Technical Report

Slope Analysis and Its Impact on Residential and Non-Residential Development

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1. Executive Summary

Existing development capacity models primarily quantify plan-enabled capacity and do not explicitly account for physical site constraints such as terrain slope, which can affect the feasibility of residential and non-residential development at the parcel level.

This project assessed parcel-level slope conditions across Hamilton City to identify where terrain may constrain residential and non-residential development. Using a high-resolution LiDAR-derived Digital Elevation Model (DEM) and GIS-based spatial analysis, slope was calculated in degrees and classified into slope categories explicitly linked to development constraints, derived from planning, hazard, and engineering literature. Slope characteristics were analysed at city, zone (Residential and Non-Residential), and parcel scales.

The analysis was implemented as a fully automated Python/ArcPy workflow, enabling consistent, reproducible results and efficient re-running of the analysis when input datasets, slope thresholds, or constraint definitions are updated.

Results indicate that Hamilton City is predominantly characterised by low to moderate slopes at the city and zone scales. However, parcel-level analysis reveals that a small subset of parcels—primarily within residential areas—contain moderate to high proportions of steep slopes. These parcels are spatially clustered and closely associated with underlying terrain features such as river corridors.

Overall, the findings demonstrate that slope is not a city-wide constraint on development capacity but represents a site-specific constraint affecting a limited number of parcels. The parcel-level outputs provide a practical screening tool to support early-stage planning and development feasibility assessments by identifying locations where further investigation or site-specific design considerations may be required.

2. Introduction and Planning Context

Under the **National Policy Statement on Urban Development (NPS-UD 2020)**, Hamilton City is classified as a Tier 1 urban environment and is therefore required to ensure that sufficient development capacity is provided across short-, medium-, and long-term timeframes. This requirement is not limited to enabling development through planning rules alone, but also implies that development should be realistically achievable on the ground.

The **Hamilton City District Plan** gives effect to the NPS-UD by translating national policy requirements into local planning controls, such as zoning provisions, height limits, density standards, and subdivision rules. Development capacity assessments derived from these controls—such as plan-enabled capacity or theoretical dwelling yield estimates—are commonly used to inform strategic planning and growth management. However, these approaches typically assume that all zoned parcels are uniformly developable and do not explicitly consider physical site constraints that may affect development feasibility.

Physical characteristics of land can play a significant role in determining whether plan-enabled development can be practically delivered. Among these factors, terrain slope is a key constraint influencing development feasibility. Slope affects a range of development-related considerations, including earthworks requirements, stormwater behaviour, infrastructure servicing, site access, and geotechnical stability. As slope increases, development may remain technically possible, but often requires additional engineering intervention, leading to increased costs, design complexity, and feasibility risks.

As a result, a potential gap can arise between plan-enabled development capacity and land that can be realistically developed under existing terrain conditions. This project responds to that gap by providing **a parcel-level assessment of slope conditions** across Hamilton City. By analysing slope at city, zone (Residential and Non-Residential), and parcel scales, the study aims to identify locations where terrain may act as a site-specific constraint on development and where further investigation or tailored design responses may be required to support informed planning and development decision-making.

3. Project Objectives and Data

3.1 Project Objectives

This project was initiated to address two core objectives identified by Hamilton City Council:

- Understanding slope at the parcel level across the city
- Understanding how slope may influence housing development feasibility

To support these objectives, the project is set out to:

- Develop a literature-informed slope classification framework relevant to planning and development feasibility
- Apply parcel-level GIS analysis to quantify steep slope exposure across Residential and Non-Residential land
- Develop a Python-based automated GIS workflow to produce reproducible datasets, maps, and documentation that can be efficiently updated when input data or assumptions change

3.2 Data Sources

The analysis used the following datasets:

- 1 m resolution LiDAR-derived Digital Elevation Model (DEM), obtained from publicly available geospatial data sources.
- NZ Primary Land Parcels, obtained from publicly available cadastral datasets.
- Hamilton City boundary, obtained from publicly available administrative boundary datasets.
- Zoning layers including Residential and Non-Residential land, provided by Hamilton City Council.
- Planning constraint layers: Facilities Zone, Knowledge Zone, Open Space Zone, and Significant Natural Area, provided by Hamilton City Council.

All datasets were clipped to the Hamilton City boundary and standardised to a common projection. Constraint areas were removed from parcels prior to analysis so that slope metrics were calculated only for potentially developable land.

Outputs and documentation

All analysis outputs, including spatial datasets, tabular summaries, and publication-ready figures, are documented in the README file for this project. The README specifies output locations, dataset descriptions, and instructions for reproducing the results by re-running the automated workflow. The technical report focuses on analytical rationale and findings, while detailed output definitions are maintained in the README to avoid duplication.

4. Methodology and Automated Workflow

This analysis examines slope characteristics at three spatial scales: city-level, zone-level (Residential and Non-Residential), and parcel-level. A consistent workflow is applied across all scales to support comparison, while the parcel scale is used as the primary unit for assessing site-specific slope constraints.

A workflow diagram (Figure 1) summarising the analytical process is provided below. The text that follows focuses on key methodological decisions rather than step-by-step processing details.

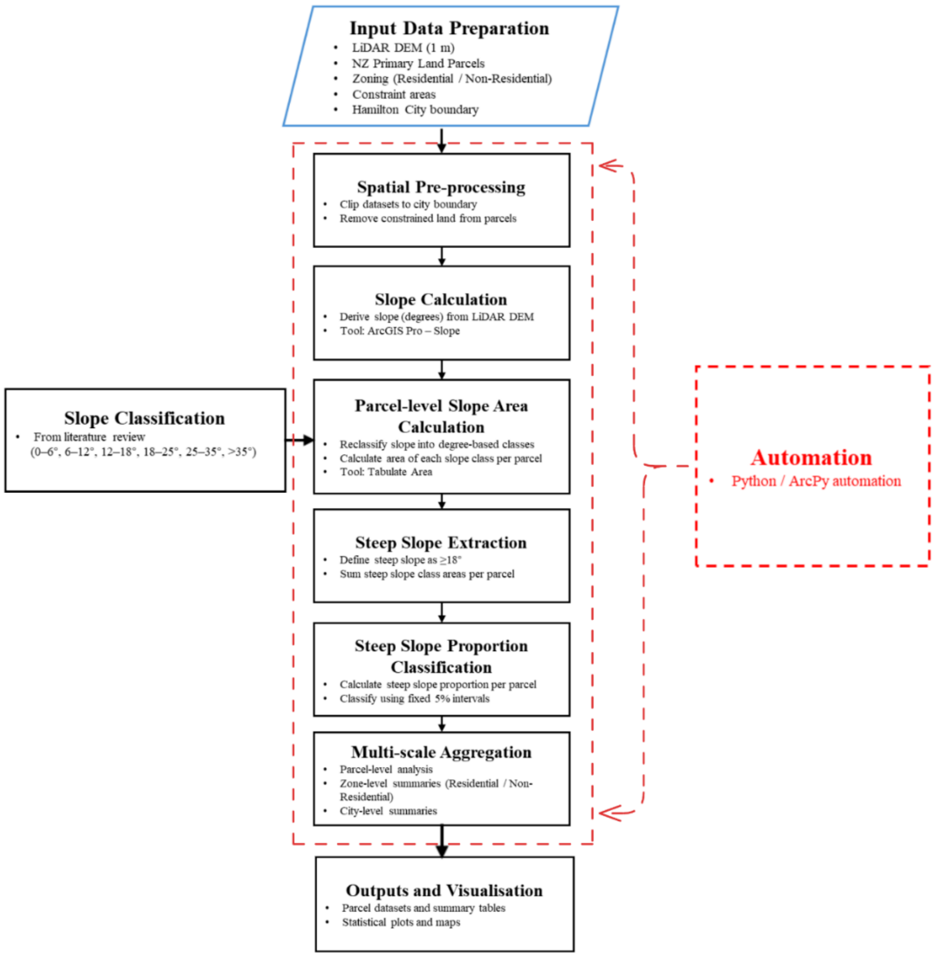

Figure 1. Workflow diagram of the slope analysis methodology.

4.1 Study area and data preparation

The study area covers the full Hamilton City urban boundary. The analysis uses a 1 m LiDAR-DEM, NZ Primary Land Parcels, zoning layers distinguishing Residential and Non-Residential areas, constraint layers, and the Hamilton City boundary.

All datasets were clipped to the city boundary to ensure consistent spatial extent. Constraint areas were removed from parcel geometries so that slope analysis was limited to land that is potentially developable. This ensures that slope statistics are not influenced by areas already excluded from development.

4.2 DEM selection and slope calculation

Slope was derived from the LiDAR DEM using the **Slope**[1] tool in ArcGIS Pro. Slope values were calculated in degrees to maintain consistency with planning, hazard, and engineering literature used to define slope thresholds. The resulting slope raster provides a continuous

[1] Esri documentation on Slope tool.
https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/slope.htm

representation of terrain steepness across the study area and serves as the input for subsequent parcel-level analysis.

4.3 Parcel-level slope area analysis

Parcel-level slope characteristics were analysed using an area-based approach rather than summary measures such as mean or maximum slope. This approach quantifies how much of each parcel is affected by different slope categories and provides a clearer basis for development feasibility assessment.

Slope values were reclassified into discrete slope classes (0–6°, 6–12°, 12–18°, 18–25°, 25–35°, and >35°) based on thresholds derived from international literature. The classification was implemented to support parcel-level area calculation rather than as a standalone analytical outcome.

The **Tabulate Area**[2] tool in ArcGIS Pro was used to calculate the area of each slope class within individual parcels. The resulting parcel-by-slope-class area table forms the primary input for subsequent steep slope identification and proportion analysis.

4.4 Steep slope definition and proportion classification

Steep slopes were defined as slope values equal to or greater than 18 degrees. For each parcel, the total area of steep slope was calculated by summing the areas of all slope classes at or above this threshold.

Steep slope proportion was calculated by dividing steep slope area by total parcel area and expressed as a percentage. To support comparison across parcels and zoning categories, steep slope proportions were classified into fixed 5% intervals (e.g. 0–5%, 5–10%, 10–15%).

4.5 Parcel-level analysis rationale

While city- and zone-level summaries provide useful context, development decisions are made at the parcel scale. At aggregated scales, steep slopes may appear insignificant due to their small overall area. However, when steep terrain intersects individual parcels, even limited slope coverage can affect earthworks, building layout, access, drainage, and construction feasibility.

For this reason, parcel-level steep slope proportion is adopted as the key analytical measure. This allows direct comparison of slope exposure between individual parcels and avoids reliance on zone-wide averages that may mask site-specific constraints.

4.6 Automation and validation

All analytical steps were first tested manually in ArcGIS Pro to confirm logic and output correctness. The workflow was then implemented as an automated **Python/ArcPy** pipeline to

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[2] Esri documentation on Tabulate Area.
https://pro.arcgis.com/en/pro-app/3.4/tool-reference/spatial-analyst/tabulate-area.htm

ensure consistency and repeatability.

Post-processing of tabular outputs was undertaken using Python, with **pandas**[3] used for data handling and aggregation, and **matplotlib**[4] used for generating summary plots. Validation was carried out by comparing automated outputs with manual results and through visual inspection of spatial patterns.

5. Results

5.1 Literature-Derived Slope Classification Criteria

5.1.1 Slope as a physical constraint on development feasibility

Slope is widely recognised as a fundamental physical factor influencing land suitability and development feasibility. Across land capability, geomorphological, and urban planning research, slope is consistently linked to soil stability, erosion processes, and construction difficulty. As slope increases, land conditions become less favourable for standard development due to reduced soil depth, higher erosion potential, and greater structural risk.

Akinci, Özalp, and Turgut (2013) identify slope as a dominant variable in land suitability assessment, showing that steeper slopes are associated with thinner soils and reduced capacity to support development. Drawing on earlier geomorphological work, they note that slope directly controls both surface runoff behaviour and erosion intensity. Koulouri and Giourga (2007) similarly demonstrate that soil erosion rates increase sharply with slope gradient, particularly where land has been modified or disturbed. These processes reduce ground stability and increase the need for engineering intervention.

Together, this body of research establishes slope as a first-order physical constraint that must be considered when assessing development feasibility, rather than a secondary or optional factor.

5.1.2 Slope thresholds in urban development suitability studies

Urban development studies consistently show that slope not only affects physical conditions, but also shapes the spatial pattern of urban expansion. Gentle slopes are repeatedly identified as preferred development areas, while steeper slopes act as natural constraints that limit or redirect growth.

Boussetti (2025), in a GIS-based urban suitability assessment, identifies slope as one of the most influential variables controlling future urban expansion. The study shows that

[3] pandas documentation.
https://pandas.pydata.org/docs/
[4] matplotlib documentation.
https://matplotlib.org/stable/index.html

development suitability declines progressively as slope increases, with clear threshold ranges separating suitable, constrained, and unsuitable land. Similar conclusions are reported by Thapa et al. (2025), who emphasise that slope interacts with erosion risk, hazard exposure, and construction feasibility in urban environments.

These studies demonstrate that slope thresholds are not arbitrary. Instead, they reflect consistent empirical relationships between terrain steepness and development difficulty. As a result, slope classification is commonly used at the planning stage to screen land suitability and identify areas where development feasibility may be reduced.

5.1.3 Hazard-based slope thresholds and planning relevance

Beyond general suitability considerations, slope is also closely linked to geotechnical hazard. Hazard-oriented studies provide clear threshold values beyond which slope conditions are associated with increased landslide or rockfall risk.

Fell et al. (2008), in international guidelines for landslide susceptibility and land-use planning, identify slopes of approximately 20°–35° as commonly associated with rapid landslide movement, with steeper slopes generally linked to higher hazard levels and reduced long-term stability. Copons and Vilaplana (2008) further show that steep slope geometry plays a critical role in initiating rockfall and controlling hazard intensity and runout behaviour.

From a planning perspective, these hazard-based thresholds are particularly important. Even if development on steep slopes is technically possible in some cases, the associated risk level and long-term instability often make such land unsuitable for standard residential development at the planning scale.

5.1.4 Engineering and cost implications of steep slopes

While slope classification is often applied at the planning stage, its practical significance lies in how increasing slope translates into changes in construction methods, engineering requirements, and development cost. Engineering studies consistently show that once slope exceeds moderate thresholds, standard construction pathways become inadequate.

Kukina et al. (2020) document residential construction on landslide-prone slopes and show that steep terrain restricts the use of conventional earthmoving equipment and standard foundation systems. Development on such slopes requires specialised foundations, retaining structures, and adapted construction techniques, leading to higher construction complexity and labour input.

Quantitative evidence further supports this relationship. Ding and Forsythe (2013), through a life-cycle energy analysis of dwellings built on sloping sites, demonstrate a clear positive relationship between slope angle and construction-phase energy consumption. Their results show that cut-and-fill excavation, retaining structures, and drainage systems dominate construction effort on steeper terrain. Whole-life cost modelling by Reid and Clark (2000) further indicates that long-term maintenance and remediation costs on steep or unstable slopes can exceed initial construction costs.

Engineering design guidance reinforces these findings. Guidelines for reinforced soil slopes and mechanically stabilised earth walls indicate that stabilising steep terrain requires high-grade structural systems with substantial unit costs. This represents a qualitative shift in engineering approach at the planning and design scale rather than a marginal increase in construction difficulty (FHWA, 2001).

5.1.5 Summary and implications for slope classification

Synthesising the findings from land suitability studies, urban development research, hazard-based guidelines, and engineering cost analyses, a classified slope framework was developed for this project. Rather than adopting a single classification scheme from an individual study, the slope thresholds presented here are derived through integration of multiple literature-based criteria, reflecting physical, hazard-related, and engineering considerations relevant at the planning scale.

The resulting classification translates continuous slope values into discrete categories that align with commonly reported threshold ranges in the literature, including transitions associated with increased erosion risk, geotechnical hazard, construction complexity, and cost escalation. This approach allows slope-related constraints to be interpreted consistently across the study area and supports their use in parcel-level development feasibility assessment.

Table 1 summarises the slope classification and associated development suitability categories adopted in this study. **This classification framework was reviewed and confirmed with the industry mentor and is used as the slope classification scheme for the subsequent spatial analysis and parcel-level development feasibility assessment.**

Table 1. Slope classification and development suitability framework

Class	Slope range (°)	Suitability Category	Interpretation
S1	0–6°	Highly suitable	Flat–very gentle; minimal erosion hazard and earthworks; suitable for standard residential structures.
S2	>6–12°	Suitable	Gentle slopes; feasible with routine construction; moderate engineering requirements.
S3	>12–18°	Moderately	Noticeable slopes;

		suitable	engineering complexity and cost increase; development remains possible.
S4	>18–25°	Low suitability	Steeper slopes requiring retaining structures, specialised drainage, and substantial earthworks.
N1	>25–35°	Generally unsuitable	Very steep slopes with elevated instability risk; not suitable for standard dwellings.
N2	>35°	Unsuitable / High-hazard zone	Slopes commonly associated with high landslide risk; unsuitable for new residential development.

5.2 City-level slope characteristics

5.2.1 City-level slope composition and area distribution

Table 2. Area and percentage distribution of slope classes across the study area.

Slope class (°)	Area (m²)	Percentage of total area (%)
0–6	50,911,172	80.0
6–12	7,612,230	12.0
12–18	2,503,704	3.9
18–25	1,386,761	2.2
25–35	895,762	1.4
35–90	341,757	0.5
Total	**63,651,386**	**100.0**

As shown in table 2, at the city scale, slope analysis shows that Hamilton City is dominated by low to moderate terrain. Slopes below 18 degrees (classes S1–S3) account for approximately 95.9% of the total study area. In particular, very gentle slopes (0–6°) form the largest component, representing around 80% of the city area.

Steeper slope classes associated with lower development suitability occupy only a small proportion of the city. Slopes between 18–25° account for approximately 2.2% of the area, while slopes above 25° together represent less than 2%. Slopes steeper than 35°, which are commonly associated with high hazard, are rare and spatially limited.

These results indicate that, at an aggregated city-wide scale, slope is not a dominant constraint on urban development. The majority of land falls within slope classes that are generally suitable or moderately suitable for dwelling development. However, city-level summaries do not reveal how steep terrain intersects individual land parcels, which is critical for development feasibility assessment.

5.2.2 City-level spatial distribution of slope classes

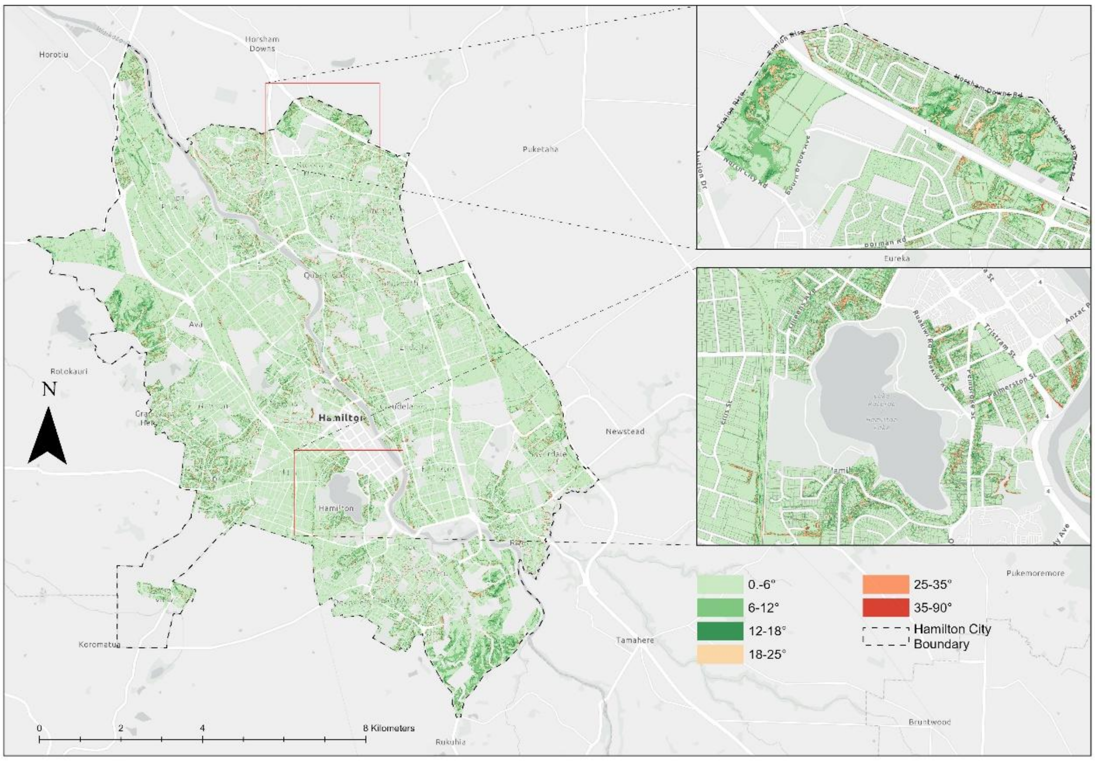

Figure 2. City-level spatial distribution of slope classes (S1–N2) across Residential and Non-Residential Zones, with inset maps highlighting local terrain context.

Mapping the spatial distribution of slope classes across Hamilton City (see figure 2) confirms the strong dominance of low to moderate slopes. When all slope classes are displayed together, steep slopes appear visually minor and fragmented, often difficult to distinguish from surrounding terrain.

Steep slope classes (≥18°) occur in small, spatially localised areas and are typically associated with specific terrain features such as river corridors, valley margins, and local escarpments. These areas are not evenly distributed across the city but form discrete clusters or linear patterns aligned with underlying landforms.

This spatial pattern highlights an important limitation of city-scale mapping. When all slope classes are shown simultaneously, areas of potential constraint can be visually diluted by the overwhelming presence of gentle terrain. As a result, city-scale maps are useful for providing general context but are insufficient for identifying development-relevant slope constraints.

5.3 Zone-level slope characteristics

5.3.1 Zone-level slope composition and area distribution

5.3.1.1 Residential Zone

Table 3. Area and percentage distribution of slope classes in the Residential Zone

Slope class (°)	Area (m²)	Percentage of total area (%)
0–6	36,645,184	77.0
6–12	6,576,021	13.8
12–18	2,129,874	4.5
18–25	1,156,269	2.4
25–35	762,061	1.6
35–90	305,076	0.6
Total	**47,574,485**	**100.0**

Note: Percentages may not sum to 100% due to rounding.

Within the Residential Zone (see table 3), low to moderate slopes (0–18°) account for approximately 95.3% of the total area. Gentle slopes (0–6°) alone represent around 77% of residential land, indicating that most residential areas are located on terrain that is generally suitable for development.

Steeper slopes (≥18°) occupy approximately 4.6% of the Residential Zone. This proportion is slightly higher than the city-wide average. While the total area of steep slopes remains small, their presence within residential land is more pronounced than in other zoning categories.

These results suggest that, at the zone scale, residential land is marginally more exposed to steep terrain than the city as a whole. However, zone-level percentages do not show whether steep slopes affect entire parcels or only small portions of them.

5.3.1.2 Non-Residential Zone

Table 4. Area and percentage distribution of slope classes in the Non-Residential Zone

Slope class (°)	Area (m²)	Percentage of total area (%)
0–6	14,265,988	88.8
6–12	1,036,209	6.4
12–18	373,830	2.3
18–25	230,492	1.4
25–35	133,701	0.8
35–90	36,681	0.2
Total	**16,076,901**	**100.0**

Note: Percentages may not sum to 100% due to rounding

The Non-Residential Zone is even more strongly dominated by gentle terrain. Slopes below 18 degrees account for approximately 97.5% of the total non-residential area (see table 4). Very gentle slopes (0–6°) alone represent nearly 89% of this zone.

Steep slopes (≥18°) account for approximately 2.2% of the Non-Residential Zone, which is substantially lower than both the city-wide average and the Residential Zone. Slopes steeper than 35° are negligible in extent.

This indicates that non-residential land is less exposed to steep terrain at the zone scale. However, as with residential land, zone-level statistics do not indicate how steep slopes intersect individual parcels.

5.3.2 Comparison of slope composition between Residential and Non-Residential Zones

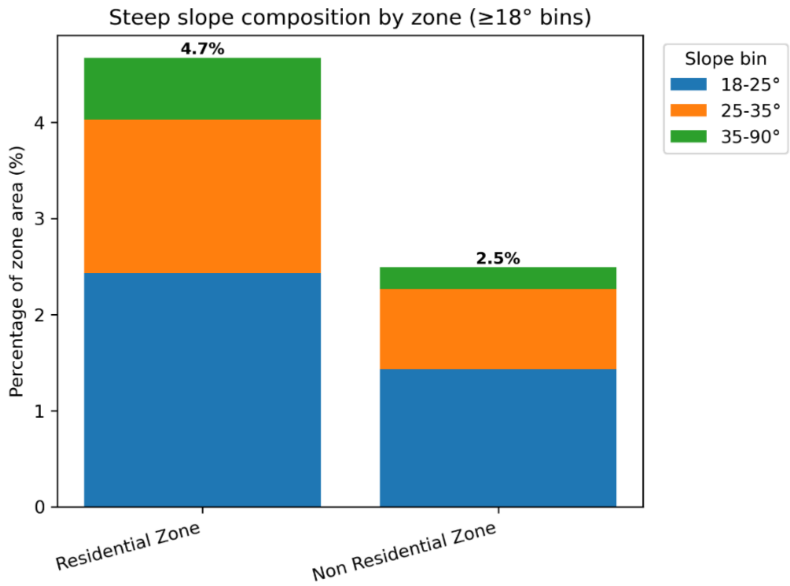

Figure 3. Stacked bar chart showing the proportional composition of steep slope classes (≥18°) within Residential and Non-Residential Zones.

Comparing the two zones shows a clear difference in steep slope exposure (see figure 3). Although both zones are dominated by low to moderate slopes, the Residential Zone contains a higher proportion of steep slope classes than the Non-Residential Zone.

This difference is mainly driven by greater contributions from the 18–25° and 25–35° slope classes in residential areas. Extremely steep slopes (>35°) remain rare in both zones.

From a planning perspective, this result suggests that slope-related constraints are more likely to be relevant within residential land, even though they affect only a small proportion of total area. Zone-level results therefore provide useful context but remain insufficient for identifying which specific parcels may face reduced development feasibility.

5.3.3 Spatial distribution of steep slopes by zone

5.3.3.1 Residential Zone

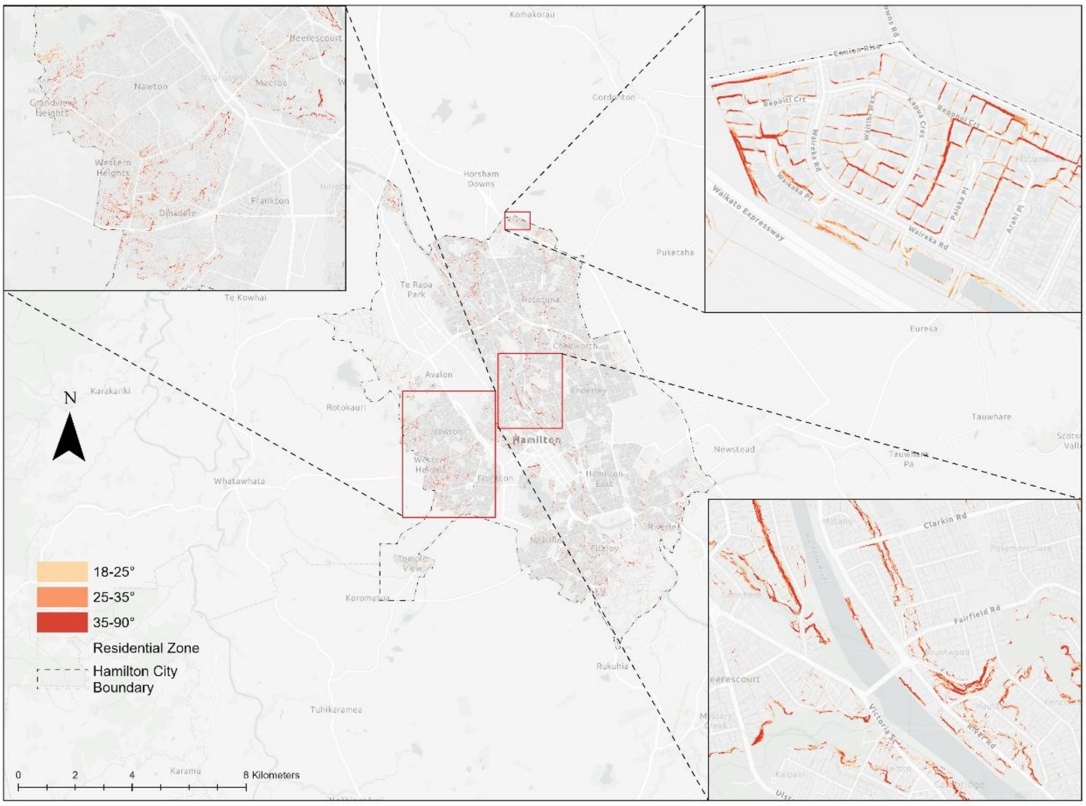

Figure 4. Residential steep slope distribution map

Figure 4 shows the spatial distribution of steep slope classes (S4–N2) within the Residential Zone, with three inset maps highlighting representative spatial patterns.

At the zone scale, **steep slopes are unevenly distributed across residential zone**. While many residential areas contain little or no steep terrain, other locations show **higher local concentrations of S4–N2 slopes**.

The upper-right inset highlights areas where steep slopes occur **mainly along parcel boundaries**, rather than covering entire parcels. The lower-right inset shows steep slopes associated with river corridors, where S4–N2 slopes **follow linear terrain features**. The upper-left inset illustrates areas where steep slopes are clustered within **specific residential locations**, while nearby areas show minimal steep slope presence.

Overall, Figure 4 indicates that steep slopes within the Residential Zone are **spatially localised rather than evenly distributed.** Although steep slopes occupy only a small proportion of residential land by area, their **clustered and terrain-related patterns** support the need for parcel-level analysis to identify affected properties.

5.3.3.2 Non-Residential Zone

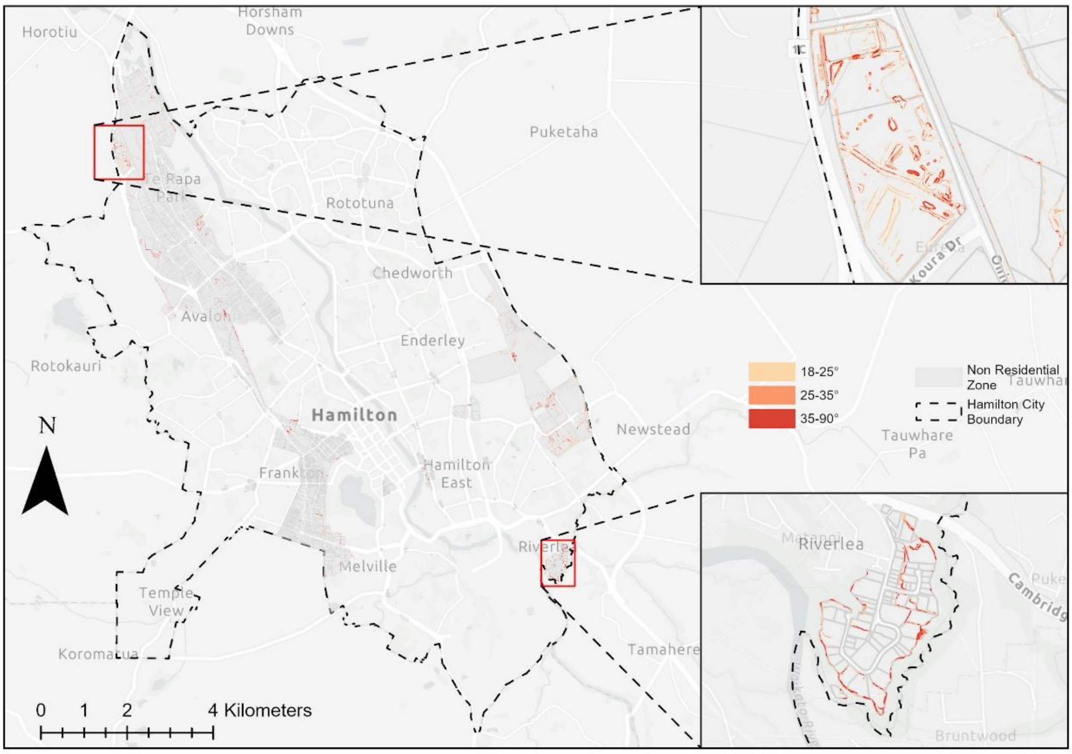

Figure 5. Non-Residential steep slope distribution map

Figure 5 shows the spatial distribution of steep slope classes (S4–N2) within the Non-Residential Zone, with two inset maps highlighting representative spatial patterns.

At the zone scale, steep slopes are **limited in extent and unevenly distributed**. Large areas of non-residential land contain little or no steep terrain, while steep slopes occur in a small number of specific locations.

The upper-right inset highlights steep slopes associated with local terrain features, where S4–N2 slopes form linear or clustered patterns **aligned with the underlying landform**. The lower-right inset illustrates areas where steep slopes occur **mainly along parcel boundaries, appearing as narrow, linear features rather than large continuous areas.**

Overall, steep slopes within the Non-Residential Zone are **spatially localised and occur primarily as boundary-aligned or terrain-related features.** Although their total area is small, their clustered distribution supports the need for parcel-level analysis to identify affected non-residential properties.

5.4 Parcel-level steep slope exposure

5.4.1 Statistics Analysis

Table 5. Distribution of parcels by proportion of steep slope area

Steep slope proportion (%)	All parcels (count)	All parcels (%)	Residential parcels (count)	Residential parcels (%)	Non-residential parcels (count)	Non-residential parcels (%)
0–5	43,863	77.7	40,696	76.7	3,167	91.9
5–10	4,657	8.2	4,536	8.6	121	3.5
10–15	3,010	5.3	2,946	5.6	64	1.9
15–20	1,844	3.3	1,812	3.4	32	0.9
20–25	1,199	2.1	1,179	2.2	20	0.6
25–30	706	1.2	694	1.3	12	0.3
30–35	473	0.8	464	0.9	9	0.3
35–40	267	0.5	260	0.5	7	0.2
40–45	158	0.3	156	0.3	2	0.1
45–50	85	0.2	84	0.2	1	0.0
50–55	72	0.1	70	0.1	2	0.1
55–60	32	0.1	32	0.1	0	0.0
60–65	23	0.0	23	0.0	0	0.0
65–70	18	0.0	17	0.0	1	0.0
70–75	12	0.0	10	0.0	2	0.1
75–80	10	0.0	10	0.0	0	0.0
80–85	10	0.0	10	0.0	0	0.0
85–90	7	0.0	7	0.0	0	0.0
90–95	5	0.0	5	0.0	0	0.0
95–100	11	0.0	10	0.0	1	0.0

Note: Percentages may not sum to 100% due to rounding

Parcel-level analysis reveals a more detailed picture of slope exposure (see table 5 and figure 6). Across the study area, the majority of parcels contain little or no steep terrain. Parcels with less than 5% steep slope coverage account for approximately 77.7% of all parcels, while nearly 86% of parcels fall below the 10% threshold (see table 5).

Within the Residential Zone, parcels with less than 5% steep slope coverage account for approximately 76.7%. A further 8.6% fall within the 5–10% range. Parcels with moderate steep slope exposure (10–25%) collectively account for a noticeable minority of residential parcels, while parcels with higher exposure levels (>25%) become progressively less common.

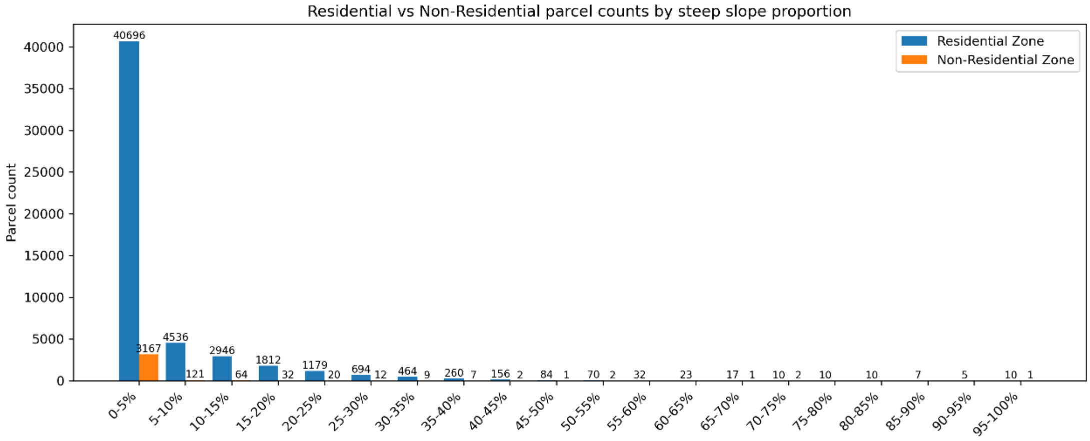

Figure 6. Comparison of residential and non-residential parcel counts by steep slope proportion

In contrast, the Non-Residential Zone shows a stronger concentration of parcels with minimal steep slope exposure. Approximately 91.9% of non-residential parcels fall below the 5% threshold, and parcels with more than 10% steep slope coverage are relatively rare.

These results indicate that while steep slopes affect only a small subset of parcels, residential parcels are more frequently intersected by moderate levels of steep terrain than non-residential parcels.

5.4.2 Spatial Distribution Analysis

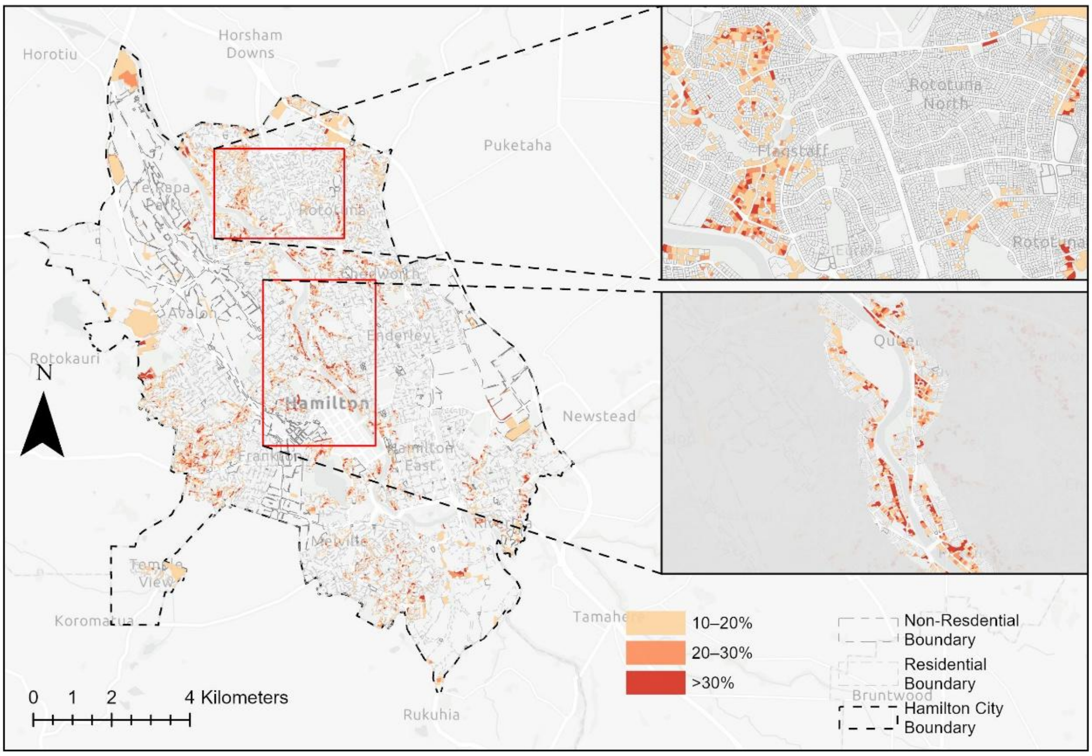

Figure 7. Spatial distribution of all parcels with ≥10% steep slope coverage, classified into 10–20%, 20–30%, and >30% proportion categories, with inset maps highlighting key locations.

Mapping parcels with at least 10% steep slope coverage shows that affected parcels are not evenly distributed across the city (see figure 7). Instead, they form clear spatial clusters and linear patterns aligned with major terrain features.

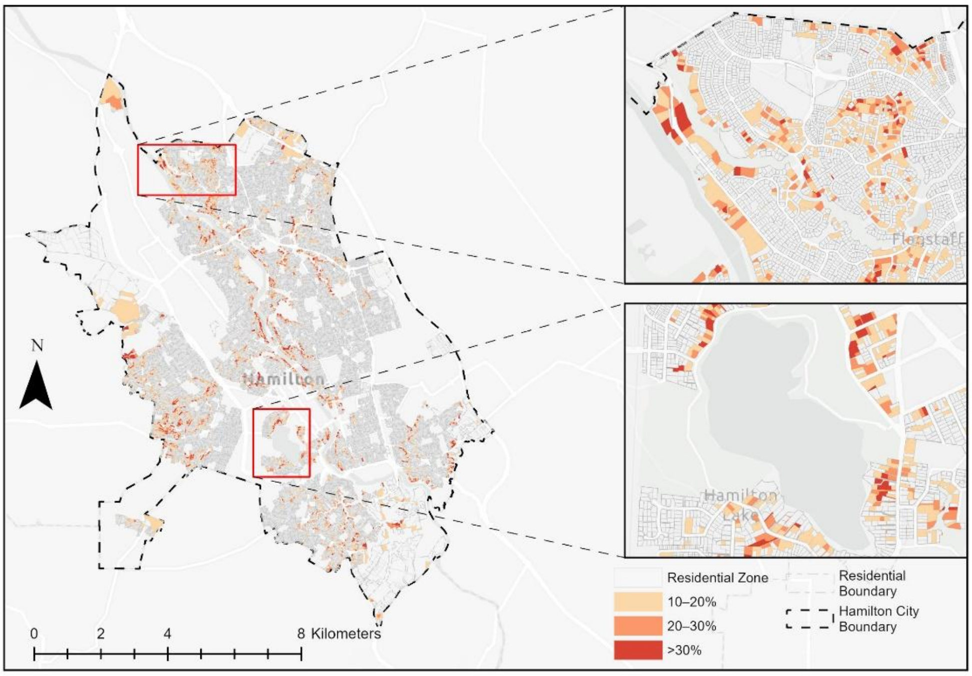

Figure 8. Spatial distribution of residential parcels with ≥10% steep slope coverage, classified into 10–20%, 20–30%, and >30% categories, with selected insets highlighting areas of planning interest.

In residential areas, parcels with moderate to high steep slope exposure commonly occur along river corridors, valley margins, and locally elevated terrain (see figure 8). These parcels are often grouped together rather than isolated, indicating that steep slope exposure is strongly controlled by underlying landform structure.

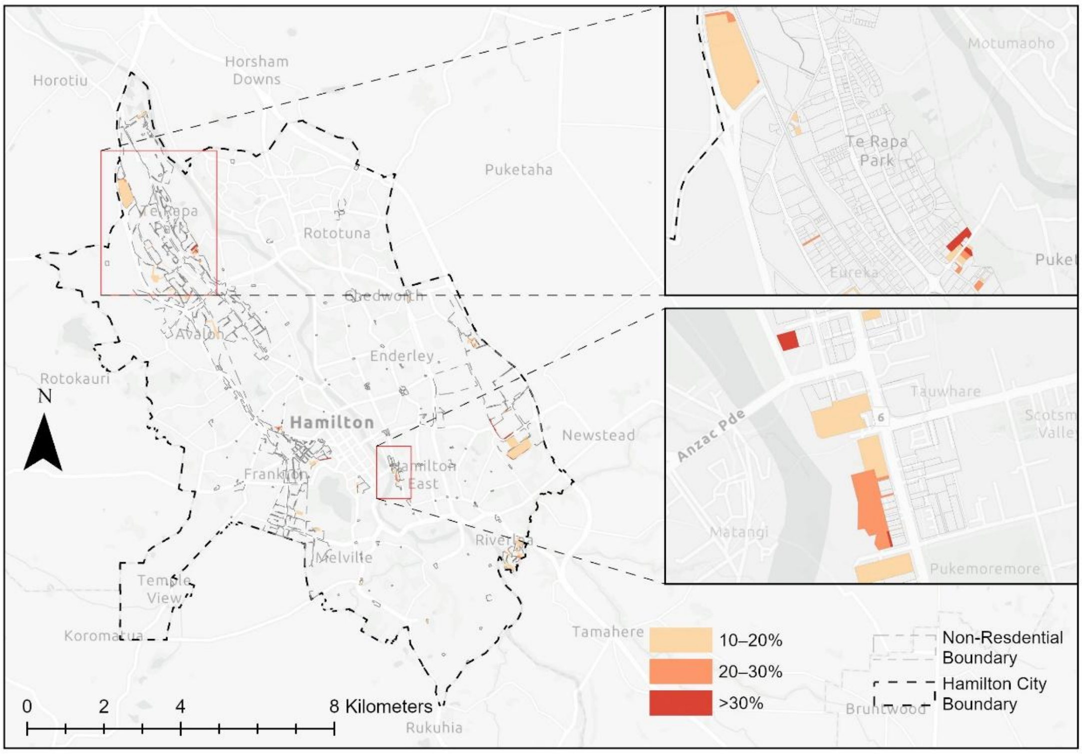

Figure 9. Spatial distribution of non-residential parcels with ≥10% steep slope coverage, classified into 10–20%, 20–30%, and >30% categories, with selected insets highlighting areas of planning interest.

In non-residential areas, parcels with similar levels of steep slope exposure are fewer and more spatially concentrated (see figure 9). Affected parcels tend to occur in specific locations rather than being spread across the zone.

This spatial pattern demonstrates that slope-related constraints are highly localised and site-specific. Parcel-level mapping therefore provides critical information that cannot be derived from city- or zone-level summaries alone.

6. Limitations and Future Work

6.1 Limitations

Several limitations should be acknowledged:

- **Scope of constraints**
  - The analysis focuses solely on slope and does not account for other factors influencing development feasibility, such as soil type, groundwater conditions, flood risk, or infrastructure capacity.
  - These factors may interact with slope and further constrain development feasibility

at specific sites.

- **DEM resolution and terrain noise**
  - The analysis is based on a high-resolution (1 m) LiDAR-derived DEM.
  - While this resolution captures fine-scale terrain variation, it may also introduce local noise and micro-topographic irregularities.
  - No specific noise reduction or smoothing techniques were applied in this project, and small-scale slope variability may therefore influence parcel-level slope proportions in some locations.
- **Parcel proportion classification intervals**
  - Fixed slope thresholds and 5% parcel proportion intervals were used to represent steep slope exposure in a simplified and interpretable manner.
  - The 5% interval classification was adopted as a pragmatic, experience-based choice to highlight differences between parcels.
  - However, this approach does not necessarily reflect engineering-based feasibility thresholds.
  - More accurate classification schemes could be developed using unequal interval ranges derived from engineering evidence, for example 5–15%, 10–30%, or 30–70% steep slope coverage.

6.2 Future Work

Several potential future work is listed below.

- Extend the analysis by integrating additional constraint layers, such as soil stability, flood hazard, and infrastructure availability, to support a more complete feasibility assessment.
- Incorporate cost-related indicators to better link slope exposure with development outcomes.
- Apply the parcel-level slope metrics as inputs to development capacity models or to prioritise sites for further investigation.
- Perform additional analysis by comparing parcels across zones with different density requirements to assess how slope constraints interact with planned development intensity.

7. Conclusion

This project examined how slope affects dwelling development feasibility in Hamilton City using a parcel-level GIS approach. By deriving slope from a high-resolution DEM, classifying slope into planning-relevant categories, and quantifying steep slope exposure within individual parcels, the analysis provides a clear and defensible representation of terrain constraints.

The results show that, at the city scale, slope is not a dominant constraint on development, as most land falls within low to moderate slope classes. Zone-level analysis indicates that residential land is slightly more exposed to steep slopes than non-residential land, but steep terrain remains limited in overall extent. However, parcel-level analysis reveals that slope-related constraints are concentrated in a small subset of parcels, particularly within residential areas, and are strongly associated with specific terrain features.

These findings demonstrate that slope-related constraints are best understood at the parcel scale rather than inferred from aggregated summaries. An area-based parcel-level approach provides practical value for early-stage development feasibility assessment by identifying where additional investigation or design consideration may be required.

Overall, this project shows that integrating parcel-level slope information into planning workflows can improve the alignment between development capacity assumptions and real-world site conditions. The approach developed here offers a transparent and reproducible framework that can support more informed planning and feasibility analysis.

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