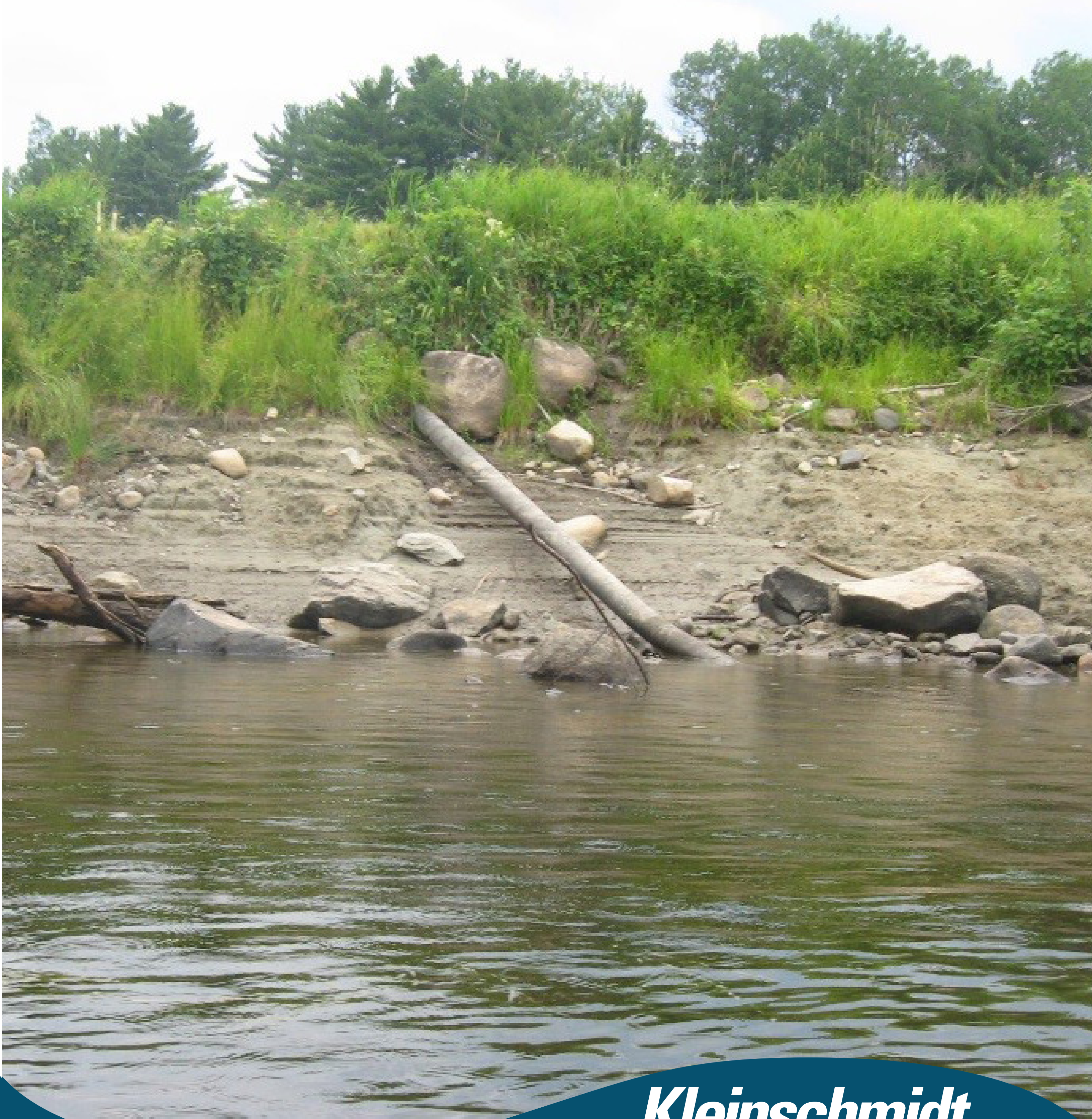
PIPELINE STABILITY
at Waterbody Crossings



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Pipeline Stability at Waterbody Crossings:

Pre-Construction and In-Service Risk Reduction through Individual Site Assessment

By Tyler Kreider, P.E.
(tyler.kreider@kleinschmidtgroup.com)
Ecological Engineer, Kleinschmidt

Pipeline Owners and Operators need expert evaluation of water flow near pipelines and the risk of scour (erosion) to
- **Protect their assets**
- **Ensure public safety**
- **Protect the environment**

Natural hazards such as floods and landslides have presented a perennial concern for pipeline infrastructure, which by its nature must traverse varied terrain, including streams and rivers (ASCE 1995). Pipeline damage at or near waterbody crossings poses an enhanced risk given the sensitivity of aquatic ecosystems and additional cleanup costs compared to a pipeline failure in an upland area. A recent Advisory Bulletin (ADB–2015–0105, updated in ADB-2016-01; Docket No. PHMSA–2015–0283) from the Pipeline and Hazardous Materials Safety Administration (PHMSA) recommends that owners of proposed pipelines and pipeline operators "utilize experts in river flow, such as hydrologists or fluvial geomorphologists, to evaluate a river's potential for scour or channel migration at each pipeline river crossing" [to] "prevent and mitigate damage to pipeline facilities and ensure public and environmental safety in areas affected by flooding." The Advisory Bulletin highlights 14 actions that operators are urged to take to prevent and mitigate damage to their facilities.

This document explains and provides potential solutions to address the recommendations in the PHMSA Advisory Bulletin as it pertains to

- Action 1: **Evaluate channel stability at each river crossing;**
- Action 2: **Evaluate pipeline installation method;**
- Action 3: **Determine the flood event that risks pipeline integrity**; *and*
- Actions 12 and 13: **Post-flood depth of cover assessment.**

The other actions in the Advisory Bulletin generally pertain to ensuring access to pipeline facilities during flooding and coordination of response efforts during major flood events and are assumed to be covered by pipeline operators' standard operating procedures.

Rivers are dynamic features of the landscape. Over the design life of a pipeline, rivers may incise vertically or erode their banks, causing the stream either to migrate laterally or have reduced cover over the pipeline as a result of natural fluvial processes. River channel adjustment is episodic; most scouring and channel migration occurs during flooding events, whose frequency may vary from annual to very infrequent depending on the climate and type of river. Though the forces that cause river channel adjustment are episodic, the change in river geometry may be gradual or sudden. Gradual adjustments include steady erosion of stream banks or beds, usually by more frequent storm events. Sudden adjustments include landslides caused by undercutting or channel avulsion (formation of a new channel), typically caused by larger storm events. In smaller drainages, streams are generally steeper, and vertical incision dominates movement; however, some lateral adjustment is possible. As drainage area increases, lateral adjustment through bank erosion and deposition becomes the dominant form of river movement. In large rivers with mobile beds (sand and gravel bed rivers), temporary vertical incision (bed degradation) may occur over the course of a single, high-flow event (ASCE 1995).

Local influences, such as disturbance of the bank or bed during pipeline installation, removal of riparian vegetation, or grazing, can exacerbate river channel movement. Watershed-scale perturbations (e.g., increasing area of impervious surface) can also contribute to enhanced river movement by increasing runoff rates and peak flows, leading to further channel instability. Kleinschmidt has observed that even relatively small increases in runoff from impervious surfaces and stormwater routing, such as stormwater discharges from an interstate crossing, can lead to dramatic vertical incision or lateral migration in some small, steep streams (Figure 1). This means that a relatively stable stream could de-stabilize if runoff rates increase due to localized disturbances or if in-stream activities cause instability in previously stable areas.

ACTION 1: **EVALUATE CHANNEL STABILITY AT EACH RIVER CROSSING**

Per PHMSA ADB-2015-0105, PHMSA urges operators to:

1. Utilize experts in river flow, such as hydrologists or fluvial geomorphologists, to evaluate a river's potential for scour or channel migration at each pipeline river crossing.

PHMSA recommends using hydrologists or fluvial geomorphologists to evaluate proposed and existing pipeline river crossings because these experts understand how waterbodies change over time and can assist in protecting the pipeline from potential damage. Streams and rivers are not static systems and can adjust gradually or rapidly, based on many factors, including flood events, local and watershed-scale disturbances, riparian vegetation management, changes in sediment supply, local headcuts and culverts, and the potential for debris jams. Experts in this field can help pipeline designers and operators understand the risk of these factors and their potential impact on the pipeline integrity. Consultation during the initial routing of the pipeline can avoid problematic areas and reduce future risk of pipeline exposure and potential rupture, similar to the geotechnical analysis currently performed during pipeline routing. Consultation prior to flooding can provide an estimate of the risk of pipeline exposure and lead to the implementation of preventative measures in advance of pipeline failure. Finally, consultation after a major flood event that caused pipeline exposure or rupture will provide additional information about the future tendencies of the channel and can help inform proposed restoration methods, including the consideration of alternative crossing methods.

ACTION 2: **EVALUATE PIPELINE INSTALLATION METHODS AT RIVER CROSSINGS**

Per PHMSA ADB-2015-0105, PHMSA urges operators to:

2. Evaluate each pipeline crossing a river to determine the pipeline's installation method and determine if that method (and the pipeline's current condition) is sufficient to withstand the risks posed by anticipated flood conditions, river scour, or river channel migration. In areas prone to these conditions and risks, consider installing pipelines using horizontal directional drilling to help place pipelines below elevations of maximum scour and outside the limits of lateral channel migration.

During the pipeline routing it is important to select river crossings methods that can withstand the anticipated flood conditions, river scour (vertical incision), and river channel migration (lateral migration). By consulting a fluvial

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geomorphologist as part of the design process, pipeline owners can make a more informed crossing method selection (open cut trench, direct pipe, conventional bore, or horizontal directional drill [HDD]) at waterbody crossings. This is especially important at crossings with higher risk of vertical incision or lateral migration, and does not typically correspond to stream width or depth, as many other local factors can influence channel stability. The fluvial geomorphologist can analyze the proposed risks at each crossing and provide a recommendation to the pipeline engineer regarding minimum depth of cover, sag-bend setback distance, and anticipated channel stability that will allow the engineer to select a crossing method that adequately protects the pipeline. Trenchless crossing methods can be used to inimize the disturbance of the channel bed and banks, which can prevent the potential to introduce significant instability at the proposed crossing, thereby lowering the risk at that site.

ACTION 3: **DETERMINE THE FLOOD EVENT THAT RISKS PIPELINE INTEGRITY**

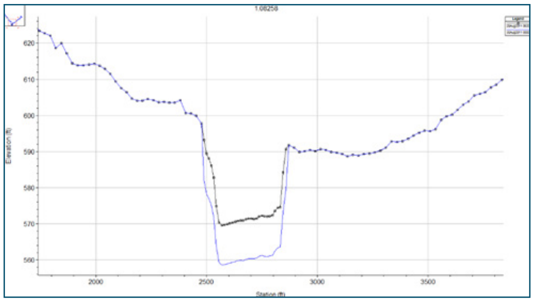
Per PHMSA ADB-2015-0105, PHMSA urges operators to:

3. Determine the maximum flow or flooding conditions at rivers where pipeline integrity is at risk in the event of flooding (e.g., where scour can occur) and have contingency plans to shut down and isolate those pipelines when those conditions occur.

Solutions:

- **Use hydrologists and fluvial geomorphologists to evaluate pipeline river crossings for potential risks**
- **Consult with scientists and ecological engineers during pipeline design process**
- **Research flood history, ascertain risk, and develop a collaborative mitigation plan with an experienced team of experts, including geologists, pipeline engineers, and geomorphologists**

While smaller flood events can combine to develop lateral and vertical channel adjustment, the most severe migration tends to occur during the larger flood events. During a flood event, temporal scour and bank erosion may occur that is later backfilled by sediment deposition processes on the receding (after the peak flow) limb of the hydrograph. Temporal vertical incision is more typical on sand and gravel bed streams, where a local scour hole develops due to localized conditions (e.g., hydraulic conditions, channel confinement, debris jam). As the flows return to base flow these scour holes can be filled in, but there is a risk to the pipeline if a scour hole develops over the pipeline crossing and there is not an adequate depth of cover. Hydraulic engineers and fluvial geomorphologists can utilize bed scour and bank stability models to estimate the anticipated lateral and vertical channel adjustment under anticipated flood events, which can indicate when the pipeline may become exposed. If such conditions are anticipated, the operator can consider shutting down and isolating that section of the pipeline to minimize the risk at the waterbody crossing. This analysis will require knowledge of pre-flood depth of cover and channel geometry to define the hydraulic model parameters at the crossings of concern.



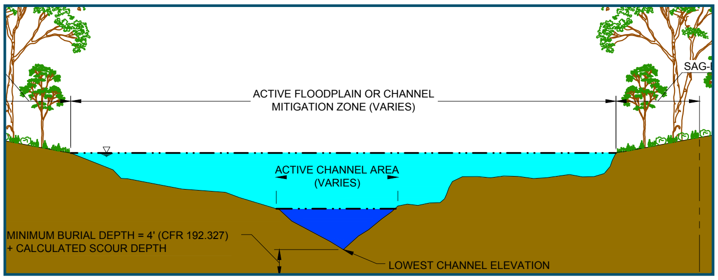
ACTIONS 12 AND 13: **POST-FLOOD DEPTH OF COVER ASSESSMENT**

Per PHMSA ADB-2015-0105, PHMSA urges operators to:

12. Following floods, and when safe river access is first available, determine if flooding has exposed or undermined pipelines because of new river channel profiles. This is best done by a depth of cover survey.

13. Where appropriate, surveys of underwater pipe should include the use of visual inspection by divers or instrumented detection. Pipelines in recently flooded lands adjacent to rivers should also be evaluated to determine the remaining depth of cover. You should share information gathered by these surveys with affected landowners. Agricultural agencies may help to inform farmers of potential hazards from reduced cover over pipelines.

After a flood has occurred, it is important to understand what the current conditions are at the waterbody crossings, even if there was not a pipeline failure. This depth of cover survey should be carried out according to the operators Pipeline Depth Monitoring Program (PDMP), or in accordance with the American Pipeline Institute's Pipeline Depth of Cover document (API, 2016) if no PDMP is in place. This information is important to document so that a determination can be made as to the potential risk of pipeline exposure in subsequent flood events. It is important to document the depth of cover not only in the waterbody, but also in the riparian areas near the waterbody and in agricultural areas. Areas near the waterbody and agricultural areas could have local erosion of gullies that formed during the flood event, significantly reducing the cover over the pipeline in these areas. This reduced cover could reduce the protection available for future flood events or even exacerbate the risk for pipeline rupture through contact with a farmer's plow in an agricultural field. These inspections should be carried out after each flood event and documented by the operator to evaluate trends in the depth of cover and to provide a reference point for decision making in advance of future flood events.



RISK MITIGATION

General mitigation strategies for vertical incision or lateral migration at high risk stream crossings include increased vertical and lateral setback distances during pipeline installation and in-channel mitigation, such as stream-bank stabilization and grade-control measures. In addition, enhanced monitoring protocols (as outlined in the Advisory Bulletin) targeted to the relative risk of instability at the stream crossing site may identify potential problems before catastrophic failure. Important aspects of a comprehensive risk mitigation and monitoring plan may include:

- stockpiling and replacement of coarse stream bed material during construction to prevent future scour through the replacement of existing substrate materials;
- revising the restoration planting plan with additional bank stabilizing plant species;
- maintaining or increasing depth of cover over the pipeline across the width of active floodplains and other alterations to standard pipeline installation;
- enhanced monitoring of high-risk waterbody crossing sites;
- event-based monitoring at flood-effected, high risk sites;
- installation of surface-based pipeline infrastructure outside of floodplain areas;

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• installation of additional shut off valves near unstable locations;
• repeated depth of cover surveys at crossings to document any channel adjustments over time; *and*
• coordination with local agencies and property owners to obtain information on channel stability at waterbody crossings as well as pipeline exposure after flood events.

Each of these aspects may have cost, permitting, and engineering considerations that should be evaluated by the combined expertise of fluvial geomorphologists, hydrologists, environmental scientists, pipeline engineers, and pipeline operators. The ultimate goal should be to reasonably minimize the risk of damage or failure over the life cycle of the pipeline by applying the technical expertise of those familiar with the many factors that can influence pipeline integrity.

Benefits of Selecting Kleinschmidt

Kleinschmidt Associates is a national consulting company that works primarily with energy companies in North America to protect and enhance the environment without compromising performance. We work at the intersection of regulatory requirements, environmental science, and engineering solutions.

As a result of our relevant experience, we provide pipeline owners and operators with practical solutions to complex problems that:
• Reduce risk of damage to assets
• Mitigates potential for human suffering
• Minimizes threat of product release into the environment

References:
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ASCE (1995). Pipeline Crossings. ASCE Manuals and Reports on Engineering Practice No. 89. Available at <http://cedb.asce.org/CEDBsearch/record.jsp?dockey=0102368>.