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Self Mitigating Protection for Pipeline Crossings in Degraded Streams: A Case Study from Woodward Creek, Washington

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ABSTRACT: Buried pipelines cross thousands of creeks in United States and can be vulnerable to channel adjustments such as incision and lateral migration. Channel incision not only poses a serious threat to the pipelines but also results in adverse environmental impacts such as extreme in-stream flow conditions and a loss of floodplain connectivity. Traditional approaches to protect pipelines are expensive and typically impact stream ecosystems. Simply lowering the crossing fails to treat the incision which will continue to adversely impact habitat and other infrastructure. Constructing a weir can pose problems for fish passage. In 2006, a 2 m headcut moved up Woodward Creek and exposed an important high pressure natural gas pipeline. The 21 km^2 Woodward Creek watershed lies on the North side of the Columbia River Gorge. The Woodard reek gradient at the pipeline crossing is over 3.5%, with a 2-yr peak flow of approximately 11 m^3/s and a boulder /cobble substrate. Downstream of the project reach there is clear evidence of channel incision with abandoned floodplain surfaces situated about 2 m above gravel bars within the active creek channel. To protect the pipeline and fulfill permit requirements, a unique approach was taken based on recognizing the processes threatening infrastructure and emulating natural structures to provide the necessary protection. A morphologically complex grade control structure was constructed in August 2008 to raise the creek bed about 2 m over a 15 m length of the creek. The approach demonstrates a sustainable approach to protecting important infrastructure that also delivers net benefits to the environment.

Introduction

Pipelines cross tens of thousands of streams and often require major maintenance when they become exposed by channel migration or incision. An understanding of the fluvial geomorphology of each stream crossing provides the information necessary for robust designs that will reduce operation and maintenance costs over the lifetime of the project. Alluvial streams have deformable beds and banks and are susceptible to moving side to side and up and down. A relatively simple geomorphic assessment of the stream can quantify the magnitude of changes that have occurred historically and predict future changes.

Pipelines that aren't designed to accommodate channel change can pose significant environmental and pubic safety risks. In situations where a pipeline has become exposed there are two basic alternatives: 1) relocate the line or 2) protect in place. In both options it will benefit the project to better understand the geomorphology and stream dynamics at the site so that the most cost effective approach is selected to protect the pipeline and the environment. In some circumstances pipeline maintenance can offer an opportunity to enhance a degraded creek, particularly if the approach uses a natural channel design approach. Designs that include habitat improvement can streamline permitting and reduce the overall project costs. This type of win-win approach to pipeline maintenance was done for a 24 inch high pressure gas pipeline that became exposed in Woodward Creek in Southwestern Washington.

Historic pipeline crossings focus on spanning the bankfull stream channel and rarely consider the potential for lateral channel migration or channel incision. A typical pipeline crossing will consist of lowering the pipe to 5 ft below the creek bed and extending that grade to 15 ft into either bank (the lowered segment of pipeline equal to the channel width plus 30 ft). This approach may work on a stable channel, but in many situations channels are prone to move much more than 15 ft to either side and experience general scour to depths greater than 5 ft – both situations that put the pipeline at risk. In situations where the pipeline can be protected in place, maintenance typically involves building rock revetments to limit lateral migration and rock weirs to reverse channel incision. These traditional approaches to pipeline protection result in cumulative impacts to the environment and are increasingly difficult to permit, resulting in longer and more costly permitting. In some situations the pipeline segment needs to be replaced in its entirety, both of these actions involve regulatory challenges and significant costs. Pipeline maintenance also presents an opportunity to assess geomorphic processes and develop designs that can improve regulatory relationships and reduce future operation and maintenance (O&M) costs. The Woodward Creek crossing presents an example of how new geomorphological approaches was successfully applied to protect a pipeline threatened by channel incision.

Woodward Creek is located in Southwest Washington and flows into the Lower Columbia River (Figure 1). The watershed is 21 km^2, has a relief of 1010 m and a mainstem channel length of 9.7 km. The basin geology is dominated by Columbia River basalt and the steep creek valley is susceptible to large landslides. The creek gradient at the pipeline crossing is approximately 3.5% with a boulder/cobble substrate. The project reach grade loss is dominated by a series of steep boulder-cascade steps. The valley bottom is about 32 m wide and has an immature mixed riparian forest of Red Alder, Red Cedar, Western Hemlock and Douglas Fir. Valley slopes are steep and susceptible to landslides that can redirect or temporarily impound the creek. The bankfull channel averages about 9 m wide with a depth of 0.9 m. Basal shear stress for a bankfull flow is 309 Pa. The USGS 2-yr and 100-yr recurrence peak flows are 11 and 30 m^3/s, respectively. The watershed is not gauged, so flood frequency estimates are based on USGS regression equations and estimates for specific dates based on nearby basins. Fish species of concern in the basin include the following federally listed threatened salmonids: chum, fall Chinook, coho and winter steelhead. The basin also includes Pacific lamprey and cutthroat trout (Tetra Tech 2007). Most of the anadromous fish are limited to the lower one km (downstream of State Route 14) of the creek but coho and steelhead have been known to go 2.7 km upstream (TetraTech 2007). The pipeline crossing is located approximately 1.8 km upstream of the Columbia River (~0.8 km upstream of SR 14). Between the pipeline and SR 14 there has been severe disturbance within the channel associated with land sliding, possible dam break floods and channel incision. Floodplain surfaces are situated about 2 m above current vegetated bars. Restoration recommendations for the project reach include addition of large woody debris, improving floodplain connectivity and riparian reforestation (TetraTech 2007).

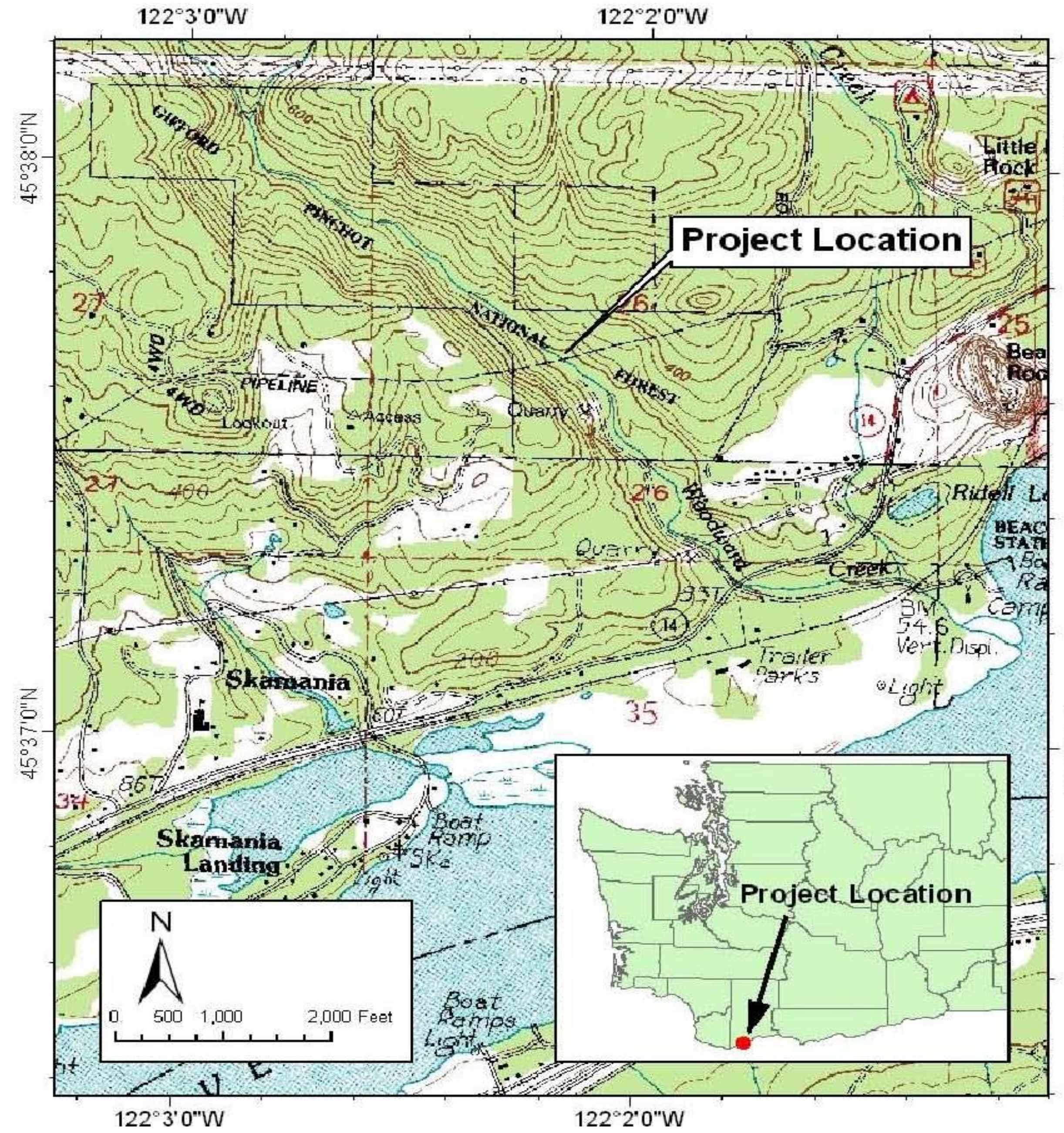

Figure 1. Lower Woodward Creek near Beacon Rock State Park, WA.. Pipeline crossing is located approximately 1.8 km upstream of confluence with Lower Columbia River.

The Problem

In the winter of 2006-2007 a 2 m headcut moved upstream through the project site and exposed the pipeline (Figure 2). The exposed pipeline created an emergency situation and an initial response in the summer of 2007 involved placing a large rock (1–2 m median diameter) weir immediately down stream of the pipeline. The weir extended across the bankfull channel and

Figure 2. Exposure of pipeline in summer of 2007 after over 2 m of channel incision. Note coarse boulder substrate. Initial treatment was to construct large rock weir immediately downstream of pipeline crossing.

created a fish passage barrier. To improve fish passage an unplanned boulder cascade was constructed out of native alluvial from the site that raised the creek bed about 1.6 m and allowed for partially burial of the rock weir (Figures 3 and 4). The construction contractor came up with the boulder cascade based on a natural one located about 60 m upstream of the pipeline crossing. But the slope of constructed cascade was more than twice that of the natural one and the constructed channel over the cascade was only about half the width. After only one peak flow event in December 2007 the constructed boulder cascade was eroded, reducing its slope all the way up to the rock weir (Figures 3 and 4). The channel also widened in response to the peak flow, particularly along the left bank (looking downstream, Figures 3 and 4). Bed degradation after only one peak flow event raised concerns that the rock weir would become fully exposed and reform a fish barrier. Channel widening had already re-exposed one of the ballast collars along the left bank which threatened to recreate the same conditions that occurred in 2007. The senior author was contacted after construction of the emergency project had been completed in the fall of 2007 to assist with a mitigation plan to place large woody debris in the channel, required by regulatory agencies for construction of the rock weir. After the channel alterations the following winter, the mitigation project became more structurally focused to stabilize the downstream cascade to ensure the rock weir and pipeline remained buried and fish passage improved.

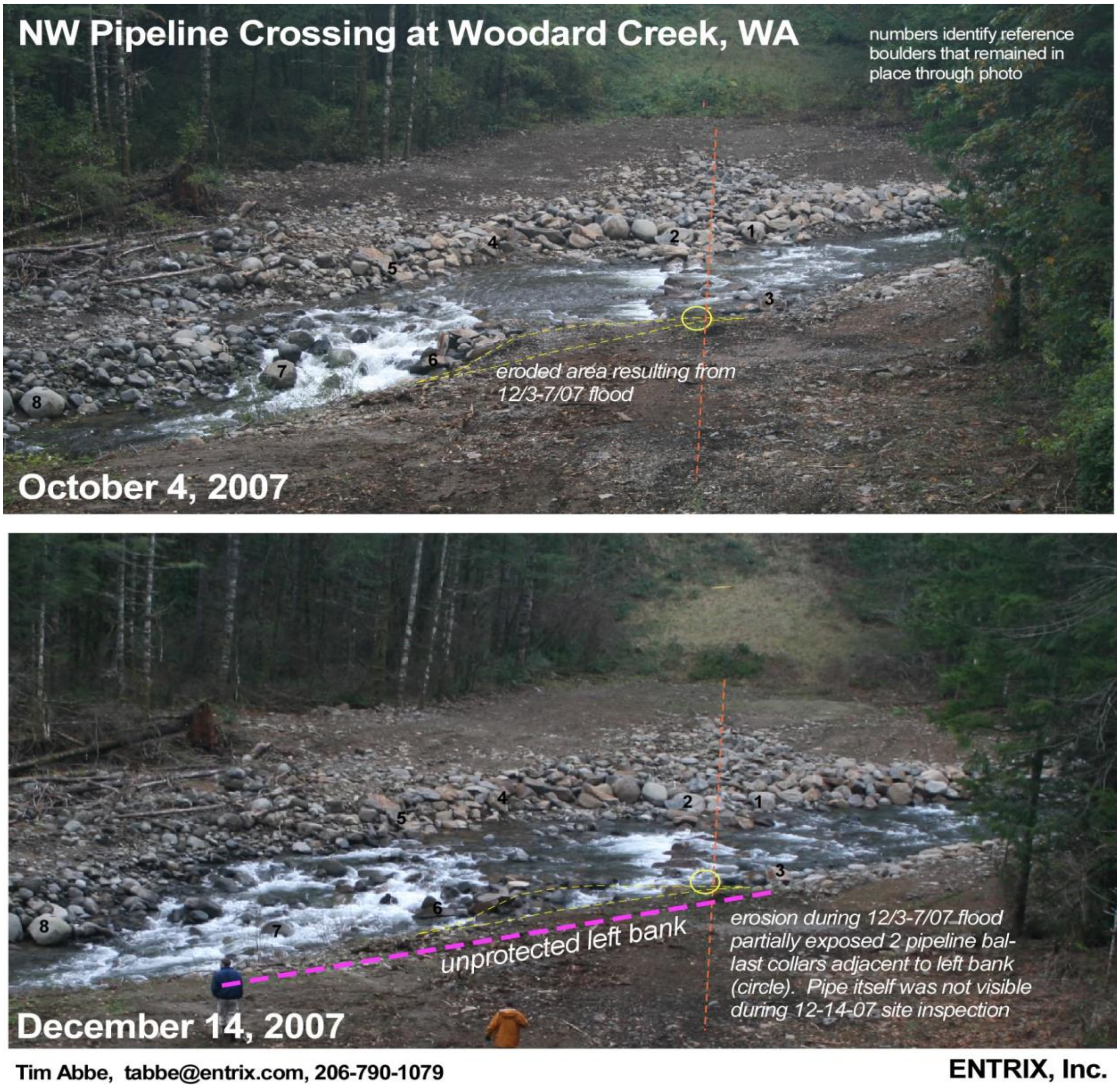

Figure 3. Project site in October 2007 after construction of rock weir (right center) and boulder riffle (left). Boulder riffle was built to raise creek bed so rock weir would not create fish barrier. Site less than 3 months later showed major deformation of boulder riffle, exposure of rock weir and erosion of left bank threatening to circumvent weir.

The regulatory agencies partly based the decision to require woody debris placement based on the deficiency of LWD currently in the system (TetraTech 2007). The large diameter and length of native Pacific Northwest trees found along Woodard creek would naturally be a important structural element of the creek, particularly in controlling grade and forcing pool riffle channel types (e.g. Abbe et al. 2003, Abbe and Montgomery 2003, Brummer et al. 2006, Montgomery and Abbe 2006, Fox and Bolton 2007). The challenge was to design a structure that incorporated timber to meet the regulatory requirements while also protecting the pipeline.

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Figure 4. Post construction view looking upstream and again after peak flow on December 7, 2007 (approximately a 1 yr recurrence event, inset photo). December 14 photo shows channel width over boulder riffle almost doubled, eroding into left bank (on right of photo), threatening to cut around weir and re-expose pipeline. Boulder riffle has also laid back its slope and resulted in more exposure of rock weir.

The Solution

Given the situation at the site and presence of large boulder cascade steps controlling the creek's grade immediately upstream of the project site, the solution was to re-construct a boulder cascade but this time in a way that better emulated the channels natural structures and incorporated timber. To start with the grade of the re-constructed cascade would be reduced significantly, raising the creek 1.8 m over 13.5m with a gradient of about 13%, opposed to the initial cascade which had a gradient of about 21%. The reinforced cascade included the following elements:

1) a complex timber matrix embedded into channel bed and banks
2) placement of timbers so they increase the pivot angle of bed material (increasing stability),
3) buried piles to increase stability of timber matrix
4) a reinforced left bank to prevent channel expansion or migration along East side of valley
5) a widened overflow channel along the right bank,
6) importation of large immobile clasts (>D100) placed into the timber matrix.

The new reinforced cascade was positioned immediately downstream and outside of the pipeline right-of-way and would raise the channel bed an additional 0.4 m above the pipeline, completely burying the rock weir (Figure 5). The design is unique from traditional step structures because of the length over which it drops the stream channel and its physical complexity which not only dissipates energy but improves fish passage over a wide range of flows. The structure is also unique in that it includes several levels of redundancy so that failure of any given element doesn't compromise its overall integrity. Failure of a single rock or log in traditional weirs can threaten the performance of the entire structure.

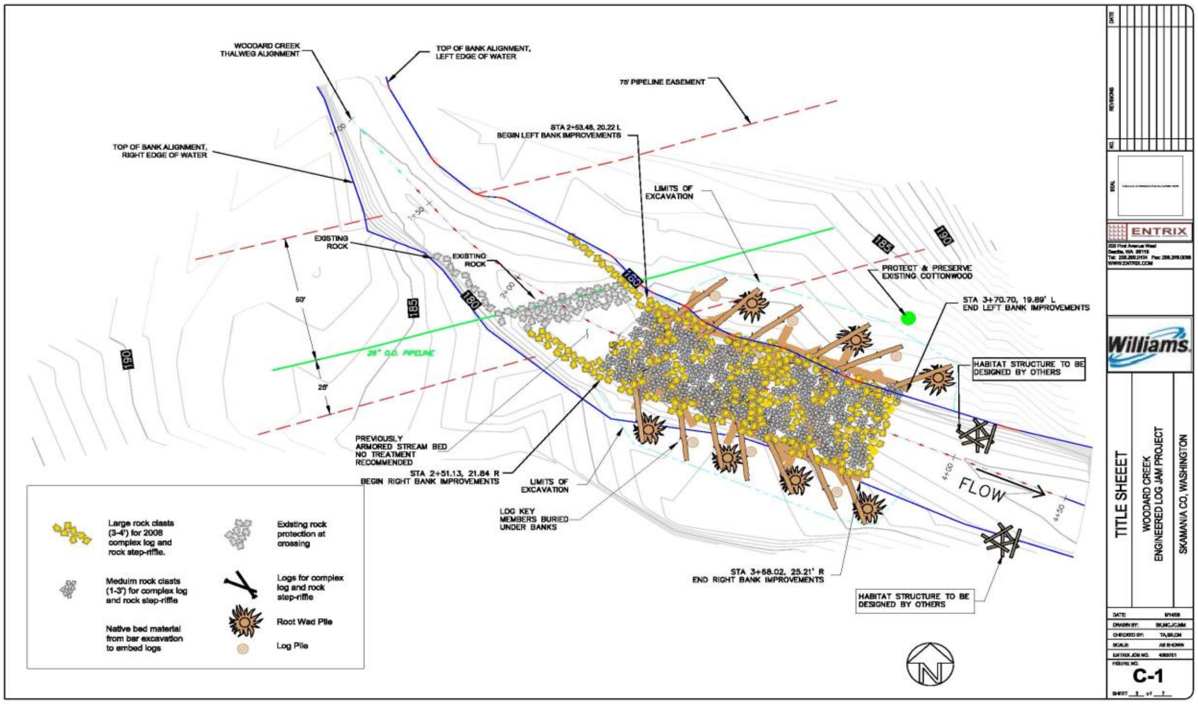

Figure 5 General layout of timber and rock reinforced riffle or multi-step grade control downstream of pipeline crossing (flow is from left to right). Structure extends over 15 along the channel and 5-6 meters into either bank. Both banks are protected by elements of the structure, with low floodplain overflow area on the right (looking downstream) bank. Trees with rootwads buried over 3 meter below creek grade form vertical piles seen in following figures.

To construct the reinforced cascade the existing channel bed needed to be excavated to a depth of 2 to 2.5 m to place the initial array of 18-21 m long timber 'ribs' (Figure 6). The ribs were oriented to create upstream 'V's to concentrate flow along the centerline of the structure. Horizontal weir logs were placed beneath the V-ribs to prevent underflow. Another set of timbers parallel to flow were buried into the creek bed in the upstream direction so that timbers protruded from the bed in the downstream direction (Figure 6). These flow-parallel timbers were used to hold down the center of the weir logs and simulate natural snags which have their upstream ends buried. All of the structural timbers had attached rootwads (Figure 6). Individual timbers were placed in a range of horizontal and vertical angles to achieve the desired embedment. Large rocks were strategically positioned within the timbers to stabilize the timber and armor the primary flow path of the cascade (Figure 7). The timber and rock was buried into both banks and a graded mix of stream bed cobble was placed into the primary channel (Figure 8). No cable or chain was used in the structure. Timber and rock placement was done to ensure the channel would not continue to incise as occurred in the rock cascade constructed in 2007. A critical aspect of the design was to ensure a low-flow channel thread meandered through the length of the cascade (Figure 8). At higher flows timber and rock steps are engaged and eventually the entire width of the structure is submerged. High flows are also intended to spread out over the right bank of the cascade which was underlain by buried timbers. The overflow surface consisted of largest clasts of the native bed material, with imported rock exceeding the D100 (diameters >1.5 m) placed along the right bank of the primary channel. The final structure was completed 2 weeks ahead of schedule and under budget.

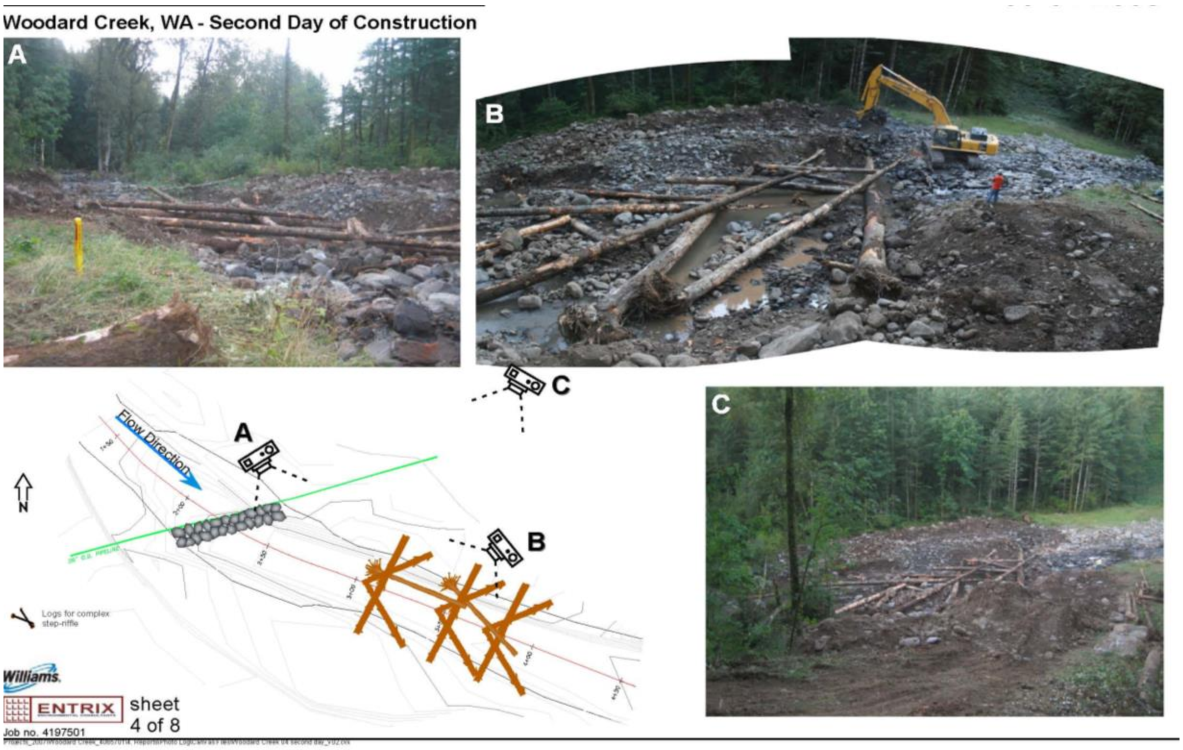

Figure 6. Summer of 2008 channel excavation and initial timber placement creating reinforced multi-step grade control structure downstream of pipeline crossing. Timber extends over 5 m into floodplain on either side of creek channel. Stream length of structure is about 14 m with vertical drop of 2 m. Orientations of photos (A-C) are depicted by camera locations in lower left.

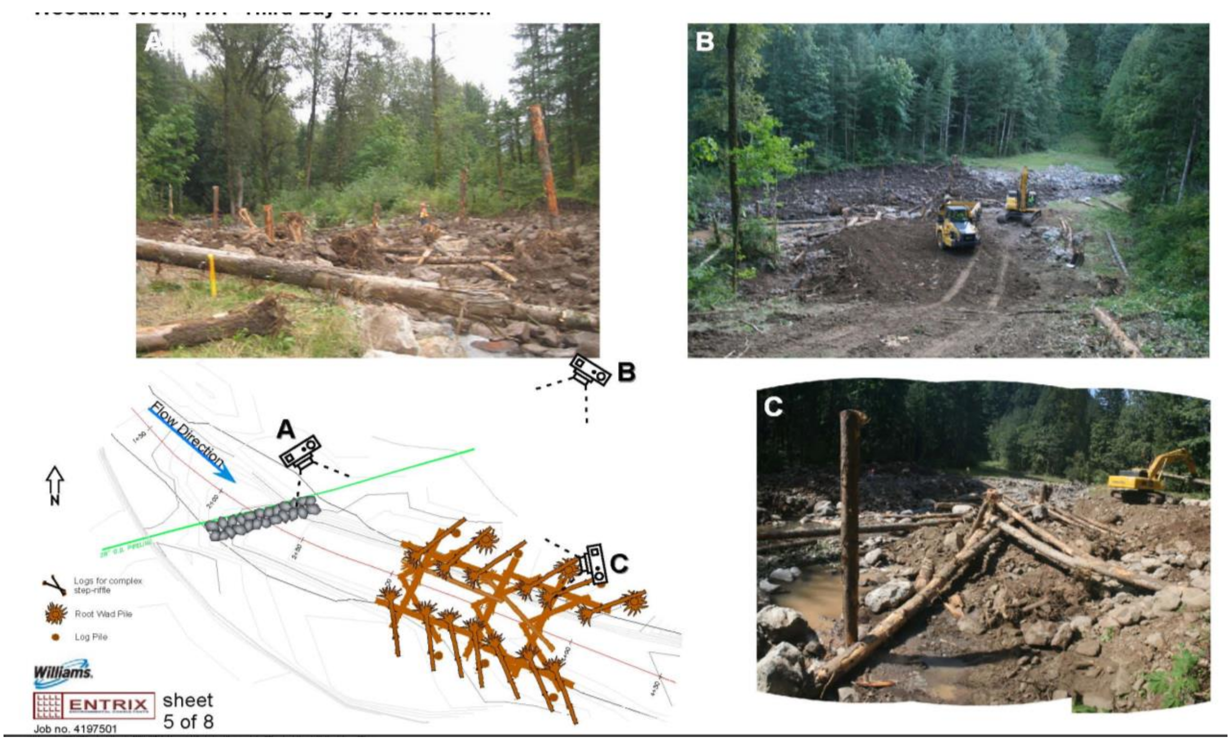

Figure 7. Placement of additional timbers, initial timber piles and boulders within timber matrix. Design included a low bank overflow area immediately along the right bank (left side of photo C) to distribute high flows. Left bank where 2007 erosion occurred was armored by grade control structure.

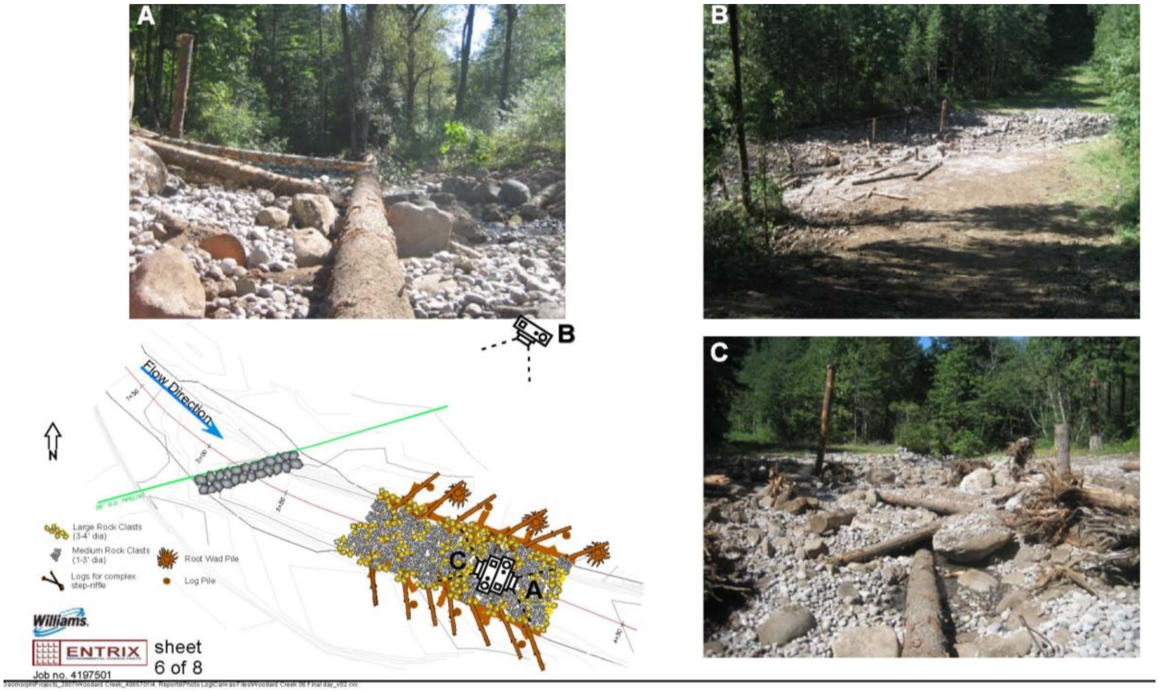

Figure 8 As-built construction in September 2008. Final structure forming a complex multi-step grade structure that raised creek about 2 m, providing about 0.4 m of additional cover over pipeline crossing. Final elevation of left bank floodplain was estimated to inundate with a 5 yr recurrence flood event..

Performance

The completed timber grade control structure was tested within short order, experiencing an estimated 5 yr peak flood recurrence event in November 2008. During an inspection after the flood event the structure was performing as intended with a series of alternating steps from side to side over the length of the cascade and no deformation was observed (Figure 9). The overflow area along the right bank was partially engaged during the inspection.

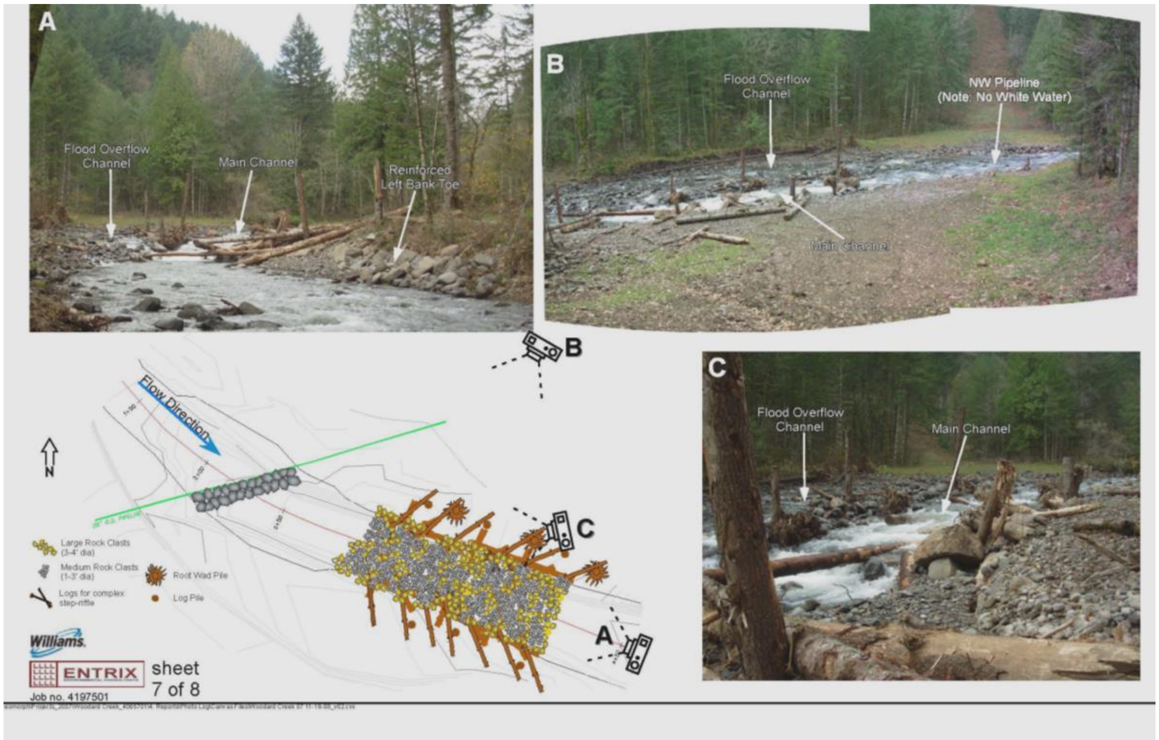

Figure 9 Woodward Creek grade control structure on November 18, 2008 after a 5 yr recurrence flow. Structure is completely intact with overflow area on right bank activated (left of photos A and C). Peak flows were contained within channel and right bank overflow area.

In January of 2009 Western Washington experienced a major storm event that resulted in record flooding from the Lower Columbia to Seattle. Based on nearby gages we estimated that flow in Woodward Creek was approximately 25 m^3/s, corresponding to a 50 yr flood. An inspection of the site shortly after the peak flow showed the creek channel and its overflow area completely inundated Figure 10). After the flood it was clear that bedload transport occurred within the creek and through the reinforced cascade (Figure 11). The structure was completely intact with no observed changes in channel geometry and no bank erosion.

Figure 10. January flood showing inundation of low right bank floodplain. Fine sediment deposition indicated water just barely inundated left bank floodplain but was not sufficient to move any of unanchored wood on ground surface.

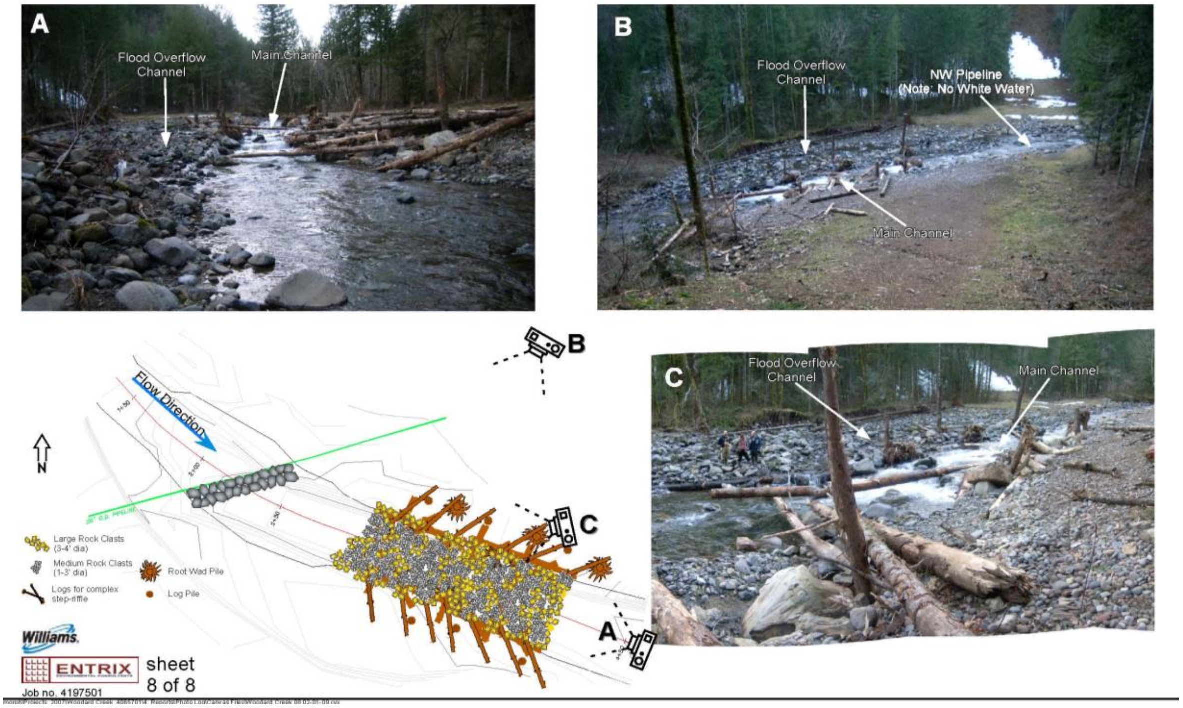

Figure 11. Project site on February 1, 2009 after January flood which was estimated to be have a recurrence interval of approximately 50 years. Structure completely intact with no signs of significant deformation. Flow remained concentrated in the channel and right bank overflow area.

The results improved regulatory relationships and demonstrated the viability of the approach not only for enhancing habitat and fish passage, but protecting the pipeline. If this approach had been taken initially in 2007 the project would have been considered self-mitigating and saved the cost of the first response and then remobilizing the following year. Innovative and comprehensive solutions provided at Woodward Creek provide long-term treatments that are economic, environmental and community based. Solutions should be founded in the local geomorphology, particularly with regards to addressing channel dynamics, local ecology, engineering design life and regulatory concerns.

Conclusion

Buried pipelines cross thousands of creeks in the Pacific Northwest and can be vulnerable to channel adjustments such as incision and lateral migration. Channel incision can not only expose pipelines but, also result in more extreme in-stream flow conditions and a loss of floodplain connectivity. Lateral channel adjustment in response to incision can then lead to additional threats. When channel changes threaten the pipeline they require expensive maintenance actions and can impose additional environmental impacts. Traditional approaches to protect threatened pipelines either involve lowering the crossing beneath the adjusted creek bed or constructing a grade control weir. Lowering the crossing fails to treat the incision, which will continue to adversely impact habitat and other infrastructure. Constructing a grade control structure can halt incision and re-establish the required burial for the crossing but may pose problems for fish passage if the drop is too severe or low-flow passage is not ensured. Channel incision on Woodward Creek, near Stevenson, Washington provided an opportunity to construct the timber/boulder grade control to self mitigate the impacts of construction by establishing a low-flow fish passage, improve fish habitat, while protecting an important pipeline. The 21 km^2 Woodward Creek watershed lies on the North side of the Columbia River Gorge immediately West of Beacon Rock State Park. The small watershed has a relief of 1010 meters and most of the creek is characterized by steep cascade channels.

References

Abbe, T. B., A. P. Brooks, and D. R. Montgomery. 2003. Wood in river rehabilitation and management. Pages 367-389 in S. V. Gregory, K. L. Boyer, and A. M. Gurnell, editors. *The ecology and management of wood in world rivers*. American Fisheries Society, Symposium 37, Bethesda, Maryland.

Abbe, T.B. and D.R. Montgomery. 2003. Patterns and Processes of Wood Accumulation in the Queets River Basin, Washington. *Geomorphology* 51:81-107.

Montgomery, D.R. and T. Abbe. 2006. Influence of logjam-formed hard points on the formation of valley-bottom landforms in an old-growth forest valley, Queets River, Washington, USA. *Quaternary Research* 65, 147-155.

Brummer, C., T.B. Abbe, J.R. Sampson, and D.R. Montgomery. 2006. Influence of vertical channel change associated with wood accumulations on delineating channel migration zones, Washington, USA. *Geomorphology* 80, 295-309.

Fox, M. and Bolton, S. 2007. A regional and geomorphic reference for quantities and volumes of Instream Wood in unmanaged forested basins of Washington State. *North American Journal of Fisheries Management* 27:342–359.

TetraTech and Anchor Environmental 2007. Woodward Creek Habitat Restoration Project Siting and Design Report. Prepared for Lower Columbia Fish Enhancement Group and Lower Columbia Fish Recovery Board.