Chapter 3

Engineering Design Principles for Stream Restoration

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Abstract

Climate change has led to alterations in precipitation patterns, with an increase in extreme rainfall events and the emergence of drought trends. These changes have significantly increased the risk of flooding in streams, particularly in residential areas. Consequently, the evaluation of stream rehabilitation must extend beyond the confines of hydraulic conveyance capacity, encompassing hydro-geomorphological stability, ecosystem services, and socio-economic considerations. The present chapter delineates the engineering design principles for structures employed in the context of stream restoration, with a particular emphasis on the integration of hydraulic, ecological, and morphological processes. The discussion focuses on the equilibrium between conventional hard-engineering interventions and process-based, nature-based approaches, with particular emphasis on cross-section design, flow-velocity control, and bed and bank stability. A case study from the Darveta and Köyiçi Streams in Halkalı Village (Elazığ, Türkiye) is examined, including Q_{100}-Q_{500} design discharges, Manning roughness estimation using the Cowan method, hydraulic performance of culverts, grade-control weirs, concrete bed lining, and stability analyses of 1.60 m high retaining structures. The study emphasises the necessity of an engineering-driven yet interdisciplinary framework that collaboratively addresses flood safety and ecological functionality.

1. Introduction

Rivers are dynamic water bodies that play a vital role in the hydrological cycle of their catchments and are essential for the functioning of natural ecosystems. Due to the impacts of climate change, the deterioration of rainfall regimes and the increase in extreme precipitation events have elevated flood risks in river systems (Tabari, 2020; Taşkın et al., 2022). In

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recent years, severe flood events have made river restoration and stream rehabilitation critical fields of study from both engineering and ecological perspectives. Increasing flood risk, water quality problems, biodiversity loss and urbanization pressure necessitate reconsideration of river systems not only in terms of hydraulic capacity but also in relation to ecosystem services and societal benefits. Despite the rising number of projects, the literature indicates that most stream restoration efforts lack systematic post-implementation assessment, leading to repeated mistakes across different catchments (Kondolf & Micheli, 1995; Kondolf, 1995).

River restoration is a multi-component process aimed at improving ecosystem functions, reducing flood risk and re-establishing hydromorphological continuity. Achieving multiple objectives such as hydraulic safety, ecological enhancement and improved water quality requires watershed-scale planning. Figure 1 schematically illustrates the diverse benefits generated by catchment-based management practices for both society and ecosystems (River Restoration Centre, 2023).

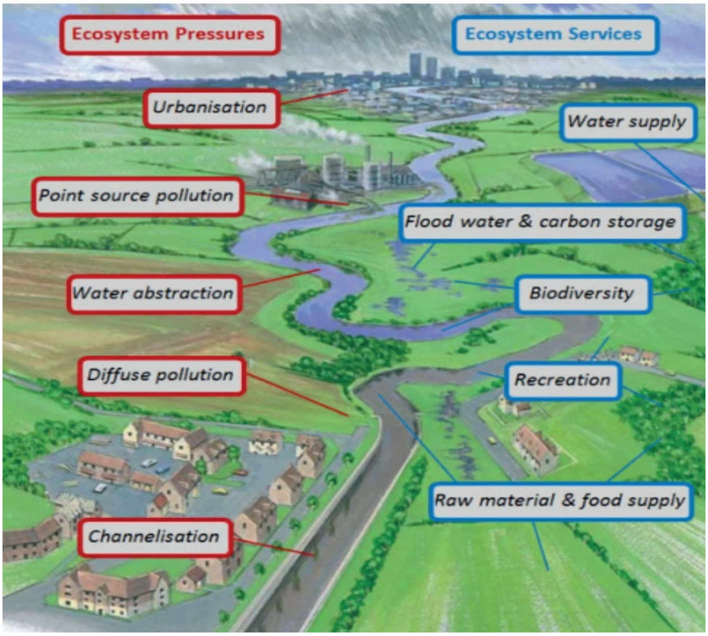

Figure 1. Pressures and Ecosystem Services at the Catchment Scale in the Context of River Restoration (Adapted from RRC)

Palmer et al. (2014) state that restoration has shifted from a historical focus on returning systems to "wilderness-like" conditions toward a framework emphasizing the recovery of ecosystem services that provide direct benefits to people, such as flood mitigation, water quality improvement, and sediment and nutrient retention. Particularly in urban areas, streams have often been converted into "stormwater management structures," involving substantial morphological modifications intended to increase hydraulic retention and reduce peak discharges. However, such intensive engineering interventions may enhance certain services while causing losses in others or generating new environmental impacts, underscoring the necessity of a holistic ecosystem perspective (Palmer et al., 2014).

Hydraulic engineering literature emphasizes that restoration design cannot be limited to cross-sectional sizing. Shields et al. (2003) define the primary objective of restoration as achieving a functional state "as close as possible to the remaining natural potential" of a degraded stream system, highlighting the tension between natural fluvial processes and structural stability. Accordingly, an intermediate-level engineering approach is proposed that combines watershed geomorphology, characteristic discharge analysis and one-dimensional flow and sediment transport modeling. Similarly, Niezgoda and Johnson (2005) argue that in urban streams, structural constraints and disrupted flow and sediment regimes make morphology-based reference designs inadequate, and that process-based approaches and revised definitions of form–process relationships are required.

The ecological dimension of river restoration has also gained increasing importance. Lake et al. (2007) emphasize that many restoration projects are insufficiently grounded in ecological theory, often neglecting essential concepts such as species life cycles, dispersal processes, refugia, longitudinal and lateral connectivity, food-web dynamics, and assembly rules. This perspective demonstrates that stream rehabilitation involves not only hydraulic safety or bank protection, but also the reconstruction of ecosystem processes and biodiversity. Biotechnical bank protection approaches (Li & Eddleman, 2002) and studies highlighting the ecological functions of structural elements such as vanes, weirs and SPSC systems (Hickman, 2019) show that nature-based alternatives to traditional hard-engineered solutions are feasible.

More recent studies reveal that river restoration has a strong social and governance dimension. Gariépy-Girouard et al. (2025) show that restoration projects are often shaped not by scientific–technical principles but by public pressure, funding conditions and stakeholder expertise, which may lead to the neglect of hydro-geomorphological principles. Robins et al. (2025) highlight the weakness of data-driven decision-making in catchment-scale river restoration planning and the need for clearer definitions of pressure–

impact relationships and standardized planning frameworks. Studies conducted in Türkiye indicate similar challenges: in İstanbul, stream rehabilitation efforts aimed at reducing flood risk face difficulties due to issues related to land ownership, zoning and institutional authority (Bodur, 2018); while in the case of Bitlis Merkez Stream, rehabilitation and urban transformation projects offer opportunities for enhancing local capacity, unveiling historical–cultural heritage, and reducing disaster risk, though institutional coordination remains critical (Yıldırım & Çelik, 2025).

Overall, the literature demonstrates that stream rehabilitation and river restoration are not limited to structural interventions such as culverts, retaining walls, weirs or channel linings. Instead, they constitute multidisciplinary fields requiring the integrated consideration of geomorphology, ecology, hydraulics, socio-economic context, governance, and long-term monitoring. While ecological engineering approaches aim to support natural processes and ecosystem services (Woo et al., 2005; Palmer et al., 2014), guidance documents and technical notes (Doll et al., 2020) provide systematic frameworks for practitioners. Accordingly, the fundamental engineering components used in stream rehabilitation such as weirs, culverts, retaining structures and biotechnical bank protection should be evaluated not only in terms of hydraulic performance but also in relation to hydro-geomorphological compatibility, contributions to ecosystem services and long-term monitoring requirements.

Increasing degradation in river ecosystems, rising flood risk and the pressures of urbanization have transformed stream rehabilitation and river restoration into a multidisciplinary engineering–ecology field. Despite the large number of restoration projects implemented over the past three decades, many have lacked adequate hydromorphological assessment and long-term monitoring (Kondolf & Micheli, 1995), contributing to high failure rates and slowing the advancement of restoration science. Palmer et al. (2014) emphasize that restoration is shifting away from solely re-creating natural conditions toward restoring ecosystem services most needed by society, such as flood mitigation, water quality improvement and sediment management. In this context, Shields et al. (2003) argue that restoration design must maintain natural fluvial processes while ensuring engineering stability, requiring both geomorphological and hydraulic analyses.

This literature framework aligns strongly with stream rehabilitation practices in Türkiye, particularly in settlements intersected by stream corridors. In the case of Halkalı Village in Alacakaya, Elazığ, the existing sections of Darveta and Köyiçi Streams were found incapable of conveying design flood discharges, placing residential and agricultural areas at high risk. Field assessments revealed the necessity of concrete bed lining due to high tractive forces, the installation of weirs for flow-velocity control, and the use of Q_{100} and Q_{500} design discharges due to residential constraints. Hydraulic analyses were conducted for three culverts of varying dimensions (4.00×2.00 m, 2.00×2.00 m and 3.00×2.00 m), and stability analyses were performed for 1.60-m-high retaining walls. These applications reflect the interaction and sometimes tension between engineering requirements, ecological considerations and social constraints highlighted in the literature. As noted by Gariépy-Girouard et al. (2025), river restoration is shaped not only by technical considerations but also by social acceptance, institutional capacity and local expectations. In the Halkalı Village case, the fact that the stream corridor passes entirely through residential areas directly influenced section dimensions and structure types, illustrating restoration as an inherently social practice.

In conclusion, both the literature and field applications demonstrate that stream rehabilitation is not merely the implementation of structural elements (e.g., weirs, culverts, retaining walls), but rather a comprehensive engineering approach requiring the integrated consideration of hydro-geomorphological processes, ecosystem services, social expectations and long-term monitoring. The following section examines the fundamental engineering components used in stream rehabilitation within this broad framework.

2. Stream Rehabilitation in the Context of River Restoration at Halkalı Village

Hydraulic analyses conducted by the General Directorate of State Hydraulic Works (DSİ) in Halkalı Village revealed that the existing cross-sections of Darveta and Köyiçi Streams are unable to convey the Q_{100} and Q_{500} design flood discharges. Due to high flow velocities and narrow sections, bed scour and bank instability were observed; therefore, the project included concrete bed lining, the placement of weir (grade-control) structures for flow-velocity control, and the design of culverts with appropriate spans. In addition, due to spatial constraints within the settlement, the stability of retaining structures with a wall height of 1.60 m was evaluated.

The project area map presented in Figure 2 shows the locations of Darveta and Köyiçi Streams within the residential area, the chainage (km) points, and the rehabilitation alignment defined by DSİ. The map combines the regional location of the project area with detailed river geometry, thereby providing the spatial context for the analyses.

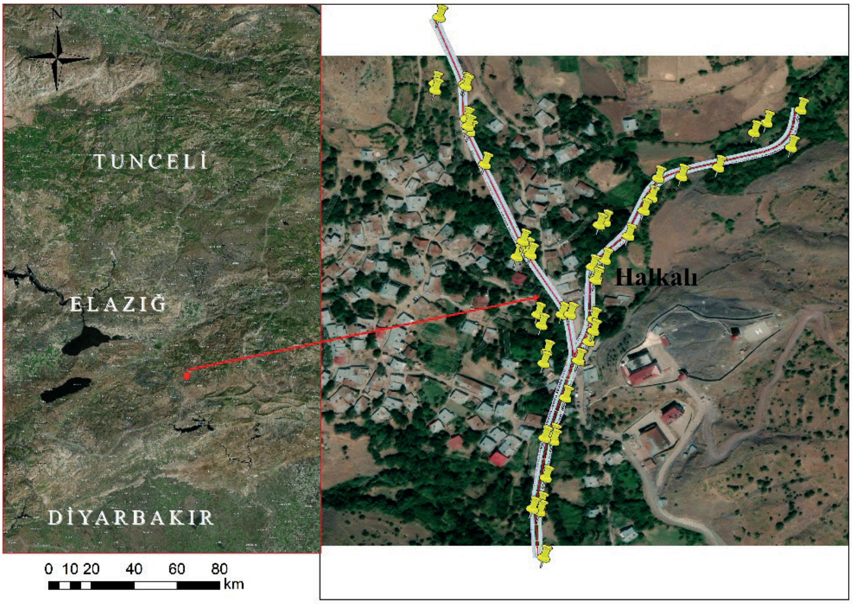

Figure 2. Project area of Darveta and Köyiçi Streams in Halkalı Village

2.1. Characteristics of the Project Area

Halkalı Village is fed by two main streams:

- Darveta Stream
- Köyiçi Stream

Both streams flow through the settlement and continue along extensive agricultural lands. The inability of the existing sections to convey flood discharges has created a significant risk for the settlement. The stream corridor passes through relatively narrow valleys, and the steep topographic slopes in certain reaches increase flow velocities and, consequently, flood hazard. Because the village's built-up area is located very close to the streambeds, the inadequacy of the existing cross-sections has led to both hydraulic and structural problems.

The topographic map provided in Figure 3 illustrates the spatial relationship between the valley system, slope configuration, settlement areas and tributaries within the project area, and reveals the morphological conditions that form the basis for hydraulic design.

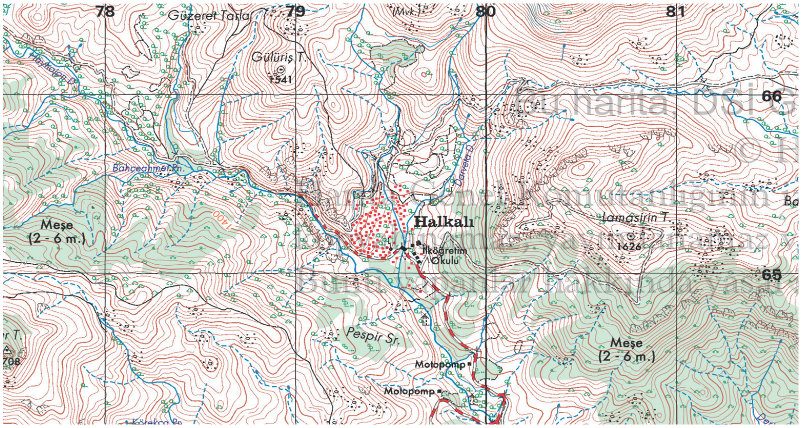

Figure 3. Topographic map of Halkalı Village and its surroundings

2.2. Identified Problems

- Inadequate existing cross-sections
- Flow areas directly adjacent to residential zones
- Loss of life and property following flood events
- Bed scour and lateral erosion
- Undersized culverts
- High tractive force

As shown in Figure 4, the existing cross-sections in Darveta and Köyiçi Streams are quite narrow and do not allow the safe conveyance of flood flows. Irregular bed geometry, lateral erosion, bank instability and high tractive forces during flood events are among the main problems identified in the field.

Figure 4. Narrow existing sections and flood-prone areas in Darveta and Köyiçi Streams

3. Objectives and Scope of Stream Rehabilitation

Stream rehabilitation is an engineering practice aimed at reducing flood risk, erosion, morphological degradation and environmental hazards in river systems, based on the integrated assessment of hydraulic, geomorphological, ecological and socio-economic components. Today, the objective of stream rehabilitation is not limited to securing the controlled conveyance of water; it also includes protecting the ecological functions of river systems, reducing risks to settlements and infrastructure, supporting sustainable land use, and ensuring public safety. For this reason, stream rehabilitation plays a multidimensional role as both a technical and a socio-ecological management tool.

Stream rehabilitation is a multi-faceted process encompassing a broad range of engineering and ecological activities. Before implementation, it requires detailed analysis of the existing conditions, identification of hydraulic cross-sections, examination of sediment characteristics, and assessment of bed–bank stability. Within this scope, high-risk areas are identified; Q_{10}–Q_{500} design flood discharges are calculated for hydraulic and morphological design; and structures such as weirs, grade-control structures and spillways are planned accordingly. Where necessary, bed lining is applied; and infrastructure components such as walls, revetments, culverts, bridges and road crossings are designed or rearranged, accompanied by measures to prevent backwater effects. In addition to engineering interventions, biotechnical practices such as riparian vegetation and rehabilitation of the riparian zone support the sustainability of the stream ecosystem. The social and institutional dimension of the process includes risk reduction activities, land-use management and coordination with local stakeholders. Thus, stream rehabilitation is not limited to technical engineering solutions; it is a comprehensive field of practice that integrates ecological, social and governance strategies.

3.1. Reducing Flood Risk

The primary objective of stream rehabilitation is to minimize the hazards posed by river floods to residential areas, agricultural lands and critical infrastructure. The infilling of stream sections over time, unplanned development, uncontrolled interventions and morphological changes reduce discharge conveyance capacity and increase flood risk. Designing appropriate cross-sections based on flood return periods (Q_{10}, Q_{50}, Q_{100}, Q_{500}, etc.), eliminating critical constrictions, and correcting inadequacies in culvert and bridge spans constitute the main activities undertaken within this scope.

In DSİ practices in Türkiye, designing for Q_{100}–Q_{500} in densely populated areas is a standard approach to ensuring life and property safety. As in the case of Darveta and Köyiçi Streams in Halkalı Village, the inability of existing sections to convey design flood discharges directly threatens settlement safety; therefore, widening of sections, bed lining and the construction of weir structures become indispensable.

3.2. Ensuring Hydraulic and Morphological Stability

River systems are natural environments operating in a state of dynamic equilibrium, with ongoing feedback between flow regime, sediment transport and channel morphology. One of the key objectives of stream rehabilitation is not to suppress these natural processes entirely, but to establish a sustainable hydro-geomorphological balance. In this context, preventing bed degradation, controlling erosion, regulating sediment transport capacity and reducing flow velocity to safe levels are critical hydraulic targets in rehabilitation projects.

As observed in Darveta and Köyiçi Streams, high tractive forces and the mobility of bed material disrupted natural stability; therefore, concrete bed lining and energy-dissipating weirs were employed to achieve a safe morphological balance.

3.3. Protecting Water Quality and Ecosystem Services

Contemporary restoration approaches recognize that stream rehabilitation should not only provide physical safety but also contribute to the preservation of ecosystem services that are critical to society, such as nutrient retention, habitat provision, functioning of floodplains and opportunities for recreation. Palmer et al. (2014) describe this shift as a transition "from recovering wild ecosystems to improving ecosystem services."

3.4. Ensuring Infrastructure and Settlement Safety

In rapidly urbanizing and industrializing regions, streams are often enclosed or modified in an uncontrolled manner, leading to serious safety problems. Road crossings, bridges, culverts, sewer lines and drinking-water pipelines are all directly affected by stream rehabilitation measures.

Therefore, stream rehabilitation is critical not only for the safety of the river system itself but also for maintaining infrastructure integrity. Correct hydraulic design of culverts, bridges and retaining walls, prevention of backwater effects and maintaining flow continuity are among the fundamental objectives of such projects. In the Halkalı Village case, three culverts were subjected to detailed hydraulic verification, and the design of wall stability and bed lining were evaluated within this scope.

3.5. Addressing Socio-Economic and Institutional Requirements

An increasingly discussed dimension in the literature is that stream rehabilitation is also a social and governance process. Public acceptance, land ownership issues, local government capacity, user expectations and institutional coordination directly influence the technical framework of rehabilitation. As demonstrated in the cases of İstanbul (Bodur, 2018) and Bitlis Stream (Yıldırım & Çelik, 2025), project success depends not only on technical design but also on planning, authority sharing and public engagement.

4. Key Hydraulic Design Parameters in Stream Rehabilitation

The engineering components used in stream rehabilitation projects consist of structural and biotechnical interventions that regulate the hydraulic behavior of river systems, reduce flood risk and protect settlements. Modern approaches aim not only to control flow but also to sustainably enhance aquatic ecosystem functioning, morphological stability and ecosystem services. International literature emphasizes the importance of preserving fluvial processes while ensuring stability, achieving hydro-geomorphological compatibility, supporting ecosystem services and establishing long-term monitoring requirements in rehabilitation projects (Shields et al., 2003; Palmer et al., 2014; Kondolf & Micheli, 1995).

In Türkiye, DSİ practices primarily translate these approaches into measures focused on flood control, velocity reduction, stability and cross-sectional safety. The Elazığ, Alacakaya Halkalı Village flood protection project provides a good example of how these components are integrated in the field.

4.1. Roughness Coefficient (Manning 'n')

The Cowan method was first developed by W. L. Cowan in 1956 and later revised by the U.S. Geological Survey in 1989 (Cowan, 1956). In Türkiye, the DSİ Flood Expertise Commission further refined the method by introducing the "channel bank condition (n_1)" parameter into roughness calculations, giving the method its final form.

In the modified Cowan method, the Manning roughness coefficient is calculated as follows:

$$n = n_b + n_1 + n_2 + n_3 + n_4$$

$$n_{\text{total}} = n \times m$$

One of the most critical inputs in hydraulic calculations is the roughness coefficient. DSİ computes Manning's n using a table-based component analysis (n_b, n_1, n_2, n_3, n_4). In the Halkalı project, roughness values for both Darveta and Köyiçi Streams were determined using this method, and cross-section geometry was optimized accordingly (Demir & Keskin, 2019; DSİ, 2016). The roughness coefficient forms the basis for determining flow velocities, positioning of weirs, air clearance and culvert hydraulics.

Table 1. Manning roughness coefficient components for Darveta and Köyiçi Streams

Component-Parameter	Description	Darveta Stream	Köyiçi Stream
n_b	Bed roughness (concrete)	0.016	0.016
n_1	Cross-section irregularity (right–left masonry walls; $n_1a + n_1b$)	0.005	0.005
n_2	Channel section variation	0.000	0.000
n_3	In-channel obstructions (deposits, mounds, boulders)	0.000	0.000
n_4	Vegetation (low)	0.005	0.005
Total n	Manning roughness coefficient	0.026	0.026
Stream length (m)	Length measured along the channel	685	410
Straight-line length (m)	Direct distance from start to end	663.25	370.42
D/L (stream / straight line)	Sinuosity ratio	1.03	1.11
m (meander coefficient)	$D/L < 1.2 \rightarrow m = 1.0$	1.00	1.00

4.2. Sizing and Cross-Section Design

The hydraulic adequacy of culvert sections designed on Köyiçi and Darveta Streams was evaluated according to DSİ's design flood discharge criteria. For each culvert, design discharge values were used together with bed width, section height, project slope and Manning roughness to obtain $Q_{calculated}$ values. The hydraulic verification results are summarized below.

Köyiçi Stream – KM: 0+009.25 (3.00 × 2.00 m Culvert)

At this location, a rectangular culvert with a 3.00 m bed width and 2.00 m height was designed. The Manning coefficient was taken as $n = 0.026$ and the project slope as 0.30%. For Q_{100} and Q_{500}, considering the hydraulic radius and flow parameters of the culvert, a $Q_{calculated} = 36.07$ m³/s was obtained. Since this value is significantly higher than $Q_{500} = 14.10$ m³/s, the cross-section is considered hydraulically adequate.

Darveta Stream – KM: 0+560.00 (2.00 × 2.00 m Culvert)

At this location, a culvert with a 2.00 m bed width and 2.00 m height was proposed. The project slope is 0.30%, and Manning's n is 0.026. For $Q_{100} = 5.60$ m³/s and $Q_{500} = 7.40$ m³/s, hydraulic calculations yield *Q_calculated* = 20.335 m³/s. Since *Q_calculated* exceeds Q_{500}, the culvert section is considered safe.

Darveta Stream – KM: 0+224.32 (4.00 × 2.00 m Culvert)

Here, a culvert with a 4.00 m bed width and 2.00 m height was designed. Manning's n is 0.026 and the project slope is 0.30%. Using Q_{100} = 14.90 m³/s and Q_{500} = 19.70 m³/s, the hydraulic analysis yields ***Q_calculated* = 53.294 m³/s**. This value is approximately three times Q_{500}, indicating that the culvert has sufficient hydraulic capacity.

4.3. Weir (Grade-Control) Structures and Velocity Control

Weirs (grade-control structures) are key rehabilitation elements used to reduce flow velocity, prevent bed scour and dissipate energy within the channel, particularly in steep or high-discharge reaches.

In the DSİ report:

- A maximum velocity of v = 5.00 m/s was adopted.
- Weir structures were deemed necessary in sections where this limit is exceeded.

International studies similarly emphasize that velocity control is critical for sediment transport and channel stability (Shields et al., 2003; Niezgoda & Johnson, 2005).

4.4. Bed Linings (Concrete, Stone and Natural Materials)

In streams with high tractive forces, bed linings are used to prevent bed degradation. In the Halkalı Village project:

- DSİ recommended **concrete lining** due to high tractive forces.

Alternative linings include:

- Stone lining (a traditional practice in Anatolia for bank improvement)
- Natural bed enhancement methods (commonly preferred in ecological restoration projects)

4.5. Culvert Design and Hydraulic Verification

Culverts are critical structures for ensuring safe flow conveyance where roads intersect with streams. In DSİ applications, culvert dimensions are verified through:

- Hydraulic calculations,
- Velocity–head relationships,
- Air-clearance considerations,

- Stability analyses.

Culverts used in the Halkalı Village project are as follows:

- Darveta Stream: 4.00×2.00 m and 2.00×2.00 m
- Köyiçi Stream: 3.00×2.00 m

International literature emphasizes that culvert design should be evaluated not only hydraulically but also in terms of ecological connectivity, such as fish passage and habitat continuity.

4.6. Slope and Wall Stability

An important component of stream rehabilitation is the stability of sidewalls, slopes and retaining structures. DSİ applies classical engineering analyses based on checks for sliding, overturning and bearing capacity.

In the Halkalı Village project:

- Static and reinforced concrete calculations were performed for walls with a height of $\boldsymbol{h = 1.60\ \mathrm{m}}$.
- Wall cross-sections were strengthened with settlement safety in mind.

4.7. Biotechnical Applications and Ecological Approaches

In addition to conventional rehabilitation methods, modern literature recommends the following biotechnical applications:

- Permeable bank protection,
- Vegetation combined with stone-supported hybrid structures,
- Slope stabilization with deep-rooted plants,
- Timber piles / live fascines and hedges.

Li and Eddleman (2002) emphasize that biotechnical methods are "more economical and more ecosystem-friendly than hard-engineered solutions." Hydro-geomorphology-based projects, on the other hand, advocate evaluating the river system as an integrated whole (Gariépy-Girouard et al., 2025).

4.8. Nature-Based Solutions

International trends in river restoration increasingly promote:

- Setback levees and corridor widening,
- Re-activation and multifunctional use of floodplains,

- Restoration of riparian forests,
- Improvement of channel meanders.

Palmer et al. (2014) justify this approach by the need to place ecosystem services at the center of restoration efforts.

4.9. Long-Term Monitoring and Evaluation

According to the principles emphasized by Kondolf & Micheli (1995) and in the "Five Elements for Effective Evaluation" framework:

- Every restoration project is essentially an **experiment**.
- The successes and failures of projects must be **systematically documented**.
- Monitoring periods should extend to **at least 10 years**.

In DSİ's field practices, the duration of monitoring varies by project; however, it is progressively converging toward these international standards.

5. Conclusions

The complex, multidimensional field of stream rehabilitation and river restoration is situated at the intersection of engineering and ecological sciences. A comprehensive review of the extant literature, together with an analysis of international methodologies and DSİ's technical findings from field applications, as examined in this study, clearly demonstrates that contemporary stream rehabilitation practices now extend beyond the scope of traditional engineering methodologies, which were previously exclusively focused on the safe conveyance of design flood discharges.

As demonstrated in the extant literature, the success of restoration projects is contingent upon a comprehensive understanding of hydro-geomorphological processes, the preservation of ecosystem services, the compatibility of structures in terms of hydraulics and morphology, and the continuity of long-term monitoring and evaluation initiatives (Kondolf & Micheli, 1995; Palmer et al., 2014; Shields et al., 2003). Concurrently, the outcomes of projects are found to be profoundly influenced by social acceptance, the capacity of local government, funding models and stakeholder expectations. This observation underscores the notion that stream rehabilitation is not merely a technical engineering practice, but rather a process that encompasses a substantial social and governance dimension.

The Halkalı Village Darveta and Köyiçi Streams Rehabilitation Project, prepared by DSİ, provides a practical illustration of the implementation of these approaches. The selection of a concrete bed lining due to high tractive forces, the use of weir structures to control flow velocity, detailed hydraulic verification of culverts, and the adoption of Q_{100}-Q_{500} design discharges in engineering design all represent a rational and standards-compliant approach to engineering safety and flood control. Concurrently, spatial configurations aimed at safeguarding ecosystem services, ensuring settlement stability, and delivering social benefits exemplify a holistic restoration perspective at the scale of Türkiye.

The findings of this study suggest that future stream rehabilitation efforts are likely to incorporate increasing amounts of:

- The utilisation of solutions that are inspired by and in harmony with natural environments.
- The design principles underpinning ecosystem services.
- The integration of planning at the catchment scale is imperative.
- The necessity for collaboration between local governments and communities is indisputable.
- The utilisation of advanced digital hydraulic modelling techniques is imperative in this context.
- Furthermore, the necessity for long-term monitoring programmes is emphasised.

This approach facilitates a more nuanced balance between engineering interventions and ecological processes, thereby fostering the transition towards integrated and sustainable stream rehabilitation practices. In this context, the harmonisation of conventional "hard" engineering structures with biotechnical and ecological methods is anticipated to accelerate, leading to a more holistic and environmentally sustainable approach to stream rehabilitation.

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