Mountain Valley Pipeline Project

Docket No. CP16-10-000

REVISED HYDROLOGIC ANALYSIS OF SEDIMENTATION

JEFFERSON NATIONAL FOREST EASTERN DIVIDE RANGER DISTRICT

June 2017

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1.0 Introduction

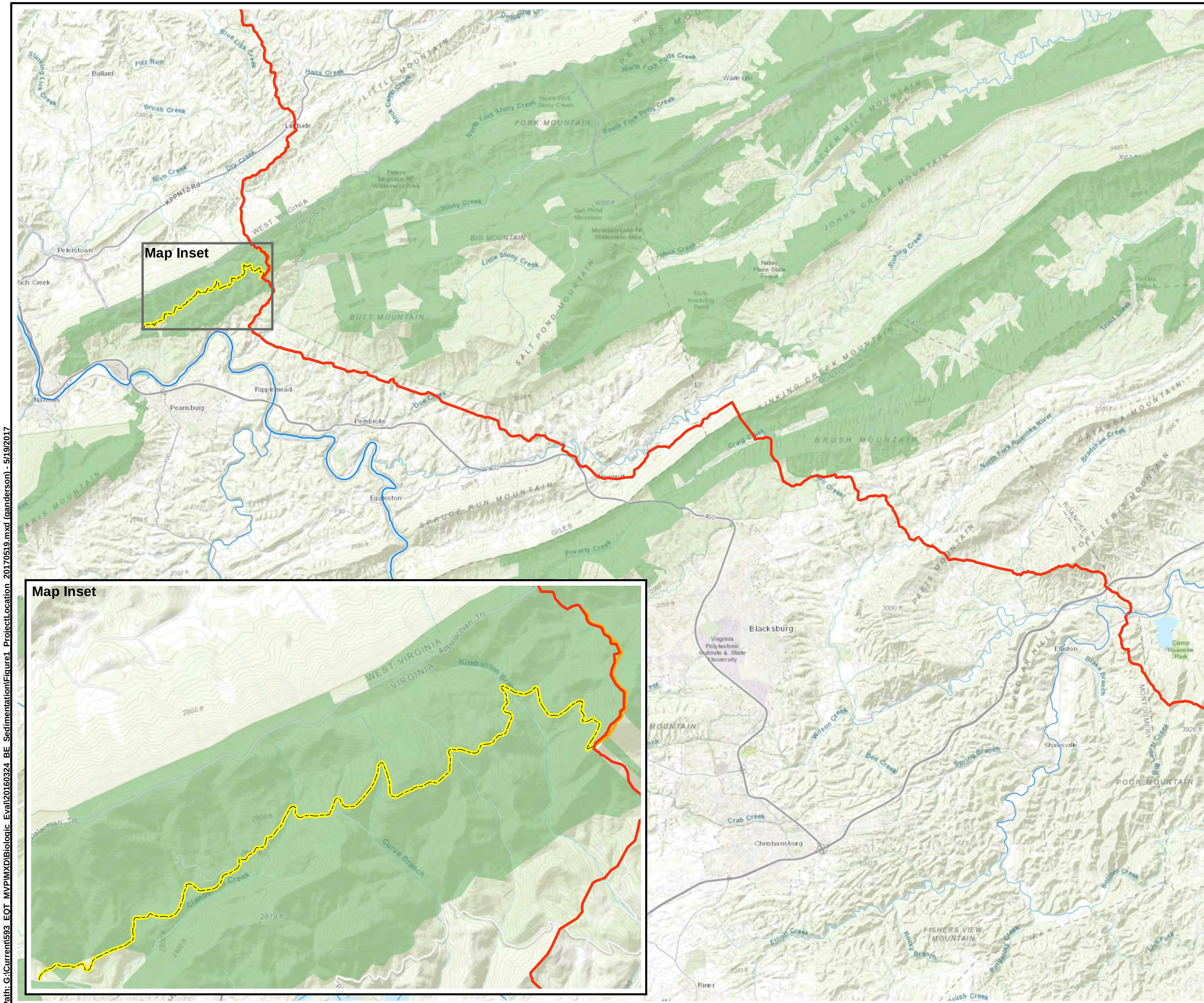
Mountain Valley Pipeline, LLC (MVP), a joint venture between EQT Midstream Partners, LP, NextEra Energy, Inc., WGL Holdings, Inc., Con Edison Gas Midstream, LLC, and RGC Midstream, LLC, is seeking a Certificate of Public Convenience and Necessity from the Federal Energy Regulatory Commission (FERC) pursuant to Section 7(c) of the Natural Gas Act authorizing it to construct and operate the proposed Mountain Valley Pipeline Project (Project) located in 17 counties in West Virginia and Virginia. MVP plans to construct an approximately 303-mile, 42-inch-diameter natural gas pipeline to provide timely, cost-effective access to the growing demand for natural gas for use by local distribution companies, industrial users, and power generators in the Mid-Atlantic and southeastern markets, as well as potential markets in the Appalachian region.

The proposed pipeline will extend from the existing Equitrans, L.P. transmission system and other natural gas facilities in Wetzel County, West Virginia to Transcontinental Gas Pipe Line Company, LLC's (Transco) Zone 5 compressor station 165 in Pittsylvania County, Virginia. In addition to the pipeline, the Project will include approximately 171,600 horsepower of compression at three compressor stations currently planned along the route as well as measurement, regulation, and other ancillary facilities required for the safe and reliable operation of the pipeline. The pipeline is designed to transport up to two-million dekatherms per day of natural gas.

Approximately 3.5 miles of the proposed alignment cross Jefferson National Forest (JNF) lands in Monroe County, West Virginia and Giles and Montgomery counties, Virginia (Figure 1). Additionally, MVP is currently proposing to use Pocahontas Road (Forest Road 972) and one mile of Mystery Ridge Road (Forest Road 11080) in Giles County, Virginia to provide access to portions of the alignment near Peters Mountain. No ancillary facilities or new access roads are proposed to be constructed on JNF lands; however, two additional temporary workspaces (ATWS) are currently proposed in Montgomery County.

Construction of the Project within the JNF and on private lands has potential to introduce excess sediment into waterways within the JNF and downstream areas, which may result in changes to water quality and potentially impact aquatic biota. Although MVP will implement specific conservation measures (i.e., erosion and sediment controls) to minimize impacts to waterways, these measures are unlikely to prevent all sediment inputs. Sedimentation of streams by erosion is a natural process, but land development and disturbance may accelerate this process. Increased

Figure 1. Location of the proposed Mountain Valley Pipeline within the vicinity of the Jefferson National Forest in Virginia and West Virginia.



Stream
Pocahontas Road
Proposed Route
U.S. Forest Service (National Forest) Lands

N
W E
S

0 2.5 5 Miles

Base Map: ESRI ArcGIS Web service - "US TOPO MAPS" accessed - 5/19/2017

ESI ENVIRONMENTAL SOLUTIONS & INNOVATIONS, INC.

Project No. 593.02

Path: G:\Current\593_EQT_MVP\MXD\Biologic_Eval\20160324_BE_Sedimentation\Figure1_ProjectLocation_20170519.mxd (ganderson) - 5/19/2017 erodibility, due to the loosening and exposure of fine particles, increases the likelihood of sediment-laden runoff from the Project into nearby waterways.

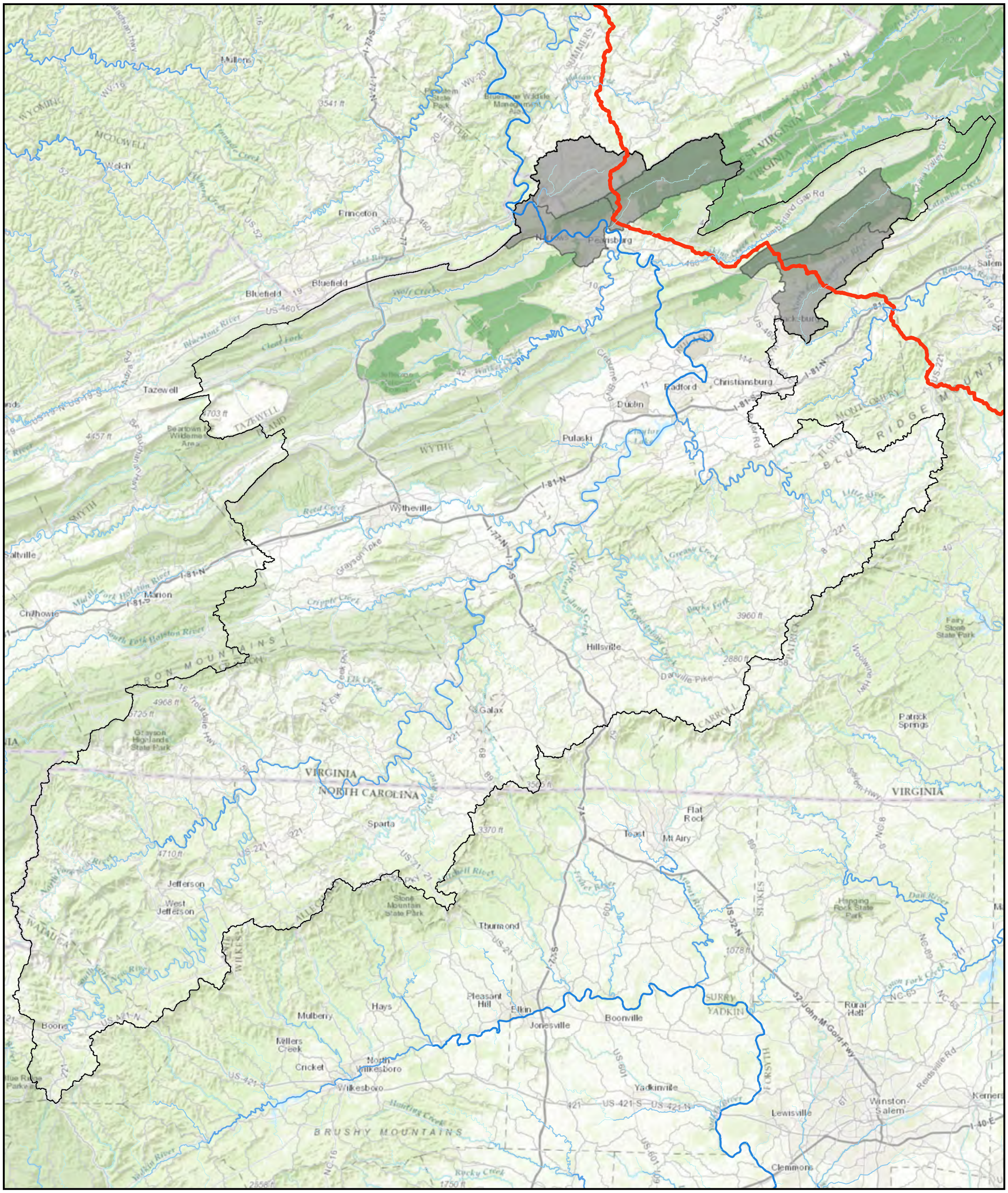
Environmental Solutions & Innovations, Inc. (ESI) was retained by MVP to provide protected-species consultations, surveys, and analyses for the Project, including threatened, endangered, and sensitive (TES) species within the JNF. In order to quantify the amount of sediment expected within waterways and associated impacts to TES species within the JNF and in downstream areas, ESI contracted a hydrogeologist (Hydrogeology Inc.) to investigate the potential for downstream sedimentation impacts. On June 7, 2016, ESI, on the behalf of MVP, submitted to the U.S. Forest Service (USFS) a *Hydrologic Analysis of Sedimentation* documenting potential sedimentation introduced during Project construction. Upon review, the USFS, ESI, and MVP discussed the analysis and how to best document the level of impacts of potential sedimentation introduced by the Project. This updated analysis includes revisions based on USFS comments and allows the USFS to review potential sediment impacts during construction on USFS lands as well as consider the cumulative effects of increased sediment as the Project transitions through post-construction phases.

2.0 Methods

In order to estimate erosion due to disruption of land from construction, restoration, and operational activities for the Project in the vicinity of the JNF, a hydrologic analysis of sedimentation was performed. This analysis uses the Revised Universal Soil Loss Equation (RUSLE; Renard et al. 1997) to estimate loss of soils due to Project activities. The RUSLE provides generalized annual estimates of erosion rates and sediment loads based on climate, soil, topography, and land use/management factors and can be used to determine sediment loads and yields for catchments within the vicinity of the Project.

2.1 Hydrologic Study Area

To assess the potential of impacts from the Project due to sedimentation within streams in and surrounding the JNF, a hydrologic study area is defined. This area is defined using subwatersheds (i.e., Hydrologic Unit Code [HUC] 12) from the U.S. Geological Survey's Watershed Boundary Dataset and is specified to contain: (1) all subwatersheds that intersect the JNF boundaries and the Project Area, (2) all subwatersheds upstream of the intersecting subwatersheds (i.e., all upstream catchment areas), and (3) subwatersheds downstream of the intersecting subwatersheds that demonstrate substantial increases in cumulative sediment loads (i.e., > 10%; Figure 2).



Stream
Proposed Route
Hydrologic Study Area
Intersecting JNF and Project Subwatershed
Subwatershed
U.S. Forest Service (National Forest) Lands

N
W E
S

Figure 2. Hydrologic study area for the Mountain Valley Pipeline within the Jefferson National Forest in Virginia and West Virginia.

Project No. 593

0 10 20 Miles

Base Map: "US Topographic Maps"

ESI ENVIRONMENTAL SOLUTIONS & INNOVATIONS, INC.

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Within the vicinity of the JNF, the Project proposes to construct and operate in four subbasins belonging to three different hydrologic regions:

- Upper New (8-digit HUC 05050001) and Middle New (05050002) subbasins of the Ohio Region
- Upper James Subbasin (8-digit HUC 02080201) of the Mid-Atlantic Region
- Upper Roanoke Subbasin (8-digit HUC 03010101) of the South Atlantic-Gulf Region

Of the 243 subwatersheds within these three subbasins, five subwatersheds overlap with the Project's Limits of Disturbance (LOD) within the JNF (Table 1).

Table 1. Subwatersheds in Virginia and West Virginia that Overlap with Limits of Disturbance for the Mountain Valley Pipeline within the Jefferson National Forest.

Subwatershed Name	HUC12	State	Subwatershed Area (ac)	Project Area (ac)	Area within JNF (ac)	Project Area within JNF (ac)
Stony Creek	050500020305	VA,WV	31,105	112	25,312	38
Clendennin Creek-Bluestone Lake	050500020602	VA,WV	24,899	22	4,883	19
Rich Creek	050500020601	VA,WV	34,089	82	808	1
Trout Creek-Craig Creek	020802011001	VA	33,173	35	24,544	27
Dry Run-North Fork Roanoke River	030101010201	VA	32,787	138	2,126	<1

The Stony Creek Subwatershed is a headwater subwatershed that contains Laurel Branch, Iron Spring Branch, Dixon Branch, Pine Swamp Branch, Kimballton Branch, North Fork Stony Creek, and Stony Creek. The outlet of the subwatershed is outside the JNF where Stony Creek flows into the New River. Forest is the dominant land cover within the subwatershed, which comprises 96 percent of the subwatershed. The Project proposes to cross 112 acres (0.36%) of the subwatershed along the west-southwestern portion, crossing the catchments and waterbodies of Kimballton Branch and Stony Creek. Of the 112 acres crossed within the subwatershed, 38 acres occur within the JNF, including the use of portions of Pocahontas Road (Forest Road 972) and Mystery Ridge Road (Forest Road 11080). These roads are currently 10 feet and 8 feet wide, respectively, and are currently gravel surfaced. MVP proposes to widen these features to 40 feet as necessary during construction, and the roads will remain graveled during and after construction.

The Clendennin Creek-Bluestone Lake Subwatershed is downstream of the Stony Creek Subwatershed and largely comprises an area draining directly to the mainstem of the New River but also contains several tributaries including Clendennin Creek, Curve Branch, Limestone Creek, and Piney Creek. The subwatershed predominantly drains private lands, but the headwaters of Clendennin Creek and Curve Branch originate within the JNF, and portions of the catchment of the mainstem New River are also within the JNF. Forest is the dominant land cover within the subwatershed, which comprises 74 percent of the subwatershed. However, developed (13%) and agricultural (9%) lands are also present within subwatershed. Within the subwatershed, the Project proposes to use and improve Pocahontas Road (Forest Road 972). Overall, the Project proposes to cross 22 acres (0.09%) of the subwatershed, of which 19 acres occur within the JNF.

Near the outlet of the Clendennin Creek-Bluestone Lake Subwatershed, the Rich Creek Subwatershed meets the mainstem of the New River. This headwater subwatershed contains Brush Creek, Crooked Creek, Crooked Run, Dry Creek, Painter Run, Rich Creek, Scott Branch, and Tigger Run. Only a small proportion of the Rich Creek Subwatershed is contained within the JNF (2.4%), and only streams within the southwestern portion of subwatershed drain JNF lands. Forest cover currently comprises 60 percent of the subwatershed, agricultural land comprises 29.5 percent, and developed land comprises 10.2 percent. The Project proposes to cross 82 acres (0.24%) of the subwatershed, of which only 1 acre occurs within the JNF.

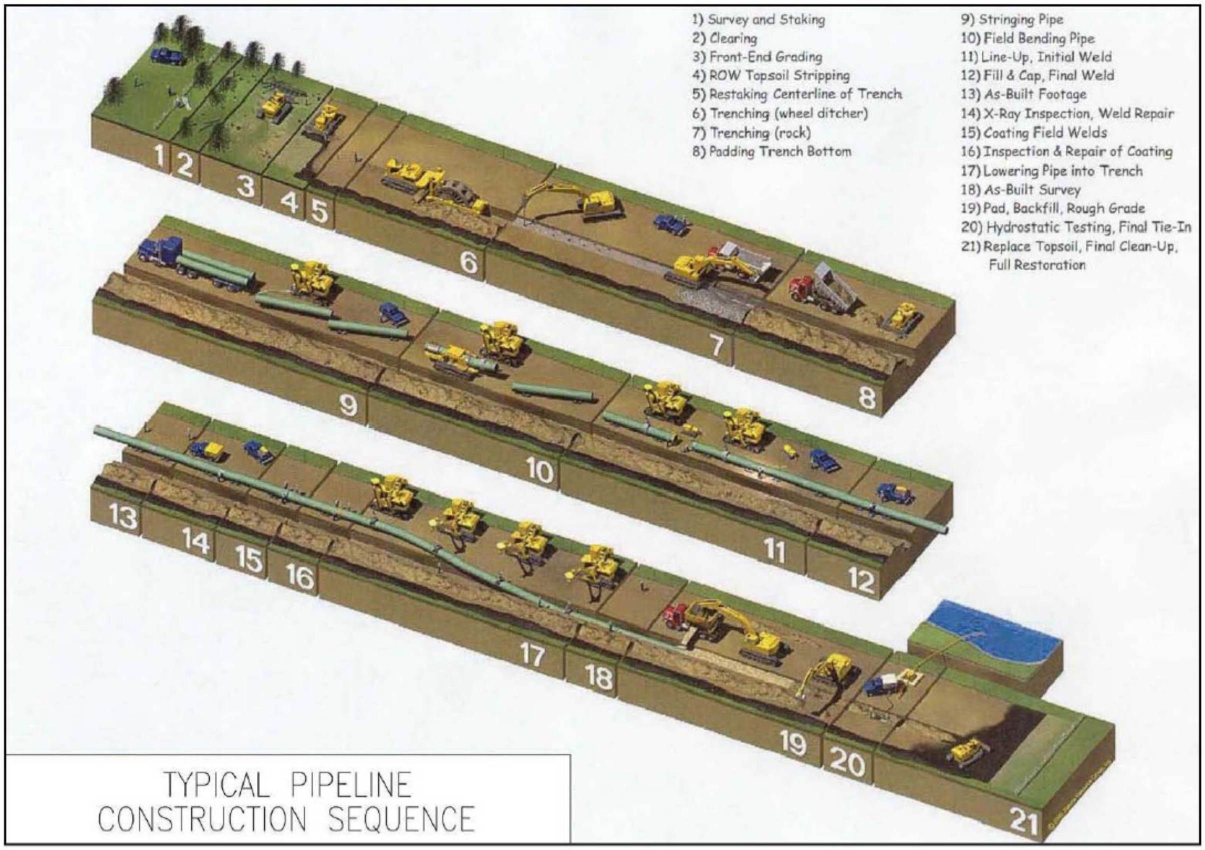
The Trout Creek-Craig Creek Subwatershed is a headwater system of the Upper James that contains Craig Creek, Trout Creek, Mill Creek, Turnpike Creek, Cabin Branch, Adaline Branch, Sandy Branch, Muddy Branch, Dickey Farm Branch, and Pickles Branch. The majority of the subwatershed is within the JNF; however, much of the Craig Creek mainstem and surrounding floodplain are not contained within the jurisdictional boundaries of the JNF. Forest land cover comprises more than 93 percent of the subwatershed. The Project proposes to cross 35 acres (0.11%)of the subwatershed during construction, of which 27 acres occur within the JNF.

A small portion (0.08 acre) of the Project is proposed to intersect the JNF and the Dry Run-North Fork Roanoke River Subwatershed. This subwatershed is a headwater system of the Upper Roanoke that drains to the North Fork Roanoke River and contains Wright Branch, Smith Run, Slate Lick Run, Sites Branch, Pepper Run, Mill Creek, Indian Run, Gallion Branch, and Dry Run. Land cover is dominated by forest, which comprises 68.5 percent. Seven percent of land cover is developed and 23 percent is agricultural. The Project proposes to cross 138 acres (0.42%) of the subwatershed during construction, of which less than 1 acre occurs in the JNF.

2.2 Impact Approach

Construction of the pipeline and associated facilities will occur in 11 separate construction spreads using conventional open-cut methods during the majority of the process. A pipeline construction spread operates as a moving assembly line performing specialized procedures in an efficient, planned sequence (Figure 3). In the

Figure 3. Typical pipeline construction sequence.



typical pipeline construction scenario, the construction contractor will construct the pipeline along the right-of-way (ROW) using sequential construction techniques, including surveying, staking, and fence crossing; clearing and grading; trenching; pipe stringing, bending, and welding; lowering-in and backfilling; hydrostatic testing; clean-up and restoration; and commissioning (Figure 3).

The following approach is taken to estimate soil loss rates from the Project. The RUSLE, as described below, is used to estimate sediment loads (tons yr^{-1}*) and sediment yields (tons/mi^2 yr^{-1}) for the catchments of all streams within the 1:24,000 National Hydrography Dataset (NHD) within the study area (Figure 2). These calculations are made using current and expected land use classes during: construction, restoration, and operation of the Project. Current sediment loads and yields are considered baseline conditions (i.e., baseline treatment) and provide a measure of the present sediment loads within streams in the vicinity of the Project.

* The notation tons yr^{-1} represents tons per year.

This baseline treatment is then used to assess potential increases of soil loss expected under Project construction, restoration, and operation (i.e., proposed action treatment).

In order to estimate potential sediment introduced into nearby streams from the Project, construction, restoration, and operation impacts are divided into three primary activities: (1) access road improvements and construction, (2) tree clearing, and (3) pipeline construction and restoration. These activities are projected on a two-week interval using a sequential, assembly line construction schedule for each construction spread in a north-to-south direction. First, the northern most access road is constructed. Once the first access road is completed, construction of the next most northern access road begins, and tree clearance begins on the pipeline LOD, associated workspaces, and ancillary sites. After trees are cleared, construction begins. The process for each one of these activities is further detailed below.

Access road improvements and construction are estimated to take two calendar weeks per access road. During this construction time, the entire LOD for the access road is treated as a bare soil land class (see Section 2.3.4 below) (Galetovic 1998), and temporary sediment erosion controls are employed. After two weeks, the road enters a recovery stage where the road will likely continue to contribute elevated sediment loads until it reaches a new equilibrium. To be conservative, the LOD for the access road is treated as a bare soil land class during this phase; however, during this time the road will have gravel applied and final grading will be complete. After four weeks of recovery, herbaceous erosion controls are assumed to be established but not mature, and the road is considered to act as an improved road until the construction spread is restored and established (see Section 2.3.4 below) (Gaffer et al. 2008). Once the construction spread is restored and established, temporary access roads are treated similarly to the ROW with periods for grass establishment, development, and maturation (see below). Permanent access roads continue to act as an improved road for the life of the Project.

Tree clearance is estimated to occur at a rate of 2,500 linear feet per day, and over a two-week period (six-day work week), approximately 30,000 linear feet are estimated to be cleared. Because vegetation would generally be cut or scraped flush with the surface of the ground, leaving rootstock in place where possible, the portion of the LOD cleared is treated as a bare soil land class scalped at the surface (see Section 2.3.4 below) (Galetovic 1998) until construction (e.g., grading) begins, and no erosion and sediment controls are assumed to be employed during this timeframe. This classification likely overestimates the sediment produced during this phase of the Project because the LOD will not be 100 percent bare soil.

Once trees are cleared, construction at any particular one-mile stretch along the pipeline route is estimated to take about three weeks to complete (19 workdays). Given this information, construction progress is estimated to occur at 3,520 linear feet every two-weeks (3,520 ft = 5,280 ft × [2/3]), and the portion of LOD under active construction is treated as a bare soil land class (see Section 2.3.4 below) (Galetovic 1998). Note that as a conservation measure, piles of topsoil and subsoil are mulched each day to minimize erosion. These areas combined represent approximately 30 feet of the LOD width and are represented by buffering the spoil side of the LOD. This area is treated as a mulched land class (see Table 2) during active construction. Once construction is complete, all areas of the ROW are mulched within seven days of backfilling and remain mulched until final grading.

Approximately 16 weeks after construction is completed, final grading takes place and areas are restored within 3-5 days of final grading. Seed areas are assumed to take approximately four weeks to reach establishment, six months to reach development, and one-year to act as a maturing crop. Until seeds are established, the LOD is classified as a mulched landscape with two tons of straw or hay applied per acre. Six months after seeding, temporary erosion controls are assumed to be removed (however, permanent erosion controls remain in place) and the ROW is treated as a developed grassland. After one year of seeding, grasses are assumed to act like a maturing crop, and the landscape is reclassified as a grassland or herbaceous landscape (see Section 2.3.4 below).

Using this schedule of events and associated land use classes, soil loss is estimated at two-week intervals and summed to estimate expected yearly loads and yields for a five-year period. Results are then compared to baseline conditions to assess potential impacts from the Project. To estimate the full spatial extent of Project impacts, maximum loads are estimated as the maximum cumulative sum of any consecutive 52-week period.

2.3 Estimating Erosion and Soil Loss

Soil loss is calculated for all stream catchments within the hydrologic study area using the RUSLE. The RUSLE takes the product of several derived metrics in order to estimate expected soil loss under different land use, management, topographic, and climatic conditions. Sediment loss (A) is estimated at a rate of tons per year using the following equation:

$$A = R \times K \times LS \times C \times P, \quad \text{Eq. 1}$$

where R is the erositvity index, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is a cover-management or land use factor, and P is a support practice factor. These factors, along with their respective derivations are discussed further below.

2.3.1 Soil Erosivity Factor

Because the RUSLE does not directly model hydrology, runoff estimates are not available to simulate erosion; instead, a rainfall erosivity factor is calculated that characterizes the potential effect of runoff on soil erosion. To calculate R, average annual precipitation estimates (PRISM Climate Group 2012) from 1980 to 2010 are used within the following formula:

$$R = 0.059 \times 0.0483 \times P_{PRISM}^{1.61}, \qquad \text{Eq. 2}$$

where P_{PRISM} is precipitation expected within a raster cell (in millimeters), and R is the rainfall erosivity in hundreds of foot-ton-inch acre^{-1} hour^{-1} year^{-1} (Renard and Freimund 1994). In this equation, 1.61 and 0.0483 are estimated regression coefficients from Renard and Freimund (1994), and 0.059 is a conversion factor to U.S. customary units. Note that in this approach, annual estimates are used due to the complexity of integrating the RUSLE into the Geographical Information System (GIS) environment (see below); however, rainfall changes seasonally, thus sedimentation impacts may depend on the season in which construction takes place.

2.3.2 Soil Erodibility Factor

The soil erodibility factor (K) accounts for variability in the inherent erodibility of soils and is a function of integrated influences, including infiltration, rainfall, composition, and overland runoff. Fortunately, this metric is currently available within the National Resources Conservation Service's SSURGO (Soil Survey Staff 2015a) and STATSGO2 (Soil Survey Staff 2015b) soil databases. Note that although the K-factor is available in these datasets, it needs to be aggregated among soil components. To accomplish this, the kwfact parameter (K-factor, Whole Soil) from the dominant condition among components is used, and no aggregation is made among horizons, but rather the surface layer is used instead.

In most areas within the hydrologic study area, the more detailed SSURGO dataset is used, but SSURGO K-factors are not readily available for all map-unit areas. Therefore, when SSURGO data are not available, the kwfact is calculated with STATSGO2 K-factors, which have lower resolution but sufficient correspondence with SSURGO factors (Breiby 2006).

2.3.3 Topographic Factor

The L and S factors within the RUSLE individually represent slope length and steepness, respectively, but combine to form what is known as a topographic factor. This topographic factor is a function of the landscape terrain. Following Moore and Wilson (1992), LS is calculated using upslope contributing area in order to account for the impact of flow convergence. For each raster cell i LS is calculated as:

$$LS_i = \left(\frac{A_{s_i}}{22.13}\right)^m \times \left(\frac{\sin \beta_i}{0.0896}\right)^n \times (m+1), \qquad \text{Eq. 3}$$

where A_{s_i} is the specific catchment area or the upslope contributing area per unit width of contour, β is the slope angle in radians, and m and n are constants. Both A_{s_i} and β_i are calculated using the standard Spatial Analyst functions within ArcGIS; however, to ensure alignment with the NHD, elevation data are adjusted to calculate A_{s_i}. In this process, elevation data (derived from the 1/3 arc-second seamless digital elevation model [DEM] available from the USGS 3D Elevation Program) are adjusted by burning in the NHD, and a flow direction and flow accumulation process is performed on these adjusted elevation data. The specific catchment area is then calculated as the product of the flow accumulation estimate and the cell resolution. As suggested by Galetovic (1998), the slope length component of this equation is truncated at 400 feet. Although the values of m and n can vary among different terrains, the parameters typically range from 0.4 to 0.6 and 1.0 to 1.4, respectively. For this analysis, m and n are set at 0.4 and 1.0, respectively. These values are chosen because of the high forest cover and complex topography (Oliveria et al. 2013).

2.3.4 Cover and Management Factor

The cover and management factor (C) accounts for the effects of vegetation, management, and erosion control practices. In the hydrologic sedimentation analysis for the JNF, baseline C-factors are generated by reclassifying the 2011 National Land Cover Database (NLCD; Homer et al. 2015) and land use classifications made during (1) bat habitat assessments and (2) wetland and stream surveys. Reclassifications are conducted using the values from Table 2, which are taken from several literature sources, including Wischmeier and Smith (1978), Dissmeyer and Foster (1980), Galetovic (1998), Mitasova et al. (2001), MTDEQ (2006), Gaffer et al. (2008), and Litschert et al. (2014).

As described above in Section 2.2, soil loss from pipeline construction and practices is estimated by applying time and activity specific C-factors to all areas of the pipeline ROW and other temporary and permanent workspaces (Table 2). For most activities, C-factors are derived for a two-week period; however, for the periods immediately following backfilling and during restoration, construction activities span less than the two-week period. For these activities, where disturbance is a shorter time frame, two-week cover management factors are derived by a weighted average of the construction specific C-factor and a mulch specific C-factor. For example, once construction is completed, areas may remain denuded for up to seven days following backfilling. Because this timeframe is less than two weeks, the C-factor is derived by multiplying the area-specific construction C-factor by 7, adding 7 times a slope-specific mulching C-factor (i.e., seven days of a mulched landscape), and dividing this sum by 14. A similar calculation is made for restoration; however, the construction C-factor is

Table 2. Conservation and management factors applied for different land uses within the study area.

Vegetative Cover Type	Management Factor (C)
National Land Cover Classes	
Deciduous Forest	0.003
Evergreen Forest	0.003
Mixed Forest	0.003
Woody Wetlands	0.006
Developed Open Space	0.003
Developed, Low Intensity	0.001
Developed, Medium Intensity	0.001
Developed, High Intensity	0.001
Shrub/Scrub	0.010
Emergent Herbaceous Wetlands	0.003
Cultivated Crops	0.240
Pasture/Hay	0.010
Grassland/Herbaceous	0.010
Open Water	0.000
Barren Land	0.001
Proposed Activities	
Access Roads	
Improvements and Construction	0.450
Improved Road (Operations)	0.250
Tree Clearing	0.150
Project Construction	
Additional Temporary Work Space	0.450
Ancillary Site	0.450
Right-of-Way	1.000
Project Restoration	
Mulched, Slope ≤10 %	0.060
Mulched, Slope 11-15 %	0.070
Mulched, Slope 16-20 %	0.110
Mulched, Slope 21-25 %	0.140
Mulched, Slope 26-33 %	0.170
Mulched, Slope ≥ 34 %	0.200
Established Grasses and Forbs (10-50% Crop Canopy)	0.150
Developed Grasses and Forbs (50-75% Crop Canopy)	0.042
Maturing Crop (≥ 75 % Crop Canopy; Operations)	0.010

multiplied by six days (i.e., one day of grading, four days between grading and restoration, and one day of restoration), and the slope-specific mulching C-factor is multiplied by 8 (i.e., 14 days in two weeks minus 6 days of the activity=8 days of mulch).

2.3.5 Practice Factor

Reported estimates of the effectiveness of erosion and sediment controls vary widely among studies and have been reported to be between 10 and 90 percent (USEPA 2009). Performance of these controls is a function of design, frequency and duration of rainfall events, particle sizes, sediment accumulation, and the extent to which field maintenance has been performed. For the proposed Project, a variety of erosion and sediment control practices will be used. Erosion control practices include, but are not limited to, trench breakers, permanent slope breakers, temporary seeding, mulching, soil stabilization mats and blankets, and surface roughing. According to a review conducted by the United States Environmental Protection Agency (USEPA 1993), erosion control on construction sites can average as high as 85 percent under proper application of erosion control best management practices. These erosion control practices are the first line of defense in preventing sedimentation into nearby waterways. In addition to erosion control practices, MVP will implement a variety of sediment containment practices, including, but not limited to: the establishment of construction entrances, creation of sedimentation barriers (e.g., silt fences [including j-hook fences], straw bales, compost filter socks), temporary ROW diversions, and sediment basins and traps.

As a first step in any land-disturbing activity, sediment basins, traps, and barriers are constructed and installed. Sediment basins are designed to promote settling of sediment by reducing flow velocities. As with most sediment containment practices, performance estimates vary widely among studies with some estimates as low as 55 percent (USEPA 1993); however, according to Zech et al. (2012), these features can remove approximately 85 percent of suspended solids within sediment laden runoff. Galetovic (1998) suggested that these basins can be thought of as closed-outlet terraces for the purpose of estimating soil containment, and containment is a direct function of particle or aggregate size, with coarse particles having a containment as high as 99 percent and fines having a containment of 86 percent. According to a USEPA study on the impacts of oil and gas exploration on water quality, modeled annual average sediment reductions ranged from 77 to 93 percent (Banks and Wachal 2007); interestingly, the study also found that reductions did not decrease with increased slopes but rather decreased as a function of rainfall intensity.

In addition to sediment basins and traps, sediment barriers are installed to intercept and detain sediment from disturbed areas and to decrease the velocity of sheet flows. Silt fences are the current industry standard because of their long lifespan (six-month effectiveness), strong construction, and high removal efficiencies (Banks and Wachal 2007). Their reported performance varies among numerous studies. Most laboratory studies conducted using flumes show relatively high rates of containment. For example, Farias et al. (2006) demonstrated sediment reduction between 93 and 96 percent, and Risse et al. (2008) evaluated containment at varying slopes (up to 59 percent) and found that containment remained upwards of 80 percent across all trials. Bench-scale testing studies have also suggested high efficiencies, ranging from 72 to 89 percent containment (Faucette et al. 2008). Because of the uncontrollable nature of real storm and rain events on the landscape, containment studies involving field testing are difficult and have had mixed results. Field-scale tests represent a compromise between laboratory and field tests, allowing for the ability to incorporate conditions relevant to typical installations while operating in a controlled environment that allows for standardized testing procedures. Field-scale testing has become common practice for the assessment of erosion and sediment control best management practices (BMPs) or sediment retention devices because they incorporate full-scale, "as installed" conditions. A recent study involving field-scale testing conducted by Dubinsky (2014) evaluated containment at a variety of slopes and rainfall events and found that overall average projected performance efficiency ranged from 48 to 87 percent with a mean and median of 79 and 86 percent, respectively. The 79 percent from Dubinsky (2014) represents a reasonable expectation of overall performance efficiency.

Newly emerging sediment perimeter controls, such as compost filter socks, are more often three-dimensional unlike the planar silt fence. With the three-dimensional design, these sediment containment devices allow runoff to flow through at higher rates; thus, there is less propensity for ponding, and the lower pressure reduces the chance of failure from overtopping and undermining (Faucette et al. 2009). For example, Faucette et al. (2008) and Faucette et al. (2009) found that removal efficiencies of compost filter socks ranged between 64 and 88 percent with a mean of approximately 80 percent.

Within the RUSLE, sediment containment is incorporated through the use of a support practice factor; however, many of the erosion control practices are likely to affect the cover and management factor as well. Using the review provided above, a support practice factor of 0.21 (i.e., 79% containment) is used to model the benefits of erosion and sediment control practices. This value is chosen because it is the mean reported value for both silt fences and compost filter socks, two predominant controls proposed to be used on the Project ROW.

In addition, these field-scale tests look exclusively at the performance of the perimeter control in isolation without consideration of other erosion controls and sediment detention devices. MVP intends to use a variety of BMPs in addition to sediment barriers, including, but not limited to, trench breakers, permanent slope breakers, temporary seeding, mulching, soil stabilization mats and blankets, rock check dams, temporary ROW diversions, and/or sediment basins and traps. Denuded areas remaining idle for more than 14 days will be stabilized with temporary seeding. Stabilization through temporary seeding will occur within seven days for areas within a Clean Water Act 303(d)-impaired watershed and in Craig Creek Watershed areas. In addition, temporary spoil piles will be mulched/seeded at the end of each day that they are generated within the Craig Creek Watershed. Although mulching and seeding have been incorporated into the estimate of the cover management factor within the RUSLE applied for the proposed pipeline, these BMPs have not been incorporated directly into the cover management factor of the model. The use of these devices will further limit soil erosion and slow and/or pond runoff to encourage sedimentation within the limits of disturbance rather than at the sediment perimeter control. In combination, these measures will reasonably attain a sediment containment of 79 percent or higher.

MVP recognizes and understands the variability in sediment control performance as a function of proper installation and maintenance. For that reason, MVP is committed to proper installation, maintenance, and frequent inspections to reduce BMP failures or inadequacies. MVP, at the request of the Virginia Department of Environmental Quality (VADEQ), has developed Project-Specific Annual Standard and Specifications for review and approval. The Annual Standards and Specifications outline the BMPs, stormwater management methods, and site restoration measures that are proposed for use on the Project and explain in specific detail the installation and maintenance requirements of all proposed BMPs. The Annuals Standards and Specifications outline the inspection staffing requirements for Project activities in Virginia, including, at a minimum, one Lead Environmental Inspector and at least one Environmental Inspector per construction spread. In addition to the MVP inspectors, the FERC will employ a third-party inspector, and the VADEQ will also have inspectors. VADEQ oversight of the Project will include pre-scheduled and random site inspections for the Project. BMP inspections will occur:

- immediately following initial installation of erosion and sediment controls;
- on a daily basis in areas of active construction or equipment operation;
- on a weekly basis in areas with no construction or equipment operation;
- to ensure revegetation/restoration requirements are being met;
- within 24 hours of a rainfall event producing 0.25 inch of rain or greater over 24 hours; and
- until Project completion.

Based on these commitments and increased inspection requirements and presence of both federal and state environmental inspectors, it is reasonable to assume 79 percent sediment containment. However, most sediment controls are designed only to withstand runoff from a 2-year, 24-hour storm event. If rainfall were to exceed this amount, sediment containment may be less.

2.3.6 Special Conservation Measures within the Craig Creek Drainage

During preliminary analyses, it was recognized that sediment produced by the Project may impact the Craig Creek mainstem up to several miles downstream of the Project footprint. In order to limit this potential, several conservation measures were developed for this basin that will help minimize sedimentation into this important waterbody. These measures include: 1) a construction timeline that immediately follows tree clearance with the Craig Creek drainage, 2) a restoration timeline that follows within eight weeks of temporary stabilization, 3) a regimen that includes mulching areas denuded for more than four days, 4) a schedule that involves mulching backfilled areas of the trench within four days, and 5) the continuation of temporary sediment controls for one year after seeding. All of these factors are included within this analysis.

2.4 Estimating Sediment Delivery

The RUSLE provides an estimate of the expected soil loss per unit of interest for the entire study area; however, not all sediment is expected to continue into downstream areas. The proportion that does continue downstream is expected to vary with catchment size, with the headwaters producing relatively more sediment than lower, flatter portions of the watershed. Based on this concept, sediment delivery ratios are used to predict the proportion of sediment expected to reach the outlet of each catchment. More specifically, the sediment delivery ratio is modeled using Boyce (1975) upland theory as:

$$SDR_w = 0.417762 \times A_w^{-0.134958} - 0.127097, \qquad \text{Eq. 4}$$

where A_w is the drainage area of the stream segment in square miles and SDR_w is the estimated sediment delivery ratio based on the curve within the sedimentation section of the Natural Resources Conservation Service (NRCS) National Engineering Handbook (1983). Thus, to calculate the expected sediment load for any given stream segment (L_w), the following equation based on Fernandez et al. (2003) is used:

$$L_w = \sum_{i=1}^{n} (A_i * a) * SDR_W\ , \qquad \text{Eq. 5}$$

where i indexes the n raster cells within the catchment, A_i is the expected sediment loss for cell i based on the RULSE from Eq. 1, and a is a conversion factor from square meters to acres. In this study, 10-meter (32.8-ft) resolution rasters are used with a cell area of 100 square meters (1076.4 ft^2). Thus, to convert to standard units, a is equal to 0.0247105.

Calculating sediment loads in this manner assumes that sediments are continually transported downstream; however, most sediments will likely stop at the nearest dam. Although the ultimate fate of anthropogenic sediments are estuarine and/or marine environments (e.g., Gulf of Mexico), instream impoundments (e.g., mill, low-head, reservoir, etc.) can arrest the majority of these sediments (Maneux et al. 2001). To account for this phenomenon, two types of upstream catchments are delineated: (1) total catchment area and (2) catchment area below impoundment. Only cells that are members of the catchment area below impoundment can contribute to the sediment load calculation in Eq. 5. Both total catchment area and catchment area below impoundment are calculated using ArcHydro, which utilizes both raster information (e.g., flow direction grid) and vector networks (i.e., NHD) to delineate catchments and adjoining catchments. To account for impoundments within the stream network, the NHD waterbodies layer is used; however, only features with the FType of "Lake,", "Pond," or "Reservoir" are used as potential impoundments. Although this layer represents an underestimate of the number of impoundments present within a given stream network (compared to the National Inventory of Dams ([NID]); the NHD waterbodies are georeferenced to the NHD and provide common identifiers to join the two feature layers together.

Using the sediment load calculated in Eq. 5, a sediment yield is calculated by dividing the load by the catchment area.

2.5 Identifying Areas for Sediment Deposition

The RUSLE does not include a model for sediment transport or deposition. Instead, transport is included by applying a sediment delivery ratio, as in Eq. 4 and 5, to estimate the sediment loads within waterbodies using Boyce (1975) upland theory. Although quantifying the amount of sediment deposition requires a complex hydrological model, identifying the likely locations of deposition can be done remotely without extensive field measurements. Sediment transport is directly related to stream power (Ω), which can be approximated as the product of stream discharge (Q), energy gradient (S), the density of water (ρ), and gravity (g):

$$\Omega = \rho \times g \times Q \times S, \qquad \text{Eq. 6}$$

where S is equivalent to channel slope in uniform flow and ρ and g are constants of 62.3 lb/ft^3 at 68^{0}F and 32 ft/s, respectively (Bagnold 1977). Dividing stream power by the flow width (w) provides an estimate of the energy expenditure per unit bed area of channel (i.e., mean stream power; ω):

$$\omega = \Omega/w. \qquad \text{Eq. 7}$$

Stream power represents the functional forces available for sediment transport. Whereas Ω is related to river channel dimensions and channel mobility thresholds, ω is related to channel dynamics, bedload transport, and bed sediment entrainment (Lea and Legleiter 2016). Thus, the mean stream power gradient ($\partial\omega/\partial s$) may indicate areas where transport capacity increases (i.e., erosional areas) and decreases (i.e, depositional areas). Following Lea and Legleiter (2016), mean stream power gradient is estimated as:

$$\frac{\partial \omega}{\partial s} = \frac{\omega_i - \omega_{i-1}}{l}, \qquad \text{Eq. 8}$$

where $\partial \omega$ represents change in power, ∂s represents change in space, ω_{i-1} is the mean stream power at the outlet of the next upstream stream segment on the largest flow path, ω_i is the mean stream power at the outlet of the segment of interest, and l is the length of the stream segment.

Stream power is estimated using bankfull discharges and widths derived from regional curves for streams (Keaton et al. 2005) and slopes based on the DEM (see Appendix A). More specifically, a hydrologic network is generated from the DEM, and stream slopes are estimated as the quotient of the change in elevation and the stream length. Bankfull discharges are estimated as:

$$Q = 43.249 \times (A_w)^{0.7938}, \qquad \text{Eq. 9}$$

where Q is the discharge in cubic-feet-per-second and A_w is the drainage area of the stream segment in square miles. Stream width (w) in feet is estimated as:

$$w = 12.445 \times (A_w)^{0.4362}. \qquad \text{Eq. 10}$$

Areas of deposition are identified as stream segments with a negative stream power gradient within segments downstream of the LOD with a 10 percent increase or larger in sediment load.

2.6 Data Analysis

Using the RUSLE, soil loss, sediment loads, and sediment yields are compared for both baseline and proposed action treatments. All parameters are developed within a GIS environment using a 10-meter (32.8-foot) resolution. Given that the NLCD has a coarser resolution, nearest neighbor resampling is used to align the database with other datasets. A descriptive analysis is provided in Appendix A that includes Python, R, and ArcGIS Raster Calculator scripts used to generate soil loss and sediment delivery.

Using these methods, sediment loss is investigated at several scales. First, active sediment detachment within the LOD is investigated by estimating soil loss using the RUSLE for both baseline and proposed action treatments. Second, sediment delivery within intersecting catchments is investigated by estimating sediment yields for both baseline and proposed action conditions. These sediment yields are restricted to the amount that is expected to be transported into the respective stream reach. Yields are reported on a yearly rate. Third, expected sediment loads within streams are estimated for all stream reaches within the study area intersecting and downstream of the Project area within the JNF. Note that the RUSLE analysis is performed using the entire Project line and not just the construction corridor within the JNF. Thus, impacts downstream represent cumulative impacts of construction, restoration, and operation. Because no sediment routing is performed within stream reaches, sediment delivery is assumed to be a function of drainage area (see Section 2.4).

Unfortunately, no nationally accepted sedimentation standard or exceedance threshold is available. Attempts to establish such a standard have been stymied by five ecological realities (Kemp et al. 2011): 1) the amount of sediment inputs to streams exhibits substantial natural variation, 2) sedimentation regimes may differ in portions of the same stream based on highly localized factors such as riparian land cover, 3) sediments from different geological sources may have different physical properties and biological effects, 4) even closely related aquatic taxa may respond in markedly different ways to similar levels of sediment, and 5) different life stages of a single species may respond in markedly different ways to similar levels of sediment. Without a nationwide standard, different regulatory entities use a wide variety of metrics, such as turbidity and total suspended solids, to assess potential changes associated with sedimentation. Threshold values may vary widely among state and tribal agencies (USEPA 2003), and metrics such as turbidity are sensitive to a variety of chemical and biological factors (such as algae and tannins) and may not clearly represent conditions related specifically to sediment inputs. Despite these inconsistencies, one commonly used impact threshold is one in which the metric of impact is increased by 10 percent or more (USEPA 2003). This approach recognizes the biological reality that even a relatively small (in absolute terms) amount of sediment may degrade a pristine stream, while a larger amount might be needed to further degrade a historically impacted stream. Therefore, to identify the extent of sedimentation effects from the proposed action on JNF (i.e., Cumulative Effect boundaries), stream segments downstream with a 10 percent increase over baseline in maximum yearly load are delineated.

From a sensitive-species perspective, a 10 percent increase over background would likely be within the normal variance experienced in a stream system. NCASI (1999) demonstrated that the natural variation in streams is relativity high such that a 50 to 100 percent increase in sediment yield represents one standard deviation of the long-term mean (i.e., the coefficient of variation). With this high variability, detecting sediment increases in streams is fairly difficult. For example, following the equations provided in NCASI (1999), detecting a 10 percent increase in sediment load or yield given a coefficient of variation of 50 percent would require 96 years of data:

$$96 \approx \left(\frac{1.96}{10} \times 50\right)^2. \qquad \text{Eq. 11}$$

In implementing the Endangered Species Act (USFWS and NMFS 1998), the U.S. Fish and Wildlife Service has indicated that insignificant effects relate to the size or severity of the impact and are effects that are undetectable, not measurable, or so minor that they cannot be meaningfully evaluated.

3.0 Results

One hundred and seven subwatersheds are within the hydrologic study area for the proposed action. These subwatersheds contain a cumulative drainage area of 3,944 square miles spanning over the Eastern Continental Divide with 3,677 square miles draining to the New River, 112 square miles draining to the James River, and 51 square miles draining to the Roanoke River. The majority of the study area is forested (64%), but developed and planted/cultivated land uses account for 7 and 27 percent, respectively, according to the 2011 NLCD. Approximately 12 percent (478 mi^2) of the study area is within the JNF.

The proposed action within the JNF is largely confined to three subwatersheds within the study area: Stony Creek, Clendennin Creek-Bluestone Lake, and Trout Creek-Craig Creek. In addition to these subwatersheds, the proposed action also crosses the Rich Creek (050500020601) and Dry Run-North Fork Roanoke River (030101010201) subwatersheds; however, within the JNF, the proposed action only comprises a small portion of each of these catchments. In total, the proposed action within the JNF intersects the unique catchments of 29 stream segments (Table 3): 8 within the Stony Creek Subwatershed, 13 within the Clendennin Creek-Bluestone Lake Subwatershed, 6 within the Trout Creek-Craig Creek Subwatershed, 1 within the Rich Creek Subwatershed, and 1 within the Dry Run-North Fork Roanoke River watershed.

3.1 Baseline Erosion and Soil Loss

Baseline soil loss within the LOD varies substantially within the vicinity of the JNF. Mean soil loss is lowest within the Rich Creek subwatershed and highest within the Clendennin Creek-Bluestone Lake subwatershed (Table 3). Maximum estimated soil loss is 140 tons per acre per year occurring within the proposed LOD within the Kimballton Branch catchment (Table 3).

Although soil loss is moderate under baseline conditions, it is not expected that all sediment will reach streams immediately downgradient, but rather, only a portion of the sediment produced will be transported to the stream (i.e., sediment delivery). Furthermore, this soil loss is out of context of other land uses within the catchment. When put into this context, sediment yields also vary substantially over the study area. Expected soil yields (calculated at the study area outlet) are greatest within the Upper

Table 3. Predicted soil loss rates within the limits of disturbance for baseline and proposed actions for the Mountain Valley Pipeline Project in intersecting catchments within the Jefferson National Forest.

				Baseline Soil Loss in LOD‡		Proposed Action Soil Loss in LOD‡					
						Tree Clearing		Active Construction		Operations	
Reach Code*	Permanent ID*	Stream Name*	LOD† (ac)	Mean	Max	Mean	Max	Mean	Max	Mean	Max
02080201000529	40757923	Craig Creek	10.43	1	2	27	97	36	135	2	6
02080201000529	40757927	Craig Creek	2.52	<1	1	17	51	17	70	1	3
02080201000529	40757943	Craig Creek	7.14	<1	2	9	54	9	48	1	4
02080201008435	40757955	UNT to Craig Creek	5.56	<1	1	18	59	20	79	1	4
02080201008436	40757961	UNT to Craig Creek	5.72	<1	1	25	69	28	96	2	5
02080201008439	40757993	UNT to Craig Creek	2.47	<1	1	16	49	10	66	1	3
03010101005175	4432363	UNT to Mill Creek	1.43	1	1	26	45	25	63	2	3
05050002000818	43656529	Rich Creek	5.99	<1	1	17	45	22	62	1	3
05050002000843	43657617	Curve Branch	0.16	8	46	17	46	9	17	23	46
05050002000844	43657525	Curve Branch	2.76	6	108	24	108	13	43	35	113
05050002000845	43657527	UNT to Curve Branch	1.1	10	64	26	64	14	34	36	91
05050002000846	43657299	UNT to New River	1.63	8	88	24	88	13	39	35	102
05050002000869	43656979	Kimballton Branch	2.03	12	127	27	127	14	57	34	150
05050002000869	43657067	Kimballton Branch	1.58	13	140	48	140	27	53	54	140
05050002000869	43657573	Kimballton Branch	13.13	2	107	14	107	13	106	7	107
05050002003140	43656977	UNT to Kimballton Branch	15.72	0	54	7	54	7	58	2	74
05050002003160	43657065	UNT to Kimballton Branch	4.08	4	120	10	120	7	48	12	126
05050002003188	43657219	UNT to Stony Creek	2.07	0	6	4	28	1	13	0	6
05050002003200	43657297	UNT to New River	0.67	10	87	18	87	9	33	24	87
05050002003226	43657457	UNT to Stony Creek	9.45	0	2	13	91	15	127	1	6
05050002003250	43657611	UNT to Curve Branch	1.9	9	97	26	97	14	40	38	106
05050002003266	43657667	Clendennin Creek	3.75	10	72	21	72	11	36	29	95
05050002003270	43657709	UNT to Clendennin Creek	0.55	4	49	25	62	15	39	39	103
05050002003292	43657801	UNT to Clendennin Creek	1.03	4	65	11	65	6	25	16	65
05050002003339	43658059	UNT to Clendennin Creek	3.19	3	74	9	74	5	29	13	77
05050002007484	43658057	Clendennin Creek	3.28	4	54	10	51	5	28	14	74
05050002007485	43657799	Clendennin Creek	1.45	9	71	24	71	13	38	35	99
05050002007486	43657713	Clendennin Creek	0.3	3	31	14	31	8	19	21	49
05050002009526	-	UNT to Stony Creek	2.29	1	18	3	18	2	13	3	19

* Derived from National Hydrography Dataset; UNT=Unnamed Tributary.
† Area of Limits of Disturbance (LOD) within the unique catchment
‡ Sediment Loss is reported in ton/ac/yr and only represent sediment loss rates occurring in the LOD. Note that proposed tree clearing and construction will last less than one year

Table 4. Predicted yearly sediment yields for baseline and proposed action conditions for the Mountain Valley Pipeline Project in intersecting catchments within the Jefferson National Forest.

						Proposed Action									
						Year 1		Year 2		Year 3		Year 4		Year 5	
Reach Code*	Permanent ID*	Stream Name*	Area† (ac)	LOD‡ (ac)	Baseline Yield§	Yield§	Percent Inc.	Yield§	Percent Inc.	Yield§	Percent Inc.	Yield§	Percent Inc.	Yield§	Percent Inc.
02080201000529	40757923	Craig Creek	204.03	10.43	149	213	43	157	5	157	6	157	6	157	6
02080201000529	40757927	Craig Creek	107.79	2.52	53	67	27	55	4	55	4	55	4	55	4
02080201000529	40757943	Craig Creek	70.5	7.14	46	78	70	51	11	51	12	51	12	51	12
02080201008435	40757955	UNT to Craig Creek	149.35	5.56	122	166	36	129	6	130	6	130	6	130	6
02080201008436	40757961	UNT to Craig Creek	194.52	5.72	97	141	45	105	8	105	8	105	8	105	8
02080201008439	40757993	UNT to Craig Creek	71.81	2.47	195	237	22	200	3	201	3	201	3	201	3
03010101005175	4432363	UNT to Mill Creek	82.83	1.43	130	231	78	157	21	143	10	136	4	136	4
05050002000818	43656529	Rich Creek	249.77	5.99	72	143	99	93	30	80	11	76	6	76	6
05050002000843	43657617	Curve Branch	128.77	0.16	141	141	0	141	0	144	2	145	3	145	3
05050002000844	43657525	Curve Branch	144.58	2.76	121	127	5	127	4	225	85	261	115	261	115
05050002000845	43657527	UNT to Curve Branch	89.65	1.1	140	138	0	130	0	199	42	224	60	224	60
05050002000846	43657299	UNT to New River	165.31	1.63	115	116	1	114	0	159	38	176	52	176	52
05050002000869	43656979	Kimballton Branch	256.07	2.03	118	119	0	111	0	145	23	158	33	158	33
05050002000869	43657067	Kimballton Branch	43.81	1.58	206	276	34	213	3	422	105	497	142	497	142
05050002000869	43657573	Kimballton Branch	344.61	13.13	108	160	48	120	11	135	25	139	29	139	29
05050002003140	43656977	UNT to Kimballton Branch	223.83	15.72	36	112	216	58	62	59	66	59	66	59	66
05050002003160	43657065	UNT to Kimballton Branch	72.3	4.08	140	158	13	119	0	216	55	251	80	251	80
05050002003188	43657219	UNT to Stony Creek	270.18	2.07	67	72	7	69	2	68	1	68	<1	68	<1
05050002003200	43657297	UNT to New River	63.18	0.67	148	142	0	133	0	171	16	185	25	185	25
05050002003226	43657457	UNT to Stony Creek	99.71	9.45	77	357	361	159	105	116	50	92	19	92	19
05050002003250	43657611	UNT to Curve Branch	153.58	1.9	166	166	1	163	0	225	36	249	50	249	50
05050002003266	43657667	Clendennin Creek	306.51	3.75	108	105	0	98	0	141	32	158	47	158	47
05050002003270	43657709	UNT to Clendennin Creek	110.73	0.55	107	111	3	113	5	144	34	156	45	156	45
05050002003292	43657801	UNT to Clendennin Creek	177.25	1.03	111	111	<1	111	0	123	11	128	15	128	15
05050002003339	43658059	UNT to Clendennin Creek	522.78	3.19	99	99	1	99	0	108	9	111	13	111	13
05050002007484	43658057	Clendennin Creek	365.27	3.28	100	100	0	99	0	110	10	114	15	114	15
05050002007485	43657799	Clendennin Creek	79.05	1.45	144	143	0	137	0	205	42	230	59	230	59
05050002007486	43657713	Clendennin Creek	67.43	0.3	99	100	1	101	2	112	14	116	18	116	18
05050002009526	-	UNT to Stony Creek	206.11	2.29	31	35	12	32	3	35	13	36	17	36	17

* Derived from National Hydrography Dataset; UNT=Unnamed Tributary.
† Unique area draining to stream segment.
‡ Area of Limits of Disturbance (LOD) within the unique catchment
§Sediment Yields are reported in $ton/mi^2/yr$ and only represent sediment produced within the respective unique catchment.

Roanoke portion of the study area (85 tons/mi^2 yr^{-1}) and lowest within the New River portion of the study area (15 tons/mi^2 yr^{-1}). Within catchments crossed by the proposed Project, baseline sediment yields range from 31 to 206 tons per square mile per year (Table 4). Given the large hydrologic study area, sediment loads in streams downstream of the Project area vary greatly. As expected, total sediment loads (i.e., loads accounting for all upstream catchment areas) are smallest with the headwater systems and increase with catchment area (Table 5). At the three most downstream points within the study area in the New River, Craig Creek, and North Fork Roanoke River, expected baseline sediment loads are 18,471; 4,924; and 3,723 tons per year, respectively. Note that these estimates do not include any sediment produced upstream of a lake or reservoir (e.g., Claytor Lake).

3.2 Proposed Action Erosion and Soil Loss

Average soil loss within the LOD is expected to occur at a higher rate than baseline conditions for all areas of the Project within the vicinity of the JNF (Table 3). Soil loss is expected to be highest during tree clearing and active construction and lowest during operations.

All catchments that intersect the proposed route and the JNF are expected to have increased sediment yields due to the proposed action (Table 4), and nearly all catchments are predicted to have an increase in sediment yield of 10 percent or greater within the first year (Table 4). During the first year, the highest expected percent increase in sediment yield will likely occur within an Unnamed Tributary to Stony Creek where yields increase from 77 tons/mi^2 yr^{-1} to 357 ton/mi^2 yr^{-1}. Increases in excess of 75 percent are also expected in unnamed tributaries to Mill Creek, Kimballton Branch, Stony Creek, and Painter Run as well as directly in Rich Creek (Table 4).

Although for most catchments, sediment yields decrease with each consecutive year after construction, yields for several smaller order streams (n=8) continue to be in excess of 50 percent over baseline after the landscape has transitioned into a steady equilibrium (i.e., year 5; Table 4). These higher equilibriums are in relation to a pre-existing Forest road (Pocahontas Road; Figure 1), which will be improved for the Project. Catchments for streams that contain this road demonstrate a pattern with: (1) increased sediment during initial construction and improvement, (2) decreased sediment once construction is complete but erosion controls remain in place, and (3) increased sediment once temporary controls are removed. It should be noted that the pattern within the latter two periods represents a change in sediment delivery due to temporary erosion controls being in place and then removed, and this pattern is not due to increased soil loss within the LOD after the construction and restoration phases.

To better examine potential impacts on aquatic biota downstream of construction activities, sediment loads were also put into the context of actual stream segments with

Table 5. Total expected sediment loads in downstream streams and associated percent increase in sediment loads expected from Mountain Valley Pipeline Project in the Jefferson National Forest.

				Proposed Action									
				Year 1		Year 2		Year 3		Year 4		Year 5	
Waterbody	Location	Drainage Area (mi²)	Baseline Load*	Load Above Baseline*	Percent Inc.	Load Above Baseline	Percent Inc.	Load Above Baseline*	Percent Inc.	Load Above Baseline*	Percent Inc.	Load Above Baseline*	Percent Inc.
Craig Creek	Above Confluence with Muddy Branch	22.98	1,153	31	3	4	<1	5	<1	5	<1	5	<1
	Above Confluence with Cabin Branch	30.42	1,477	28	2	4	<1	4	<1	4	<1	4	<1
	Above Confluence with Trout Creek	44.44	1,982	26	1	4	<1	4	<1	4	<1	4	<1
	Above Confluence with McAfee Run	58.20	2,539	24	1	3	<1	4	<1	4	<1	4	<1
	Above Confluence with Broad Run	77.01	3,084	22	1	3	<1	3	<1	3	<1	3	<1
	Above Confluence with Meadow Creek	97.39	3,877	20	1	3	<1	3	<1	3	<1	3	<1
	Above Confluence with Johns Creek	109.78	4,924	20	<1	3	<1	3	<1	3	<1	3	<1
	Above Confluence with Barbours Creek	230.24	6,694	15	<1	2	<1	2	<1	2	<1	2	<1
Mill Creek	Above Confluence with North Fork Roanoke River	4.22	504	133	26	52	10	25	5	8	2	7	1
North Fork Roanoke River	Above Confluence with Indian Run	35.22	3,363	207	6	104	3	39	1	2	<1	1	<1
	Above Confluence with Slate Lick Run	45.43	3,625	194	5	98	3	36	1	2	<1	<1	<1
	Above Confluence with Wilson Creek	48.77	3,723	190	5	96	3	36	1	2	<1	<1	<1
Stony Creek	Above Confluence with Laurel Branch	36.79	1,058	0	0	0	<1	1	<1	1	<1	1	<1
	Above Confluence with Kimballton Creek	43.53	1,346	23	2	6	<1	3	<1	1	<1	1	<1
	Above Confluence with New River	48.36	1,740	111	6	17	1	16	1	10	1	10	1
Kimballton Creek	Above Confluence with Stony Creek	1.72	150	71	48	15	10	53	36	66	44	66	44
Curve Branch	Above Confluence with New River	1.20	133	1	1	0	0	34	25	46	35	46	35
Clendennin Creek	Above Confluence with New River	3.64	237	0	0	0	0	34	14	48	20	48	20
Rich Creek	Above Confluence with Mud Run	11.73	505	88	17	29	6	7	1	5	1	5	1
	Above Confluence with Crooked Creek	15.86	763	82	11	27	4	7	1	5	1	5	1
	Above Confluence with Scott Branch	25.75	1,250	73	6	24	2	6	<1	4	<1	4	<1
	Above Confluence with Brush Creek	33.04	1,410	68	5	23	2	6	<1	4	<1	4	<1
	Above Confluence with New River	52.18	2,114	61	3	20	1	5	<1	3	<1	3	<1

				Proposed Action									
				Year 1		Year 2		Year 3		Year 4		Year 5	
Waterbody	Location	Drainage Area (mi^2)	Baseline Load*	Load Above Baseline*	Percent Inc.	Load Above Baseline	Percent Inc.	Load Above Baseline*	Percent Inc.	Load Above Baseline*	Percent Inc.	Load Above Baseline*	Percent Inc.
New River	Above Confluence with Curve Branch	3421.74	17,530	166	1	64	<1	25	<1	17	<1	17	<1
	Above Confluence with Clendennin Creek	3427.18	17,551	166	1	64	<1	30	<1	23	<1	23	<1
	Above Confluence with Wolf Creek	3440.88	17,535	164	1	63	<1	35	<1	32	<1	31	<1
	Above Confluence with Rich Creek	3682.54	17,983	148	1	56	<1	32	<1	28	<1	28	<1
	Above Confluence with East River	3815.57	18,471	154	1	58	<1	31	<1	27	<1	27	<1

* Sediment loads are presented in tons yr^{-1}

total sediment loads (Table 5). Whereas the unique catchment sediment yield (Table 4) only considers the area uniquely draining to a stream segment, the total sediment load represents the amount of sediment expected to be transported to a stream outlet based on soil loss calculated from the RUSE for the entire catchment (i.e., all upstream areas) and a sediment delivery ratio (see Eq. 5). In this context, loads above baseline originate from catchments crossed by the proposed action and are expected to be transported to streams downstream of the Project Area outside the catchment of origin. Based on this approach, substantial increases in sediment loads from the proposed action are largely confined to headwater systems (i.e., 1-3 order streams; Table 5). The majority of sediment load increases are less than 10 percent; however, there are several notable exceptions, including Rich Creek (Table 5) and a portion of Craig Creek (Table 6 and Figure 4).

To further investigate the spatial extent of increased sediment loads (i.e., Cumulative Effects boundaries), maximum yearly loads (i.e., maximum load of any consecutive 52-week period) were delineated (Figure 4 and Table 6). The Clendenin Creek-Bluestone Lake Subwatershed is expected to have the largest spatial extent (12.17 miles) of sediment load increases over 10 percent. Within the Dry Run-North Fork Roanoke River, Rich Creek, and Stony Creek subwatershed, the cumulative impact area is under five miles and, with the exception of Rich Creek and Kimballton Branch, is restricted to unnamed tributaries. The smallest cumulative impact area is within the Trout Creek-Craig Creek Subwatershed, where sediment load increases in excess of 10 percent are restricted to approximately 2.21 stream miles; however, this includes a 0.29-mile stretch of the Craig Creek mainstem (Figure 4).

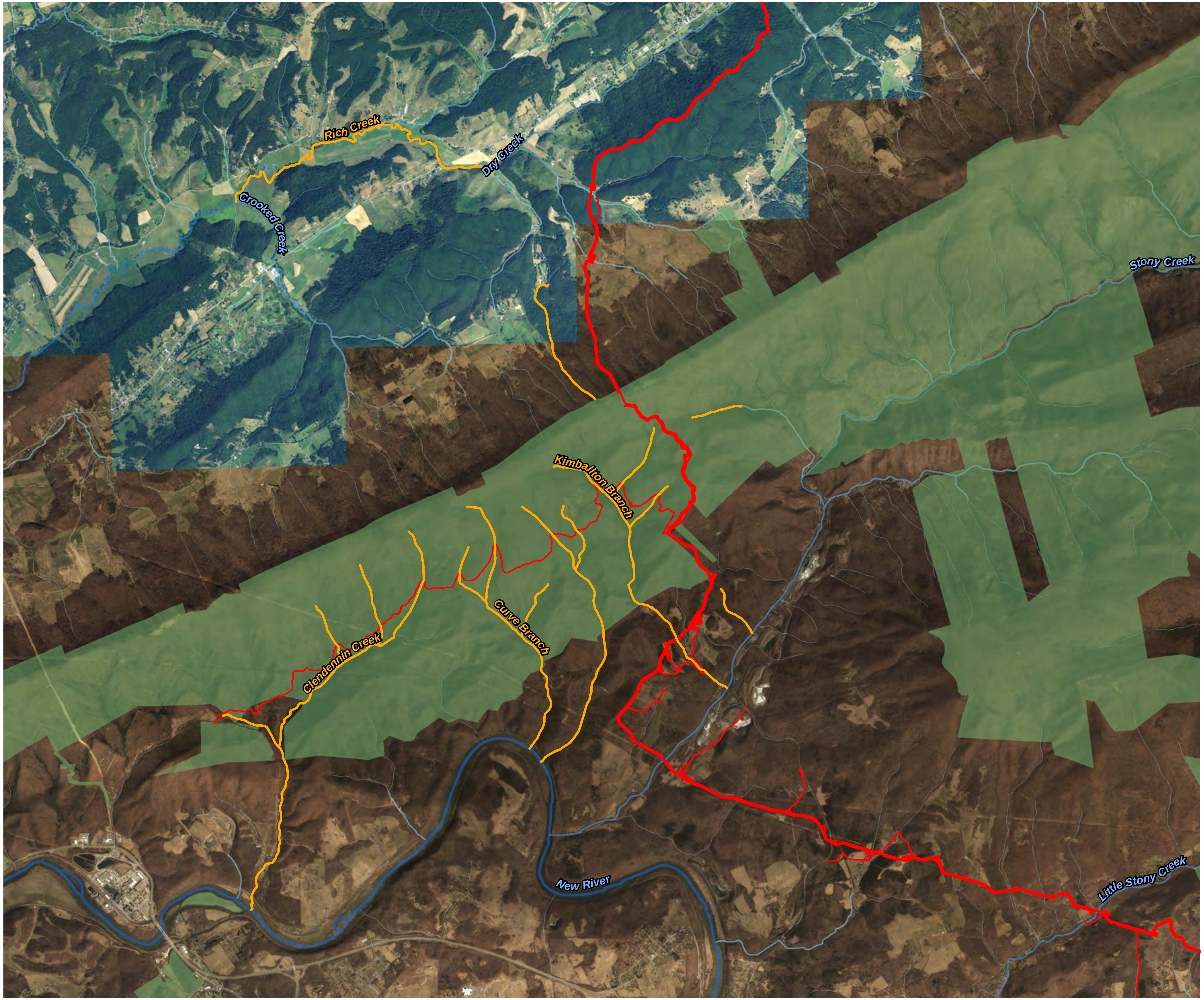
Cumulatively, approximately 28 miles of stream segments downstream of the Project Area within the JNF and within the study area are expected to have a 10 percent increase in sediment loads or more (Table 6). A large portion (nearly 13 miles) of stream impacts can be attributed to the pre-existing Pocahontas Road that will be improved for Project use.

3.3 Potential Areas of Sediment Deposition

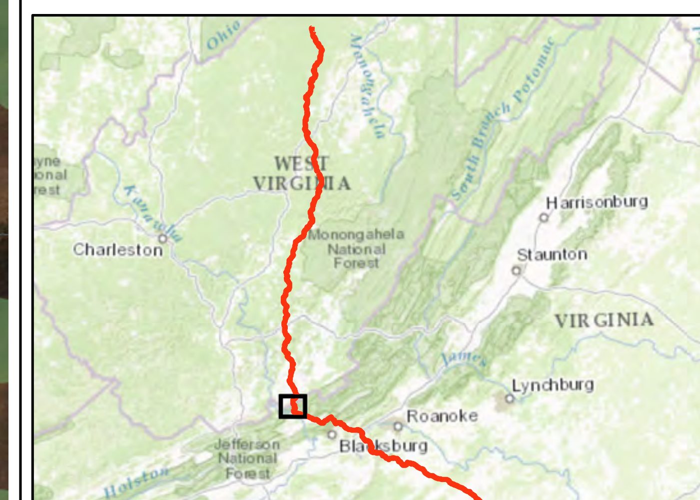
Using the mean stream power gradient ($\partial\omega/\partial s$) as an indicator of potential sediment deposition, several stream segments were identified within the cumulative impact boundaries as potential areas for sediment deposition (Table 7). The majority of these stream segments are within Craig, Mill, Rich, and Clendennin creeks and are third order or larger. It should also be noted that, in addition to stream power, channel geometry and morphology can also influence sediment deposition. For example, meander pools may have sufficient energy to mobilize sediment but not necessarily a positive stream power. Unfortunately, limited information is available within publically available datasets regarding channel geometry and morphology, and these attributes are beyond the scale of the dataset used to derive sediment loads and stream power.

Figure 4. Cumulative Effects boundaries for sedimentation increases from the proposed Mountain Valley Pipeline within the vicinity of the Jefferson National Forest in Virginia and West Virginia.

Map 1 of 2



- Stream
- Cumulative Effect Boundaries
- Proposed Route
- U.S. Forest Service (National Forest) Lands



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0 0.5 1 Miles

Base Map: ESRI ArcGIS Web service - "World Imagery" accessed - 5/19/2017

ENVIRONMENTAL SOLUTIONS & INNOVATIONS, INC.

Project No. 593.02

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Figure 4. Cumulative Effects boundaries for sedimentation increases from the proposed Mountain Valley Pipeline within the vicinity of the Jefferson National Forest in Virginia and West Virginia.

Map 2 of 2

- Stream
- Cumulative Effect Boundaries
- Proposed Route
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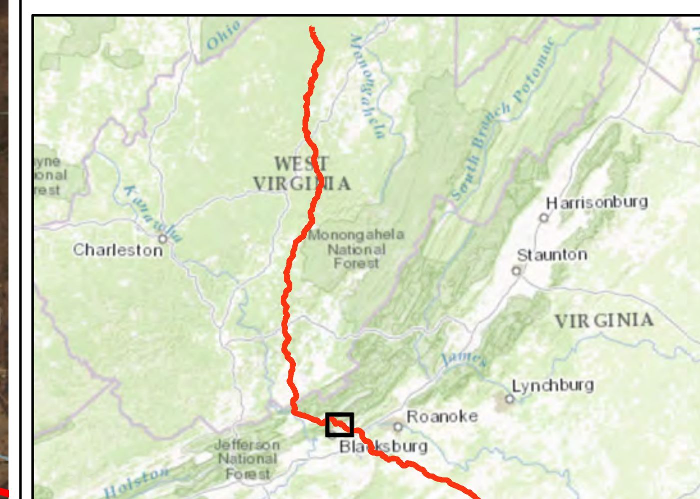

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Base Map: ESRI ArcGIS Web service - "World Imagery" accessed - 5/19/2017

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Table 6. Stream lengths in miles for streams with an expected increase in sediment load of 10 percent or greater from the proposed Mountain Valley Pipeline within the vicinity of the Jefferson National Forest.

Waterbody	Subwatershed	Stream Miles Impacted
Unnamed Tributaries to Craig Creek	Trout Creek-Craig Creek	1.92
Craig Creek	Trout Creek-Craig Creek	0.29
Unnamed Tributary to Mill Creek	Dry Run-North Fork Roanoke River	1.57
Mill Creek	Dry Run-North Fork Roanoke River	3.22
Unnamed Tributaries to Stony Creek	Stony Creek	0.88
Unnamed Tributaries to Kimballton Branch	Stony Creek	1.16
Kimballton Branch	Stony Creek	2.56
Unnamed Tributaries to Clendennin Creek	Clendennin Creek-Bluestone Lake	1.79
Clendennin Creek	Clendennin Creek-Bluestone Lake	3.82
Unnamed Tributaries to Curve Branch	Clendennin Creek-Bluestone Lake	1.05
Curve Branch	Clendennin Creek-Bluestone Lake	2.37
Unnamed Tributaries to New River	Clendennin Creek-Bluestone Lake	3.14
Rich Creek	Rich Creek	4.26

Table 7. Expected sediment depositional areas in downstream waterbodies of the Mountain Valley Pipeline within the vicinity of the Jefferson National Forest with an expected sediment load of 10 percent or greater over baseline.

Reach Code*	Permanent ID*	Stream Name	Subwatershed	Stream Length (miles)	Power Gradient
02080201000529	40757911	Craig Creek	Trout Creek-Craig Creek	0.02	-0.03
02080201000529	40757923	Craig Creek	Trout Creek-Craig Creek	0.27	-0.03
03010101000892	44325129	Mill Creek	Dry Run-North Fork Roanoke River	0.87	-0.07
03010101000893	44323513	Mill Creek	Dry Run-North Fork Roanoke River	0.51	-1.20
05050002000374	43656237	Rich Creek	Rich Creek	1.19	-0.01
05050002000375	43655711	Rich Creek	Rich Creek	0.12	-0.01
05050002000375	43655739	Rich Creek	Rich Creek	0.05	-0.01
05050002000375	43655755	Rich Creek	Rich Creek	0.05	-0.01
05050002000376	43655679	Rich Creek	Rich Creek	0.30	-0.01
05050002000378	43655365	Rich Creek	Rich Creek	0.05	-0.01
05050002000378	43655367	Rich Creek	Rich Creek	0.02	-0.01
05050002000378	43655427	Rich Creek	Rich Creek	0.02	-0.01
05050002000378	43655431	Rich Creek	Rich Creek	0.38	-0.01
05050002000378	43655437	Rich Creek	Rich Creek	0.09	-0.01
05050002000378	43655443	Rich Creek	Rich Creek	0.03	-0.01
05050002000378	43655459	Rich Creek	Rich Creek	0.07	-0.01
05050002000378	43655483	Rich Creek	Rich Creek	0.11	-0.09
05050002000843	43657931	Curve Branch	Clendennin Creek-Bluestone Lake	1.03	-0.09
05050002003339	43658059	Unnamed Tributary to Clendennin Creek	Clendennin Creek-Bluestone Lake	0.57	-0.12
05050002007482	43658655	Clendennin Creek	Clendennin Creek-Bluestone Lake	0.36	-0.11
05050002007483	43658523	Clendennin Creek	Clendennin Creek-Bluestone Lake	1.05	-0.05
05050002007484	43658057	Clendennin Creek	Clendennin Creek-Bluestone Lake	0.96	-0.01

4.0 Conclusions

The proposed Project route traverses the JNF by crossing five separate subwatersheds belonging to the New River, James River, and Roanoke River drainages. Results from the hydrologic analysis of sedimentation show that catchments within these subwatersheds are expected to experience increases in sediment yield over baseline conditions during construction, restoration, and operation with the highest expected increases occurring during the construction timeframe for most waterbodies. Sediment loss from the proposed action will likely be transported into downstream waterbodies; however, predicted total sediment loads demonstrate that these impacts will largely be confined to tributary systems and not larger order rivers (e.g., New River, North Fork Roanoke River). Notable exceptions include Rich Creek, where sediment impacts are expected to extend for greater than four miles downstream of the Project LOD. These impacts, however, can be attributed to actions that will occur on private lands and not the JNF.

For most waterbodies studied in this analysis, expected impacts to streams are greatest during the active construction phase of the Project. This pattern was also reflected in monitoring data for the Jewell Ridge Lateral natural gas pipeline in southwest Virginia (Moyer and Hyer 2009). As part of the Biological Opinion for that pipeline, East Tennessee Natural Gas was required to develop a real-time sediment input within the Indian Creek watershed of the Clinch River system. Over the 24-month monitoring period, significant increases in turbidity were observed during the construction phase; however, the magnitude of the increase was relatively small (less than 2 Formazin Nephelometric Units) and much less than the threshold (i.e., 15% increase) that was determined to be within the acceptable range. Furthermore, patterns indicated that upland runoff was the primary source of the increased turbidity, but the increase did not adversely alter the long-term water-quality conditions of the creek (Moyer and Hyer 2009).

Based on this analysis, it is expected that sediment loads and yields will reach a new sediment equilibrium approximately four to five years from the start of the Project. For the majority of streams, this new sediment equilibrium represents a one percent or less increase in sediment load over baseline conditions. However, for several streams within the New River drainage, sediment loads in excess of 10 percent over baseline are expected to represent a new sediment equilibrium. Most of these streams are in relation to the use of a pre-existing Forest road (Pocahontas Road) which will be improved for construction and operations of the Project.

It is important to note that this analysis assumes strict adherence to the FERC 2013 Upland Erosion Control, Revegetation, and Maintenance Plan and the Project Erosion and Sediment Control Plan during construction. Sedimentation is greatly influenced by the amount of bare soil exposed to erosive forces and the distance and method of transport of the eroded soil to the stream system. Adherence to these plans, as well as site-specific erosion and sedimentation control plans, will reduce sedimentation into waterbodies. In general, temporary erosion and sedimentation controls (e.g., silt fences) will be installed prior to disturbance to the soil and will be maintained throughout construction and restoration phases of the Project until permanent erosion controls are installed, restoration is complete, and planted grasses and vegetation have matured enough to inhibit erosion. Environmental Inspectors will be present at each construction spread and will aid in determining if erosion controls are properly installed, maintained, or if additional measures are necessary.

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APPENDIX A
DESCRIPTIVE ANALYSIS

Mountain Valley Pipeline Project

Docket No. CP16-10-000

APPENDIX A

METHODS USED IN HYDROLOGIC ANALYSIS OF SEDIMENTATION

JEFFERSON NATIONAL FOREST EASTERN DIVIDE RANGER DISTRICT

June 2017

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1.0 Introduction

This appendix provides examples of the analytical methods used to perform the Hydrologic Analysis of Sedimentation for the Mountain Valley Pipeline (Project) within the Jefferson National Forest (JNF). Where appropriate, references are made to the report for the Hydrologic Analysis of Sedimentation (hereafter Report).

Most operations for the Report were performed using the ArcGIS Python module ArcPy; however, a few map algebra expressions were also performed using the ArcGIS Raster Calculator tool. Data summarizations were performed using R, a free, open-source statistical package. Scripts from ArcPy, Raster Calculator, and R are provided when and where appropriate.

2.0 Data Pre-processing

Before running the Revised Universal Soil Loss Equation (RUSLE), several datasets were compiled and processed, including the National Hydrograph Dataset (NHD), the Soil Survey Geographic Database (SSURGO; Soil Survey Staff 2015), the 2011 National Land Cover Dataset (NLCD; Homer et al. 2015), the Parameter Elevation Regression on Independent Slopes Model (PRISM; PRISM Climate Group 2012), and a digital elevation model (DEM) from The National Map: 3D Elevation Program (3DEP). These datasets, by default, are a mixture of vector and raster files with different cell sizes and projections. An initial step, therefore, was to pick a common projection and cell size. All files were reprojected into the Universal Transverse Mercator Zone 17 North coordinate system, and rasters were resampled to a 10-meter (32.8-foot) resolution with an alignment to a 0,0 registration point (with all rasters using the same alignment).

In order to estimate the soil erodibility factor (K) within the RUSLE, the National Resources Conservation Service's (NRCS) SSURGO soil database was used. Although the K-factor is available within this dataset, it needs to be aggregated among soil components and/or horizons. To accomplish this, the kwfact parameter (K-factor; Whole Soil) from the dominant condition among components was used, and no aggregation was performed among horizons; the surface layer was used instead. This process was performed using the Soil Data Viewer for ArcGIS available from the

NRCS[1]. Once the kwfactor was aggregated, it was converted to a raster using the projection and alignment noted above. For a few map units, the SSURGO dataset did not contain kwfactors. In these cases, kwfactors from the STATSGO dataset were spatially joined to create a continuous dataset.

Although already in raster format, the NCLD, DEM, and PRISM rasters were reprojected into the common alignment. For continuous data, resampling was performed using cubic convolution, and for discrete data, a nearest neighbor resampling technique was used.

In addition to reprojecting the DEM, the DEM was processed to fill any sinks and burn in the NHDFlowline from the National Hydrography Dataset. This process was performed using the Automatic Watershed Delineation Toolset within the ArcGIS extension, ArcSWAT. Outputs of this process include the creation of a flow direction raster and a flow accumulation raster.

3.0 Estimating Baseline Soil Loss

As explained in the Report, a soil loss raster was estimated using the RUSLE, which takes the product of several derived metrics including land use, management, topographic, and climatic conditions. Within ArcGIS, this can be calculated as a simple raster multiplication using either ArcPy or the Raster Calculator available within the Spatial Analyst toolbox of ArcGIS. Before performing the raster multiplication, rasters must be derived representing the erositvity index (R), the topographic factor (LS), and cover and management factor (C). Note that the practice factor (P) is assumed to be 1, and thus, no practice factor raster was needed for the baseline treatment.

3.1 Soil Erosivity Factor

To calculate the R raster, the PRISM raster representing annual precipitation estimates from 1980 to 2010 was used within the following formula

$$R = 0.059 \times 0.0483 \times P_{PRISM}^{1.61}, \qquad \text{Eq. 1}$$

where P_{PRISM} is precipitation expected from the PRISM raster cell (in millimeters), and R is the rainfall erosivity in hundreds of foot-ton-inch acre^{-1} hour^{-1} year^{-1} (Renard and Freimund 1994). In this equation, 1.61 and 0.0483 are estimated regression coefficients from Renard and Freimund (1994), and 0.059 is a conversion factor to U.S. customary units. Within ArcGIS this operation can easily be performed using either the

[1] https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053620

Raster Calculator or ArcPy. For example, the ArcPy syntax for this operation is provided in Panel 1.

Panel 1. ArcPy script to calculate soil erosivity raster (`R`) given a projected and resampled PRISM raster (`Prism`).

```
import arcpy
from arcpy import env
from arcpy.sa import *
arcpy.CheckOutExtension("Spatial")
outPower=Power(Prism,1.61)
outTimes=Times(Times(outPower,0.0483),0.059)
outTimes.save(R)
```

3.2 Topographic Factor

Following Moore and Wilson (1992), the topographic factor (LS) was calculated using upslope contributing area in order to account for the impact of flow convergence. For each raster cell i, LS was calculated as:

$$LS_i = \left(\frac{A_{s_i}}{22.13}\right)^m \times \left(\frac{\sin\beta_i}{0.0896}\right)^n \times (m+1), \qquad \text{Eq. 2}$$

where A_{s_i} is the specific catchment area or the upslope contributing area per unit width of contour, β is the slope angle in radians, and m and n are constants. As suggested by Galetovic (1998), the slope length component of this equation is truncated at 400 feet. This operation can easily be performed using either the Raster Calculator or ArcPy; the ArcPy syntax for this operation is provided in Panel 2.

Panel 2. ArcPy script to calculate the topographic factor (`LS`) given a digital elevation model (`dem`) and a flow accumulation raster (`fac`).

```
import arcpy
from arcpy import env
from arcpy.sa import *
arcpy.CheckOutExtension("Spatial")
env.snapRaster = dem
env.extent = dem
env.cellSize = arcpy.GetRasterProperties_management(dem,
'CELLSIZEX').getOutput(0)
out=Divide(Times(fac,pow(int(env.cellSize),2)),int(env.cellSize))
outCon = Con(out, 0, out, "VALUE > 121.92")
out = Slope(dem, "DEGREE")
out.save(outSlope)
out=Times(Times(Power(Divide(outCon,22.13),0.4),
```

```
Power(Divide(Sin(Times(outSlope,0.01745)),0.0896),1)),(0.4+1))
out.save(LS)
```

3.3 Cover and Management Factor

The cover and management factor (C) was generated by reclassifying: the 2011 National Land Cover Database (NLCD; Homer et al. 2015) and land use classifications made during (1) bat habitat assessments and (2) wetland and stream surveys for the Project. Reclassifications were conducted using the values from Table 2 in the Report and were generated using the ArcPy script provided in Panel 3.

Panel 3. ArcPy script to calculate the baseline cover and management factor (`C`) given a projected and resampled NLCD raster (`nlcd`).

```
import arcpy
from arcpy import env
from arcpy.sa import *
arcpy.CheckOutExtension("Spatial")

out=Divide(Float(Reclassify(nlcd, "VALUE",
"11 0;21 3;22 1;23 1;24 1;31 1;41 3;42 3;43 3;52 10;71 10;81 10;82 240;90
6;95 3" ,
"DATA")),1000)
out.save(C)
```

3.4 Soil Loss

Baseline soil loss for all areas within the hydrologic study area was estimated as a product of the factors listed above. Soil loss (A) was estimated at a rate of tons per year using the following equation:

$$A = R \times K \times LS \times C \times P. \qquad \text{Eq. 3}$$

In the case of the baseline estimates, P was assumed to be 1. This operation can be easily performed in ArcPy using the syntax provided in Panel 4.

Panel 4. ArcPy script to calculate the soil loss raster (`RUSLE`) given a: erosivity raster (`R`), topographic raster (`LS`), baseline cover and management raster (`C`), and erodibility raster (`K`).

```
import arcpy
from arcpy import env
from arcpy.sa import *
arcpy.CheckOutExtension("Spatial")

P=1
```

```
out=Times(Times(Times(Times(R,K),LS),C),P)
out.save(RUSLE)
```

3.5 Estimating Sediment Loads

As described in the report, the RUSLE provides an estimate of soil loss per unit of interest for the entire study area; however, not all sediment is expected to reach waterbodies and/or continue into downstream areas. In order to estimate this quantity, a sediment delivery ratio was modeled using the Boyce (1975) upland theory as:

$$SDR_w = 0.417762 \times A_w^{-0.134958} - 0.127097, \qquad \text{Eq. 4}$$

where A_w is the drainage area of the stream segment in square-miles and SDR_w is the estimated sediment delivery ratio (NRCS 1983). Following Fernandez et al. (2003), sediment loads were estimated as:

$$L_w = \sum_{i=1}^{n} (A_i * a) * SDR_W , \qquad \text{Eq. 5}$$

where i indexes the n raster cells within the catchment, A_i is the expected sediment loss for cell i based on the RULSE from Eq. 3, and a is a conversion factor from square meters to acres. These operations were performed using a Zonal Statistic function available within the Spatial Analyst toolbox of ArcGIS. Panel 5 provides an example operation performed in ArcPy for a given identified and delineated catchment. Note that the functions used for the analysis were slightly different than those in Panel 5 given the large spatial extent; the operations in Panel 5 were provided in order to give an example.

4.0 Estimating Soil Loss from the Action

The approach to estimating soil loss and sediment loads from the proposed action was similar to the approach described for estimating baseline soil loss. The major difference was that different C and P factors were used for the Limits of Disturbance (LOD). For most activities, C factors were activity specific; however, for several restoration and erosion control measures, C factors are also spatially explicit, varying by slope (see Raster Inputs section below).

4.1 Vector Inputs

Because sediment loss was estimated using a moving assembly line approach (see Section 2.2 of the Report), a vector feature class was created that tracked the progress of different activities across the LOD with the respective cover and management factor.

Panel 5. ArcPy script to calculate sediment delivery and load for an identified catchment (`ucat`) given a soil loss raster (`rusle`). The catchment feature class should contain an estimate of the contributing catchment area (`wsarea`) in square-meters and a unique identifier (`GridID`).

```
import arcpy
from arcpy import env
from arcpy.sa import *
arcpy.CheckOutExtension("Spatial")

ZonalStatisticsAsTable(ucat,"GridID",rusle,ruslecat)
arcpy.JoinField_management(ucat, in_field="GridID", join_table=ruslecat,
join_field="GridID", fields="SUM")
arcpy.AddField_management(ucat, field_name="sdr",field_type="DOUBLE",
field_alias="Sediment Delivery Ratio",field_is_nullable="NULLABLE",
field_is_required="NON_REQUIRED")
codeblock = """def fun(x):
    y=0.417762*pow(x *0.0000003861,-0.134958)-0.127097
    if y > 1:
        return 1
    else:
        return y"""

arcpy.CalculateField_management(in_table=ucat, field="sdr",
expression="fun( !wsarea!)", expression_type="PYTHON_9.3",
code_block=codeblock)
arcpy.AddField_management(ucat, field_name="sed_load",
field_type="DOUBLE", field_alias="Sediment Load",
field_is_nullable="NULLABLE", field_is_required="NON_REQUIRED")
arcpy.CalculateField_management(in_table=ucat, field="sed_load",
expression="!sdr!* !SUM!*0.0247105",
expression_type="PYTHON_9.3", code_block="")
```

As mentioned in Section 2.2 of the Report, construction, restoration, and operation impacts were divided into three primary activities: (1) access road improvements and construction, (2) tree clearing, and (3) pipeline construction and restoration. The first step to derive the appropriate information for access roads was to sequentially numberthe access roads within a construction spread in a north-to- south direction. This sequential number is multiplied by 2, and 1 is subtracted from the product to arrive at the bi-weekly interval. For tree clearing and construction, the Linear Referencing Toolset available within ArcGIS was used. First, a linear route was created representing the progress of tree clearing at a rate of 30,000 linear feet per two-week period. Using this linear route, the LOD was split into two-week intervals representing

Table 1. Example feature class table for construction progress by week on the Limits of Disturbance.

Construction	Backfilling and Mulching	Restoration	Seeded	Establishment	Development	Reclaimed
5	7	23	25	29	51	77
7	9	25	27	31	53	79
⋮	⋮	⋮	⋮	⋮	⋮	⋮

the progress of tree clearing. A second linear route representing construction progress was created at a rate of 3,520 linear feet every two-weeks. Note that in order to account for the conservation measure of mulching piles of topsoil and subsoil, a 10-meter wide area was delineated by buffering the spoil side of the proposed pipeline centerline. This area was erased from the original LOD and merged back in as a distinct feature within the feature class. This new feature class was then split into two-week intervals representing the progress of construction. Based off of the respective construction progress, a series of different activities were projected on two week intervals, including: backfilling and mulching, restoration, seeding, establishing phase of grasses, development phase of grasses, and a reclaimed phase for the ROW. An example of this schedule is provided in Table 1. A similar schedule of events was created for the access road feature class with a schedule of events that included: 'construction', 'recovery', and 'improved' time periods with 'recovery' following 2 weeks after 'construction' and 'improved' following 4 weeks after the beginning of 'recovery' (see Section 2.2 of the Report). Note that each of these activities has an associated C-factor and in most cases a P-factor. The respective C factors are reported in Table 2 of the Report.

As noted above, three separate feature classes were created representing: access roads, tree clearance, and pipeline construction. These three feature classes were merged using a series of select queries focusing on the week of construction, erase functions, and a final merge within ArcGIS. More specifically, the total number of construction weeks were iterated, and the model diagramed in Figure 1 was applied. The output of this model was a series of feature classes that represented impacts by two-week interval. Note that the construction progress was erased from the tree clearing layer such that an area cleared would be treated as a cleared landscape until construction began within that same area. This model was iterated until all tree clearing areas were overlayed with construction progress and all access roads were populated in the dataset. As noted above, the construction and access road feature classes contained different activities representing construction, restoration, and operation (i.e., reclaimed). Based on these schedules, fields representing the respective C-factor and P-factor for the activity on a two-week interval were populated using the values provided in Table 2 and Section 2.3.5 in the Report. For time periods of mulching, backfilling, and restoration, slope specific C-factors were used (see Raster Inputs below).

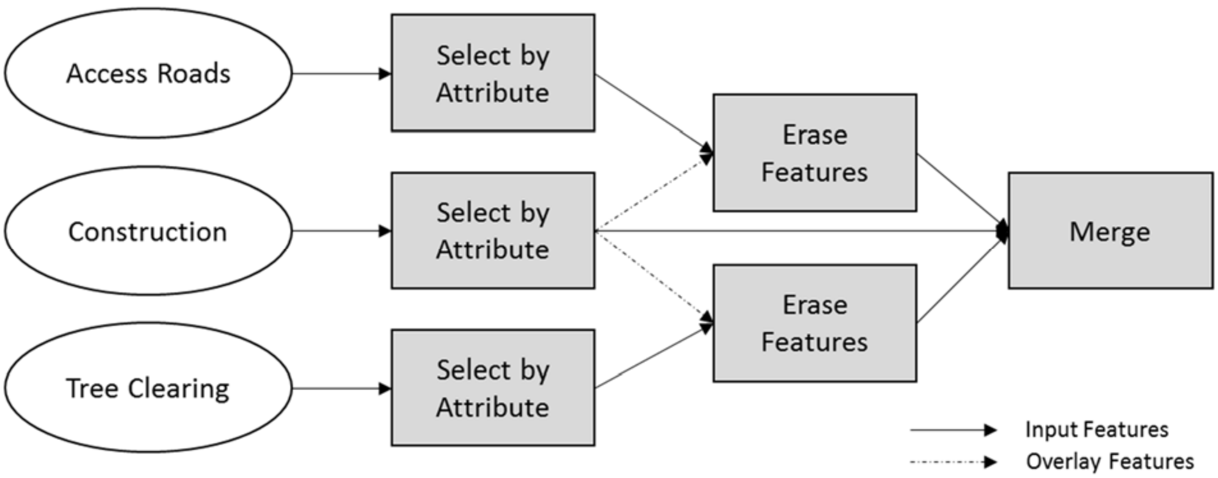

Figure 1. Example select, erase, and merge diagram to populate weekly progress feature class.

4.2 Raster Inputs

Before the RUSLE model was performed, four rasters were created that represented the cover management factor: (1) during construction, (2) when the landscape is mulched, (3) immediately following backfilling, and (4) during restoration (see Section 2.3.4 of the Report). The first raster was created by a raster conversion function in ArcGIS (see Panel 6 for an example operation in ArcPy).

Panel 6. ArcPy script to: (1) convert limits of disturbance feature class (`lod`) to a cover factor raster representing the cover management factor during construction and (2) calculate slope given a digital elevation model (dem). Note that the lod feature class requires a field entitled C_factor representing the cover factor during active construction.

```
import arcpy
from arcpy import env
from arcpy.sa import *

arcpy.FeatureToRaster_conversion(lod, 'C_factor', ccon, 10)
out=Slope(dem,"PERCENT_RISE")
out.save(slopepct)
```

The latter three rasters were directly related to the percent slope within the LOD, which was calculated using the Slope function within the Spatial Analyst toolbox within ArcGIS (see Panel 6).

With slope calculated, the C-factor for mulch was determined based off of a simple reclassification routine in either Raster Calculator or ArcPy using the values in Table 2 of the Report. An example Raster Calculator syntax is provided below:

```
Con("slopepct"<=10,0.06,Con("slopepct"<=15,0.07,Con("slopepct"<=20,
   0.11,Con("slopepct"<=25,0.14,Con("slopepct"<=33,0.17,0.2)))))
```

The output mulch raster was then used to calculate a raster representing soil loss after backfilling and during restoration. Both of these activities span less than then a two-week period, which was time frame scale in which sediment loss was measured (see Section 2 of the Report). Because disturbance is expected to be a shorter time frame, two week cover management factors were derived by a weighted average of the construction specific C-factor and a mulch specific C-factor. For example, once construction is completed, areas may remain denuded for up to 7 days following backfilling. Because this timeframe is less than 2-weeks, the C-factor was derived by multiplying the area specific construction C-factor by 7, adding 7 times a slope-specific mulching C-factor (i.e., 7 days of a mulched landscape), and dividing this sum by 14. Below is an example Raster Calculator function given a construction cover raster (`ccon`) and a mulch cover raster (`cmulch`):

```
("ccon"*7)+("cmulch"*7)/14
```

A similar calculation was made for restoration; however, the construction C-factor was multiplied by 6 days (i.e., 1 day of grading, 4 days between grading and restoration, and 1 day of restoration), and the slope-specific mulching C-factor was multiplied by 8 (i.e., 14 days in two weeks minus 6 days of the activity=8 days of mulch). Below is an example Raster Calculator function:

```
("ccon"*6)+("cmulch"*8)/14
```

4.3 Soil Loss

With the inputs calculated, estimating soil loss for a two-week period during construction was similar to the approach taken for baseline soil loss. The major difference is that within the LOD, C-factors specific to construction, restoration, or operation were used instead of the baseline C-factors. Additionally, when relevant, P-factors were also used within the LOD. An example ArcPy script to calculate soil loss for a given week is provided in Panel 7.

Panel 7. ArcPy script to calculate soil loss from the proposed action given a: digital elevation model (`dem`), mulch raster (`cmulch`), backfill raster (`backfill`), restoration raster (`rest`), erosivity raster (`R`), topographic raster (`LS`), baseline cover raster (`cbase`), erodibility raster (`K`), and limits of disturbance feature class (`lod`) containing construction, restoration, or operational C-factors. Note that the `lod` feature class has values of '999', '888', and '666' to signify areas where the mulch, backfill, and restoration rasters, respectively, are used to estimate cover factors in the RUSLE.

```
import arcpy
from arcpy import env
from arcpy.sa import *
arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput=True

env.snapRaster = dem
env.extent = dem
env.cellSize = arcpy.GetRasterProperties_management(dem, 'CELLSIZEX').get
Output(0)
arcpy.env.snapRaster = dem
desc=arcpy.Describe(dem)

arcpy.FeatureToRaster_conversion(lod, 'C_factor', rasout, 10)
arcpy.FeatureToRaster_conversion(lod, 'P_factor', rasout2, 10)
Cprop=Con(Raster(rasout)==999,cmulch,rasout)
Cprop1=Con(Raster(rasout)==888,backfill,Cprop)
Cprop2=Con(Raster(rasout)==666,rest,Cprop1)
Cnull=IsNull(Cprop2)
C=Con(Cnull==1,cbase,Cprop2)
Pnull=IsNull(rasout2)
P=Con(Pnull==1,1,rasout2)
out=Divide(Times(Times(Times(Times(R,K),LS),C),P),26)
out.save(RUSLE_PROP)
```

4.4 Estimating Sediment Loads

Sediment loads in downstream waterbodies were estimated using the approach described for baseline sediment loads in Section 3.5. An example ArcPy script is provided in Panel 5.

4.5 Identifying Cumulative Impact Areas

As described in the Report, sediment loads were compared for baseline and proposed action treatments. Using the methods provided in Sections 4.3 and 4.4, expected sediment loads within streams were estimated for all stream reaches within the study area intersecting and downstream of the Project Area. To identify the extent of sediment effects from the proposed action on JNF (i.e., Cumulative Effect boundaries), stream segments downstream with a 10 percent increase over baseline in maximum yearly load (i.e., maximum load of any consecutive 52-week period) were delineated. To estimate this increase, baseline and proposed sediment loads were exported into a comma-separated values (CSV) file with rows representing sediment loads for different catchments and columns representing each 2-week interval. Yearly loads for each 2-week interval were calculated as the cumulative sum in sediment load over the next 52 weeks. For example, the yearly load beginning in the 5th week of the Project would contain the sum of the loads between week 5 and week 56. An example script of this process is provided in Panel 8. Outputs of this script include the baseline sediment load, the maximum yearly load, the expected percent increase, and a binary indicator representing membership within the Cumulative Impact Area (1=Yes, 0=No).

Panel 8. R script to identify a Cumulative Impact Area from sedimentation. Script inputs include a comma-separated values (CSV) file with rows representing sediment loads for different catchments and columns representing each 2-week interval. Note that a column representing the yearly baseline sediment load estimate must precede the proposed action load columns.

```
#path_to_loads_csv=...
#path_to_output_csv=...
incat<-read.csv(path_to_loads_csv)

yrload<-sapply((which(names(incat)=="baseline")+1):min(seq(to=ncol(
  incat),length.out=26)),function(x)rowSums(incat[,seq(x,
  length.out=26)]))
yrload<-cbind(yrload,sapply((min(seq(to=ncol(incat),length.out=26)
  )+1):ncol(incat),function(x)rowSums(cbind(incat[,seq(x,
  length.out=26-which((min(seq(to=ncol(incat),length.out=26))+1
  ):ncol(incat)==x))],replicate(which((min(seq(to=ncol(incat),
  length.out=26))+1):ncol(incat)==x),incat[,ncol(incat)])))))
yrload<-cbind(yrload,replicate(130-ncol(yrload),incat[,ncol(incat)]*26))
maxs<-apply(yrload,1,which.max)
maxload<-sapply(1:length(maxs),function(x)yrload[x,maxs[x]])
pctload<-ifelse((maxload-incat$baseline)/incat$baseline*100<0,0,
                (maxload-incat$baseline)/incat$baseline*100)
sedimp<-ifelse(pctload>=10,1,0)
write.csv(data.frame(GridID=incat$GridID,baseline_load=incat$baseline,
  max_prop_load=maxload,pct_increase=pctload,cum_imp_area=sedimp),
  file=path_to_ouputput_csv)
```

4.6 Identifying Sediment Deposition Areas

As described in the Report, areas of sediment deposition were identified by calculating mean stream power gradient following Lea and Legleiter (2016). Stream power was estimated using bankfull discharges and widths derived from regional curves for streams within the Valley and Ridge physiographic province (Keaton et al. 2005), and stream slopes based on the DEM. In order to ensure alignment with the DEM, a hydrologic network was generated directly from the DEM using the Automatic Watershed Delineation Tool available within the ArcGIS extension ArcSWAT. Streams were set to originate at 0.25 km^2, which was chosen to be a sufficiently small catchment size in order to evaluate the areas for potential deposition. Outputs of this operation provide maximum and minimum elevations, stream lengths, and catchment areas. This information was then used to estimate stream power gradient using the R script provided in Panel 9. The output of this script was then joined to the feature class representing the hydrologic network generated from the DEM. Segments with a negative stream power gradient were then identified and manual overlayed with the National Hydrograph Dataset used in the analysis to identify areas of deposition.

Panel 9. R script to identify sediment depositional areas using mean stream power gradient. Inputs include a file geodatabase containing a feature class representing a hydrologic network as provided from ArcSWAT. Features in the network should include the following attributes: maximum elevation (MaxEl), minimum elevation (MinEl), stream length (Len2), and catchment area (AreaC). Discharge assumptions are based off of Keaton et al. (2005).

```
library(foreign)
library(rgdal)
#path_to_geodatabase="..."
#feature_class="..."
#path_to_output_csv=...
rch<-readOGR(path_to_geodatabase,layer=feature_class)@data
rch$slope<-with(rch,(MaxEl-MinEl)/Len2)
rch$w<-(12.445*(rch$AreaC*0.00386102)^0.4362)*0.3048
rch$Q<-(43.249*(rch$AreaC*0.00386102)^0.7938)*0.0283168
rch$power<-with(rch,slope*Q*9.8*998)
rch$omega<-rch$power/rch$w
powergrad<-vector()

for(i in rch$Subbasin){
  if(length(which(rch$SubbasinR==i))>0){
    powergrad<-c(powergrad,(rch$omega[which(rch$Subbasin==i)
       ]-rch$omega[which(rch$SubbasinR==i)[which.max(
      rch$AreaC[which(rch$SubbasinR==i)])]])/rch$Len2[
      which(rch$Subbasin==i)])
  }
  else{
    powergrad<-c(powergrad,NA)
  }
}
```

```
rch$powergrad<-powergrad
write.csv(with(rch,data.frame(Subbasin,w,Q,power,omega,
     powergrad)),file=path_to_output_csv,row.names=FALSE).
```

5.0 Literature Cited

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