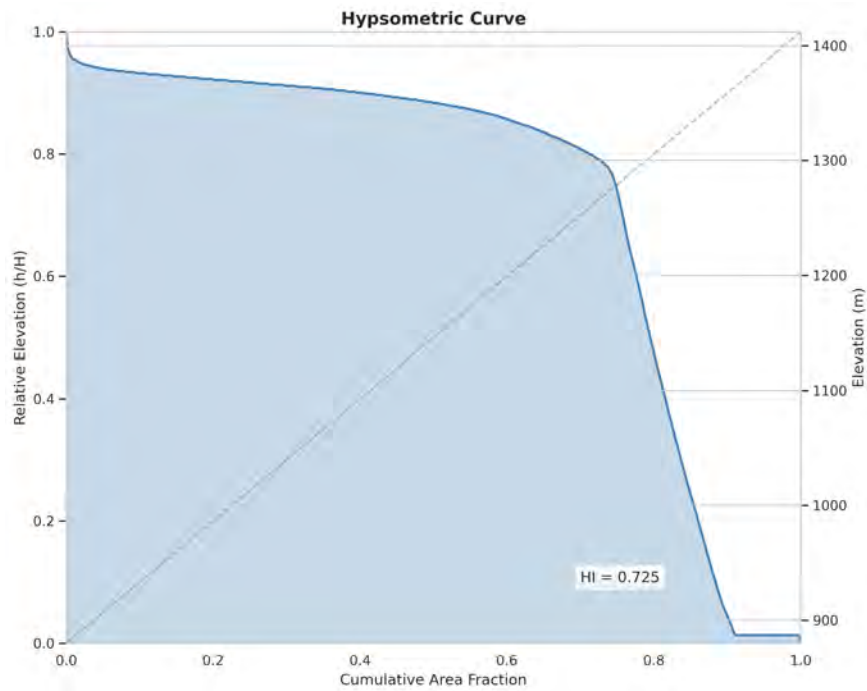
14.3 Figure 3: Hillshade Relief



Hillshade Relief

Shaded relief visualization highlighting topographic features.

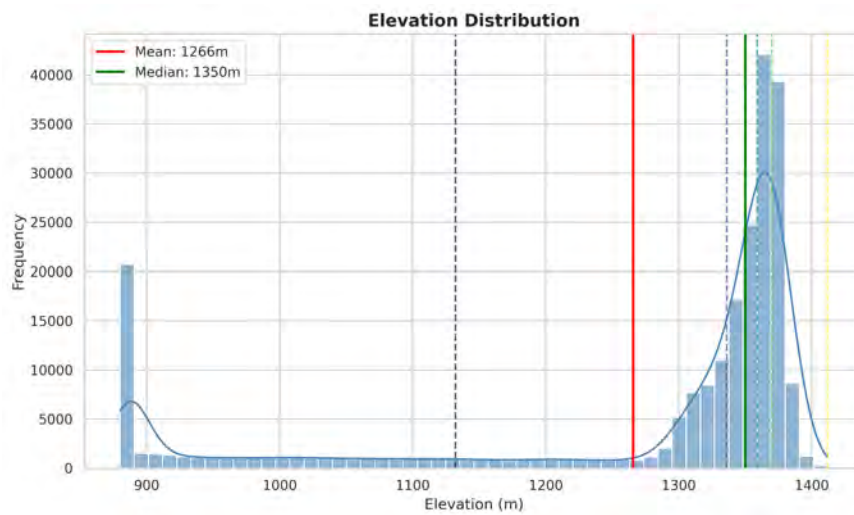
14.4 Figure 4: Hypsometric Curve



Hypsometric Curve

Relationship between elevation and cumulative area, with hypsometric integral (HI) indicating landscape maturity.

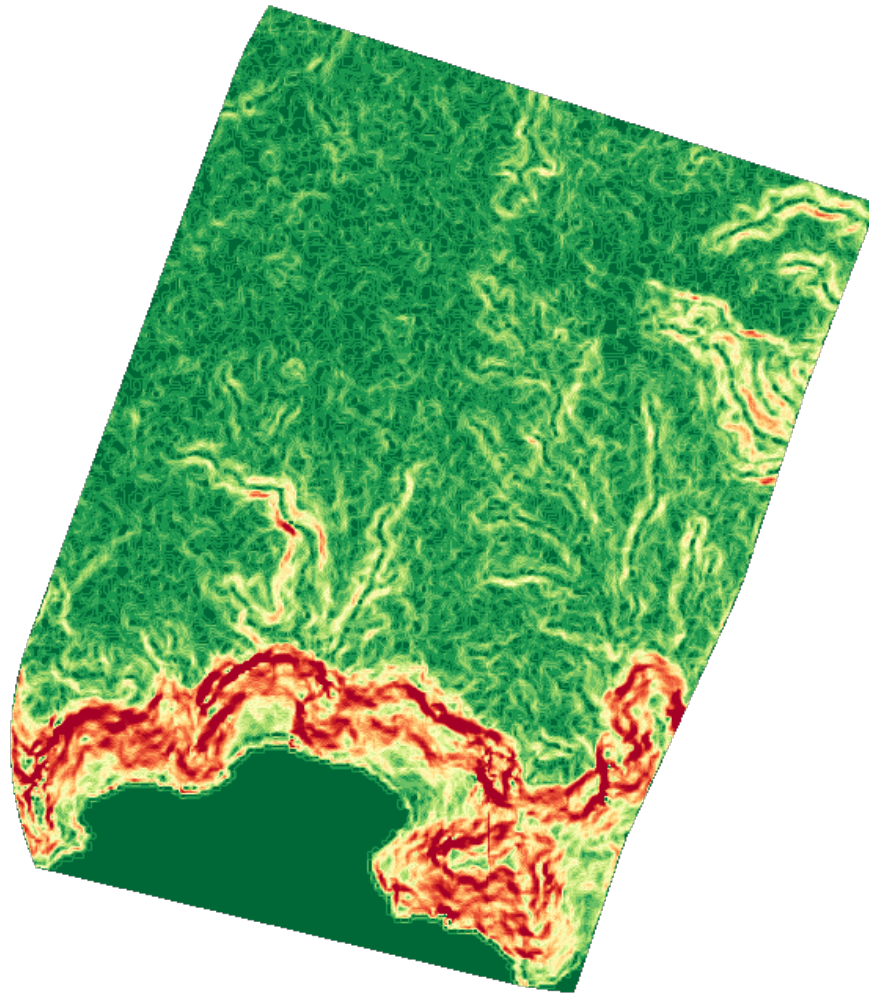
14.5 Figure 5: Elevation Distribution



Elevation Distribution

Histogram of elevation values with zone boundaries and statistical markers.

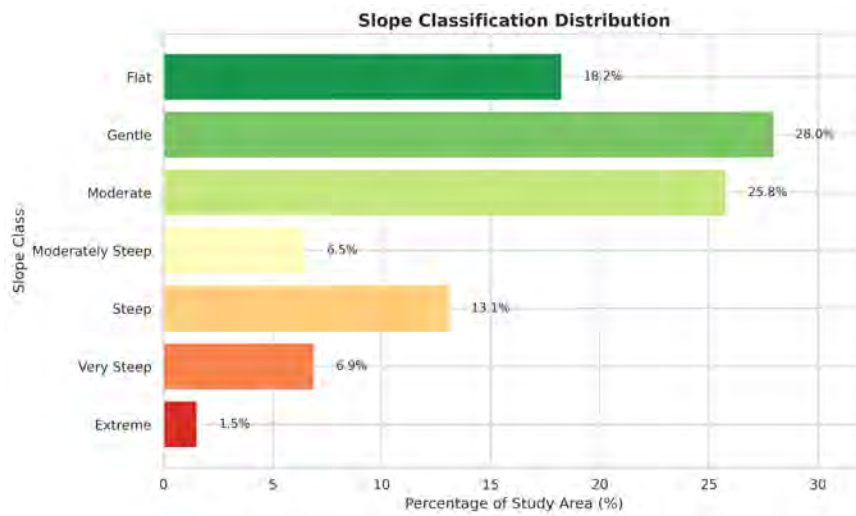
14.6 Figure 6: Slope Gradient Map



Slope Gradient Map

Spatial distribution of slope angles (degrees) across the study area.

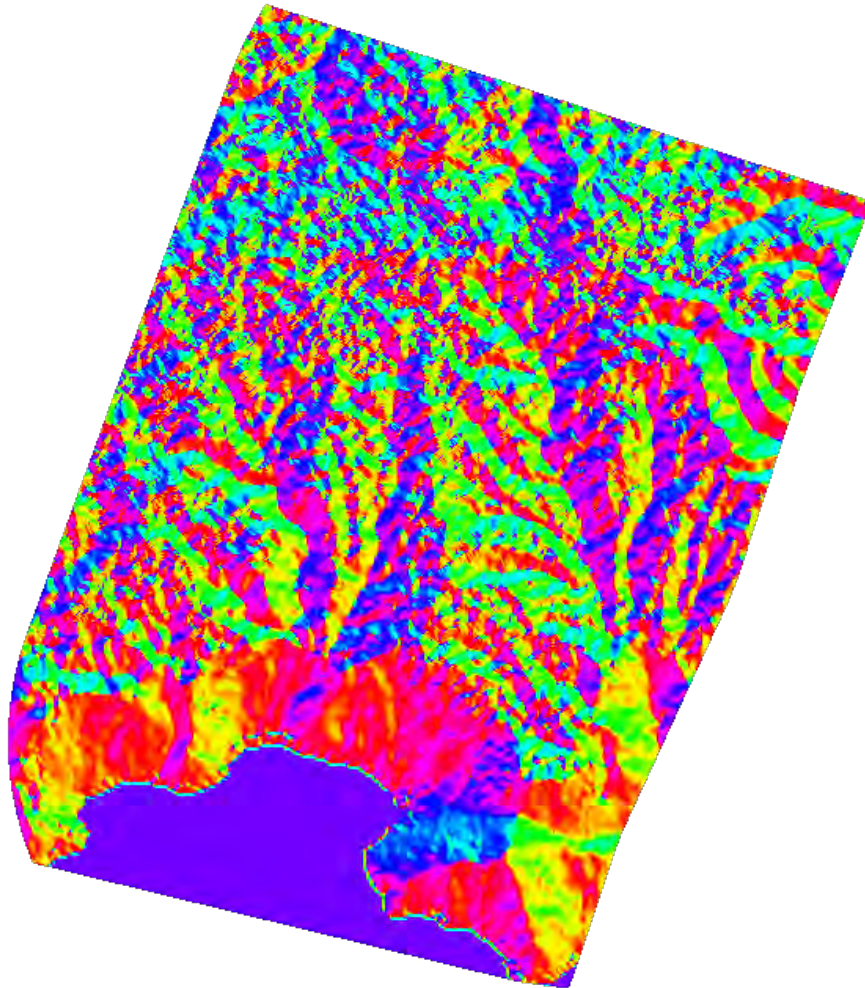
14.7 Figure 7: Slope Class Distribution



Slope Class Distribution

Horizontal bar chart showing percentage of study area in each slope class.

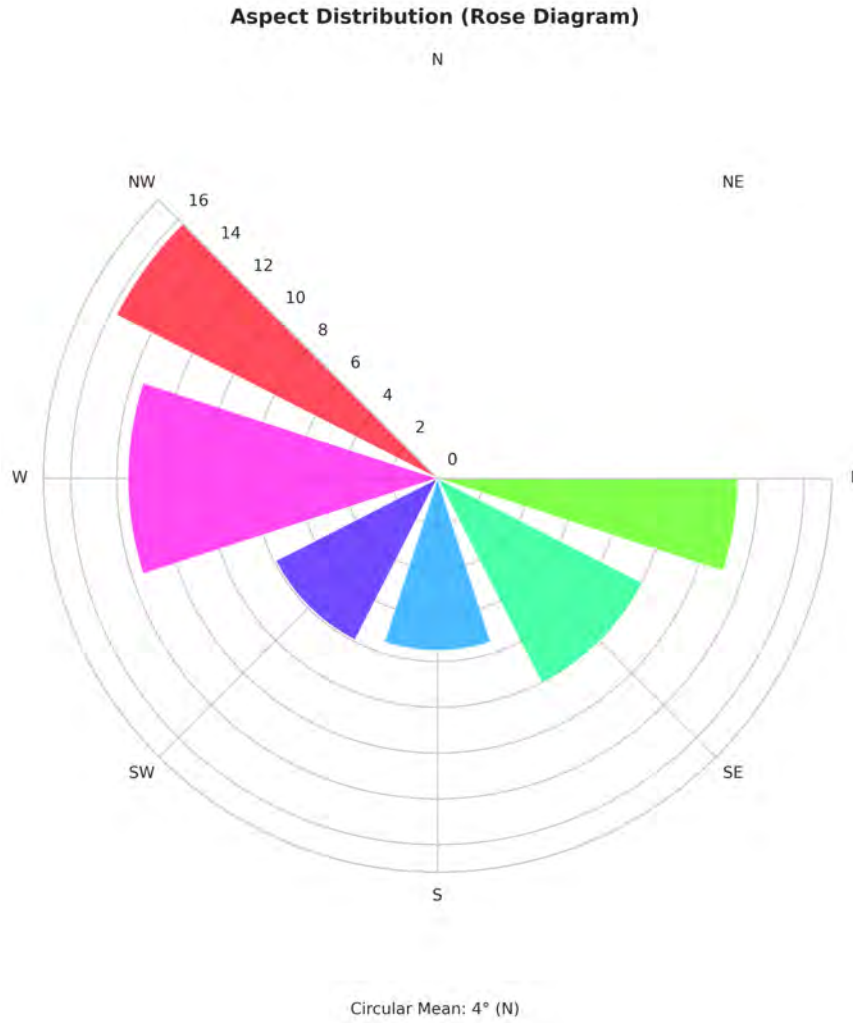
14.8 Figure 8: Aspect Map



Aspect Map

Slope orientation (compass bearing) showing terrain facing directions.

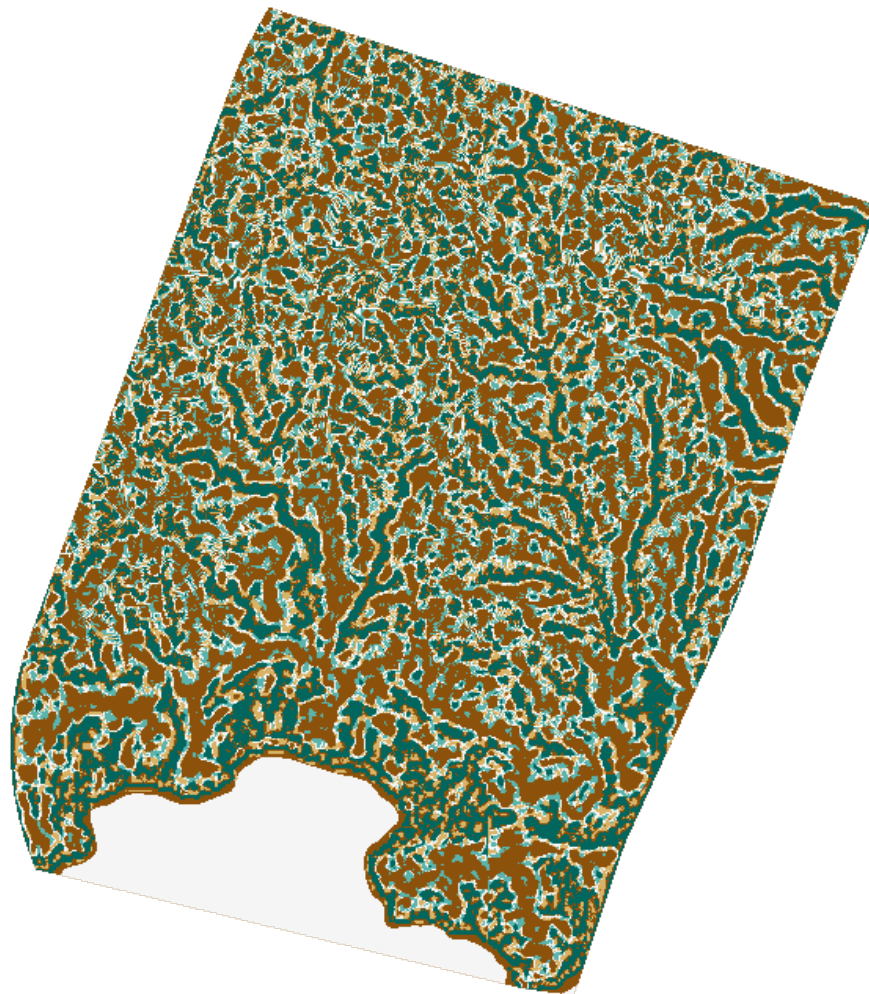
14.9 Figure 9: Aspect Rose Diagram



Aspect Rose Diagram

Polar plot showing distribution of slope orientations with circular mean direction.

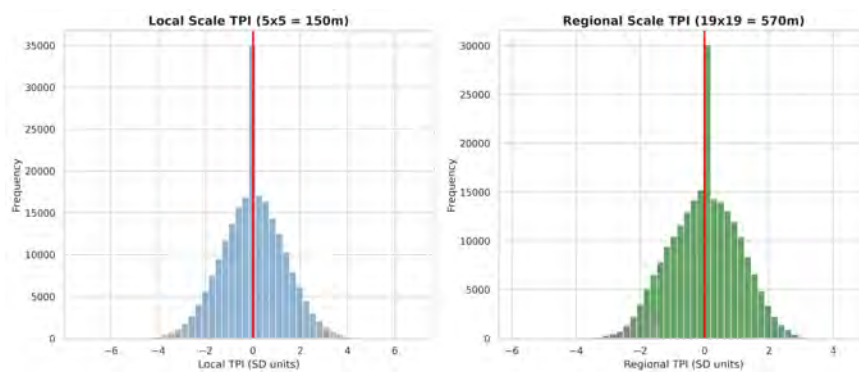
14.10 Figure 10: Landform Classification Map



Landform Classification Map

Weiss landform classification based on dual-scale TPI analysis.

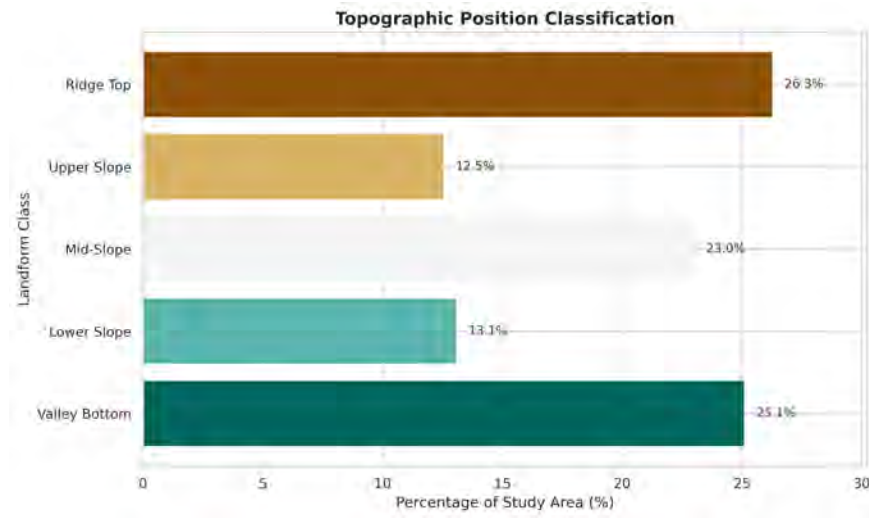
14.11 Figure 11: TPI Distributions



TPI Distributions

Histograms of Topographic Position Index at local and regional scales.

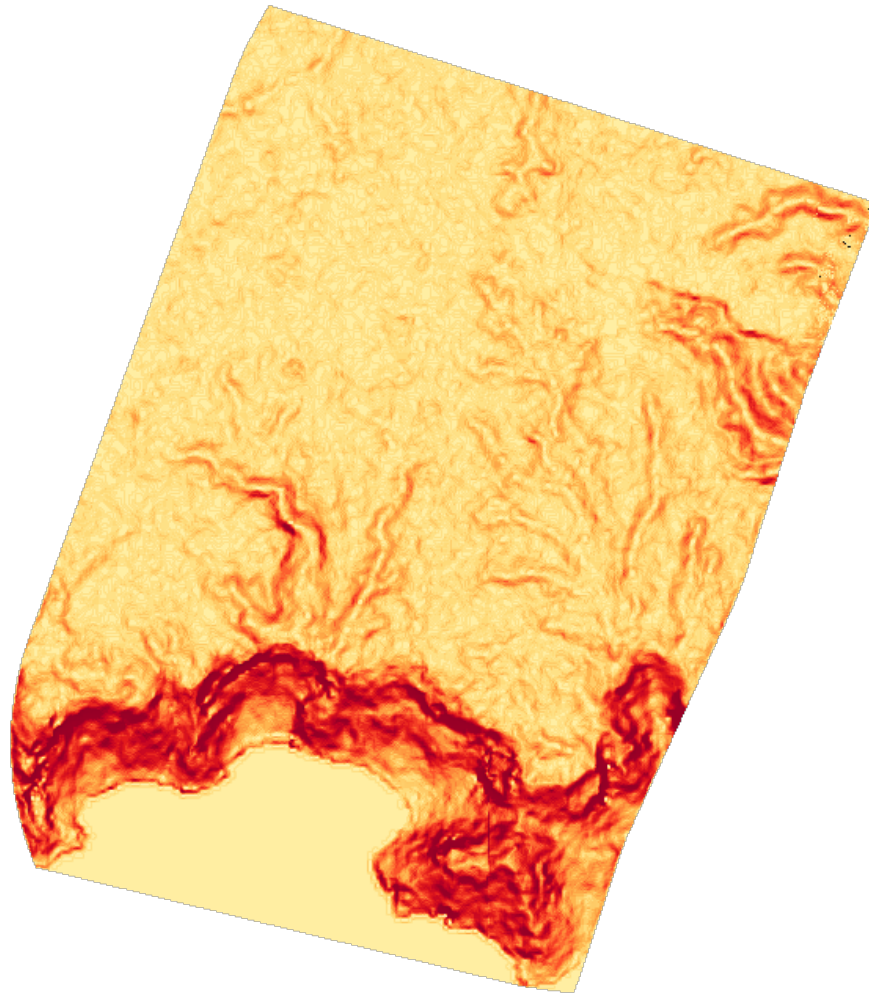
14.12 Figure 12: Landform Class Proportions



Landform Class Proportions

Distribution of Weiss landform classes across the study area.

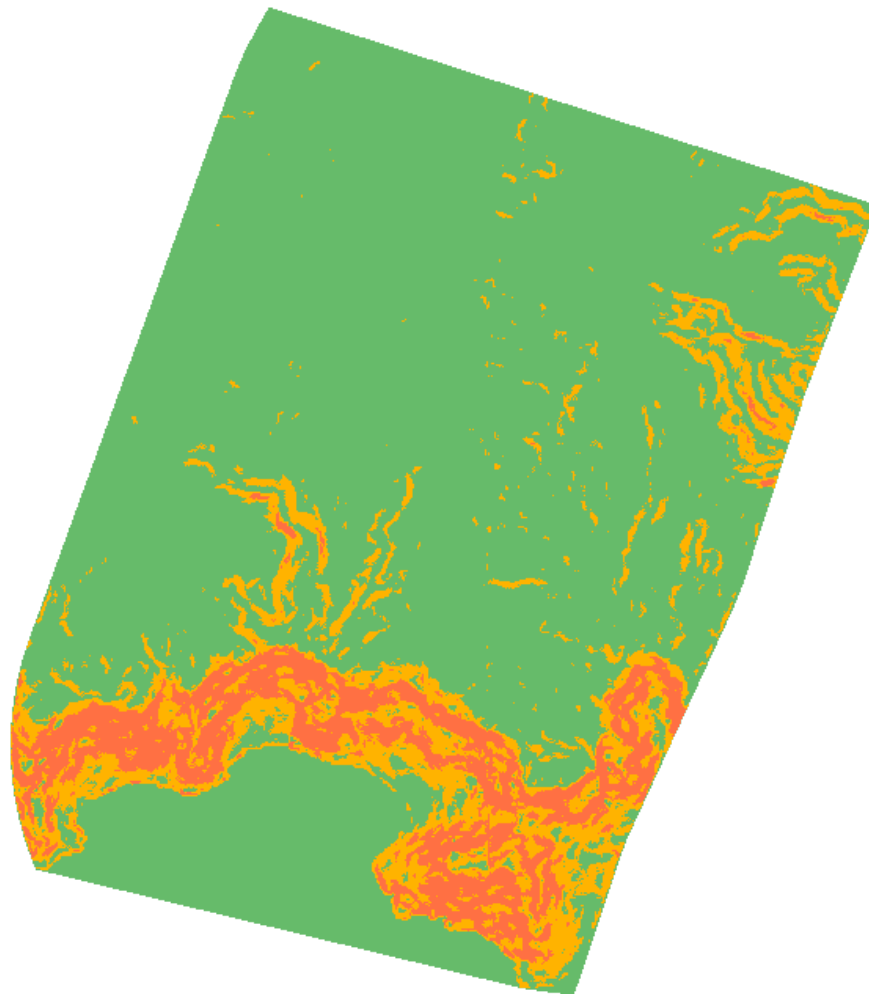
14.13 Figure 13: Erosion Susceptibility Index



Erosion Susceptibility Index

Continuous erosion susceptibility index (0-1) based on terrain parameters.

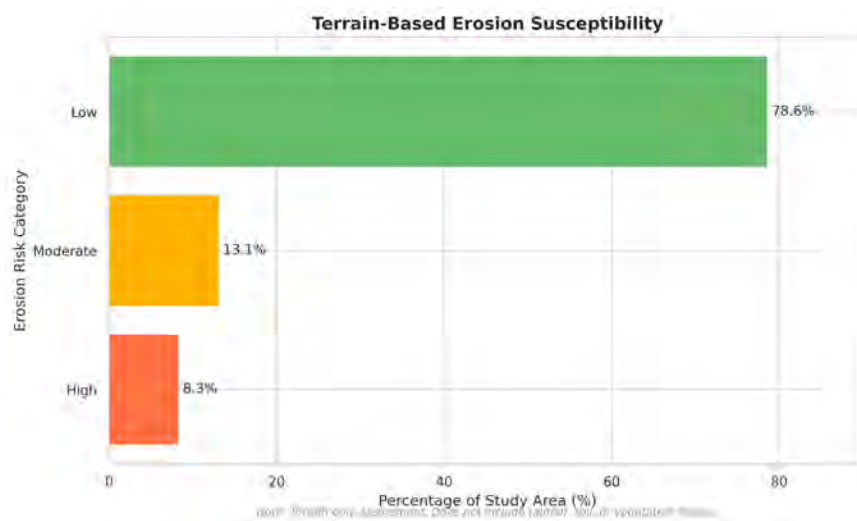
14.14 Figure 14: Erosion Risk Classification



Erosion Risk Classification

Classified erosion risk categories (Low, Moderate, High).

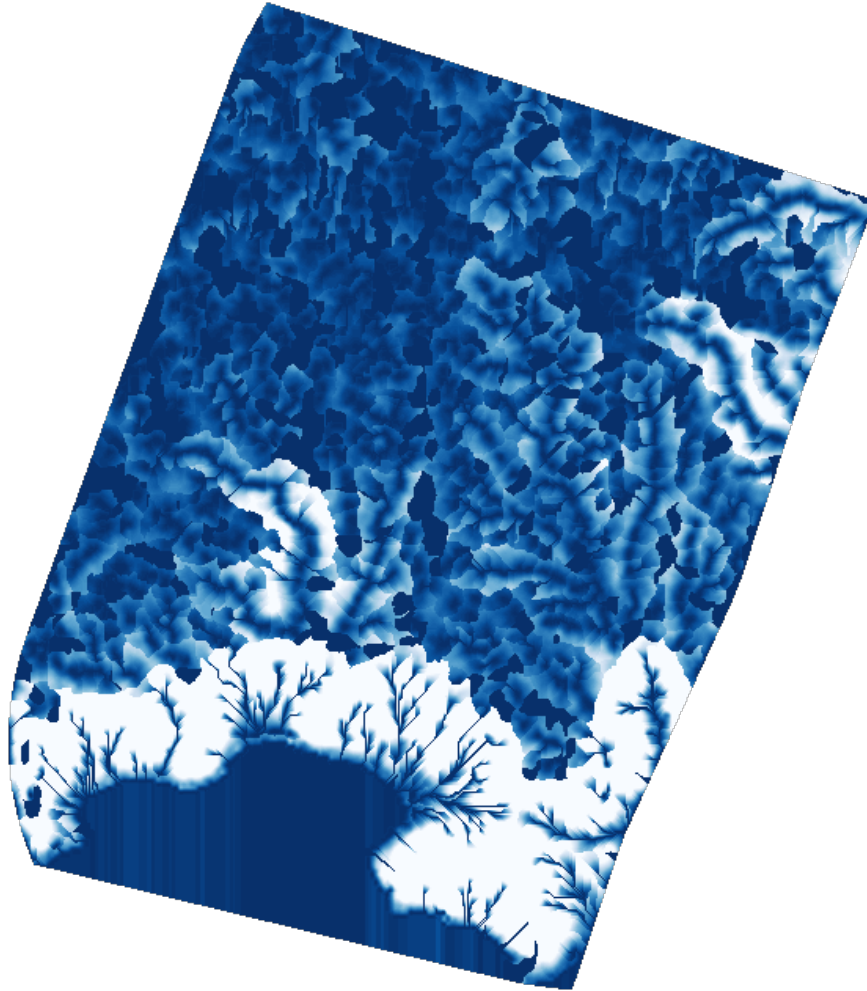
14.15 Figure 15: Erosion Risk Distribution



Erosion Risk Distribution

Percentage of study area in each erosion risk category.

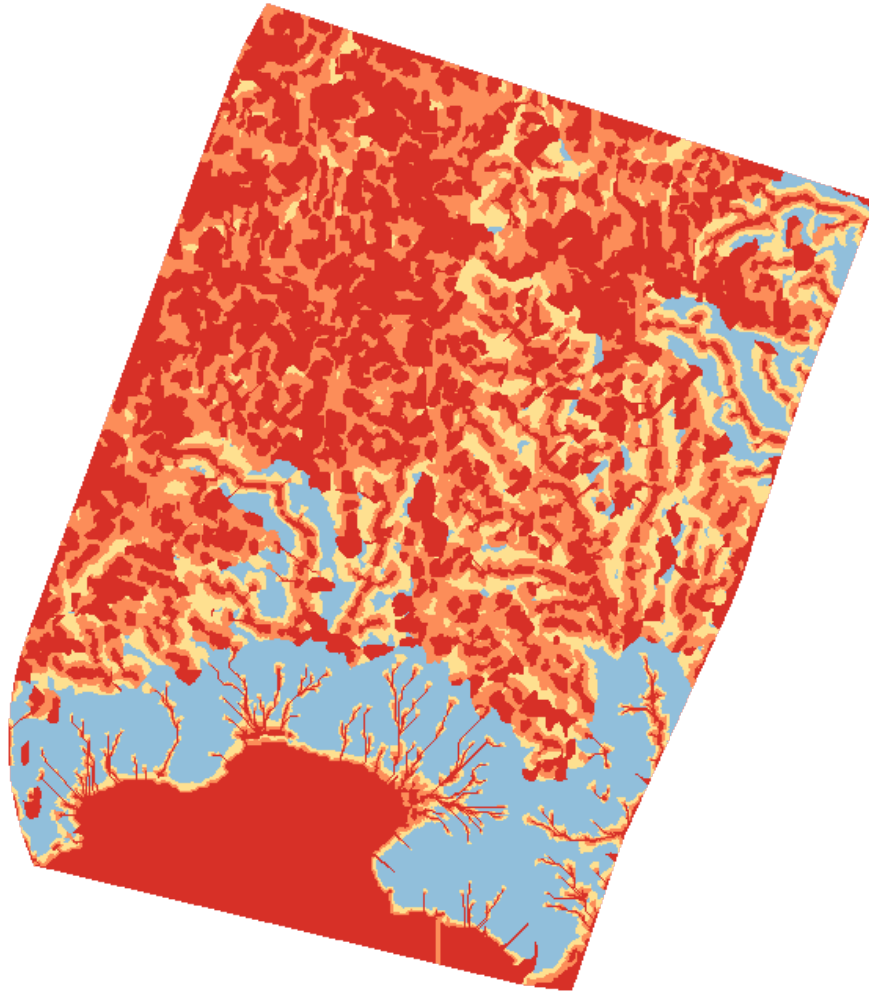
14.16 Figure 16: Height Above Nearest Drainage (HAND)



Height Above Nearest Drainage (HAND)

Vertical distance to nearest drainage channel in meters.

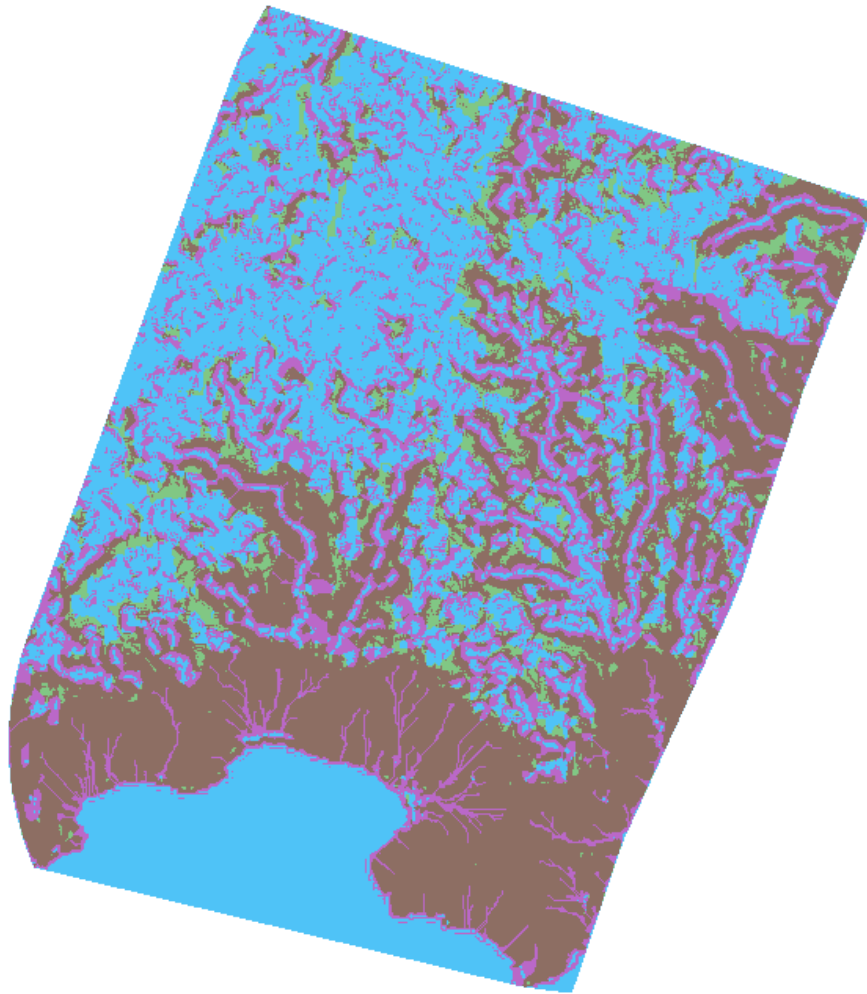
14.17 Figure 17: Flood Susceptibility Classification



Flood Susceptibility Classification

HAND-based flood susceptibility categories.

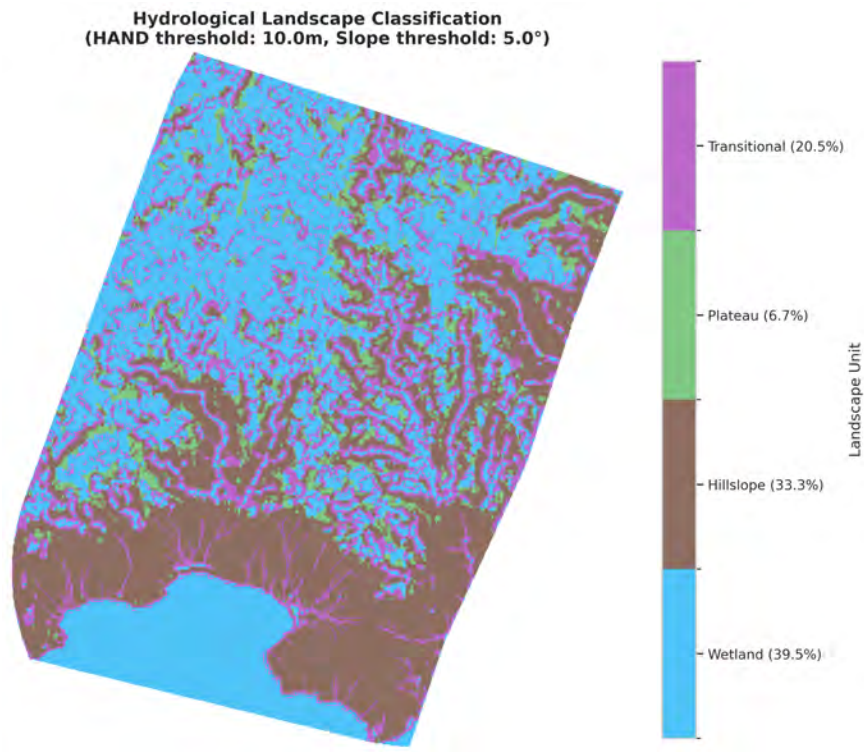
14.18 Figure 18: Hydrological Landscape Units



Hydrological Landscape Units

Combined HAND-slope terrain classification.

14.19 Figure 19: Landscape Unit Distribution



Landscape Unit Distribution

Spatial distribution of hydrological landscape units based on HAND and slope.

15.0 Appendix: Output Files

15.1 Output File Inventory

File	Description
terrain_baseline_data.json	Complete statistics in JSON format
terrain_baseline_data.yaml	Complete statistics in YAML format
rasters/dem_clipped.tif	Clipped DEM (GeoTIFF)
rasters/slope.tif	Slope in degrees (GeoTIFF)
rasters/aspect.tif	Aspect in degrees (GeoTIFF)
rasters/tpi_local.tif	Local-scale TPI (GeoTIFF)
rasters/tpi_regional.tif	Regional-scale TPI (GeoTIFF)
rasters/landform.tif	Landform classification (GeoTIFF)
rasters/erosion_index.tif	Erosion susceptibility index 0-1 (GeoTIFF)
rasters/erosion_risk.tif	Erosion risk classification 1-3 (GeoTIFF)
rasters/hand.tif	Height Above Nearest Drainage in meters (GeoTIFF)
rasters/landscape.tif	Hydrological landscape classification 1-4 (GeoTIFF)
rasters/hillshade.tif	Hillshade visualization (GeoTIFF)

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