Remediation of Low Cover in the South Fork Nemaha River - A Case Study

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Abstract

The challenge of many erosion remediations of pipeline water crossings is to balance the need to protect the pipeline with adequate, robust cover while also minimizing impact to aquatic life and the natural development of the water body. Many projects resort to pipe lowering, an expensive option that is also disruptive to both the environment and the operation of the pipeline, resulting in service outages and profit losses. While the result of such projects is a pipeline with low integrity risk and a naturally developing water body, the cost of such remediation has been seen to reduce the available funding to other such integrity concerns, which can lead to low cover and exposure sites degrading further as they wait for funding.

The South Fork Nemaha crossing of the Enbridge L41 pipeline experienced low cover due to both downward and lateral scour. This case study will outline the 5 different methodologies used to maintain adequate pipeline protection and provide aquatic life passage at typical low-flow river conditions. First, the project team identified two reasons for the increased scour – two upstream structures changing the historical flow patterns - and addressed those root causes as much as possible. Second, a concrete mat system was used to provide cover directly over the pipeline while minimizing the rise in riverbed. Third, the bank was regraded from near-vertical scour and slough prone to a 2:1 slope that allows for more gentle flooding during high intensity rain events. Fourth, the toe of the bank was armored with traditional riprap up to the ordinary high water mark to protect against the typical annual high flow events. Finally, the bank above the high water mark was revegetated by life-staking willow species that flourishes in this region, propagates easily, and roots well on river banks to provide soft erosion protection during the highest flood events. While the project is slated for construction in the third quarter of 2024 and will not have data to report on the success of such a system, the individual components are all proven methods throughout various industries. It is expected that these different components will all provide key functions right where they are needed most, keeping impact to the river to a minimum.

Project overview

Erosion as a pipeline integrity threat

Erosion poses a unique challenge to pipeline integrity. On a larger scale, it typically acts as a time-dependent threat, with soil eroding gradually and predictably over extended periods. However, on a smaller scale, erosion can be far less predictable. A single heavy rainfall can trigger sudden, catastrophic soil loss, shifting the threat from a time-dependent process to an event-driven one.

Erosion often has impacts that extend far beyond the boundaries of a pipeline's Right-of-Way (ROW). Addressing the root cause of an integrity threat requires operators to consider a significantly larger scope for remediation, which drives up project costs, lengthens timelines, and introduces permitting

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complexities. Consequently, operators frequently address only the symptoms of the problem, leaving the underlying cause unresolved. This approach allows the issue to persist, continuing to affect the ROW over time. As weather continues to change and the land around pipeline ROWs continues to be developed, water bodies will experience dramatically different hydraulic circumstances than what was anticipated when pipelines were constructed. This leads to exposed or unsupported pipe, raising integrity concerns including increased strain, inappropriate or damaged coatings, and increased risk of third-party damage.

Natural hydrology

Erosion is a natural process that occurs wherever water flows. In many untouched waterways, a dynamic balance forms, where the sediment load of the water matches the sediment transport capacity. The channel slope, flow velocity, and stream power align with the strength of the streambed and bank materials, creating stable conditions similar to those shown in Figure 1 and Phase I of Figure 2. This balance supports essential riverbed features like steps, riffles, runs, and pools, which help dissipate energy from the flowing water. Larger creeks, streams, and rivers often develop a sinuous shape, with a narrow primary channel and a broad floodplain that only floods during higher-than-average flows. Strong riparian stabilizers further reinforce the primary channel, such as natural rock formations or dense local vegetation.

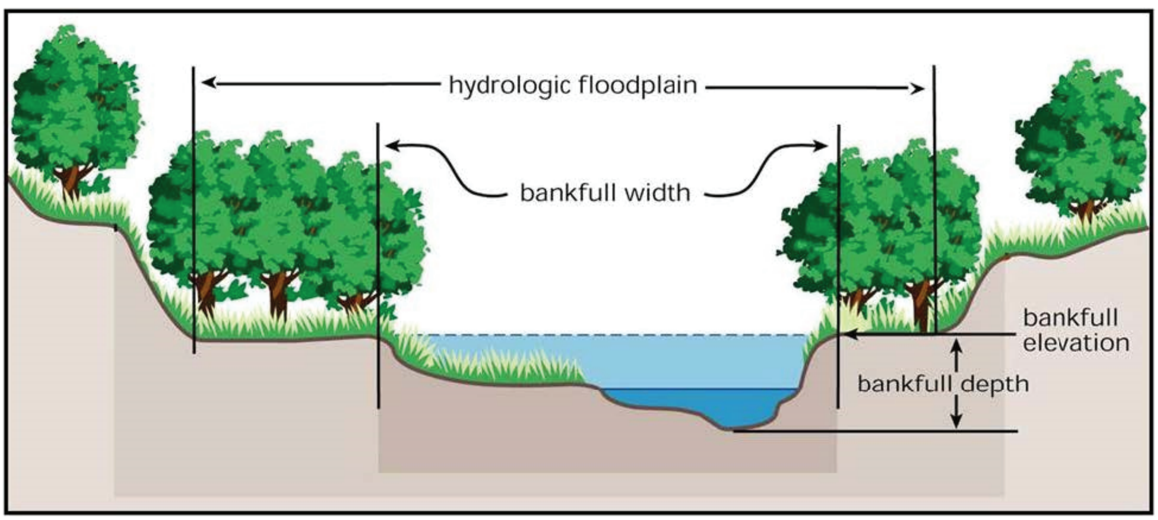

Figure 1. Natural Channel Profile

Hydrologic impact of land development

Human development around rivers places significant stress on their natural balance. Urbanization within a river's drainage basin—through the construction of impervious surfaces or the removal of vegetation—leads to increased river discharge during rainfall. This often disrupts the equilibrium between water flow and the resistance of bed materials, resulting in sediment being eroded from the riverbed. Such erosion triggers channel incision, where the river cuts downward, forming a primary channel with steep, deep banks. This process ultimately disconnects the river from its floodplain, further altering its natural dynamics.

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Direct modifications to a river can significantly disrupt its natural hydrology. Efforts to straighten a river near properties, roads, or agricultural fields often create steeper gradients compared to the river's natural curves, increasing the energy of its flow. Ironically, flood and erosion control measures can sometimes exacerbate erosion. Hard surfaces like riprap provide less friction and are less effective at dissipating energy than vegetative riparian materials. Similarly, berms, by design, block access to floodplains, leading to channel incision. This phase of channel erosion is seen in Phases II and III of Figure 2.

Over time, the river adapts by carving out a new floodplain and forming a sinuous primary channel, though at a much lower elevation as can be seen in Phase V of Figure 2.

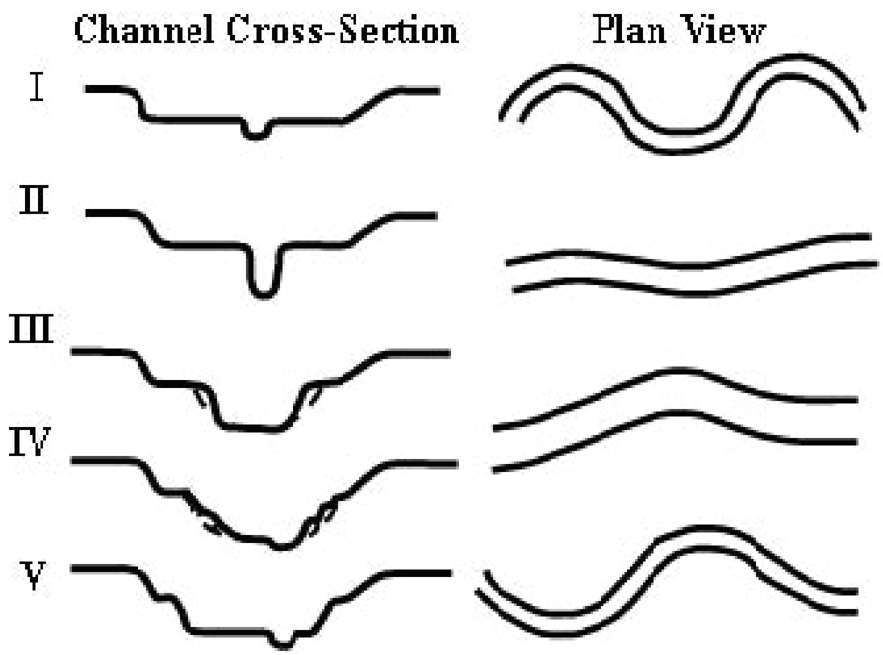

Figure 2. Phases of Channel Degradation

Poor substrate

Many sites already affected by erosion face a secondary challenge: poor subgrade materials. When increased water flow removes the original riverbed and bank materials—typically composed of pebbles, gravel, and large rocks—it exposes the underlying layers to the same erosive forces. These subgrade materials, often fine-grained silts and sands, are far less resistant to erosion. As a result, scouring and lateral migration rates accelerate significantly. Under such conditions, a stable pipeline water crossing can quickly deteriorate, progressing from its original as-built state to exposed or even suspended pipelines in a short period once erosion begins.

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Project objective

During the inspection, the L41 pipeline was found to have minimal cover, though it was neither exposed nor suspended at the time. However, an analysis of scour and lateral migration rates revealed a significant risk of the pipeline becoming suspended to an unacceptable degree if mitigation measures were not implemented. This design aims to restore adequate cover over the L41, protecting its coating from UV exposure and minimizing the risk of third-party damage. Furthermore, the stabilization of the riverbed and banks is essential to prevent future erosion and ensure long-term protection.

Site conditions and hydrology

Channel shape

The South Fork Nemaha River runs in a straight, moderate channel, measuring approximately 60 feet wide and 12 feet deep, flowing from south to north. Its unnaturally linear path in this area is likely a result of human intervention, as the river passes between two agricultural fields. About 200 feet north of a county road bridge, the Enbridge L41 pipeline crosses the river at nearly a perpendicular angle. Along the right of way, the river's eastern bank shows significant erosion, with a near-vertical slope caused by lateral migration and sloughing. Beyond this area of localized erosion, the eastern bank remains steep, with a roughly 1:1 slope, densely covered in mature vegetation.

Figure 3. Looking Along the South fork Nemaha River at the L41 Pipeline Right of Way

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Upstream obstructions

Two key upstream factors are impacting the flow dynamics at the L41 crossing. The first is a significant debris pile that frequently accumulates against the western pier of the 168th Road bridge. This debris alters the otherwise straight flow of water during moderate to heavy rainfall, redirecting it toward the eastern bank near the L41 crossing. While the flow is moderate and low at the time the photo in Figure 4 was taken, the diverted angle of flow can be seen, with the eroded bank in the background. This redirected flow, combined with the absence of vegetation along the banks within the right-of-way (ROW), is believed to be a major contributor to the lateral migration of the South Fork Nemaha River in this area.

Figure 4. Debris Obstruction on West Pier of Upstream Bridge

The second factor is an articulated concrete mat armoring system installed over a nearby pipeline, approximately 375 feet upstream of the L41 crossing. While the armoring effectively prevents erosion within the pipeline's ROW, it creates a minor damming effect on the river. Under natural conditions, sediment settles evenly during low-flow periods, gradually restoring material lost during high-flow scouring events. However, the damming effect causes sediment to accumulate upstream, leaving downstream water flows—including those near the L41 crossing—depleted of sediment. This sediment deficit is particularly problematic in riverbeds and banks composed of sand and fine silts, such as those in the South Fork Nemaha. Over time, this lack of sediment exacerbates downward scouring, eroding the protective layer originally placed during the construction of the L41 pipeline.

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Challenges

Restoring cover with minimal riverbed rise

One of the key challenges in restoring pipeline cover within a water crossing is the inevitable rise in riverbed elevation. While pipelines are typically installed with a minimum of 3 feet of cover while maintaining the natural riverbed grade, vertical scour over time may erode this protection. Restoring the original cover while preserving the newly developed natural channel grade often requires significant reshaping of the riverbed, extending at least 1,200 feet in both upstream and downstream directions, and potentially further, depending on the river's gradient.

Maintaining a natural riverbed grade and preventing ponding is crucial for several reasons. Ponding or damming can disrupt natural hydraulic flows, causing excessive sediment loss downstream. It can also negatively impact water quality by altering dissolved oxygen and suspended sediment levels, which can harm local ecosystems and wildlife. Additionally, ponding may obstruct the migration of aquatic species, hindering their ability to access food sources, reproduce, and complete their life cycles. At the L41 South Fork Nemaha crossing, the Plains Minnow has been identified as a species experiencing a population decline in the region. To support its survival, a minimum flow depth of 5 inches must be maintained during low-flow conditions throughout its spawning period.

Restoring full pipeline cover while keeping the river's natural gradient intact is often impractical due to high costs and stringent permitting requirements. While certain design solutions, such as step pools to aid aquatic passage or baffles to redirect flow and prevent ponding, can address specific issues, few approaches comprehensively resolve all challenges associated with raising the riverbed elevation. As a result, the most feasible approach may involve replacing the pipeline cover while minimizing elevation changes to the riverbed.

Site specific challenges

The bed and banks of the South Fork Nemaha River are composed entirely of fine-grained sands and silts. Under normal flow conditions, the river forms a braided pattern around constantly shifting sandbars. During high flows, this loose material is easily eroded, particularly along the eastern bank, which lacks vegetation and is actively forming an outer bank. While these materials present significant challenges for implementing river stability measures, they also create a dynamic environment with shifting gradients and ever-changing river centerlines. To address this, conducting a high-resolution survey, ideally using LiDAR technology, as close as possible to the design phase, is critical to appropriately align remediation efforts with the natural gradients of the river.

Surveying a river, however, comes with its own obstacles. At the South Fork Nemaha site, multiple survey attempts were made, but typical river depths posed a unique challenge. The water was not deep enough for underwater survey methods like bathymetry, yet too deep for LiDAR to provide

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precise measurements. The solution involved combining LiDAR with traditional ground surveys to gather the necessary data for the design process.

Another complication was the absence of local hydrology data. The closest stream gauge was located more than 40 miles downstream, after the confluence of several other forks, and measured a drainage area approximately 13 times larger than that of the South Fork Nemaha at the L41 pipeline crossing. Standard practice suggests using a gauge site with a drainage area between 0.5 and 1.5 times that of the target site. As a result, a reference reach with a more comparable drainage area, land use, and rainfall patterns was selected to estimate the hydrology for the project. This reference reach was used exclusively for hydrology purposes and not as a model for the river's planform or channel geometry at the crossing site.

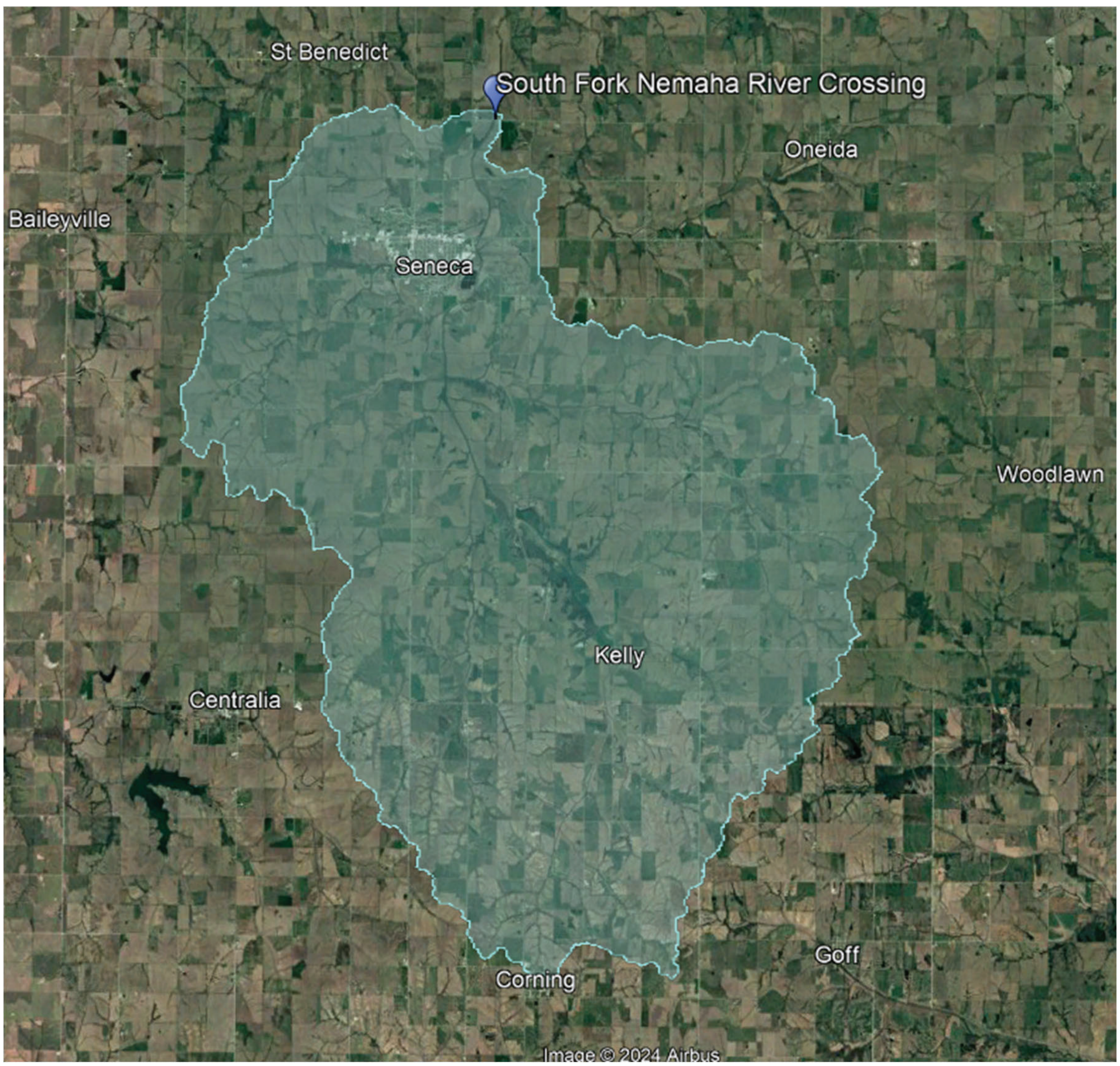

Figure 5. Drainage Area for the Project Site

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Design Solutions

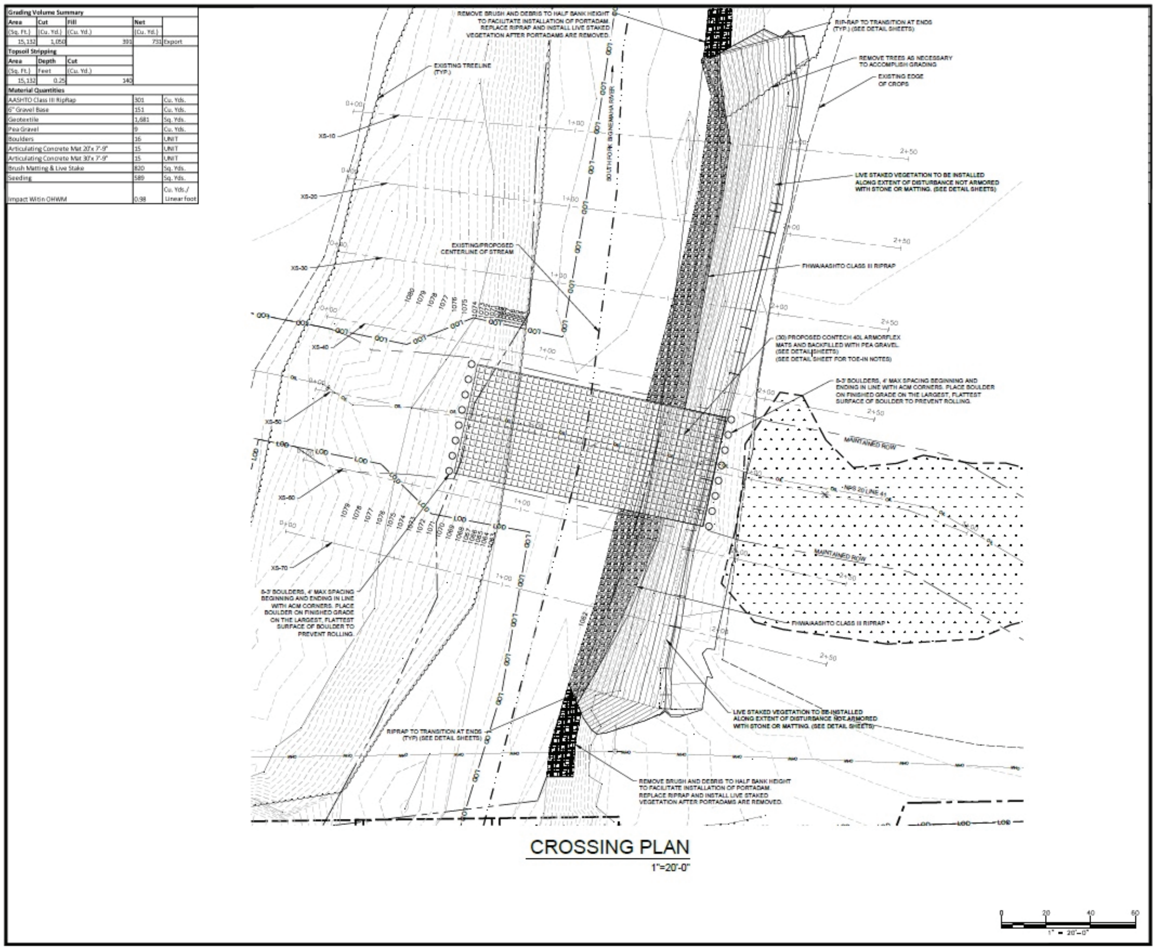

Figure 6. Remediation Concept Drawing

Articulated Concrete Matting System

The cornerstone of the remediation effort was the use of an Articulating Concrete Mat (ACM) system. Commonly employed in geotechnical pipeline projects, this system consists of interlinked concrete blocks, forming large mats approximately 20 feet by 80 feet in size, connected by steel cables in a running bond pattern. As its name implies, the ACM is designed to adapt to shifting subgrades and can partially self-repair as the river channel evolves. It also provides robust, long-lasting protection with minimal elevation gain. The mats used in this project were 4.75 inches thick and required no additional subgrade construction beyond a layer of geotextile fabric. This feature was critical to achieving the project's goal of minimizing riverbed elevation changes over the pipeline.

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Figure 7. ACM System Spanning the ROW to Top of Banks

Riprap

The Hydrology and Hydraulics study conducted during the research phase determined that, unlike the thinner ACM, riprap with a nominal size of 28 inches (AASHTO Class III) was necessary to withstand the required shear forces. This material would be used to fortify the toe of the slope and the banks up to the ordinary high water mark (OHWM), reinforcing the new grades along the eastern bank. Although the creation of a floodplain on the east bank was not feasible due to project footprint constraints, a 2:1 slope was established to provide a gentler transition during flood events compared to the existing steep shear banks. This regraded slope, combined with large riprap, is designed to protect the eastern bank against erosion during typical annual rainfall.

While ACMs may have a smaller profile, riprap offers superior long-term performance due to its ability to self-heal. ACMs have a limited capacity to withstand deflection before failing in situations like channel scour or plunge pool formation. These failures often result from neglecting the underlying causes of erosion or improperly keying in the downstream edges of the mats. In contrast, a properly installed and well-sized riprap armoring and key-in section adjusts naturally to changes in grade as downstream erosion occurs, maintaining its integrity over time. By carefully matching the

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natural grade and designing a stable channel shape, the risk of downstream erosion can be mitigated or even eliminated entirely.

Figure 8. Overview of East Bank

Brush Mattressing and Live Staking

The western bank of the south Fork Nemaha at the L41 pipeline crossing is benched below the OHWM, allowing for flows approximating floodplain conditions during rain events exceeding the annual average. The larger cross-section and corresponding lower flow velocity in the regraded areas presented an opportunity to implement a brush mattress system and live willow stakes for bank stabilization above the Ordinary High Water Mark (OHWM). This approach, though less common in the pipeline industry due to its complex installation process and narrow planting window, offers significant long-term benefits. The plants must be installed while dormant, but once established, the resulting dense riparian vegetation not only stabilizes the soil but also further reduces flow velocity along the banks. This dual effect helps prevent erosion and promotes sediment deposition, creating a self-sustaining system over time.

For the L41 remediation project, the stabilization system incorporated a live fascine bundle positioned parallel to the upper edge of the riprap at the OHWM. Vertically oriented willow branches, each less than 1.5 inches in diameter and measuring 8 to 10 feet in length, were layered along the slope. A second layer of branches, laid perpendicular to the first, was secured with stakes and tied with twine. Native soil was then worked into the spaces between the layers. These branch layers serve two key purposes: they protect the exposed, graded soil against minor erosive forces while the vegetation takes root, and they can also sprout themselves, becoming part of the riparian stabilization system.

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The second component of the revegetation effort involved live stake cuttings, measuring 2 to 3 feet in length, driven into the soil. These stakes offer the highest likelihood of rooting and establishing a robust riparian buffer. The willow species Salix integra (S. purpurea) was selected for its exceptional survival rate in northeastern Kansas's Zone 6a. This species grows rapidly, reaching heights of 2 to 8 feet within two years, and maintains a shrub-like form when left uncultivated. Its fast growth and propagation capabilities make it ideal for bank stabilization projects.

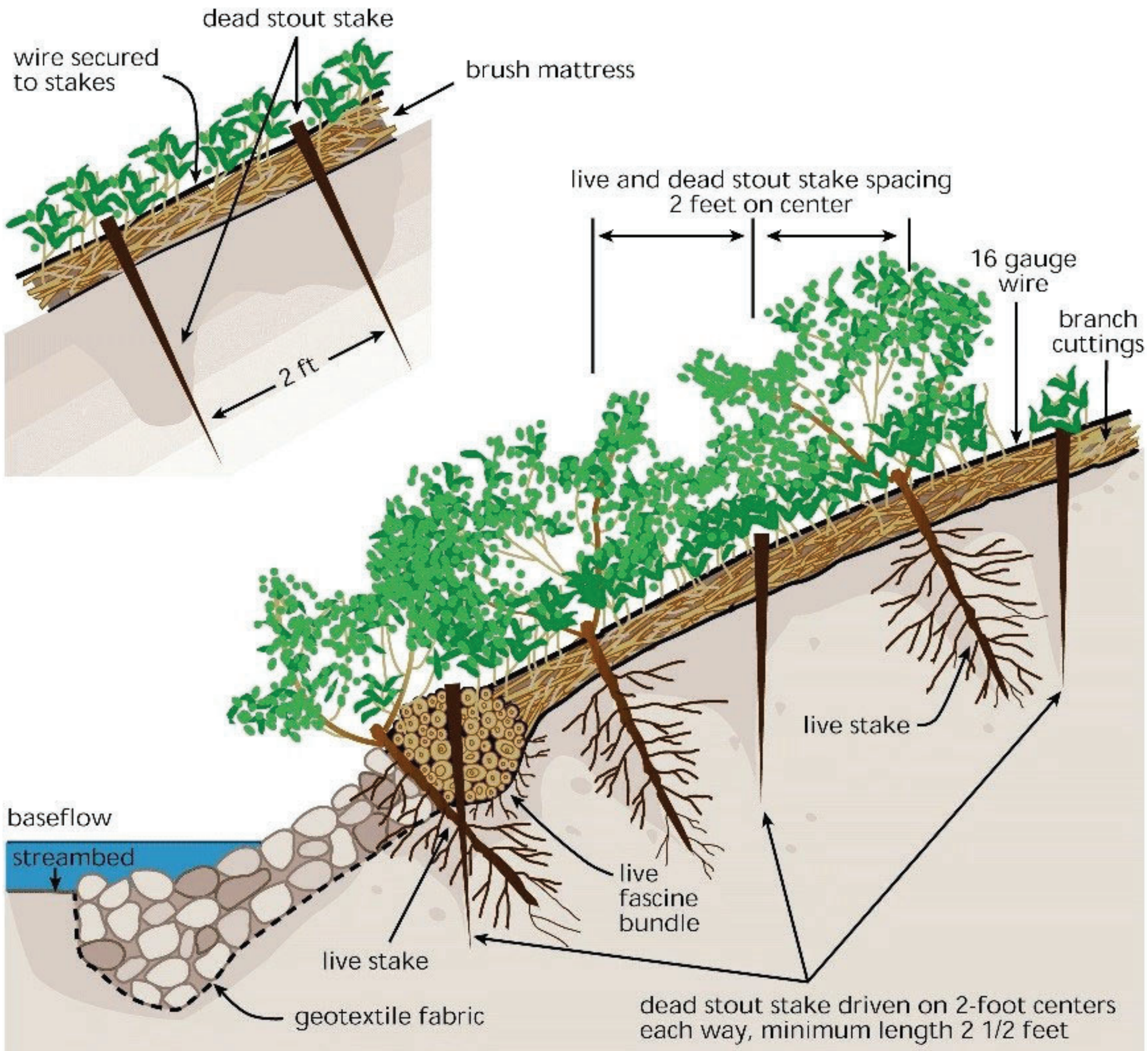

Figure 9. Typical Brush Mattress, Live Stake, and Riprap Detail

Under optimal conditions, up to 80% of the stakes and mattress branches are expected to take root, forming a thriving riparian system. However, the L41 project scope does not allow for regular groundwater monitoring or plant maintenance. To compensate, the stakes were planted in a dense 2-foot grid—much closer than the species' natural spacing. This high-density approach ensures sufficient vegetation coverage, even with a reduced survival rate of around 40%.

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Figure 10. Partial Installation of The Brush Mattress and Live Stakes

Conclusion

Erosion poses a dynamic threat to pipeline integrity, demanding equally dynamic solutions to effectively address its root causes. Successful long-term mitigation requires not only pipeline protection but also the promotion of healthy, natural water systems, which also sustain local ecosystems. To achieve this, adopting a multifaceted approach that combines the strengths of various industry practices while minimizing their weaknesses is essential when designing erosion control strategies.