COMPARISONS OF SEDIMENT LOSSES FROM A NEWLY CONSTRUCTED CROSS-COUNTRY NATURAL GAS PIPELINE AND AN EXISTING IN-ROAD PIPELINE

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Abstract.—Sediment loads were measured for about one year from natural gas pipelines in two studies in north central West Virginia. One study involved a 1-year-old pipeline buried within the bed of a 25-year-old skid road, and the other involved a newly constructed cross-country pipeline. Both pipelines were the same diameter and were installed using similar trenching and backfilling techniques. Erosion was measured from both pipelines at the outfall of waterbars, and sediment losses were expressed on a per area basis to compare the pipeline segments. Average sediment yields per sampling period (i.e., generally individual storm events) were a magnitude larger from the pipeline installed in the skid road than from the cross-country pipeline. Compaction and poor vegetation establishment on the skid road pipeline appear to have resulted in excessive runoff and elevated soil losses, even though the skid road segments were less steep and shorter than the cross-country pipeline segments. Reducing compaction to encourage infiltration and successful vegetation establishment is essential for controlling sediment losses, regardless of the land management activity or type of disturbance.

INTRODUCTION

Natural gas development is undergoing massive expansion in the eastern United States, particularly in the Mid-Atlantic States. Substantial concerns about the social, economic, and environmental effects of drilling and hydraulic fracturing have spurred the initiation of research to address those concerns.

To transport the natural gas extracted from the new wells, pipeline construction has simultaneously been expanding. For example, 1,854 km of pipeline were constructed in 2005, and 7,662 km were planned for construction in 2008 (Energy Information Administration 2009). More recently, in 2012, construction length was projected to be more than 5.5 times that constructed in 2011 (Smith 2013). Because of their substantial length, pipelines will have more spatially extensive impacts than those associated with drill pad development; however, there has been little research into their effects. Fragmentation may be the most common environmental concern associated with pipelines, but many other concerns also exist, including water quality effects from pipeline leaks or ruptures, stream sedimentation, and creation of corridors that could speed the spread of invasive species.

Best management practices (BMP) developed by the oil and gas industry exist to help control these adverse effects, but they do not eliminate all undesirable outcomes. One BMP recommended to address some of the concerns associated with pipelines is to install them in existing corridors, such as within existing transmission (power or pipeline) lines or roadways or in the rights-of-ways of those corridors. Although this construction technique is broadly accepted as effective, there are few data to illustrate or support its advantage.

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Consequently, this paper compares erosion losses from two previously completed case studies in north central West Virginia. One involves a pipeline installed in an existing, but no longer used skid road, and the second involves a cross-country pipeline installed outside an existing transportation corridor. The two case studies were typical of their respective types of installations. They were performed 2 years apart with slightly different experimental designs, but essentially the same equipment and sampling approaches.

METHODS

Both studies were performed on pipelines located in Tucker County, West Virginia. The two study locations are about 11.8 km apart. The area is characterized by relatively steep hillsides that support mixed mesophytic hardwoods. Precipitation in the area averages about 130 cm annually and is distributed fairly evenly throughout the year. Mean air temperature is 9.25 °C; mean growing season (May through October) and dormant season (November through April) temperatures are about 16.2 °C and 2.1 °C, respectively (Edwards and Wood 2011).

Data for the first case study used in this analysis originate from Holz (2009). This study was conducted in the lower Sugarland area of Tucker County. An 8.9-cm-diameter natural gas pipeline was installed during the summer of 2006 by burying it beneath the longitudinal center of a 3- to 4.5-m-wide skid road that had been constructed 25 years earlier. Due to the slope of the hillside, the skid road was built using cut and fill techniques, but it was constructed as a temporary, unimproved road and was used only for removing logs using a rubber-tired skidder (dragging with one end on the road surface); there was no truck traffic on the road. After the skid road was "put to bed" after logging was completed, waterbars were installed to control runoff.

Following backfilling of the pipeline, waterbars were re-installed for water control on the skid road. The skid road surface and cutbank were limed, fertilized, and reseeded by hand; all of the amendments were completed within 2 weeks of installing the pipeline (by October 15, 2006). Lime and fertilizer (10-20-20) rates were 4,483.4 kg/ha and 168.13 kg/ha, respectively. A mixture of 19 native herbaceous and grass species were included in the seed mixture (Table 1); annual rye grass (*Lolium multiflorum*) and partridge pea (*Chamaecrista fasciculate*) served as nurse crops.

Barriers were installed at the base of the skid road where it intersected a county road after the waterbars were installed. However, no barriers were installed at the top of the road where it ended at private land. There was evidence of unauthorized all-terrain vehicle (ATV) use on the skid road between the period of pipeline installation and the beginning of equipment installation for this study. Tire tracks ranging from 30 to 46 cm wide and less than 1cm deep were evident on the road, particularly on the waterbars. Consequently, at about the time of study-equipment installation, additional barriers were installed at the top of the skid road to eliminate all vehicular use there.

In 2006, the skid road held segments (defined below) that could be visibly separated into those that were densely vegetated and those that were sparsely vegetated. Consequently, two segments of each type were included to represent the overall skid road/pipeline surface conditions. Because densely and sparsely vegetated segments were interspersed longitudinally throughout the skid road, differences in vegetative cover were assumed to be due to factors such as incoming solar radiation rather than

Table 1.—Native seeds and rates applied to the skid road after pipeline installation

Common name	Scientific name	Seeding rate
		(kg/ha)
Annual rye grass	*Lolium multiflorum*	16.81
Partridge pea	*Chamaecrista fasciculate*	16.81
Virginia wild rye	*Elymus virginicus*	50.44
Rough avens	*Geum laciniatum*	11.21
False Solomon's seal	*Smilacina racemosa*	10.09
Heath aster	*Aster pilosus*	6.73
Riverbank wild rye	*Elymus riparium*	5.60
Thimbleweed	*Anemone virginiana*	4.48
Ox-eye sunflower	*Heliopsis helianthoides*	4.48
Zig zag aster	*Aster prenanthoides*	3.36
Blue cohosh	*Caulophyllum thalictroides*	3.36
Black cohosh	*Actaea racemosa*	3.36
Big leaf aster	*Eurybia macrophylla*	2.24
Sweet cicely	*Osmorhiza berteroi*	2.24
Blackberry	*Rubus allegheniensis*	2.24
Eastern columbine	*Aquilegia Canadensis*	0.56
Jack-in-the-pulpit	*Arisaema triphyllum*	0.56
White wood aster	*Eurybia divaricata*	0.56
Greek valerian	*Polemonium reptans*	0.56
Total		112.09

soil compaction. Soils in the skid road are Gilpin channery silt loam, which is described as highly erodible, largely due to the steep hillside slope (Losche and Beverage 1967).

Data for the second case study are from Harrison (2011). This study was performed on the Fernow Experimental Forest where a 9-m-wide new cross-country pipeline was constructed during fall 2008 through late spring 2009. Erosion was measured from 15 sections of pipeline in the Harrison (2011) study, but data from only three sections were used in this analysis because they were similar in slope to the skid road. The soil associated with this section of the pipeline was mapped and classified from a soil pit excavated immediately adjacent to the pipeline. It was described as a residuum Calvin silt loam soil (Harrison 2011), which is considered moderately erodible.

After the forest overstory was removed and stumps were grubbed from the corridor, the 8.9-cm-diameter pipeline was buried at a 76-cm depth. After the trench was backfilled, waterbars were installed for water control using a trackhoe, and no further mechanical traffic was permitted on the pipeline. During the last few days of April 2009, the pipeline was seeded with a mixture of native seeds (Table 2). Annual rye grass and partridge pea, along with oats, again were used as nurse crops. Fertilizer (10-20-10) was applied at a rate of 672 kg/ha, and lime and uncut straw mulch were applied at 4.48 metric tons/ha each.

In both studies, erosion was measured from segments of the skid road or pipeline defined by waterbars (i.e., the area extending from crest to crest of adjacent waterbars) (Fig. 1). Physical characteristics of each of the segments are given in Table 3. The slopes of the skid road pipeline segments are less than those of the cross-country segments because transportation requirements and skid road BMPs

Table 2.—Native seeds and rates applied to the cross-country corridor after pipeline installation

Common name	Scientific name	Seeding rate
		(kg/ha)
Annual rye grass	*Lolium multiflorum*	33.6
Partridge pea	*Chamaecrista fasciculate*	2.24
Oats	*Avena sativa*	3.36
Canada milkvetch	*Astragalus canadensis*	2.24
Little bluestem	*Andro-pogon scoparius*	3.36
Autumn bentgrass	*Agrostis penennans*	4.48
Deer tongue	Panicum clandestinium	6.72
Total		56.0

Table 3.—Physical characteristics of the pipeline segments

Section	Slope	Length	Area	Aspect	Vegetative cover[a]
	(%)	(m)	(m^2)		(%)
Skid road pipeline					
Segment 1	13.57	32.50	121.61[b]	NE	16.45
Segment 2	12.44	25.99	84.02	E	20.20
Segment 3	13.32	32.37	125.24	NE	82.13
Segment 4	12.75	28.60	129.32	NE	77.06
Cross-country pipeline					
Segment 1	26.8	18.94	119.69	NW	26.46
Segment 2	20.7	25.58	143.32	NW	47.45
Segment 3	18.6	19.44	110.64	NW	29.25

[a]Percent vegetative cover determined using photographic image analysis techniques described in Holz (2009) for the skidroad pipeline and in Harrison (2011) for the cross-country pipeline.
[b]Skid road pipeline area includes the road surface and the cutbank because both can contribute sediment and runoff to the waterbar.

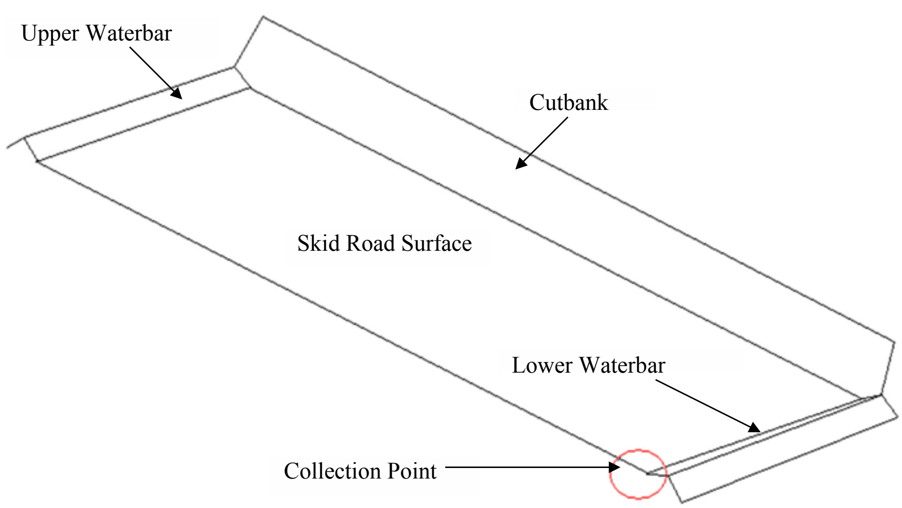

Figure 1.—Schematic illustrating a pipeline segment that extends from crest to crest of adjacent waterbars. The flume is installed at the base of the interior side of the downslope waterbar (i.e., the collection point). For the pipeline installed in the skid road, as shown here, the segment included the cutbank as well as the road surface. For the cross-country pipeline, the segment included only the surface of the disturbed corridor.

Figure 2.—Photograph showing a sediment collection device at a waterbar outlet. Runoff and sediment collected in the flume were diverted downslope into a collection tank by gravity. Samples were collected from a spigot at the base of the tank. Photo by Pam Edwards, U.S. Forest Service.

necessitate gentler slopes. The cross-country segments are shorter because the steeper slopes require more closely spaced waterbars. The contributing areas of the two types of segments are similar because the cross-country pipeline right-of-way is wider than the skid road (including the cutbanks).

A small metal or wooden flume was installed at the outlet of each waterbar, and the soil and flume were sealed together using hydraulic cement. Drainage and associated eroded soil were diverted from the skid road/pipeline section by the waterbar through the flume and then transported by gravity drainage to a collection tank downslope of the waterbar (Fig. 2).

Samples were collected from the pipeline in the skid road from July 25, 2007, through December 12, 2007, and then from April 11, 2008, through May 28, 2008. From December to April, the inlet pipes were disconnected from the tanks to avoid freezing and breakage (Holz 2009). Sampling from the cross-country pipeline began June 12, 2009, following equipment installation after seeding and mulching. Sampling continued for one full year (Harrison 2011). Tanks were not disconnected during the winter, but there was little melt from about mid-January through March. In both studies, sampling was primarily performed after individual precipitation or melt events; however, some collection periods included multiple events when they occurred on weekends or holidays.

Three replicate samples, approximately 1L each, were collected from each tank in both studies per sampling event. Before and during sample collection, the contents of the tanks were stirred with a long-handled brush to keep the solid materials suspended and help ensure each sample was representative of the tank contents. The volume of water present in each tank also was recorded to the nearest gallon before collecting the samples, using the volume demarcations printed on the side of each tank. Tank contents were emptied after sample collection.

All samples were analyzed for sediment concentrations using U.S. EPA method 160.2 (Keith 1991). This procedure involves vacuum filtering samples to separate solids from water. However, in the case of the cross-country pipeline, some of the samples collected during the first several months after pipeline construction had solid concentrations that were too high to allow direct filtration. These samples were centrifuged before filtering to separate most of the solids from the water. The organic portion of the samples was then removed from the mineral sediment by combusting the filters and the centrifuged solids at 550 °C until they reached a constant post-combustion weight (a minimum of 2 hours). Tank volumes were applied to the mineral sediment concentrations to obtain total mineral sediment losses from each section by sampling period and for the entire study.

In both case studies, percentage of vegetative cover was determined using ArcGIS and image analysis of digital photographs. Vegetative cover of the cutbank was included in the analyses for the skid road corridor because both the road surface and cutbank could contribute sediment to the associated segment. The field and image analysis techniques follow those described in Bold et al. (2010) and are detailed for each case study in Holz (2009) and Harrison (2011). In brief, the entire area of each corridor section was photographed using a digital camera mounted on a prism pole. This was accomplished by dividing each section into multiple subsections using PVC-pipe frames and photographing each subsection individually. The percentage of vegetative cover in each subsection was quantified after developing and validating signature files capable of isolating green shaded pixels (vegetation) from all other pixel colors in each photograph. Total percentage of vegetative cover for each section was determined from the results of all the subsections.

RESULTS AND DISCUSSION

The cross-country pipeline segments all had lower sediment yields than the pipeline segments installed in the skid road (Table 4). The overall mean sediment loss from segment 1 of the cross-country pipeline (10.44 kg/ha) was close to the lowest mean loss from the skid-road pipeline (14.34 kg /ha for segment 4), but the former still was lower by almost one-third. Additionally, sediment yields from cross-country segments 2 and 3 were a unit of magnitude lower than any of the skid road pipeline segments. The mean sediment loss across the four skid road pipeline segments over the 8 months of measurements (27.1 kg/ha/8 mo) was more than 4.5 times greater than the mean sediment loss across the three cross-country pipeline segments over a full year (5.65 kg/ha/yr). Because the numbers of runoff events and sampling period lengths were not the same for the two studies, the focus of this analysis is not on total losses (i.e., the right hand column of Table 4). However, given these results, it is not surprising that the total sediment losses over the shorter study (i.e., from the skid road segments) were greater from each of the skid road pipeline segments.

Because precipitation affects runoff and erosion and the two studies were performed during different time periods, the influence of precipitation on the results deserves some attention. Not surprisingly, both Holz (2009) and Harrison (2011) reported that rainfall intensity (i.e., 30-minute intensities) was the most important precipitation variable, of the several examined, for explaining sediment

Table 4.—Mineral sediment load summaries for the two pipelines

Section	Sediment load per sample period: Mean	Sediment load per sample period: Standard error	Mean load across all segments[a]	Total load for each segment[a]
	-------kg/ha-------		(kg/ha/8 mo)	(kg/ha/8 mo)
Skidroad pipeline				
Segment 1	48.58	19.30		1,797.6
Segment 2	32.87	9.15		1,183.3
Segment 3	15.48	4.21		572.9
Segment 4	14.34	3.13		530.5
			27.1	
Cross-country pipeline			(kg/ha/yr)	(kg/ha/yr)
Segment 1	10.44	3.18		396.9
Segment 2	3.08	1.12		110.8
Segment 3	3.42	1.09		116.2
			5.65	

[a]Mean loads and total loads for the skid road pipeline are expressed for an 8-month time period, while those for the cross-country pipeline are over a full year.

concentrations. Other investigators also reported rainfall intensity as important in sediment losses (Bold et al. 2010, Reid and Anderson1999). However, the years associated with these studies were not characterized by the occurrence of extreme individual events or by unusual (high or low) precipitation totals (U.S. Forest Service, unpublished data). Total precipitation for the 8 months of the study involving the skid road pipeline was about 77.3 cm (Holz 2009), and total precipitation during the year of the cross-country pipeline study was about 128.5 cm (Harrison 2011). If the 8-month study were normalized to a yearlong period, the resulting annual precipitation (116.0 cm) would be similar to, but still less, than the Harrison study (128.5 cm). Consequently, the greater loads from the pipeline associated with the skid road do not appear to be attributable to differences in precipitation between the two years.

Loadings are the product of sediment concentrations and the runoff volume in the collection tank at each sampling event; therefore, examination of these two variables can provide information about whether the greater loadings (kg/ha per sampling event) from the skid road pipeline were attributable to greater runoff, greater erosion rates (i.e., sediment concentrations), or the combination of both. Overall, differences in sediment losses from the skid road segments appear to be controlled primarily by erosion rates rather than runoff. Mean runoff volumes were similar among skid road pipeline segments; indeed, segments 1 and 2 had lower mean total runoff values than segments 3 and 4 (Table 5). By comparison, segments 1 and 2 had much higher mean sediment concentrations (Table 5) and higher loadings than segments 3 and 4 (Table 4).

So what drives the differences in erosion rates among segments on the skid road pipeline that are relatively close to one another and are influenced by the same general soil characteristics? In this situation, the density of vegetation (Table 3) appears to be an important factor in determining the degree of erosion that occurs. Although only two replicate segments in each of the dense and sparse vegetative cover categories cannot be compared statistically, sediment concentrations (mg/L) and

Table 5.—Mean sediment concentrations and runoff volumes by location and pipeline section

Section	Sediment concentration		Runoff volume		
	Mean	Standard error	Mean	Standard error	Total
	-----------mg/L-----------		--------------------L--------------------		
Skid road pipeline					
Segment 1	2,039.8	1094.5	366.5	24.8	13,561
Segment 2	698.0	190.4	322.3	32.1	11,602
Segment 3	457.4	118.9	378.3	24.8	13,997
Segment 4	429.5	85.2	381.8	24.4	14,125
Cross-country pipeline					
Segment 1	322.7	89.4	311.3	43.3	11,829
Segment 2	280.3	64.5	83.1	16.9	2,993
Segment 3	467.4	124.8	37.1	8.9	1,262

loadings (kg/ha) were clearly greater from segments with low vegetative cover (segments 1 and 2) (Tables 4 and 5). Greater sediment losses with sparse vegetative cover are consistent with scientific literature. Many other studies found that effective erosion control occurs only when cover reaches 50 to 75 percent (Gifford 1985, Gutierrez and Hernandez 1996, Loch 2000, Orr 1970, Quinton et al. 1997, Snelder and Bryan 1995).

Sediment concentrations from all three cross-country pipeline segments were relatively similar to those from the densely vegetated segments of the pipeline in the skid road (Table 5), even though the percent cover values on the cross-country segments were much lower (Table 3) and were less than the 50 to 75 percent levels needed to control erosion. This finding may seem at odds with the statements above about the importance of vegetation and erosion control, particularly because the slopes of the cross-country segments were greater. However, the higher runoff volumes and more erodible soil associated with the skid road pipeline appear to be of greater consequence than vegetation differences between the two sites.

Segment 1 of the cross-country pipeline is somewhat of an anomaly in terms of runoff volumes compared to the other two cross-country segments. It had 3.7 to 8.4 times more runoff compared to segments 2 and 3 (Table 5). For segment 1, the elevated runoff alone appears to be the cause of the greater sediment yields (Table 4) because the concentrations are comparable among all three segments. The runoff volume for segment 1 is believed to be attributable to its location at the head of the bench, immediately below a much steeper section of pipeline. High runoff volumes were reported for other steeper segments located immediately upslope of segment 1. These runoff volumes were attributed to the presence of a fragipan-like layer at a 50-cm depth, which was identified from a soil pit excavated adjacent to the pipeline within those steeper segments (Harrison 2011). The waterbars were believed to have intercepted subsurface drainage that was diverted along the dense layer (Harrison 2011). We speculate that upslope subsurface flow diverted from this layer contributed to the elevated runoff from segment 1 even though soil mapping did not find the layer to extend into the bench (Harrison 2011). However, it is likely that much of the runoff became emergent near or in the waterbar of segment 1 so that it did not enhance erosion from the entire face of the segment. This response is supported by the elevated runoff and sediment loads with no concomitant elevation of sediment concentrations.

MANAGEMENT IMPLICATIONS

Where there were high runoff volumes, the source and pathway of the drainage influenced sediment yields. On the skid road segments, overland flow appeared to be a dominant runoff mechanism. Surface soil compaction limited infiltration, as evidenced by visible sheetflow and concentrated overland flow during and following all but the smallest precipitation and snowmelt events. Rills also developed where surface runoff concentrated. These conditions elevated soil losses.

Dense vegetation clearly helped control erosion from the skid road segments, but erosion was still higher than where waterbar discharge originated primarily from subsurface flow. There was evidence of surface erosion on the cross-country pipeline, but interrill erosion appeared to predominate: small soil pedestals were evident, but rill development was limited and surface runoff was not nearly as visible during events as on the skid road segments. Thus, vegetation density contributes to erosion control, but overland flow ultimately may trump much of the advantage that vegetative cover provides for controlling soil loss on a compacted site.

The comparisons of these two studies indicate that taking steps to increase or maintain high infiltration rates also can provide substantial benefit. Although using existing infrastructure reduces disturbance and fragmentation, this BMP may provide little advantage from an erosion and sediment control perspective if infiltration issues on existing corridors are not addressed. For example, while the excavation for pipeline installation may have increased infiltration within that narrow width, infiltration may have been increased much more by ripping the entire road width just before installing the pipeline. Ideally, ripping at the time the original skid road was closed out probably would have provided substantial benefit for the 25 years before pipeline installation. But even in the absence of ripping after skid road closure, soil ripping at the time of pipeline installation could have helped counter the legacy soil compaction and infiltration problems and likely would have improved contemporary vegetative establishment, which in turn could have contributed to better soil erosion control.

Unauthorized use of pipelines, especially by off-road vehicles, also must be controlled to maintain erosion at low levels. ATVs increase compaction, tear out vegetation or decrease its vigor, and create wheel ruts due to wheel slip and braking patterns. Wheel ruts can serve as concentrated flow channels that exacerbate erosion. Controlling unauthorized use may be one of the more difficult long-term tasks on steep, accessible corridors, because these areas attract users interested in hill climbing.

CONCLUSIONS

Sediment loads were greater from the pipeline in the skid road even though the cross-country pipeline was steeper and had only sparse vegetative cover. Greater soil compaction and poor infiltration on the skid road are believed to be the primary reasons for the greater soil yields there. Although the use of existing infrastructure for pipeline installation provides environmental benefits, such as reduced land fragmentation, the comparison of these two pipelines illustrates the importance of maintaining good infiltration on all types of corridors that have not been used for or are no longer used for transportation.

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