

RIVERBED MONITORING AND MODELING USING GIS

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Abstract. The study aims to assess the changes in the riverbed that have occurred in various periods using GIS technologies. Topographic maps of different years will be used for the analysis. The riverbed has been digitized (for each period), determining the change in displacement and dislocation. The assessed dynamics of changes allow us to monitor the changes in the riverbed that have occurred due to both natural processes and anthropogenic impact. By performing two-dimensional and three-dimensional modeling, the spatial extent and intensity of the bed change were visualized. The results obtained reflect the relationship between riverbed transformations and potential natural and anthropogenic factors, allowing us to assess long-term trends in river morphology change.

Keywords: river channel evolution, GIS, morphodynamics, channel migration, historical maps.

1. Introduction

River morphology defined by channel sinuosity, meandering, and planform complexity is a key indicator of geomorphological processes and anthropogenic influence (Yu et al., 2023). It plays a vital role in maintaining habitat diversity and ecosystem functionality (Hohensinner et al., 2018; Limaye et al., 2021; Zhou & Endreny, 2020). Human interventions such as channelization and land reclamation have significantly simplified river systems, reducing their natural complexity and compromising ecological integrity (Rachelly et al., 2021; Wolf et al., 2021). These processes are particularly pronounced in lowland regions, where rivers exhibit gentle slopes and are highly sensitive to morphological changes (Buijse et al., 2007; Eekhout et al., 2014).

Across Europe, large-scale channelization and land reclamation during the mid-20th century aimed to mitigate flood risks and expand agricultural land, often resulting in straightened river channels (Szarek-Gwiazda et al., 2023; Muhar et al., 2016). Such interventions have had long-lasting consequences for sediment transport, biodiversity, and riparian habitats (Ylla Arbós et al., 2021; Mosselman et al., 2024; Zhou & Endreny, 2020; U.S. Environmental Protection Agency, 2008). Recent studies emphasize growing interest in understanding whether and how rivers regain their natural morphology after decades of anthropogenic simplification (Pusztai-Eredics et al., 2024; Nath & Ghosh, 2024; Lazowski & Pannonhalmi, 2018).

The Liedas River, part of the Nevėžis basin, represents a typical lowland stream in Central Lithuania, characterized by a gentle slope (2.53 ‰) and slow flow. It underwent intensive channelization during the land reclamation period of the 1950s–1980s (Wolf et al., 2021). Its morphological transformation over 88 years offers valuable insights into long-term geomorphological trends and human-induced impacts. By analyzing historical topographic maps, LiDAR data, and geospatial datasets (1937–2025), this study aims to identify long-term sinuosity trends and evaluate the interaction between anthropogenic modifications and natural recovery processes (Tonina et al., 2019; Flener et al., 2013; Andréault et al., 2023).

The novelty of this research lies in its integrated GIS-based approach, providing insights into the morphological dynamics of small lowland rivers following channelization (Backes et al., 2020; Haring, 2020). These results contribute to international discussions on river restoration, hydro-morphological resilience, and the implementation of the EU Water Framework Directive objectives (Ciscato & Harris, 2024; Mosselman et al., 2024).

Research objective:

To determine the morphological change trends of the Liedas River channel over the period 1937–2025, based on historical maps, LiDAR, and geospatial datasets, and to identify anthropogenic and natural factors influencing channel sinuosity.

Research tasks:

1. Collect and georeferenced historical topographic maps and contemporary spatial datasets.

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2. Digitize the river channel for different time periods and create a database.
3. Calculate channel sinuosity and assess its temporal changes.
4. Determine the extent of anthropogenic impact caused by land reclamation works.

Hypothesis: Micro- and macro-scale factors, particularly mid-20th-century land reclamation, significantly reduced the Liedas River's sinuosity; however, subsequent decades will reveal a tendency toward natural meander recovery, reflecting long-term geomorphological dynamics.

2. Materials and methods

Study area. The study focuses on the Liedas River (Figure 1), located in Kėdainiai District, Lithuania. It belongs to the Nevėžis basin and flows into the Šušvė River, which is a right tributary of the Šušvė. The confluence is approximately 15.5 km from the Šušvė mouth. The river originates in the fields of Pernarava eldership, about 2 km southwest of Pernarava, flows east through Pelutava, crosses the northern edge of the Pernarava-Šaravai forest, and becomes highly meandering in its lower course. It crosses the Josvainiai-Ariogala road and enters the Šušvė near Juodkaimiai (<https://ezerai.vilnius21.lt/liedas-v10429.html>).

Data sources. The analysis employed historical topographic maps, LiDAR point clouds, and the Geo-referenced Cadastral Spatial Data Set (GRPK), which is dynamic and updated monthly (Table 1). Data were processed and analyzed using ArcGIS Pro 3.6.1 software.

LiDAR data enable the construction of a detailed digital terrain model and allow for the determination of riverbank elevations as well as channel gradients. In contrast, historical maps were used to reconstruct the planform position of the river channel and its temporal changes; however, due to their limited vertical accuracy and the effects of cartographic generalization, they cannot provide reliable information on terrain or bank elevations.

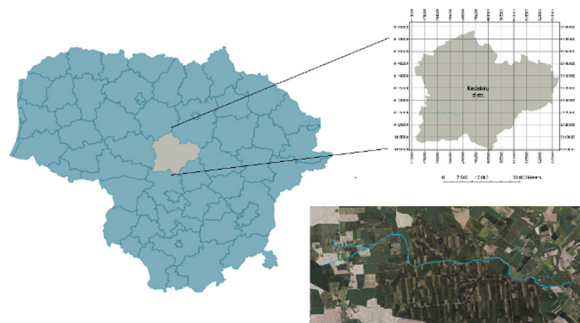

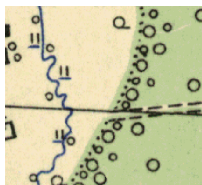


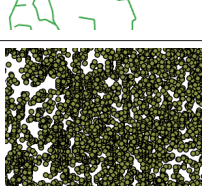


Figure 1. Location of the Liedas River

Table 1. Data sources

Data	Example
Topographic map, 1937, scale 1:25,000	
Topographic map, 1950, scale 1:25,000	
Topographic map, 1987, scale 1:25,000	
GRPK, 2025-12-31	
LiDAR, 2009	

Description of maps and other data sources:

1. Topographic map (1937), scale 1:25,000.

Compiled by the Military Staff's Topographic Division; source data derived from the 1935 instrumental ground survey.

Accuracy: horizontal position 5–10 m; vertical accuracy 0.5–1 m.

2. Topographic map (1950), scale 1:25,000.

Compiled from 1949 aerial photography.

Accuracy: horizontal position 10–15 m; vertical accuracy 2–4 m.

3. Topographic map (1987).

Compiled from 1:10,000-scale topographic maps, which themselves were based on 1959 aerial photography and updated using 1985 field and cartographic data.

Accuracy: horizontal position 5–10 m; vertical accuracy 2–3 m.

4. Digital spatial laser scanning point data (2009–2010) covering the land surface of the Republic of Lithuania.

Source: (<https://www.geoportal.lt/geoportal/>), dataset SEŽP_0,5LT.

LiDAR point density is approximately 1 point/m²; vertical accuracy $\sim\pm 0.15$ m, horizontal accuracy $\sim\pm 0.30$ m.

The 1937 map most accurately reflects river meanders due to the use of precise geodetic measurements, whereas aerial photography introduces some level of generalization. Despite these differences, the maps preserve sufficient information to analyze anthropogenic impacts on river morphology.

Data Processing. Historical maps were imported into ArcGIS Pro. The 1950 and 1987 maps were georeferenced directly, while the 1937 map required additional georeferencing using stable reference points (e.g., old churches, bridges) verified for temporal consistency. After georeferencing, the river channel was digitized, and a database was created.

A 300-meter buffer zone was established around the river, and a 3D terrain model was created using LiDAR points. Key ArcGIS Pro tools used: Georeferencing, Buffer, IDW interpolation, and Clip.

Analysis. Channel sinuosity was calculated using 1 equation. Sinuosity describes the degree to which a river meanders compared to a straight line between two points (the beginning and the end). It is a very important indicator because it reflects the morphological dynamics of a river: higher sinuosity means more meandering, lower sinuosity means a straighter riverbed (Yu et al., 2023).

$$S = \frac{L}{D}, \quad (1)$$

where, S – sinuosity index, L – actual river length along its course, D – straight-line distance between source and mouth.

If $S = 1$, the river is straight (indicative of channelization). If $S > 1$, the river is meandering. Higher S values indicate greater morphological complexity (Yu et al., 2023).

The work applied the auxiliary technical functions of AI tools: Microsoft Copilot (M365 Copilot, based on the GPT-5 chat model): as an auxiliary tool for converting translations into academic English and as an English editing tool.

2. Results and discussions

2.1. Results

A three-dimensional terrain model was generated from LiDAR data (Figure 2). The elevation within the study area ranges from 37.9 m in the east to 77.5 m in the



Figure 2. River Liedas

west, based on the LAS07 vertical reference system. The river mouth lies approximately forty meters lower than its source; however, the elevation decreases gradually without abrupt changes. This pattern is characteristic of lowland rivers, with a longitudinal slope of 2.53 ‰ (typical values for lowland rivers range from 0.1 to 5 ‰).

The digitized river channel, derived from historical topographic maps for different time periods and extracted from the Georeferenced Cadastral Spatial Data Set, is presented in Figure 3.

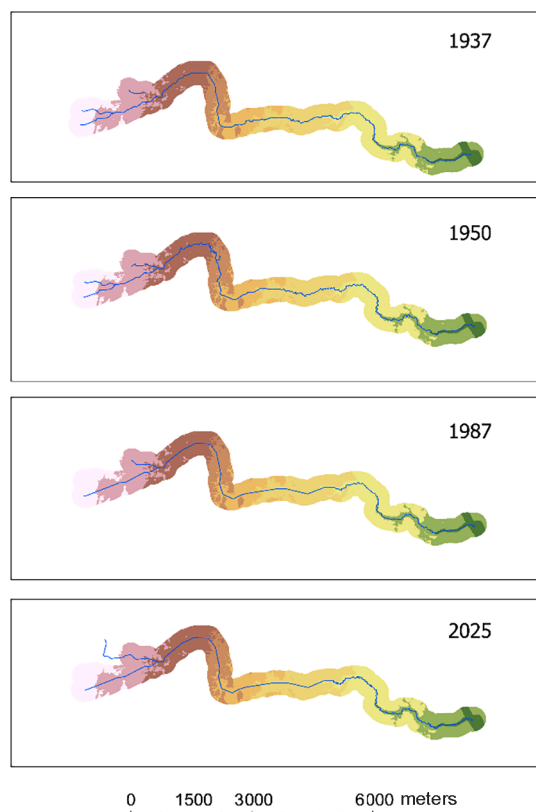


Figure 3. River Liedas in different years

The time intervals distinguishing the river channel configurations are shown in Table 2.

Table 2. Study periods

Year	Interval (years)
1935	–
1950	13
1987	37
2025	38
All	88

The entire study period spans 88 years. In Lithuania, river channels were actively straightened primarily between the 1950s and 1970s through canal excavation and levee construction, aimed at reducing flood risk and increasing the area of arable land. The investigated time-frame encompasses these years.

A more detailed examination of the river channel reveals minor discrepancies attributable to differences in data acquisition methods and cartographic generalization; however, these variations do not affect the validity of the analysis. The major meanders remain unaffected by these factors (Figure 4).

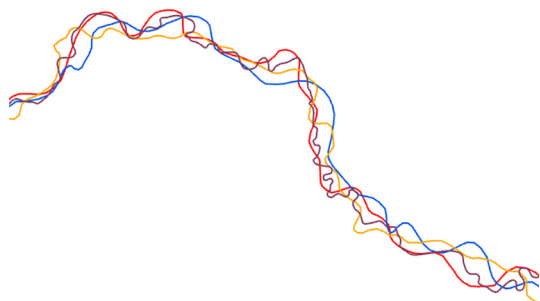


Figure 4. Differences in riverbeds

Therefore, it can be stated that although minor meanders in different measurement or observation periods may not coincide due to slight changes, measurement accuracy, or data discrepancies, the major meanders (the overall channel trajectory) remain clearly identifiable. These features reflect long-term trends in river erosion and sediment deposition, providing a reliable basis for analyzing channel evolution.

Continuing the research, a sinuosity analysis of the river was performed. The results are presented in Table 3.

Table 3. Results

Years	Sinuosity
1935	1.35
1950	1.49
1987	1.29
2025	1.43

Based on the obtained results, the following conclusions can be drawn:

- a) 1937–1950: River sinuosity increased from 1.35 to 1.49 (approximately 10% growth), indicating a natural process of meander development.
- b) Post–1950: Land reclamation works were carried out, resulting in partial channel straightening. Due to these anthropogenic modifications, sinuosity decreased to 1.29 by 1987 (approximately 13% reduction). This demonstrates that land reclamation significantly reduced channel complexity and stabilized the river course.
- c) 1987–2025: After the effects of land reclamation partially subsided, the river began to meander naturally again. Sinuosity increased to 1.43 (approximately 11% growth), reflecting natural channel dynamics and a possible gradual recovery of meanders.

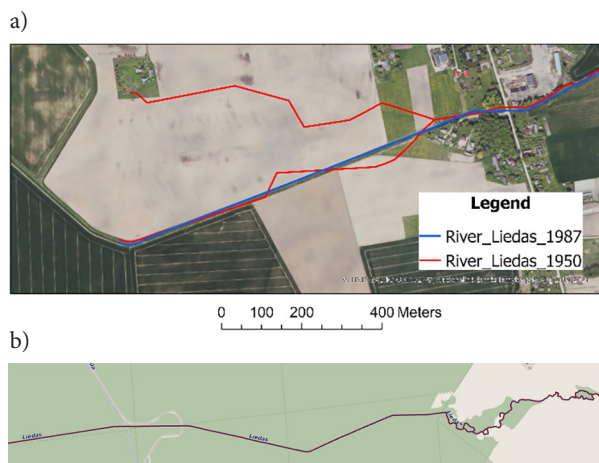


Figure 5. River Liedas: a) disappeared tributary; b) straightened and natural river channel

Following 1950, a substantial portion of the river channel was straightened. One of the tributaries disappeared (Figure 5 a–b); the area is currently occupied by cultivated fields.

The Liedas River was straightened from its source within the Pernarava forest to the forest boundary. Channelization works were also carried out within the forested area. Only after leaving the forest does the river regain its natural morphological form. Portions of the river were modified by anthropogenic activities aimed at improving agricultural conditions and forest exploitation. Table 4 presents the percentage of the original river channel that was altered.

Table 4. Condition of river channels

	River bed length, m	Percentages
River in 1937	14,749.56	100
Straightened section of the river	8,422.512	57.1
Unmodified section of the river	6,327.049	42.9

The results presented in the table indicate that more than half of the river’s total length was straightened.

When comparing the straightened river channel (Figure 5a) with the natural one (Figure 6), it becomes evident that both channel types are surrounded by



Figure 6. Natural river channel

cultivated fields; however, the natural channel is vegetated, which is ecologically favorable, whereas the straightened channel is not. In the latter case, agricultural fields extend practically up to the riverbank wherever possible.

2.2. Discussions

2.2.1. Interpretation of sinuosity change

The results indicate a three-phase trajectory: natural meander growth until approximately 1950 (S increased from 1.35 to 1.49), a pronounced reduction following land reclamation (S decreased to 1.29 by 1987), and partial recovery between 1987 and 2025 (S increased to 1.43). This pattern aligns with international research findings: recent studies suggest that $S \geq 1.5$ is typically associated with active meander development and channel migration (Limaye et al., 2021; Pusztai-Eredics et al., 2024), whereas lower values often reflect anthropogenic channel simplification (Rachelly et al., 2021; Wolf et al., 2021). Furthermore, sinuosity is directly linked to habitat diversity (Buijse et al., 2007; Muhar et al., 2016); lower S values generally correspond to reduced hydrodynamic and habitat complexity, although very high sinuosity does not always yield a linear increase in ecological diversity. Optimal sinuosity (~ 1.5) has been identified for certain hydrodynamic conditions (Hohensinner et al., 2018; Mosselman et al., 2024). The observed increase in S after 1987 is consistent with auto-denaturalization and re-meandering processes documented in regional and international examples, where channelized rivers gradually regain planform complexity or are actively restored through denaturalization projects (Ylla Arbós et al., 2021; Ciscato & Harris, 2024; Eekhout et al., 2014).

2.2.2. Impact of land reclamation (channelization) on hydro-morphology and ecosystems

The identified straightening of more than 50% of the original channel length is a typical outcome of mid-20th-century land reclamation, as discussed in European and U.S. literature. Channelization shortens river length, increases effective slope, reduces planform complexity, and diminishes natural habitat diversity. From an ecological perspective, straightened channels often exhibit declines in macroinvertebrate and fish diversity and habitat homogenization. The recorded decrease in sinuosity to 1.29 (1987) is consistent with these mechanisms and reflects regional practices in Lithuania, where land reclamation was widely implemented.

2.2.3. Methodological limitations

The main limitations arise from georeferencing historical maps (differences in scale, generalization, and data sources). While major meanders generally remain stable and reliable for analysis, minor channel shifts may vary due to cartographic processing, aerial photography quality, or instrumental survey methods. Additionally, our sinuosity assessment provides an integrated measure

(from source to mouth); future research should segment the river into reaches and evaluate local S values and their relationships with slope gradients, land cover changes (e.g., expansion of arable land), and hydrological regime variations. Such an approach would allow a more precise distinction between natural and anthropogenic dynamics.

2.2.4. Ecological and governance implications (EU policy context)

The observed partial natural recovery of meanders (S reaching 1.43) is an important indicator that even after radical straightening, river channels tend to return to a more hydro-morphologically complex state under favorable conditions. This finding aligns with EU policy directions: the Water Framework Directive (WFD) promotes hydro-morphological improvements to achieve good ecological status, while the Nature Restoration Law (NRL) (European Commission, n.d.) sets ambitious targets to restore at least 25,000 km of free-flowing rivers by 2030. In practice, denaturalization and floodplain restoration enhance hydrodynamic and habitat diversity.

2.2.5. Recommendations for further research and practice

Calculate sinuosity for individual river reaches and relate it to slope gradients and land cover changes.

Complement geomorphological analysis with biological indicators (e.g., EPT taxa, fish assemblages) to establish quantitative links between sinuosity changes and ecological status.

Over the 88-year period, the Liedas River followed a classic channelization–recovery trajectory: anthropogenic straightening reduced sinuosity and hydro-morphological diversity, followed by partial natural restoration. This pattern is consistent with theoretical frameworks on the ecological significance of sinuosity and corroborated by other studies. The integrated LiDAR–GRPK–GIS approach provides a robust basis for further hydro-morphological and ecological assessments, while the findings support EU policy objectives for river ecosystem restoration.

3. Conclusions

During the 88-year study period (1937–2025), the Liedas River underwent three distinct phases of morphological change:

- Natural meander growth until 1950 (sinuosity increased from 1.35 to 1.49);
- Pronounced straightening during mid-20th-century land reclamation (sinuosity decreased to 1.29; 57% of the original channel length was straightened);
- Partial recovery by 2025 (sinuosity increased to 1.43), indicating an ongoing natural renaturalization process.

The integration of historical maps, LiDAR data, and GIS analysis proved effective for long-term hydromorphological assessment, despite limitations related to cartographic generalization and georeferencing methods. Channel straightening significantly reduced channel complexity and likely had negative ecological impacts on habitat diversity. The observed partial recovery aligns with international evidence on river resilience and supports the EU Water Framework Directive and Nature Restoration Law objectives.

Future research should include segment-based sinuosity analysis, integration of topo-bathymetric data, and application of biological indicators to strengthen the link between morphological dynamics and ecological status.

3.1. Practical recommendations

Denaturalization measures: Restore meanders in straightened sections. Establish riparian vegetation buffers along the river to reduce soil erosion and improve habitat quality.

3.2. Management and planning recommendations

Municipalities should prioritize denaturalization projects in areas where sinuosity is low (<1.3).

Integrate GIS-based analysis into landscape planning documents to monitor river morphological dynamics and design restoration measures.

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