Kentucky Geological Survey
University of Kentucky, Lexington

The Geologic Context of Landslide and Rockfall Maintenance Costs in Kentucky

Bethany L. Overfield, Daniel I. Carey, Gerald A. Weisenfluh, Rebecca Wang, and Matthew M. Crawford

Report of Investigations 34 Series XII, 2015

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Technical Level

General Intermediate Technical

ISSN 0075-5591

Contents

Contents

Figures

Tables

Tables

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Abstract

Kentucky Transportation Cabinet maintenance cost data for landslides and rockfalls were associated with geology along Kentucky roadways in a three-phase study. Work-order costs collected over 7 yr were divided into 1-mi segments, and the segment midpoints were assigned to geologic units in order to assess the most costly and frequently repaired segments according to geologic formation. Formations that were expensive to maintain were not necessarily those that were the most frequently repaired and vice versa. Costs and frequency of repair were greater in eastern and northern Kentucky, where slope and relief are greater than in other parts of the state and shale-bearing geologic units prevail.

Introduction

Geologic hazards such as rockfalls, landslides, and sinkholes are responsible for millions of dollars of construction and maintenance costs for Kentucky's highway system. Both the engineering and geologic communities know that certain geologic units and geographic regions are more prone to these hazards, but there are few data to document those relationships so that, in advance of construction, project and maintenance costs can be more accurately predicted, or at least anticipated. The Kentucky Transportation Cabinet tracks maintenance costs for a variety of categories of work, and these are compiled in its Operations Management System database. These data provide a unique opportunity to quantify maintenance costs in the context of slope and geology so that maintenance issues can be visualized in a geospatial environment.

Because the Transportation Cabinet combines landslide and sinkhole costs in its work orders, without field checking each report, there was no definitive way to differentiate between landslide and sinkhole repairs. What little field checking that did take place found no sinkholes, and the majority of maintenance costs were for nonkarst areas. Therefore, sinkhole and landslide costs were not differentiated for this study, because the majority of costs were assumed to be associated with landslides.

Kentucky is fortunate to have published, detailed geologic maps for the entire state at a scale of 1:24,000. These maps were converted to a digital spatial database over the past decade by the Kentucky Geological Survey, which allowed analytical tools to be created that could examine geologic site conditions along with other kinds of data to produce derivative maps. KGS geologists are experienced in diagnosing the context of geologic hazards, and were able to add value to both the Operations Management System and geologic data by correlating maintenance costs to specific geologic units, rock types, or other site conditions.

Analyzing the geologic context of maintenance costs related to landslides and rockfalls allows information to be extrapolated from a single site to a general area, because the behavior of most geologic units is believed to be similar under comparable geomorphic settings. In the first phase of this 3-yr project, a computer program was developed to convert records from the database into a geospatial format. In the second phase, high-incident hazard areas were investigated to document the geologic context of the sites so that maintenance costs could be directly related to geologic conditions. Geologic maps for each transportation district showing maintenance issues as they relate to geology were developed in the final phase of the project. These maps were created to enable district personnel to assess landslide and rockfall hazards in relation to geology and to predict future maintenance activities and potential costs.

Understanding Landslides and Rockfalls

Although most landslides are at least partly influenced by human-induced slope modification, the root causes of most failures are gravitational forces, local geology, and slope geomorphology combined with rainfall and associated drainage (Highland and Bobrowsky, 2008; Crawford, 2012; Potter and others, 2013). These factors can impose stresses on a slope so that the shear strength of the slope material is exceeded, causing failure. Generally, slope modification in a naturally landslide-prone area increases the potential hazard. Landslides may occur in bedrock materials, the colluvial soils that develop on them, or both.

A stable slope balances the stresses imposed upon it with the strength of the material (both soil and rock) within it. A slope will fail if those conditions are disturbed by a change in loading that increases the stress or by a change in resistance that decreases shear strength. For example, load changes if weight at the top of a slope increases by adding fill, constructing a building, or if heavy precipitation occurs. Examples of resistance changes are an increase in relative internal pore-water pressure from rapid rainfall, or, in stream banks, from water level falling rapidly in the stream; removing vegetation; expanding and contracting swelling clay soils with wet-dry weather cycles; removing the toe of a slope by engineered cuts or natural stream erosion; and weathering of weak rocks (shales) (Crawford, 2012; Potter and others, 2013). We did not attempt to differentiate bedrock from soil failures, and assumed that the bedrock units produce distinctive colluvial soils so that the bedrock unit distribution could be used to assess landslide occurrence.

Rockfalls from natural outcrops or engineered rock cuts can have a dangerous impact on roads and motorists. Fractures, freeze-thaw cycles, rainfall, construction activity, and erosion of underlying material can cause rocks of varying size to fall, blocking and damaging roads. Rockfalls often occur when a resistant rock layer is weakened by the weathering of underlying, less durable material, resulting in an unsupported overhang of the resistant rock. In addition, massive (homogeneous) rock units are often subject to failure because of structural elements such as joints, which provide the means for increased weathering and failures. Mapped geologic units in Kentucky have distinctive and variable lithologies and bedding styles that influence the susceptibility for rockfalls from outcrops, cuts, or steep slopes.

Rock Types in Kentucky Geologic Units

Shale. The majority of landslides and rockfalls in Kentucky occur in geologic units containing shale or in soils that develop on those formations (Crawford, 2012, 2014). Shale is a sedimentary rock composed predominantly of clay- and silt-size particles. Shale is abundant in most parts of the state and is interbedded with other rock types such as limestone or sandstone (Fig. 1). Many shales absorb and hold water, causing them to weather easily, erode, and potentially create stability problems (Potter and others, 2005). Differences in grain size, clay and accessory mineral composition, organic content, sedimentary fabric, and fracturing result in many distinct varieties of shale, so consequently not all shale-bearing formations have similar susceptibility to landslides and rockfalls. Anecdotal evidence associates certain geologic units with prevalent geotechnical issues, and these units or the shale layers within them are commonly characterized by distinctive color, grain size, depositional history, or mineral composition. Associating different shale types with respective geotechnical parameters, however, was outside the scope of this study.

Sandstone, Siltstone, and Limestone. Other commonly occurring rock types in Kentucky (sandstone, siltstone, limestone, and dolomite) have low-

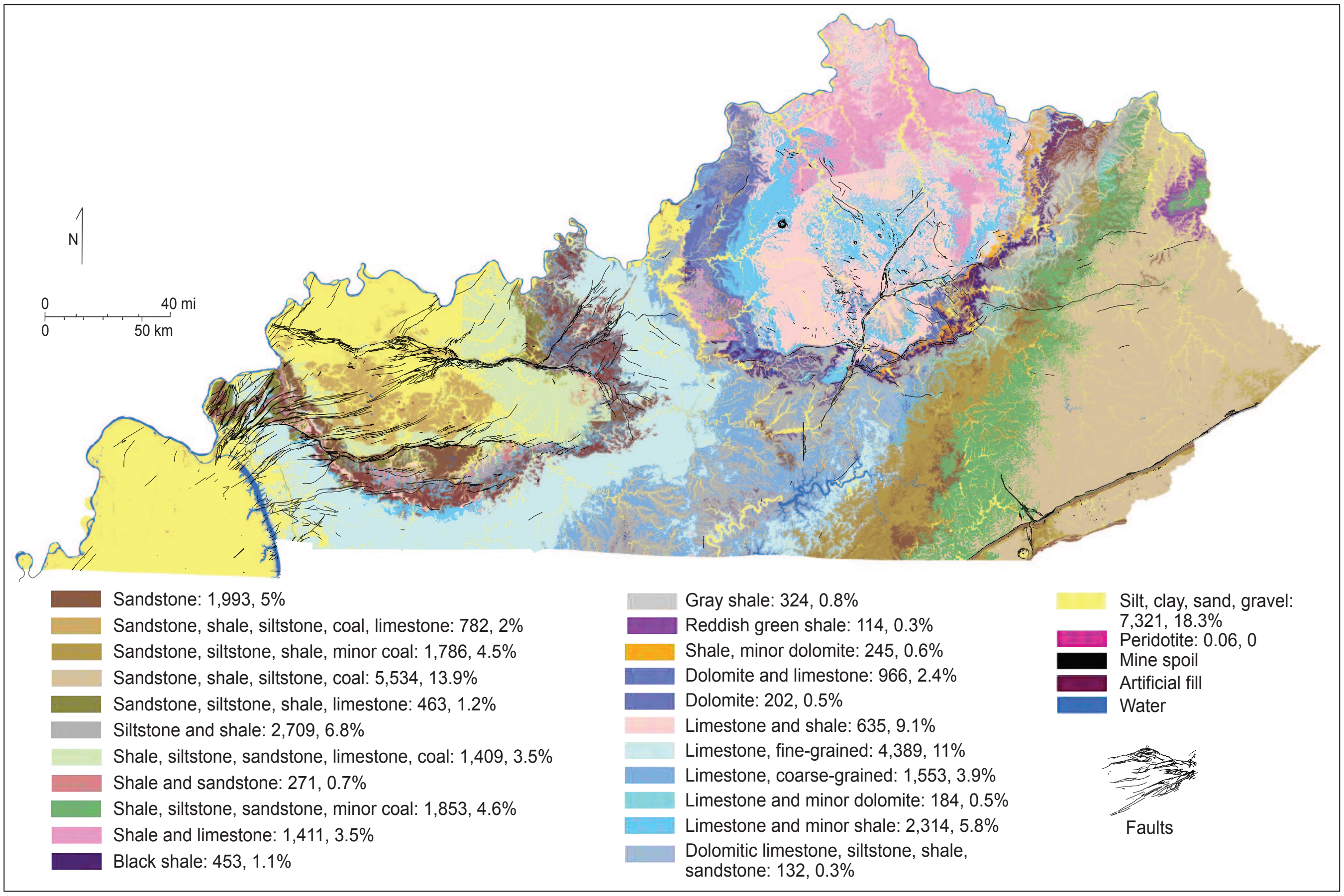


Figure 1. Percentages of bedrock and area in square miles in Kentucky.

er silicate clay contents than shale and therefore are, to varying degrees, less susceptible to weathering and landslide development. Being more resistant to erosion, these lithologies tend to form steeper slopes, however, which contribute to landslide occurrence, especially when the lithologies are interbedded with shale layers. The increased strength of these rocks when coupled with homogeneous texture and fabric makes them more susceptible to formation of through-going fractures that can contribute to rockfalls.

Geologic Maps in Kentucky

Kentucky is fortunate to have published, detailed geologic maps for the entire state at a scale of 1:24,000. The Kentucky Geological Survey converted these maps to a digital spatial database over the past decade, which allowed analytical tools to be created that could associate geologic site conditions with other data to produce derivative maps. The lithologic composition and other characteristics of the formations on these maps were described; the formations' geotechnical behaviors may have also been noted during field mapping. These data facilitated spatial comparisons between geologic formations and associated rock types to slope and other factors that may be associated with landslides and rockfalls. The Operations Management System database of maintenance costs provides measures of the occurrence of landslides and rockfalls, and is the first opportunity to quantitatively characterize the historical anecdotal information about geotechnical behavior of Kentucky geologic formations. The resulting maps can then be a useful tool for anticipating problems and attendant costs in advance of construction.

Methodology

This project was conducted in three phases. Phase I converted tabular maintenance work-order data into a GIS format, and phase II investigated the context of landslide and rockfall costs in the field. Phase III, the ultimate goal of the project, related maintenance costs to geologic context.

Phase I

Data extracts from the Operations Management System database were received for 7 yr, from 2003 to 2009. These data files contained records of maintenance work orders, in which each entry represented a specific type of activity, such as pavement repair or landslide, for a route segment along a Kentucky highway. The objectives of the data processing of these files were to divide the costs into 1-mi route segments to facilitate spatial comparison of costs and to merge the cost data with the highways layer in an ArcGIS geodatabase.

Splitting Costs Within Work Orders. Because work orders cover road segments of varying length, the costs were divided into equal-size segments for the purpose of spatial comparisons. To do this, each work order was split into 1-mi segments with a proportional amount of the work-order costs (total cost, labor, equipment, and materials) assigned to each segment. For example, if a work order for landslide repair was from highway miles 140 to 148, the cost associated with that work order would be divided into eight 1-mi segments. In cases where the mileage range did not begin or end on an even mile, partial segments were assigned a proportionally lower cost.

Aggregating Costs by Year and Activity Type. Because sites could be repaired more than once a year, costs were aggregated for individual highway segments and activity type for each year. This resulted in a new data set with only one record per 1-mi highway segment and activity type (landslide or rockfall). Summed costs were tabulated for each segment, and frequency data were added to the database to indicate how many events made up the annual costs. Some work orders referenced activities at highway locations, but without associated costs; therefore, two frequencies were tabulated: total maintenance events and only those with reported costs.

Converting Cost Data to GIS. In order to support spatial analysis, the cost data for each year were converted to geodatabase format using ArcGIS linear referencing functions. Linear referencing uses highway coverages that have been indexed with milepoint values so that tabular data located by milepoint ranges can be associated with highway segments in a GIS. The function joined the two data sets based on highway and milepoint references, and then the final data were exported to a new GIS layer to make the join permanent. Linear referencing requires a specially prepared "measure" file based on the state highway system and the corresponding 0.1-milepoint locations. Because some milepoint values may change from year to year as a result of realignments and new construction, a distinct "measure" file had to be used for each year. The Transportation Cabinet could not find some of the historical road coverages, so an adjoining year's reference file had to be used for those years.

Final Data Preparation. Maintenance-cost geodatabases were subdivided by activity type (landslide or rockfall) to facilitate analysis. In addition, the statewide geodatabases were subdivided into 12 highway districts.

Phase II

Phase II investigated maintenance repair sites in the field. Because Transportation Cabinet work orders contain no information about the geologic context of the disturbance that necessitated the work order, the context had to be investigated to fully understand the nature of the maintenance.

Creation of Base Map. The maintenance data were plotted on a map to facilitate field assessment. A comprehensive database file was created by merging all landslide and rockfall geodatabases for each year using ArcMap. This merged data file was used to create a GIS layer encompassing all transportation districts, and this layer was subsequently overlaid on a geologic formation layer.

The maintenance data set was intersected with the geology layer in ArcMap, resulting in a tabular data set that contained maintenance work information (road; beginning and ending mile segment; year of maintenance; county location; cost-labor, equipment, material, total; and number of work orders per 1-mi road segment) and geologic information (geologic formation, dominant lithology, and quadrangle).

Field Site Selection. After the base map was created, field areas were selected for site investigations based upon two main criteria: the magnitude of costs and the frequency of occurrence (repeated incidents). A number of sites had high-cost repairs; these large work orders were obvious and were indicated by high total-cost values. The repeatability value was based on the number of work orders per 1-mi road segment over the course of 7 yr. Although some of these individual cost values were small, the cumulative cost could be substantial because of multiple repairs over the years at the same location. Two other criteria in field-site selection were differing geologic settings and spatial extent of field sites. Field sites representing diverse geologic settings were selected for a more comprehensive representation of the various lithologies associated with repairs. In addition, field sites from districts with problematic repair histories were selected; therefore, sites in eastern and northern Kentucky were emphasized.

Field sites were selected based on the type of failure: landslide or rockfall. The maintenance designation was identified by the Transportation Cabinet. An effort was made to distinguish the different characteristics and mechanisms of failure resulting in landslides and rockfalls.

Field Investigations. The geologic, hydrologic, and land-use frameworks of the repaired areas were assessed at several selected field sites. Photos were taken at the repaired sites as well. During site visits, a data inventory form (Fig. 2) indicating factors relating to landslide and rockfall occurrence, geologic/geomorphologic setting, and the landslide/rockfall site was completed. Factors relating to landslide and rockfall occurrence in the field included route location and direction, county location, road usage, and mining notes. In the field, geologic/geomorphologic setting was observed, including the geologic unit(s) present, lithology, geomorphic position of failure, proximity to drainage, and outcrop details (whether an outcrop was present and vegetation coverage on outcrop). Information on landslide/rockfall site factors observed in the field included the type of failure, proximity of failure location to roadway, slope angle, and repair materials used.

The Transportation Cabinet combined landslide and sinkhole costs in its database. Without field-checking each report, there was no way to differentiate between landslide and sinkhole records. What little field checking did take place found no sinkholes, and the majority of maintenance costs were in nonkarst areas. Therefore, sinkhole and landslide costs were not differentiated for this study, because the majority of costs were assumed to be landslides.

The data inventory form was used less as an actual inventory tool (because not all repaired sites could be visited), and more as a way to assess the field parameters of interest. Understanding these parameters helped with the analytical work in phase III.

Phase III

Phase III related maintenance costs to geologic and transportation conditions. The ultimate goal of this phase was to provide Transportation Cabinet district offices with a geologically based map and accompanying report assessing maintenance repair costs. In order to complete this phase of the project, data created in phase I, along with field observations from phase II, were used to assess maintenance repair costs in each district. To fully understand the relationship between maintenance costs and geology, the area of each geologic formation in each district needed to be defined, as well as the road mileage situated in each geologic formation.

Intersecting Maintenance Data with Geologic Data. The midpoint of each 1-mi segment was determined, and a point layer was created to intersect with a statewide geologic formation layer using GIS. Midpoints were created to eliminate ambiguity along geologic unit boundaries, and to create a more manageable tabular data set. The tabular data set that resulted from the intersection assigned maintenance costs to geologic information. For every maintenance point in the data set, the geologic formation at that point was acquired, as well as the breakdown of the maintenance costs (equipment, labor, materials, and total costs). This facilitated the calculation of costs at each maintenance point in the context of geology (Fig. 3).

Calculating the Frequency of Work Orders per Mile Segment. The frequency of work orders per mile segment ("WO_CNT" column in Figure 3) was calculated by summing all work orders for a

Maintenance Project Inventory Data Sheet

Site Assessor: ___________________ Date observed: ____________________ BMP: _________ EMP: __________

# of Incidence: ____________________ Cost of repairs to date: $_______________ Year(s) repaired: _______________

Breakdown of costs: Labor ______________________ Equipment______________________ Materials___________________

LOCATION/LANDUSE INFORMATION

Route: ______________________________ *North South East West* (circle one)–bound lane

County: _______________________________________Quadrangle: ____

Road usage (circle one): *heavy moderate light* Coal/big trucks: *present prevalent*

Mining Notes (abandoned mines, active mining in area?): ____

GEOLOGIC/GEOMORPHOLOGIC SETTING

Geologic unit(s) (contact present?): ____

Lithology: ____

Geomorphic position (circle one): *upper slope mid- to upper slope mid-slope mid- to toe slope toe slope*

ridgetop floodplain terrace

Proximity to drainage: ____

Outcrop details (outcrop present? Vegetation-covered?): ____

LANDSLIDE/ROCKFALL/SINKHOLE SITE INFORMATION

General Type of failure (circle): *landslide rockfall sinkhole pavement failure*

Failure location (circle one): *above roadway above and below roadway below roadway below roadway w/stream*

natural slope natural cut slope (stream) artificial fill slope other embankment river bluffs

Slope angle/General site comments: ____

1) Y/Northing: _________________________ X/Easting: ________________________ Elevation: __________________________

Description____

2) Y/Northing: _________________________ X/Easting: ________________________ Elevation: __________________________

Description____

3) Y/Northing: _________________________ X/Easting: ________________________ Elevation: __________________________

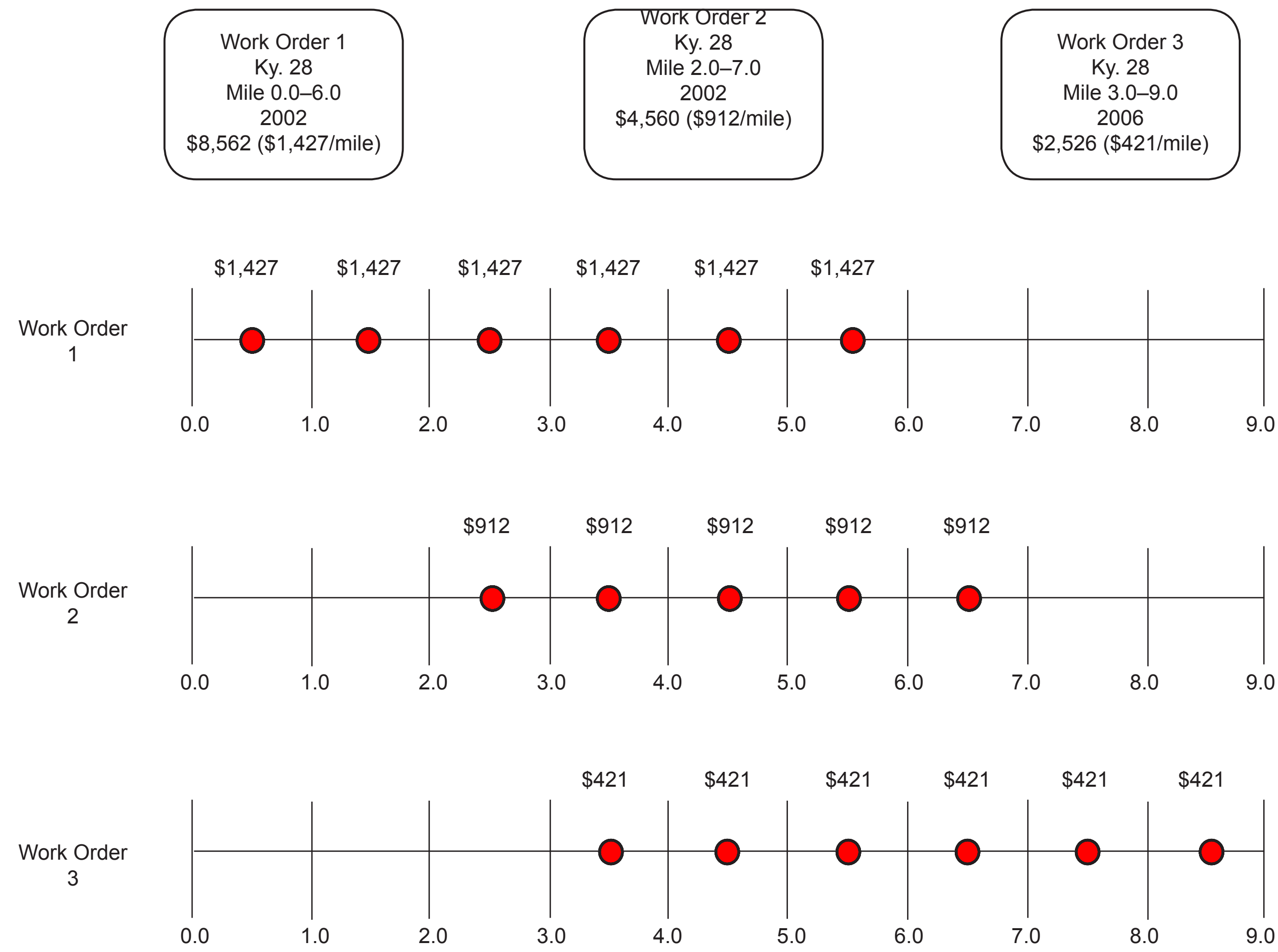
Description____

Type of repair (beams? Materials?):____

Figure 2. Phase II field data inventory form.

SegmentID	ACTIVITY_	FYEAR	RT_UNIQUE	BMP	EMP	Labor_cost	Equipment_	Material_C	Total_Cost	WO_CNT_All	formation1
FY08-09_006	Landslide	FY08-09	006-I -0064 -000	127	127.999	$7,786	$9,356	$324,090	$341,232	15	Alger Shale
FY08-09_087	Landslide	FY08-09	087-KY-0713 -000	12	12.999	$6,013	$1,994	$236,220	$244,227	22	Preachersville and R
FY08-09_087	Landslide	FY08-09	087-KY-0599 -000	3	3.999	$5,162	$3,797	$232,500	$241,459	15	Borden Formation
FY05-06_081	Rockfalls	FY05-06	081-US-0062 -000	19	19.999	$3,875	$55,558	$0	$59,433	17	Upper member of Gr
FY07-08_102	Rockfalls	FY07-08	102-US-0025 -000	26	26.999	$13,488	$11,399	$0	$24,886	8	Borden Formation
FY07-08_064	Rockfalls	FY07-08	064-KY-0645 -000	3	3.999	$6,460	$17,499	$14	$23,973	8	Hyden Formation

Figure 3. Example of the tabular data set created in phase III.



Total Cost	$1,427	$1,427	$2,339	$2,760	$2,760	$2,760	$1,333	$421	$421
No. of Work Orders	1	1	2	3	3	3	2	1	1

Figure 4. Calculation of the total cost and frequency of work orders by maintenance point using three work orders along the same road.

maintenance midpoint for all years. An example of that calculation is shown in Figure 4.

Normalizing Maintenance Costs for Exposure to Risk. Two factors could bias the analysis of maintenance costs associated with geologic units. Units with greater areal distribution would be expected to have a greater incidence of maintenance events (other factors aside). Likewise, units having more miles of developed roads would be expected to have more maintenance activities associated with them. Therefore, the total areal distribution of each geologic unit and the linear road miles in each were determined in order to control for these variables. The areal distribution of geologic units was used to rank expected outcomes. The road miles were used to normalize maintenance costs by calculating an index referred to as cost/mile/year.

Calculating Cost per Mile per Year and Data Analysis. The cost/mile/year index was calculated by intersecting the State-maintained roads GIS layer with the geologic unit layer that had previously been intersected with the Transportation Cabinet road-maintenance data. This allowed the miles of State-maintained roads in each geologic unit to be calculated. Then the maintenance cost per mile was defined. This result was divided by seven (number of years of data used) in order to calculate the cost per mile per year. Charts were created showing the number and cost of landslide and rockfall repairs per mile per geologic formation per year. Landslide repairs were separated from rockfall repairs to independently assess each type of repair.

Results

Statewide Distribution of Maintenance Costs

A statewide total of $37,465,299 was spent for work orders related to landslides and rockfalls between 2002 and 2009 (Table 1). Results are discussed in terms of Kentucky Transportation Cabinet highway districts (Fig. 5).

Of the statewide total, $27,061,529 (72 percent) was for landslide repairs. The districts with the most expensive landslide repair costs are in eastern Kentucky—Districts 9, 10, 11, and 12 (Table 1). These districts account for 63 percent of the landslide repair costs. The next most costly area to maintain is northern and central Kentucky in Districts 6 and 7, which makes up 18 percent of total landslide maintenance costs. The eastern Kentucky counties have the highest frequency of repairs.

Of the statewide total, $10,403,770 (28 percent) was for rockfall repairs. Mimicking the overall road maintenance trend and the landslide maintenance trend, the districts associated with the most expensive rockfall repair costs are in eastern Kentucky—Districts 9, 10, 11, and 12 (Table 1). These districts make up 84 percent of the rockfall repair costs. The eastern Kentucky counties have the highest frequency of repairs as well.

Road locations, topographic relief, and geology are the main contributors to the statewide distribution of maintenance costs, which are highest in eastern and northern Kentucky.

Kentucky Roads. The network of roads throughout the state is relatively evenly dispersed (Fig. 6). Population centers have more development and land-use disturbance; therefore, more roads are in these areas (most notably in the Louisville area and northern Kentucky). This might result in greater cost associations in these areas.

Relief. Another contributing factor associated with higher maintenance costs is topographic relief (Fig. 7). Roads built in areas of great topographic relief (change in elevation on the surface) have more of a chance of failure than roads in low-relief areas. Roads, especially in eastern Kentucky, are often built adjacent to waterways in steep valleys; landslides and rockfalls are prevalent in these environments. High-cost Districts 10, 11, and 12 are in areas with the highest relief in the state. Other high-relief areas occur along waterways throughout the state.

Geology. Geology is a significant contributor to high maintenance costs in the state. The two most expensive areas to maintain, eastern and northern Kentucky, are both underlain by shale units (Fig. 8). Shale is mapped in many parts of the state, but in eastern Kentucky, large heterogeneous packages of units were mapped not by lithology, but by regional marine horizons. These horizons contain mixed amounts of sandstone, siltstone, coal, and shale. Since individual shale units were not mapped separately in eastern Kentucky, they

Table 1. All maintenance repair costs and repair frequencies by district for landslides and rockfalls

Landslides					
District	*Labor Cost*	*Equipment Cost*	*Material Cost*	*Total Cost*	*Frequency of Repair*
12	$2,270,855	$1,544,377	$982,861	$4,798,092	6,441
9	$1,404,582	$1,495,979	$1,767,167	$4,667,728	3,326
10	$2,030,739	$1,170,584	$1,174,263	$4,375,586	7,482
11	$1,406,963	$812,607	$970,482	$3,190,052	5,309
6	$1,371,700	$531,127	$927,733	$2,830,561	6,686
7	$441,436	$526,781	$1,196,346	$2,164,562	1,312
2	$455,264	$468,204	$328,750	$1,252,219	1,571
4	$451,353	$338,725	$372,475	$1,162,553	2,681
8	$449,083	$240,320	$405,280	$1,094,683	1,921
5	$353,457	$220,469	$345,281	$919,207	2,442
1	$289,523	$65,129	$40,022	$394,673	426
3	$89,354	$59,472	$62,787	$211,613	835
Total	**$11,014,309**	**$7,473,774**	**$8,573,446**	**$27,061,529**	**40,432**
Rockfalls					
District	*Labor Cost*	*Equipment Cost*	*Material Cost*	*Total Cost*	*Frequency of Repair*
12	$2,021,076	$1,326,369	$29,701	$3,377,146	12,043
10	$1,628,057	$992,105	$92,334	$2,712,497	10,441
11	$874,922	$671,421	$97,896	$1,644,239	7,114
9	$458,546	$482,021	$21,681	$962,248	2,191
8	$378,135	$214,892	$42,695	$635,722	2,781
2	$102,333	$100,032	$57,984	$260,348	702
3	$114,396	$79,612	$16,422	$210,430	1,639
5	$107,339	$70,980	$4,936	$183,255	669
4	$103,246	$66,896	$6,166	$176,308	756
6	$75,513	$48,847	$5,499	$129,858	1,091
7	$50,612	$31,851	$1,289	$83,752	489
1	$16,465	$10,809	$692	$27,966	238
Total	**$5,930,640**	**$4,095,834**	**$377,296**	**$10,403,770**	**40,154**
Combined Totals	**$16,944,948**	**$11,569,608**	**$8,950,742**	**$37,465,299**	**80,586**

could not be uniquely identified and associated with repair locations.

Area and Road Miles in Geologic Formations

To assess maintenance costs according to geologic formation, the exposure to risk based on the area of each geologic formation had to be defined, as well as the amount of road mileage occurring in each geologic unit in the state (Fig. 9). Alluvium, the Pikeville Formation, the St. Louis Limestone, and loess have the greatest area and road miles occurring in them in the state. Alluvium is found throughout the state, the Pikeville Formation is found in eastern Kentucky, the St. Louis Limestone is found in south-central Kentucky, and loess occurs mainly along uplands adjacent to the Ohio River and in the Jackson Purchase Region in western Kentucky. The 19 units shown on Figure 9

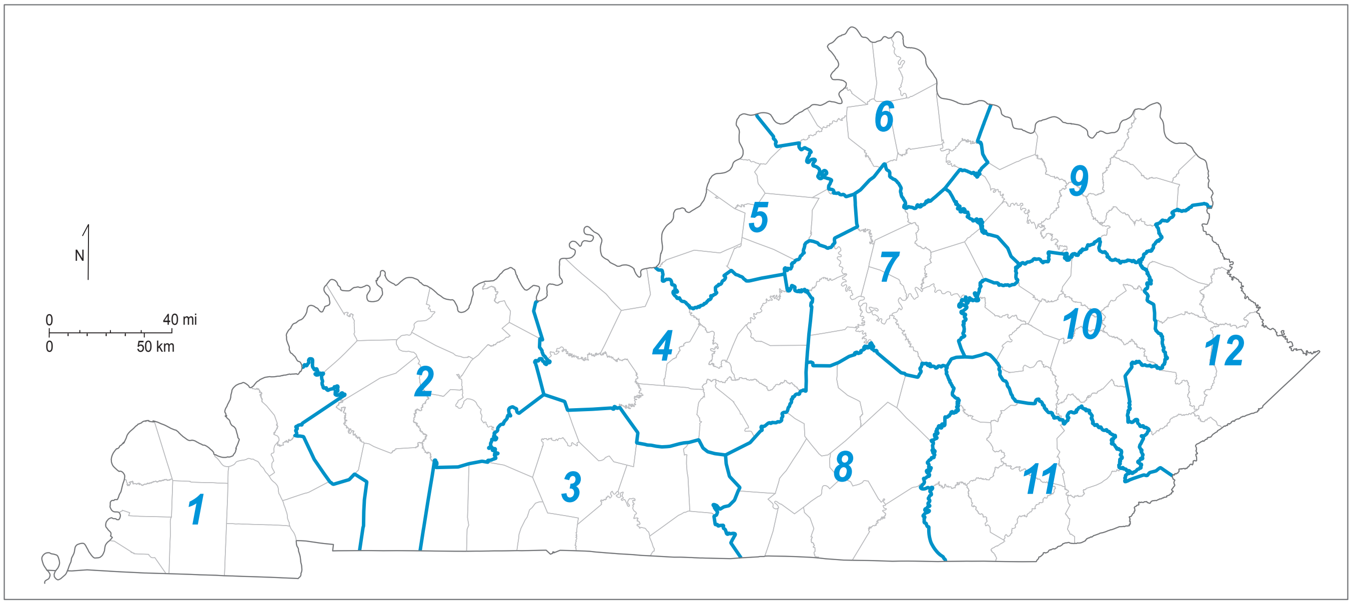


Figure 5. Kentucky Transportation Cabinet districts.

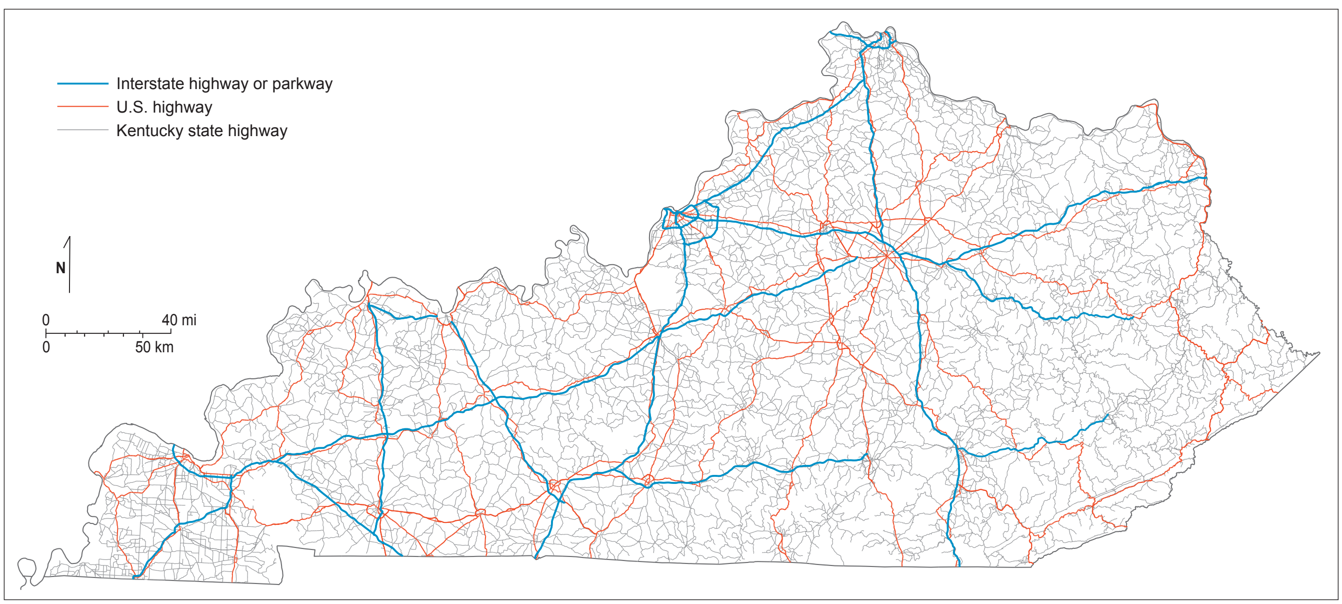


Figure 6. State highways, U.S. highways, and parkways in Kentucky.

represent only 5 percent of all mapped units in the state but make up 56 percent of the total area. Artificial fill is associated with a significant number of road miles, but was typically only mapped under roads, so those numbers can be misleading, because all roads are underlain by artificial fill to some extent. Figure 9 shows that, with some exceptions, linear road miles are correlated with areal extent of geologic units.

Alluvium

Alluvium was frequently associated with high-cost and high-frequency repairs, and is prevalent throughout the state (Fig. 10). Although it can be associated with landslides (but not rockfalls), some of the occurrences could be associated with adjoining bedrock units. Alluvium data points

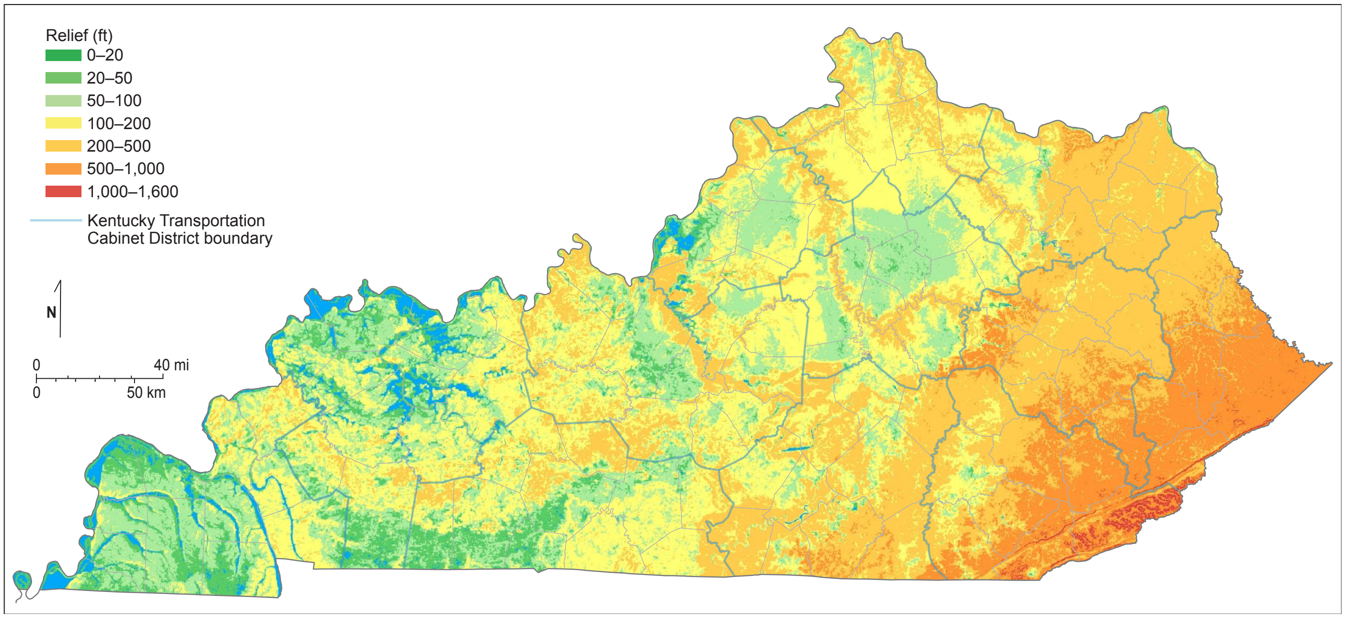


Figure 7. Topographic relief in Kentucky.

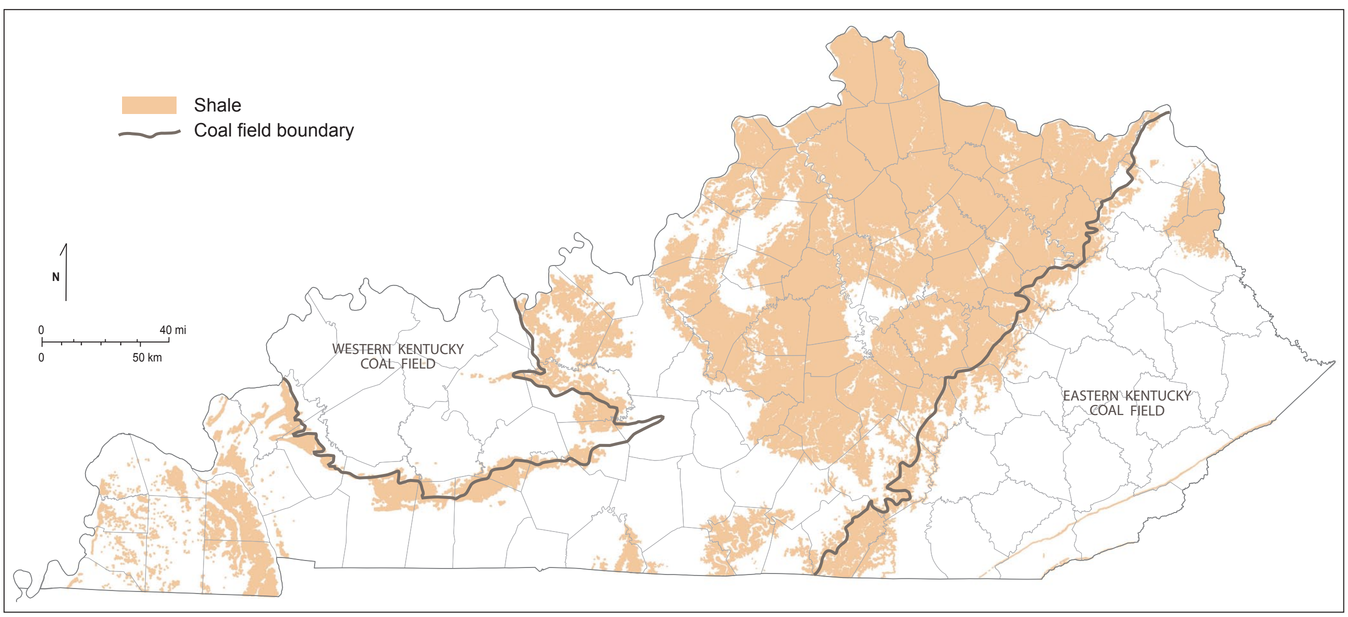


Figure 8. Geologic units, composed of more than 50 percent shale and the location of both coal fields (which contain marine horizons composed of sandstone, siltstone, coal, and shale).

were isolated using ArcGIS and converted into a layer file, then 500-ft-radius buffers were created. Those buffered points were converted to a layer file, which was intersected with the geologic formations layer file; the resulting data were exported as a tabular data set.

A comparison of the original alluvium data set with the buffered alluvium data set showed that 95 percent of the data points originally classified as alluvium were within 500 ft of another formation. Therefore, the landslide and rockfall costs and frequency of repairs associated with alluvium

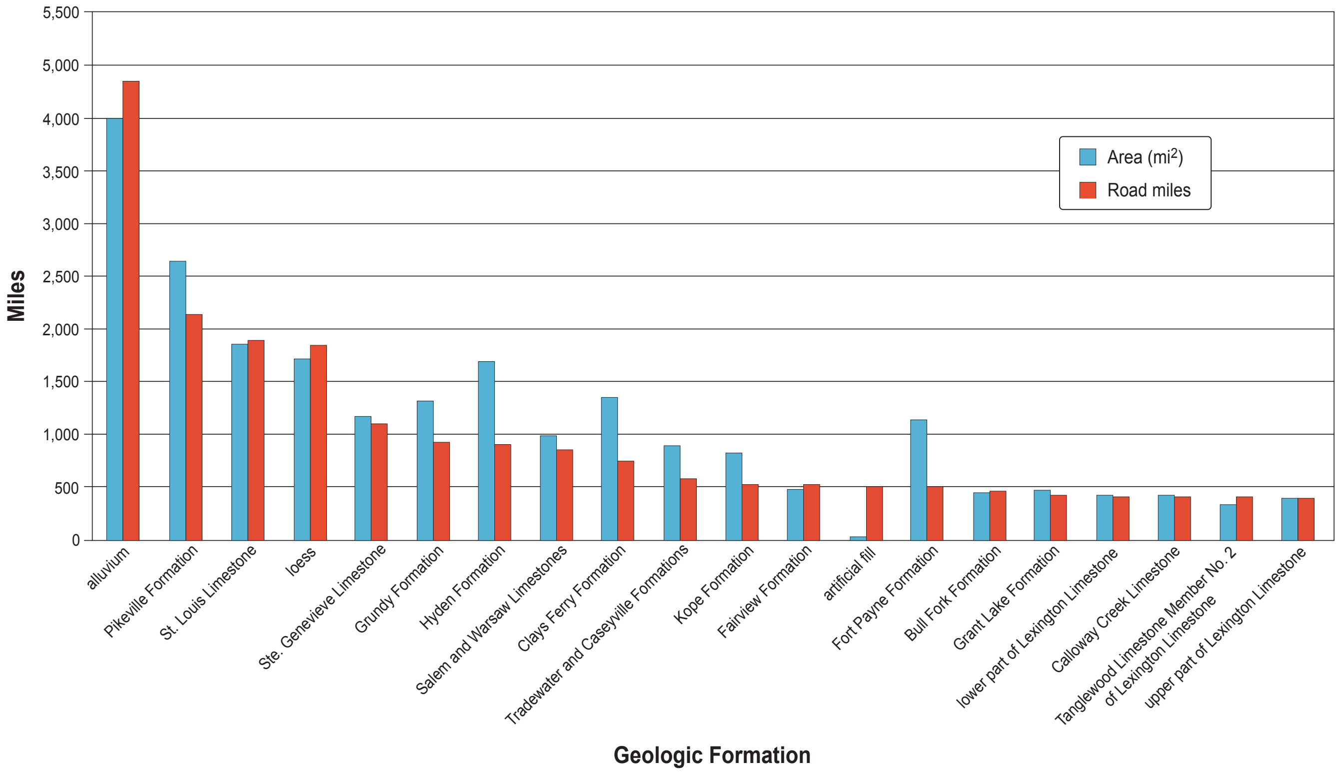


Figure 9. The geologic formations with the most area (mi^2) along with the road miles contained within their units. The y-axis shows both linear and square miles. The x-axis is ranked by the geologic formations' linear mile exposure. Only the formations with the greatest area and road miles are shown.

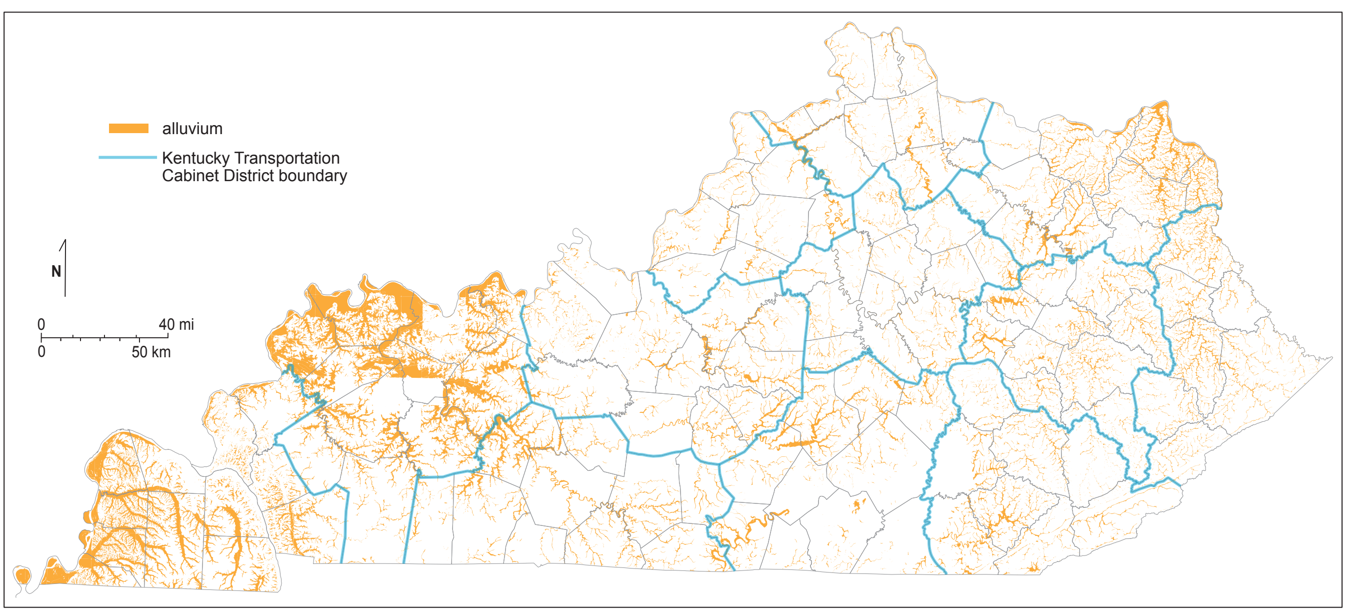


Figure 10. Spatial distribution of alluvium.

are too ambiguous to be constructive. Selected geomorphic settings (for example, stream cutbanks) are known to have high landslide potential. Differentiating these locations from repairs that should be associated with adjacent bedrock units is beyond the scope of this study. Therefore, results associating maintenance costs with alluvium were eliminated from subsequent tabular results in the report; however, they are still in the appendices.

Landslide Results

Cost per Mile per Year. The total cost per mile per year for landslides was calculated for each geologic formation and is shown in Table 2. The Newman Limestone, despite less than 1 road mile occurring in it, has the highest sum of cost per mile per year ($64,298) and has a far greater cost associated with it than any other formation in the state. This can be attributed to its location along Pine Mountain, where a significant landslide occurred in 2002. Extreme results such as this have the potential to skew the data. The Preachersville and Rowland Members of the Drakes Formation (shale and minor dolomite), with only 7.26 road miles, has the second highest cost per mile per year ($10,120). The Berea Sandstone and Bedford Shale have the

Table 2. Top 20 geologic units to maintain based on landslide costs per mile per year. Full list of geologic formations and their associated cost data are in Appendix 1.

Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Total Cost*	*Cost per Mile per Year*	*Frequency*
Newman Limestone	limestone and minor shale	0.10	0.46	$207,038	$64,298	95
Preachersville and Rowland Members, Drakes Formation	shale and minor dolomite	14.52	7.26	$245,954	$10,120	23
Berea Sandstone and Bedford Shale	shale, sandstone	7.92	0.24	$9,129	$5,503	8
Kope and Clays Ferry Formations	shale and limestone	470.96	246.30	$1,560,096	$4,684	573
Boyle Dolomite	dolomite	41.01	33.51	$192,748	$3,948	31
glacial outwash (Illinoian)	sand and gravel	1.60	3.76	$87,300	$3,315	91
Pikeville Formation	sandstone, shale, siltstone, coal	2,631.76	2,149.32	$5,006,313	$3,120	6,496
Alger Shale	gray shale	16.52	19.89	$372,856	$2,768	50
coarse clastic limestone member, Clays Ferry Formation	limestone, coarse-grained	1.38	0.84	$16,310	$2,765	9
Kope Formation	shale and limestone	835.91	537.67	$1,307,168	$2,736	1,994
Princess Formation	sandstone, shale, siltstone, coal	750.40	191.06	$352,103	$2,645	444
Four Corners Formation	sandstone, shale, siltstone, coal	1,992.81	277.76	$1,180,423	$2,593	1,270
Borden Formation	siltstone and shale	870.66	384.98	$840,209	$2,236	843
lower part, Breathitt Group	sandstone, shale, siltstone, coal	4.66	3.92	$37,348	$2,117	19
Hyden Formation	sandstone, shale, siltstone, coal	1,690.75	916.31	$2,612,288	$1,976	3,985
Jackson Formation	sand, silt, clay	3.66	2.88	$39,534	$1,961	14
Millersburg Member, Lexington Limestone	limestone and shale	1.58	1.20	$6,704	$1,732	28
Beech Creek Limestone Member, Golconda Formation	limestone and minor shale	44.33	15.20	$154,526	$1,578	38
Slade Formation	limestone and minor dolomite	158.54	52.70	$121,896	$1,356	131

third highest cost per mile per year at $5,503, and the Kope and Clays Ferry Formations (shale and limestone) have the fourth highest at $4,684. The full list of geologic formations and their associated costs is in Appendix 1.

Total Cost. The Pikeville Formation (interbedded sandstone, shale, siltstone, and coal) was the most expensive formation overall to maintain—the total landslide costs were more than $5 million (Table 3, Fig. 11); however, the cost per mile per year was not as significant as for some other formations because of the large number of road miles in it (2,149 mi). The Hyden Formation was the next most expensive formation to maintain ($2.6 million in repair cost; contains more than 1,690 road miles), and the Kope and Clays Ferry Formations was the third most costly formation to maintain ($1.5 million in repair cost; contains more than 246 road miles).

Spatial Results. Overall, on a cost per mile per year basis, the geologic units with the highest average expected landslide maintenance cost by geologic unit are located in eastern and northern Kentucky (Fig. 12). These regions both have a combination of significant topographic relief and areas of shale-dominated bedrock.

Rockfalls

Cost per Mile per Year. The lower member of the Newman Limestone has the most expensive main-

Table 3. Top 20 geologic units to maintain based on total landslide repair cost. Full list of geologic formations and their associated cost data are in Appendix 1.

Geologic Formation	*Dominant Lithology*	*Area (mi²)*	*Miles*	*Total Cost*	*Cost per Mile per Year*	*Frequency*
Pikeville Formation	sandstone, shale, siltstone, coal	2,631.76	2,149.32	$5,006,313	$3,120	6,496
Hyden Formation	sandstone, shale, siltstone, coal	1,690.75	916.31	$2,612,288	$1,976	3,985
Kope and Clays Ferry Formations	shale and limestone	470.96	246.30	$1,560,096	$4,684	573
Kope Formation	shale and limestone	835.91	537.67	$1,307,168	$2,736	1,994
Four Corners Formation	sandstone, shale, siltstone, coal	1,992.81	277.76	$1,180,423	$2,593	1,270
Grundy Formation	sandstone, siltstone, shale, minor coal	1,331.63	922.31	$1,141,798	$1,009	2,210
Borden Formation	siltstone and shale	870.66	384.98	$840,209	$2,236	843
Bull Fork Formation	limestone and shale	461.73	472.31	$462,397	$518	561
Estill Shale, Crab Orchard Group	gray shale	81.86	67.05	$377,738	$805	79
Fairview Formation	limestone and shale	485.46	532.29	$376,604	$348	934
Alger Shale	gray shale	16.52	19.89	$372,856	$2,768	50
St. Louis Limestone	limestone, fine-grained	1,852.01	1,883.25	$362,842	$152	1,228
Clays Ferry Formation	limestone and shale	1,350.72	758.81	$353,280	$771	637
Princess Formation	sandstone, shale, siltstone, coal	750.40	191.06	$352,103	$2,645	444
Preachersville and Rowland Members, Drake Formation	shale and minor dolomite	14.52	7.26	$245,954	$10,120	23
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	323.74	243.39	$239,512	$860	358
artificial fill	artificial fill	26.29	496.80	$233,077	$831	619
Grant Lake Limestone	limestone and minor shale	476.53	450.09	$209,337	$249	416
Newman Limestone	limestone and minor shale	0.10	0.46	$207,038	$64,298	95

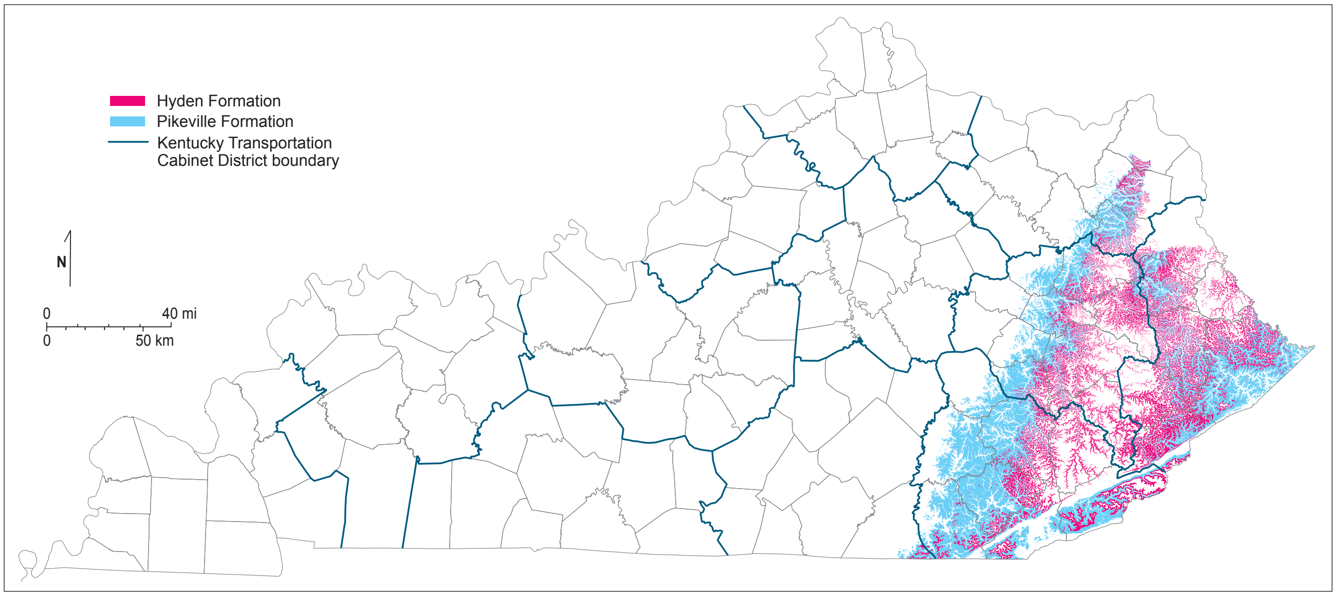


Figure 11. Spatial distribution of the Pikeville and Hyden Formations, the two most costly formations to maintain.

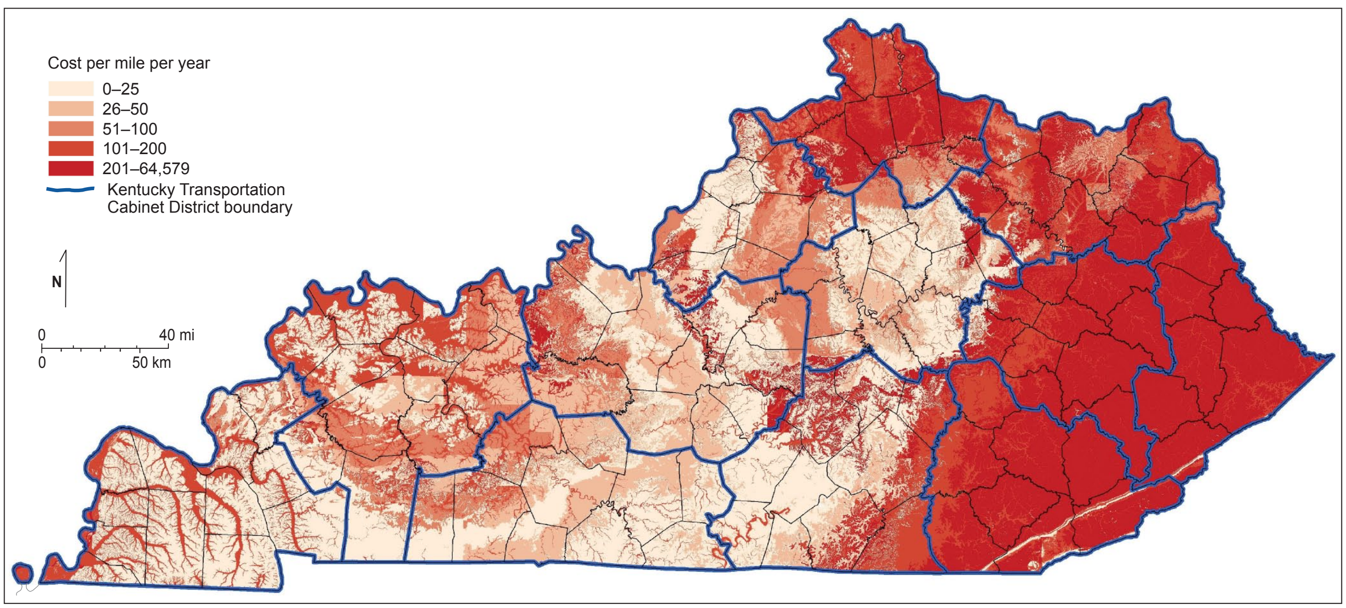


Figure 12. Average expected landslide maintenance cost by geologic unit (by cost per mile per year).

tenance cost per mile per year for rockfall repairs in the state at $2,712 (Table 4). The Hartselle Formation (shale and sandstone), with a cost of $2,163 per mile per year, and the Newman Limestone, at $2,007 per mile per year, have the next highest costs. Each of these formations contain few road miles, despite their high costs (Fig. 13). The costs associated with the Newman Limestone can be attributed to its location along Pine Mountain, where significant rockfalls occur. The total cost per mile per year for rockfalls was calculated for each formation and is shown in Table 5.

Total Cost. The most expensive geologic formations to maintain contain substantially more road miles and had lower costs per mile per year. The Pikeville Formation (sandstone, shale, siltstone, and coal) was the most expensive unit, at $2.3 million, containing 2,631 road miles (Table 5, Fig. 14).

Table 4. Top 20 geologic units to maintain based on rockfall costs per mile per year. Full list of geologic formations and their associated cost data are in Appendix 2.

Geologic Formation	Dominant Lithology	Area (mi^2)	Miles	Total Cost	Cost per Mile per Year	Frequency
lower member, Newman Limestone	limestone, fine-grained	6.24	2.51	$18,675	$2,712	46
Hartselle Formation	shale and sandstone	11.48	1.05	$15,860	$2,163	7
Newman Limestone	limestone and minor shale	0.10	0.46	$6,462	$2,007	8
Berea Sandstone	quartzose sandstone	7.03	8.56	$62,462	$1,042	25
Four Corners Formation	sandstone, shale, siltstone, coal	1,992.81	277.76	$542,360	$897	2,035
Grundy Formation	sandstone, siltstone, shale, minor coal	1,331.63	922.31	$858,935	$737	4,214
Hyden Formation	sandstone, shale, siltstone, coal	1,690.75	916.31	$1,571,200	$729	6,201
Princess Formation	sandstone, shale, siltstone, coal	750.40	191.06	$172,693	$702	513
middle part of Breathitt Group, undifferentiated	sandstone, shale, siltstone, coal	150.51	69.55	$63,244	$698	154
Pikeville Formation	sandstone, shale, siltstone, coal	2,631.76	2,149.32	$2,364,568	$578	8,132
lake area	lake	182.89	3.24	$5,459	$532	18
Borden Formation	siltstone and shale	870.66	384.98	$301,884	$510	561
Rockcastle Sandstone Member, Bee Rock Formation	quartzose sandstone	10.02	1.33	$2,530	$509	18
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	323.74	243.39	$185,293	$490	839
Bee Rock Sandstone	quartzose sandstone	18.94	7.74	$15,186	$430	32
Slade Formation	limestone and minor dolomite	158.54	52.70	$55,229	$424	151
Alvy Creek Formation	sandstone, siltstone, shale, minor coal	224.09	36.41	$22,284	$410	142
shale member, Fort Payne Formation	siltstone and shale	0.67	1.21	$3,448	$408	8

The next most costly unit, the Hyden Formation (sandstone, shale, siltstone, and coal) (Fig. 14) had $1.5 million in repair costs and 1,690 road miles.

Spatial Results. Overall, on a cost per mile per year basis, the geologic units with the highest average expected rockfall maintenance cost by geologic unit are located in eastern Kentucky (Fig. 12). Eastern Kentucky bedrock contains locally alternating beds of sandstone and shale; shale beds can quickly weather and undermine resistant sandstone beds, increasing the risk of rockfalls.

Landslides Versus Rockfalls

Landslide repair costs are significantly more expensive than rockfall repair costs. Landslide repairs average $430 per mile per year, whereas rockfall repair costs average $67 per mile per year. Most high-cost and -frequency occurrences for both landslides and rockfalls are in eastern Kentucky. The Newman Limestone contributes significantly to repair costs for both landslides (Table 2) and rockfalls (Table 4), despite being a stable unit composed of strong rock material (limestone). This can be attributed to its location along Pine Mountain,

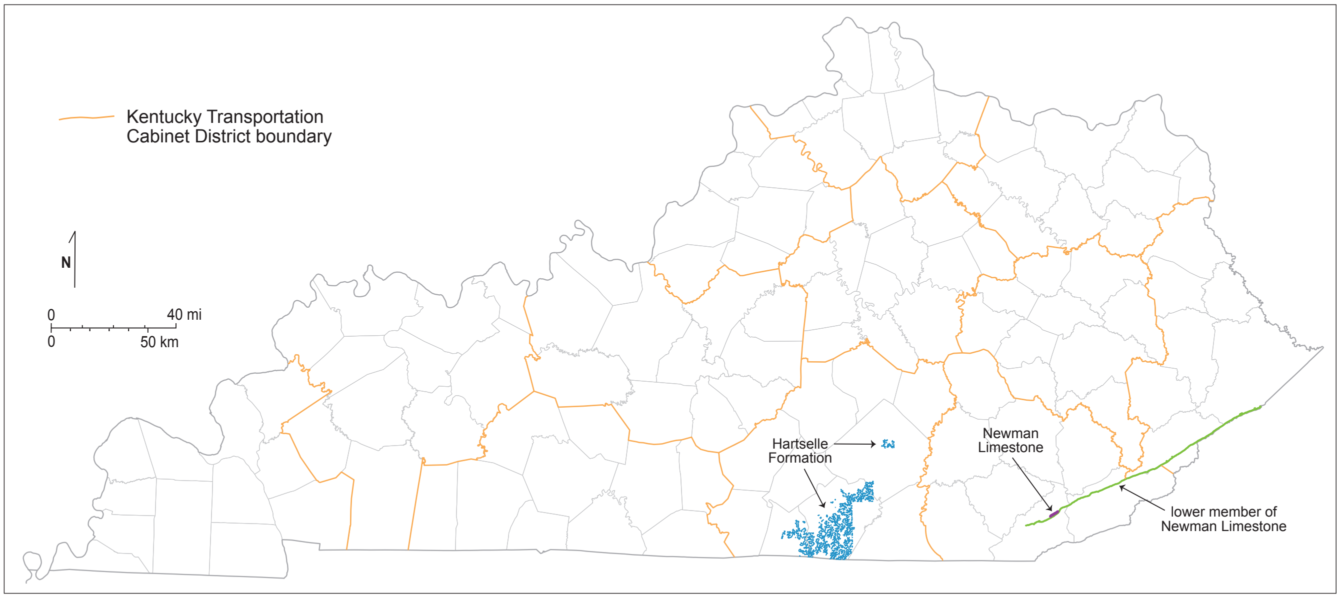


Figure 13. Geologic units with the highest cost per mile per year for rockfalls.

where rock discontinuities such as joints dominate (Fig. 13).

Frequency of Work Order Analysis

Landslides. The Pikeville Formation, Hyden Formation, Grundy Formation, and Kope Formation account for the majority of the landslide maintenance repairs in the state (Table 6). The frequency of work-order miles is not necessarily correlative to the geologic formations that cost the most to repair. Two of the higher-cost formations for landslide repairs are the Newman Limestone and the Drakes Formation; both of these units have lower frequency numbers. Repair frequency is greater in units that have more road miles. Some units, however, have fewer road miles but higher frequency of repair (such as the Kope and Four Corners Formations). For a list of the geologic units with the most road miles, see Figure 9. The full list of geologic formations and their associated work-order frequencies is in Appendix 4.

Rockfalls. The units with the highest frequency of work-order miles for rockfalls are the same as for landslides: the Pikeville Formation, Hyden Formation, Grundy Formation, and Kope Formation make up the majority of the rockfall repairs (Table 7). The most costly rockfall formations to repair (the Newman Limestone, Hartselle Formation, and Berea Sandstone) did not have the most work orders. As with landslides, more road miles in a formation resulted in a greater frequency of repairs (Table 7). The Four Corners Formation and Corbin Sandstone Member of the Grundy Formation have few road miles but are frequently repaired. The full list of geologic formations and their associated work-order frequencies are in Appendix 3.

Landslides Versus Rockfalls. The frequency of landslide repairs is similar to that for rockfall repairs. The Pikeville Formation, Hyden Formation, Grundy Formation, and Kope Formation are the most frequently repaired units. There are more work-order miles, in general, for rockfall repairs than for landslide repairs. This could be the result of the Transportation Cabinet's classification of rockfalls, in which any removal of rock along a road could be classified as a rockfall repair. Landslide repair costs are still greater than rockfall repair costs, however, because more materials are used to maintain the integrity of the slope and roadway (beams, etc.) for landslide repairs.

Results for Specific Road Segments

Costs. The highest landslide repair costs associated with specific road segments are illustrated in Table 8. The most expensive road segment to maintain in the state is Interstate 64 from miles 127 to 128 in Bath County. A total of $341,232 was spent maintaining this road segment from 2002 to 2009.

Table 5. Top 20 geologic units to maintain based on total rockfall repair cost. Full list of geologic formations and their associated cost data is in Appendix 2.

Geologic Formation	*Dominant Lithology*	*Area (mi²)*	*Miles*	*Total Cost*	*Cost per Mile per Year*	*Frequency*
Pikeville Formation	sandstone, shale, siltstone, coal	2,631.76	2,149.32	$2,364,568	$578	8,132
Hyden Formation	sandstone, shale, siltstone, coal	1,690.75	916.31	$1,571,200	$729	6,201
Grundy Formation	sandstone, siltstone, shale, minor coal	1,331,63	922.31	$858,935	$737	4,214
Four Corners Formation	sandstone, shale, siltstone, coal	1,992.81	277.76	$542,360	$897	2,035
Borden Formation	siltstone and shale	870.66	384.98	$301,884	$510	561
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	323.74	243.39	$185,293	$490	839
St. Louis Limestone	limestone, fine-grained	1,852.01	1,883.25	$177,613	$48	1,280
Princess Formation	sandstone, shale, siltstone, coal	750.40	191.06	$172,693	$702	513
Caseyville Formation	quartzose sandstone	321.40	172.28	$105,584	$183	32
artificial fill	artificial fill	26.29	496.80	$91,093	$611	341
Fort Payne Formation	siltstone and shale	1,139.25	489.67	$90,352	$64	368
Salem and Warsaw Limestones	limestone, coarse-grained	976.14	854.20	$80,158	$38	568
Bull Fork Formation	limestone and shale	461.73	472.31	$72,478	$110	97
middle part of Breathitt Group, undifferentiated	sandstone, shale, siltstone, coal	150.51	69.55	$63,244	$698	154
Berea Sandstone	quartzose sandstone	7.03	8.56	$62,462	$1,042	25
upper member, Grant Lake Limestone	limestone and minor shale	41.12	38.21	$59,722	$240	48
Cowbell Member, Borden Formation	siltstone and shale	113.16	38.39	$55,947	$208	93
Slade Formation	limestone and minor dolomite	158.54	52.70	$55,229	$424	151

Other expensive road segments are Ky. 713 (miles 12 to 13) in Montgomery County, Ky. 599 (miles 3 to 4), also in Montgomery County, and Ky. 537 (miles 12 to 13) in Bourbon County.

The most expensive rockfall repairs by road segment are listed in Table 9. The highest rockfall repair cost, at $96,716, was for Ky. 973 (miles 2 to 3) in Muhlenberg County. The next highest-costing repaired road segments were Ky. 713 (miles 10 to 11) in Menifee County, at $83,886, and Ky. 1426 (miles 6 to 7) in Pike County, at $64,962.

Frequency of Work. The most repaired road segments for landslides are listed in Table 10. The most repaired segment, Ky. 36 from miles 8 to 9, in Carroll County, was repaired 99 times. The next most frequently repaired sites were Ky. 221 in Bell County and Ky. 36 in Carroll County.

The most repaired road segments in the state resulting from rockfalls were all on Ky. 15 (Table 11). Mile segment 16–17 in Breathitt County was repaired 82 times. The second most repaired segment was Ky. 1426 (miles 6 to 7) in Pike County, repaired 81 times. The next most frequently repaired roads were all on Ky. 15 in Knott County.

Discussion

Methodology

The methodology used to assign geologic formations to landslide and rockfall repairs distin-

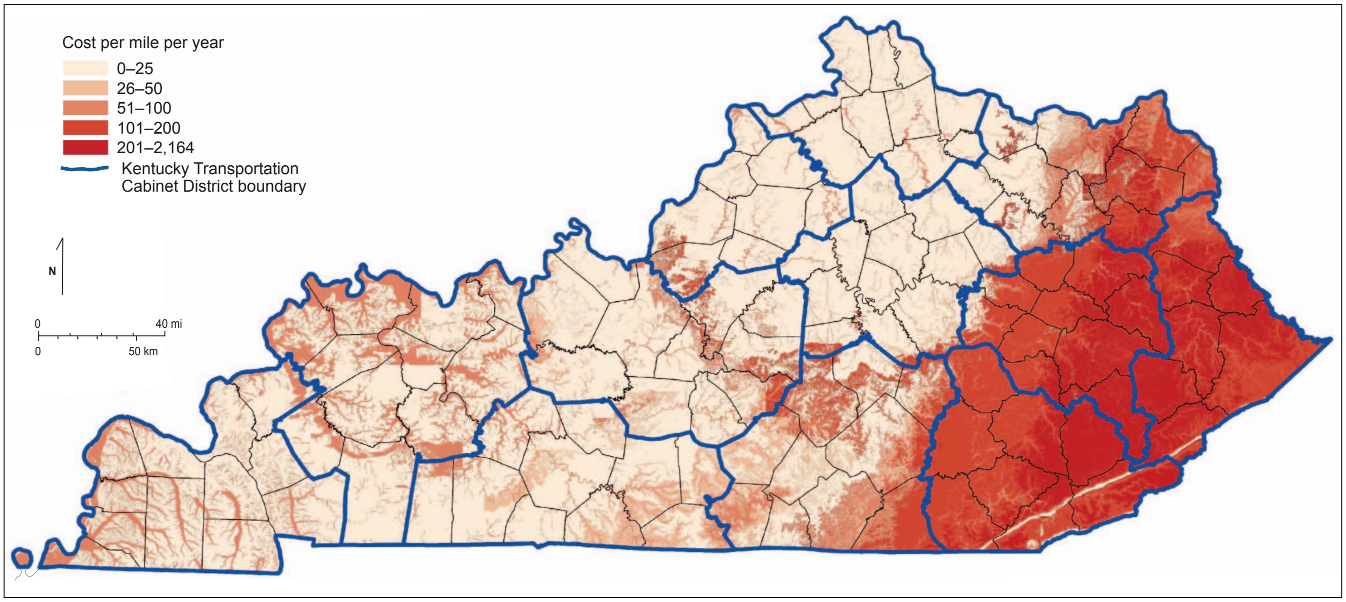


Figure 14. Average expected rockfall maintenance cost by geologic unit (by cost per mile per year).

guished the formations that were the most costly to maintain and most frequently repaired from 2002 to 2009. The maintenance work orders provided by the Kentucky Transportation Cabinet often were for several miles of a highway. Field-checking during phase II demonstrated that landslides and rockfalls often did not cover the entire mileage associated with the work orders. The data points derived from the 1-mi segments, therefore, have an estimated cost associated with them. Also, a repair may have actually occurred in the formation above or below the formation to which it was assigned. The data set was large enough, however, that these estimations most likely did not have a great impact on the results, with the exception of those for alluvium.

Geographic Distribution of Maintenance Sites

The majority of both landslides and rockfalls are concentrated in eastern Kentucky; other large concentrations are in northern Kentucky and along Kentucky waterways. The spatial distribution of maintenance repair orders can be largely attributed to topographic relief and lithology. Geologic units containing shale and those with interbedded shale that have significant road miles were costly to maintain and were frequently repaired. Dominant lithologies in eastern Kentucky are sandstone, siltstone, shale, and coal. The shale layers are distinct in eastern Kentucky and because of interbedding with other lithologies are prone to failure. Roads located along steep slopes are more prone to failure and are abundant in eastern Kentucky, where roads are frequently adjacent to waterways in steep valleys. In northern Kentucky, steep slopes along with lithology (interbedded limestone and shales) causes landslides and rockfalls.

High-cost and high-frequency units with little to no shale resulted from structural geologic issues such as the Newman Limestone occurring along Pine Mountain or being located above a shale (failure of a shale and, in turn, the unit above the shale).

Landslides Versus Rockfalls

Landslides were significantly more expensive to repair than rockfalls, although rockfall repair was more frequent. Landslide repairs are more costly because more materials and equipment are used, resulting in greater labor costs. Beams are often used at landslide maintenance sites to keep earth material stable. Rockfall repair normally consists only of removing material that has fallen in the road, and is therefore less expensive.

Cost Versus Frequency

Many geologic formations with high costs do not have frequent repairs. And there are many situations in which there are a plethora of work orders for a 1-mi segment, but costs remain minimal. Although the repairs might be relatively inexpensive,

Table 6. Frequency of landslide work-order miles for the 25 most frequently repaired geologic formations. The full list of geologic formations and associated work-order frequencies are in Appendix 3.

Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Pikeville Formation	sandstone, shale, siltstone, coal	6,496	2,149
Hyden Formation	sandstone, shale, siltstone, coal	3,985	916
Grundy Formation	sandstone, siltstone, shale, minor coal	2,210	922
Kope Formation	shale and limestone	1,994	538
Four Corners Formation	sandstone, shale, siltstone, coal	1,270	278
St. Louis Limestone	limestone, fine-grained	1,228	1,883
Fairview Formation	limestone and shale	934	532
Borden Formation	siltstone and shale	843	385
glacial outwash (Wisconsinan)	sand and gravel	781	204
Ste. Genevieve Limestone	limestone, fine-grained	662	1,106
Clays Ferry Formation	limestone and shale	637	759
artificial fill	artificial fill	619	497
Hardinsburg Sandstone	sandstone and minor shale	590	299
Kope and Clays Ferry Formations	shale and limestone	573	246
Bull Fork Formation	limestone and shale	561	472
Point Pleasant Tongue, Clays Ferry Formation	limestone and shale	541	66
loess	eolian loess	493	1,844
Princess Formation	sandstone, shale, siltstone, coal	444	191
Grant Lake Limestone	limestone and minor shale	416	450
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	358	243
Calloway Creek Limestone	limestone and minor shale	332	418
terrace deposits	mixed sediments	279	157
Salem and Warsaw Limestones	dolomitic limestone, siltstone, shale, sandstone	273	854
Salem and Warsaw Limestones	limestone, coarse-grained	273	854

if there are many of them, the cumulative costs can still be high.

Future Use of Data

This three-phase study successfully associated maintenance costs and repair frequencies with specific geologic units. This will enable transportation planners to better assess future road sites and will facilitate better maintenance budgets for current roads. Future Kentucky Transportation Cabinet maintenance data can be added to this data set to continue the road maintenance assessment.

Table 7. Frequency of rockfall work-order miles for the 25 most frequently repaired geologic formations. The full list of geologic formations and associated work-order frequencies are in Appendix 4.

Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Pikeville Formation	sandstone, shale, siltstone, coal	8,132	2,149
Hyden Formation	sandstone, shale, siltstone, coal	6,201	916
Grundy Formation	sandstone, siltstone, shale, minor coal	4,214	922
Four Corners Formation	sandstone, shale, siltstone, coal	2,035	278
St. Louis Limestone	limestone, fine-grained	1,280	1,883
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	839	243
Salem and Warsaw Limestones	dolomitic limestone, siltstone, shale, sandstone	568	854
Salem and Warsaw Limestones	limestone, coarse-grained	568	854
Borden Formation	siltstone and shale	561	385
Princess Formation	sandstone, shale, siltstone, coal	513	191
Ste. Genevieve Limestone	limestone, fine-grained	403	1,106
Fort Payne Formation	siltstone and shale	368	490
Kope Formation	shale and limestone	347	538
artificial fill	artificial fill	341	497
Tradewater Formation	sandstone, shale, siltstone, coal, limestone	210	358
Tradewater Formation	shale, siltstone, sandstone, limestone, coal	210	358
Clays Ferry Formation	limestone and shale	186	759
Tradewater and Caseyville Formations	quartzose sandstone	179	586
Tradewater and Caseyville Formations	shale, siltstone, sandstone, limestone, coal	179	586
Conemaugh Formation	reddish green shale	178	50
loess	eolian loess	178	1,844
Ste. Genevieve Limestone Member, Monteagle Limestone	limestone, coarse-grained	178	80
Point Pleasant Tongue, Clays Ferry Formation	limestone and shale	172	66
Hardinsburg Sandstone	sandstone and minor shale	157	299

Table 8. Most expensive repaired road segments for landslides.

Total Cost	*Road Route*	*Beginning Mile*	*Ending Mile*	*Geologic Formation*
$341,232	I-64	127	128	Alger Shale
$244,227	Ky. 713	12	13	Preachersville and Rowland Members, Drakes Formation
$241,506	Ky. 599	3	4	Borden Formation
$236,601	Ky. 537	12	13	Kope and Clays Ferry Formations
$206,492	Ky. 221	6	7	Newman Limestone
$192,107	Ky. 713	13	14	Boyle Dolomite
$192,003	Ky. 356	0	1	Kope and Clays Ferry Formations
$191,632	Ky. 356	1	2	Kope and Clays Ferry Formations
$163,010	Ky. 450	3	4	lacustrine and fluvial deposits
$154,469	Ky. 144	4	5	Beech Creek Limestone Member, Lexington Limestone
$151,546	Ky. 1081	15	16	Pikeville Formation
$147,677	Ky. 158	9	10	Estill Shale, Crab Orchard Group
$146,472	Ky. 36	2	3	Kope Formation
$134,635	U.S. 25	21	22	Kope and Clays Ferry Formations
$131,481	Ky. 1617	0	1	Borden Formation
$129,696	Ky. 3333	1	2	Pikeville Formation
$126,163	Ky. 57	16	17	Preachersville Member, Drakes Formation
$123,939	I-64	103	104	Kope and Clays Ferry Formations
$118,885	Ky. 210	14	15	St. Louis Limestone
$114,216	U.S. 421	17	18	Louisville Limestone and Waldron Shale
$113,579	Ky. 899	13	14	Pikeville Formation
$109,204	U.S. 60	9	10	Tazewell Outwash
$106,799	Ky. 1278	1	2	Princess Formation
$105,526	Ky. 1110	9	10	Pikeville Formation
$101,597	Hal Rogers Parkway	41	42	Four Corners Formation

Table 9. Most expensive repaired road segments for rockfalls.

Total Cost	*Road Route*	*Beginning Mile*	*Ending Mile*	*Geologic Formation*
$96,716	Ky. 973	2	3	Caseyville Formation
$83,886	Ky. 713	10	11	Borden Formation
$64,962	Ky. 1426	6	7	Grundy Formation
$59,515	U.S. 62	19	20	upper member, Grant Lake Limestone
$57,204	Ky. 56	0	1	alluvium
$51,155	I-75	19	20	Pikeville Formation
$49,655	U.S. 25	16	17	Pikeville Formation
$43,541	U.S. 23	6	7	Hyden Formation
$39,736	Ky. 15	16	17	Pikeville Formation
$39,167	Ky. 26	0	1	Corbin Sandstone Member, Grundy Formation
$36,929	U.S. 23	19	20	Grundy Formation
$34,629	Ky. 321	2	3	Pikeville Formation
$33,277	Ky. 15	4	5	Hyden Formation
$32,520	Ky. 10	13	14	Berea Sandstone
$32,045	Ky. 10	11	12	alluvium
$31,999	Ky. 1231	0	1	Hyden Formation
$31,603	U.S. 25	4	5	alluvium
$30,848	Ky. 1098	17	18	Four Corners Formation
$30,481	Ky. 80	10	11	Hyden Formation
$29,556	Ky. 15	7	8	Hyden Formation
$29,374	U.S. 23	12	13	alluvium
$28,803	Ky. 90	12	13	St. Louis Limestone
$28,317	Ky. 1274	5	6	alluvium
$28,029	Ky. 10	12	13	Berea Sandstone
$26,189	Ky. 3231	0	1	alluvium

Table 10. Most repaired road segments for landslides.

Road Route	*Beginning Mile*	*Ending Mile*	*Work-Order Frequency*	*Geologic Formation*
Ky. 36	8	9	99	glacial outwash (Wisconsinan)
Ky. 221	6	7	93	Newman Limestone
Ky. 36	0	1	92	glacial outwash (Wisconsinan)
Ky. 36	1	2	92	glacial outwash (Wisconsinan)
Ky. 36	2	3	92	glacial outwash (Wisconsinan)
Ky. 36	3	4	92	glacial outwash (Wisconsinan)
Ky. 36	4	5	92	glacial outwash (Wisconsinan)
Ky. 36	5	6	92	alluvium
Ky. 36	6	7	92	alluvium
Ky. 36	7	8	92	Kope Formation
Ky. 199	8	9	80	alluvium
Ky. 199	9	10	78	alluvium
Ky. 199	10	11	78	alluvium
Ky. 199	11	12	78	alluvium
U.S. 421	17	18	74	Louisville Limestone and Waldron Shale
Ky. 66	14	15	62	Four Corners Formation
Ky. 3485	1	2	61	Hyden Formation
Ky. 550	5	6	60	alluvium
U.S. 421	18	19	60	Bull Fork Formation
Ky. 388	8	9	59	alluvium
Ky. 388	9	10	59	Clays Ferry Formation
Ky. 70	2	3	57	Salem and Warsaw Limestones
Ky. 3035	2	3	57	alluvium
Ky. 1081	4	5	57	terrace deposits
Wendell H. Ford Western Kentucky Parkway	15	16	56	Hardinsburg Sandstone

Table 11. Most repaired road segments for rockfalls.

Road Route	*Beginning Mile*	*Ending Mile*	*Work-Order Frequency*	*Geologic Formation*
Ky. 15	16	17	82	Pikeville Formation
Ky. 1426	6	7	81	Grundy Formation
Ky. 15	4	5	74	Hyden Formation
Ky. 15	5	6	74	Hyden Formation
Ky. 80	10	11	74	Hyden Formation
Ky. 15	7	8	73	Hyden Formation
Ky. 15	6	7	72	Hyden Formation
Ky. 80	8	9	70	Four Corners Formation
Ky. 80	0	1	68	Four Corners Formation
Ky. 80	2	3	68	alluvium
U.S. 23	19	20	68	Grundy Formation
Ky. 80	3	4	67	Four Corners Formation
Ky. 80	9	10	67	Four Corners Formation
Ky. 15	3	4	66	Hyden Formation
Ky. 80	6	7	66	Hyden Formation
Ky. 15	8	9	65	Hyden Formation
Ky. 80	1	2	65	Hyden Formation
Ky. 80	7	8	65	Four Corners Formation
Ky. 1274	5	6	65	alluvium
Ky. 15	9	10	64	Hyden Formation
Ky. 80	11	12	64	Four Corners Formation
Ky. 80	4	5	63	Hyden Formation
Ky. 80	5	6	62	Four Corners Formation
Ky. 80	12	13	60	Four Corners Formation
Ky. 80	13	14	60	Four Corners Formation

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Appendix 1: Cost and Frequency of Landslide Repairs by Geologic Formation (Sorted by Cost per Mile per Year).

Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
Newman Limestone	limestone and minor shale	0.10	0.46	$207,038	$64,298	95
Preachersville and Rowland Members, Drakes Formation	shale and minor dolomite	14.52	7.26	$245,954	$10,120	23
Berea Sandstone and Bedford Shale	shale, sandstone	7.92	0.24	$9,129	$5,503	8
Kope and Clays Ferry Formations	shale and limestone	470.96	246.30	$1,560,096	$4,684	573
Boyle Dolomite	dolomite	41.01	33.51	$192,748	$3,948	31
glacial outwash (Illinoian)	sand and gravel	1.60	3.76	$87,300	$3,315	91
Pikeville Formation	sandstone, shale, siltstone, coal	2,631.76	2,149.32	$5,006,313	$3,120	6,496
Alger Shale	gray shale	16.52	19.89	$372,856	$2,768	50
coarse clastic limestone member, Clays Ferry Formation	limestone, coarse-grained	1.38	0.84	$16,310	$2,765	9
Kope Formation	shale and limestone	835.91	537.67	$1,307,168	$2,736	1,994
Princess Formation	sandstone, shale, siltstone, coal	750.40	191.06	$352,103	$2,645	444
Four Corners Formation	sandstone, shale, siltstone, coal	1,992.81	277.76	$1,180,423	$2,593	1,270
Borden Formation	siltstone and shale	870.66	384.98	$840,209	$2,236	843
lower part of Breathitt Group	sandstone, shale, siltstone, coal	4.66	3.92	$37,348	$2,117	19
Hyden Formation	sandstone, shale, siltstone, coal	1,690.75	916.31	$2,612,288	$1,976	3,985
Jackson Formation	sand, silt, clay	3.66	2.88	$39,534	$1,961	14
Millersburg Member, Lexington Limestone	limestone and shale	1.58	1.20	$6,704	$1,732	28
Beech Creek Limestone Member, Golconda Formation	limestone and minor shale	44.33	15.20	$154,526	$1,578	38
alluvium	mixed sediments	4,001.47	4,353.60	$4,262,711	$1,495	7,905
Slade Formation	limestone and minor dolomite	158.54	52.70	$121,896	$1,356	131
upper part, Slade Formation	limestone and minor shale	52.52	36.14	$61,557	$1,274	89
river area	river	262.66	10.26	$25,468	$1,251	57
lower member, Newman Limestone	limestone, fine-grained	6.24	2.51	$10,929	$1,133	17
Grier Limestone Member, Lexington Limestone	limestone and minor shale	1.07	0.78	$1,971	$1,102	18
terrace deposits	mixed sediments	107.74	157.05	$79,793	$1,053	279
lacustrine and terrace deposits	mixed sediments	9.84	7.51	$55,130	$1,049	49
Grundy Formation	sandstone, siltstone, shale, minor coal	1,331.63	922.31	$1,141,798	$1,009	2,210

Appendix 1: Cost and Frequency of Landslide Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
glacial drift (Illinoian)	sand and gravel	3.00	5.66	$37,509	$947	34
Paragon Formation	sandstone, siltstone, shale, minor coal	207.94	66.05	$195,437	$902	264
Tanglewood Limestone Member, Lexington Limestone	limestone and minor shale	0.62	1.40	$8,182	$892	11
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	323.74	243.39	$239,512	$860	358
artificial fill	artificial fill	26.29	496.80	$233,077	$831	619
Conemaugh Formation	reddish green shale	114.38	50.21	$133,355	$829	192
Estill Shale, Crab Orchard Group	gray shale	81.86	67.05	$377,738	$805	79
Louisville Limestone and Waldron Shale	dolomite and limestone	17.88	24.42	$116,189	$790	85
Clays Ferry Formation	limestone and shale	1,350.72	758.81	$353,280	$771	637
Preachersville Member, Drakes Formation	dolomite and limestone	43.90	28.75	$141,391	$703	11
Bisher Limestone	dolomite	11.24	3.91	$2,605	$677	4
Ohio Shale	black shale	86.35	33.91	$141,641	$668	47
high-level fluvial deposits	mixed sediments	65.30	61.97	$61,271	$658	106
Tyrone Limestone	limestone, fine-grained	12.28	10.96	$10,689	$639	10
Paragon and Slade Formations, undifferentiated	sandstone, siltstone, shale, minor coal	15.63	9.74	$38,900	$604	26
Bedford Shale	shale and sandstone	13.44	5.16	$20,994	$581	9
Menard Limestone	limestone and shale	72.98	36.64	$44,592	$571	5
Tar Springs Sandstone	shale and sandstone	152.65	120.53	$142,792	$542	149
glacial drift (pre-Illinoian)	sand and gravel	14.63	29.22	$59,658	$521	97
Bull Fork Formation	limestone and shale	461.73	472.31	$462,397	$518	561
Buffalo Wallow Formation	sandstone, siltstone, shale, limestone	110.21	70.22	$140,501	$507	111
Kinkaid Limestone	limestone, fine-grained	28.21	8.33	$21,373	$499	6
glacial outwash (Wisconsinan)	sand and gravel	92.77	204.10	$112,654	$483	781
Bee Rock Sandstone	quartzose sandstone	18.94	7.74	$18,042	$481	13
Haney Limestone Member, Golconda Formation	limestone and minor shale	120.38	62.44	$72,132	$476	97
Drowning Creek Formation	shale and minor dolomite	72.31	46.72	$153,635	$476	42
upper part, Borden Formation	siltstone and shale	128.09	15.36	$23,732	$462	22
middle part, Breathitt Group, undifferentiated	sandstone, shale, siltstone, coal	150.51	69.55	$73,278	$405	79
Drakes Formation	dolomite and limestone	614.25	384.40	$28,783	$401	189

Appendix 1: Cost and Frequency of Landslide Repairs by Geologic Formation (Sorted by Cost per Mile per Year).

Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
lacustrine deposits (Wisconsinan)	clay and silt	29.63	67.30	$84,899	$380	76
Fairview Formation	limestone and shale	485.46	532.29	$376,604	$348	934
Lexington Limestone	limestone and shale	15.70	23.42	$16,944	$298	84
lower part, Lexington Limestone	limestone and shale	426.23	419.03	$135,202	$297	208
Pennington Group	sandstone, siltstone, shale, limestone	21.76	38.59	$27,182	$275	57
lower shale member, Borden Formation	gray shale	7.69	4.38	$8,158	$266	8
Alvy Creek Formation	sandstone, siltstone, shale, minor coal	224.09	36.41	$41,728	$261	90
Grant Lake Limestone	limestone and minor shale	476.53	450.09	$209,337	$249	416
siltstone member, Borden Formation	siltstone and shale	69.05	16.23	$27,945	$246	20
Point Pleasant Tongue, Clays Ferry Formation	limestone and shale	36.31	65.66	$99,348	$216	541
unnamed sandstone bed, Princess Formation	quartzose sandstone	0.89	0.14	$198	$206	2
Four Corners and Hyden Formations, undifferentiated	sandstone, shale, siltstone, coal	5.35	6.22	$8,618	$198	5
colluvium	mixed sediments	8.30	15.20	$2,981	$186	8
lacustrine and fluvial deposits (pre-Illinoian)	mixed sediments	12.06	15.74	$20,328	$185	36
Hardinsburg Sandstone	sandstone and minor shale	395.60	298.65	$164,125	$184	590
Tazewell Outwash	sand and gravel	110.27	130.71	$166,583	$182	240
Reelsville Limestone and Sample Sandstone	sandstone, siltstone, shale, limestone	17.85	3.81	$4,807	$180	5
Carbondale Formation	sandstone, shale, siltstone, coal, limestone	293.47	259.14	$108,769	$175	108
older Ohio River alluvium	mixed sediments	3.56	5.01	$6,028	$172	5
continental deposits	mixed sediments	364.96	374.19	$3,689	$171	27
Sunbury Shale	black shale	10.60	2.28	$2,703	$169	3
unnamed sandstone bed, Grundy Formation	quartzose sandstone	7.08	5.38	$6,205	$165	13
lacustrine and fluvial deposits	mixed sediments	212.52	153.67	$176,138	$164	16
Mattoon Formation	sandstone, shale, siltstone, coal, limestone	34.63	28.21	$32,125	$163	18
St. Louis Limestone	limestone, fine-grained	1,852.01	1,883.25	$362,842	$152	1,228
Calloway Creek Limestone	limestone and minor shale	448.56	418.39	$101,451	$148	332
Vienna Limestone	limestone, coarse-grained	13.07	8.12	$2,008	$148	2

Appendix 1: Cost and Frequency of Landslide Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
alluvium of valley sides, meander cores, cutoff meanders, and abandoned channels	mixed sediments	10.13	7.65	$7,722	$144	21
eolian sand, dune sand	eolian sand	6.73	9.20	$4,992	$136	30
lower member, Grant Lake Limestone	limestone and minor shale	39.47	38.35	$35,179	$135	25
Tanglewood Limestone Member No. 3, Lexington Limestone	limestone and minor shale	78.79	87.04	$15,375	$134	70
New Albany Shale and Beechwood Limestone Member, Sellersburg Limestone	shale and limestone	2.34	7.48	$7,007	$134	11
Renault Limestone	limestone and minor shale	109.08	126.75	$48,708	$128	14
Girkin Formation	limestone, fine-grained	226.02	118.38	$23,347	$128	52
Big Clifty Sandstone Member, Golconda Formation	sandstone and minor shale	293.12	163.04	$62,359	$116	146
Leitchfield Formation	shale and sandstone	78.16	51.03	$26,030	$114	21
Monongahela Formation and upper part, Conemaugh Formation	shale, siltstone, sandstone, minor coal	77.97	8.51	$3,336	$107	11
Nancy Member, Borden Formation	gray shale	182.17	50.31	$36,250	$107	28
Camp Nelson Limestone	limestone and minor dolomite	8.87	5.86	$4,331	$106	11
Tanglewood Limestone Member No. 4 (upper tongue), Lexington Limestone	limestone and minor shale	108.13	81.07	$3,298	$102	29
Leipers Limestone	limestone, fine-grained	28.43	43.05	$9,734	$102	40
Claiborne Formation	sand, silt, clay	26.07	15.43	$10,765	$100	8
Cowbell Member, Borden Formation	siltstone and shale	113.16	38.39	$25,540	$95	46
New Albany Shale	black shale	311.74	303.19	$38,319	$91	171
upper part, Lexington Limestone	limestone and shale	389.65	389.52	$17,720	$88	87
Tradewater Formation	shale, siltstone, sandstone, limestone, coal	517.11	358.08	$129,114	$86	111
Pikeville and Grundy Formations, undifferentiated	shale, siltstone, sandstone, minor coal	46.87	19.26	$10,447	$77	18
Ste. Genevieve Limestone Member, Slade Formation	limestone, coarse-grained	32.16	37.00	$19,666	$77	18
alluvium and lacustrine deposits	sand, silt, clay	270.88	165.50	$38,180	$76	110
Tradewater and Caseyville Formations	shale, siltstone, sandstone, limestone, coal	896.46	585.69	$149,099	$73	137
Crab Orchard Formation and Brassfield Dolomite	shale and minor dolomite	83.81	61.79	$9,668	$72	13

Appendix 1: Cost and Frequency of Landslide Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
Caseyville Formation	quartzose sandstone	321.40	172.28	$34,957	$68	20
Chattanooga Shale	black shale	44.44	16.22	$1,299	$68	3
Reelsville Limestone	limestone and minor shale	41.67	15.00	$6,903	$66	18
Tanglewood Limestone Member No. 2, Lexington Limestone	limestone and minor shale	342.21	418.12	$21,715	$63	69
Osgood and Brassfield Formations	shale and minor dolomite	32.59	35.29	$14,818	$61	7
older alluvium	mixed sediments	19.62	15.72	$6,500	$59	20
landslide deposits	mixed sediments	2.06	7.57	$1,785	$50	4
Cumberland Formation	limestone, fine-grained	48.22	42.94	$4,127	$49	4
Estill Shale Member, Alger Shale	gray shale	9.79	6.09	$1,944	$46	3
Beech Creek Limestone Member, Golconda Formation	limestone and minor shale	3.78	1.19	$369	$44	6
Salem and Warsaw Limestones	limestone, coarse-grained	976.14	854.20	$127,966	$44	273
landslide deposits and colluvium	mixed sediments	1.45	5.18	$1,471	$43	1
Paoli Limestone	limestone, fine-grained	45.24	15.54	$4,499	$41	21
sand of Quaternary alluvium	sand, silt, clay	14.83	5.70	$1,650	$41	6
Berea Sandstone	quartzose sandstone	7.03	8.56	$2,476	$41	5
Farmers Member, Borden Formation	sandstone and minor shale	115.18	45.31	$12,552	$40	23
Beaver Bend Limestone and Mooretown Formation	limestone and shale	34.77	6.95	$1,903	$39	19
Beaver Bend Limestone, Mooretown Formation, and Paoli Limestone, undifferentiated	limestone, fine-grained	11.80	9.08	$2,466	$39	14
Haney Limestone Member, Golconda Formation	limestone and minor shale	56.46	24.35	$4,035	$37	14
Tate Member, Ashlock Formation	shale and limestone	17.47	19.94	$2,977	$37	14
lacustrine deposits (Illinoian)	clay and silt	2.59	8.68	$2,058	$34	6
Patoka Formation	sandstone, shale, siltstone, coal, limestone	104.44	118.37	$27,212	$33	16
Naese Sandstone Member, upper part of Bee Rock Sandstone	quartzose sandstone	11.00	19.31	$4,201	$31	8
Renault Limestone, Ste. Genevieve Limestone, St. Louis Limestone, and Salem Limestone	limestone and minor shale	6.05	2.73	$592	$31	1

Appendix 1: Cost and Frequency of Landslide Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
loess	eolian loess	1,709.06	1,843.75	$112,549	$29	493
Grant Lake Member, Ashlock Formation	limestone, fine-grained	19.83	25.87	$5,140	$29	7
Glen Dean Limestone	limestone and minor shale	187.57	126.48	$10,978	$29	68
Beaver Bend Limestone, Mooretown Formation, and Paoli Limestone	limestone, fine-grained	10.41	3.62	$702	$29	11
Paint Creek Limestone	limestone and shale	57.06	35.04	$3,901	$28	4
upper member, Grant Lake Limestone	limestone and minor shale	41.12	38.21	$6,418	$26	10
Rockcastle Conglomerate	quartzose sandstone	46.28	5.29	$845	$26	17
Muldraugh Member, Borden Formation	siltstone and shale	6.25	0.67	$120	$26	5
Hartselle Formation	shale and sandstone	11.48	1.05	$187	$25	1
Kidder Limestone Member, Monteagle Limestone	limestone, fine-grained	129.09	63.62	$11,302	$25	16
Fort Payne Formation	siltstone and shale	1,139.25	489.67	$24,667	$23	100
Bethel Sandstone	sandstone and minor shale	52.91	51.92	$6,612	$22	8
Sample Sandstone	sandstone and minor shale	79.36	32.03	$4,932	$22	17
Ste. Genevieve Limestone	limestone, fine-grained	1,174.75	1,106.32	$60,491	$20	662
outwash deposits (pre-Illinoian)	sand and gravel	7.59	4.25	$601	$20	9
Big Clifty Sandstone Member, Golconda Formation, and Cypress Sandstone	sandstone and minor shale	12.00	5.74	$777	$19	1
Renfro Member, Slade Formation, and Nada Member, Borden Formation	sandstone, siltstone, shale, minor coal	11.79	4.07	$539	$19	4
Tanglewood Limestone Member No. 1 (lower tongue), Lexington Limestone	limestone and minor shale	81.57	93.36	$1,718	$18	17
Renfro Member, Slade Formation	dolomite and limestone	75.81	73.99	$9,234	$18	19
Livingston Conglomerate Member, Alvy Creek Formation	quartzose sandstone	3.17	1.55	$188	$17	2
Muldraugh Member, Borden Formation	siltstone and shale	264.86	81.93	$5,421	$17	79
Big Clifty Sandstone Member, Golconda Formation	sandstone and minor shale	105.56	45.90	$2,696	$14	18
St. Louis Limestone	limestone, fine-grained	7.22	3.14	$306	$14	1
Sewanee and Warren Point Sandstones	quartzose sandstone	23.45	5.05	$237	$14	4
Burnside Member, Slade Formation	limestone, coarse-grained	36.24	41.54	$3,753	$13	12

Appendix 1: Cost and Frequency of Landslide Repairs by Geologic Formation (Sorted by Cost per Mile per Year).

Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
Ste. Genevieve Limestone	limestone, fine-grained	290.89	313.14	$28,130	$13	66
Laurel Dolomite	dolomite	120.86	147.59	$6,106	$12	66
Waltersburg Sandstone and Vienna Limestone	sandstone, siltstone, shale, limestone	34.62	35.13	$1,191	$12	5
Cary Outwash	sand and gravel	17.30	13.73	$1,125	$12	10
Palestine Sandstone	sandstone and minor shale	31.14	22.47	$893	$11	2
Ste. Genevieve Limestone and upper member, St. Louis Limestone	limestone, fine-grained	117.35	142.88	$6,023	$10	12
Rockcastle Sandstone Member, Bee Rock Formation	quartzose sandstone	10.02	1.33	$39	$10	1
Louisville Limestone	dolomite and limestone	142.15	228.30	$16,101	$10	114
Ste. Genevieve Limestone Member, Monteagle Limestone	limestone, coarse-grained	74.63	80.19	$5,722	$10	22
Shelburn Formation	sandstone, shale, siltstone, coal, limestone	221.17	197.31	$14,008	$10	63
Beaver Bend and Paoli Limestones	limestone, fine-grained	27.89	19.11	$1,324	$10	8
Louisville Limestone, Waldron Shale, and Laurel Dolomite	dolomite and limestone	25.62	36.10	$2,137	$9	2
Bond Formation	sandstone, shale, siltstone, coal, limestone	98.64	93.01	$5,675	$9	9
Hensley Member, Alvy Creek Formation	sandstone, shale, siltstone, coal	27.33	3.72	$188	$9	1
Sellersburg and Jeffersonville Limestones	limestone, coarse-grained	70.97	159.43	$8,178	$7	59
Harrodsburg Limestone	limestone, coarse-grained	78.69	47.08	$287	$6	16
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	0.90	2.20	$88	$6	2
Ashlock Formation	limestone and shale	220.46	218.44	$5,549	$5	38
lower part, Calloway Creek Limestone	limestone and minor shale	16.14	15.43	$474	$4	2
Carter Caves Sandstone	quartzose sandstone	5.59	5.25	$160	$4	2
Salem Limestone	limestone, coarse-grained	90.74	30.15	$855	$4	17
Brannon Member, Lexington Limestone	limestone and shale	64.60	71.37	$1,835	$4	24
lower member, St. Louis Limestone	limestone, fine-grained	15.37	17.98	$125	$3	3
lower member, St. Louis Limestone, and Salem Limestone	limestone, fine-grained	1.56	2.35	$52	$3	1

Appendix 1: Cost and Frequency of Landslide Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
upper part, Calloway Creek Limestone	limestone and minor shale	4.08	9.90	$190	$3	1
New Albany Shale and Beechwood Limestone Member, Sellersburg Limestone	shale and limestone	89.59	93.57	$245	$2	6
Tyrone Limestone and Oregon Formation	dolomite and limestone	36.04	20.76	$296	$2	4
sandstone member, Mooretown Formation	quartzose sandstone	5.20	5.53	$78	$2	4
St. Louis and Salem Limestones	limestone, fine-grained	189.33	155.99	$1,887	$2	1

Appendix 2: Cost and Frequency of Rockfall Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
lower member, Newman Limestone	limestone, fine-grained	6.24	2.51	$18,675	$2,712	46
Hartselle Formation	shale and sandstone	11.48	1.05	$15,860	$2,163	7
Newman Limestone	limestone and minor shale	0.10	0.46	$6,462	$2,007	8
Berea Sandstone	quartzose sandstone	7.03	8.56	$62,462	$1,042	25
Four Corners Formation	sandstone, shale, siltstone, coal	1,992.81	277.76	$542,360	$897	2,035
Grundy Formation	sandstone, siltstone, shale, minor coal	1,331.63	922.31	$858,935	$737	4,214
Hyden Formation	sandstone, shale, siltstone, coal	1,690.75	916.31	$1,571,200	$729	6,201
Princess Formation	sandstone, shale, siltstone, coal	750.40	191.06	$172,693	$702	513
middle part, Breathitt Group, undifferentiated	sandstone, shale, siltstone, coal	150.51	69.55	$63,244	$698	154
alluvium	mixed sediments	4,001.47	4,353.60	$2,290,858	$696	8,776
artificial fill	artificial fill	26.29	496.80	$91,093	$611	341
Pikeville Formation	sandstone, shale, siltstone, coal	2,631.76	2,149.32	$2,364,568	$578	8,132
lake area	lake	182.89	3.24	$5,459	$532	18
Borden Formation	siltstone and shale	870.66	384.98	$301,884	$510	561
Rockcastle Sandstone Member, Bee Rock Formation	quartzose sandstone	10.02	1.33	$2,530	$509	18
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	323.74	243.39	$185,293	$490	839
Bee Rock Sandstone	quartzose sandstone	18.94	7.74	$15,186	$430	32
Slade Formation	limestone and minor dolomite	158.54	52.70	$55,229	$424	151
Alvy Creek Formation	sandstone, siltstone, shale, minor coal	224.09	36.41	$22,284	$410	142
shale member, Fort Payne Formation	siltstone and shale	0.67	1.21	$3,448	$408	8
Monongahela Formation and upper part, Conemaugh Formation	shale, siltstone, sandstone, minor coal	77.97	8.51	$11,208	$393	27
colluvium	mixed sediments	8.30	15.20	$5,201	$254	20
Bedford Shale	shale and sandstone	13.44	5.16	$9,074	$251	3
upper member, Grant Lake Limestone	limestone and minor shale	41.12	38.21	$59,722	$240	48
mine dump or mine spoil	mine spoil	2.61	1.27	$1,718	$229	2
terrace deposits	mixed sediments	107.74	157.05	$15,493	$214	114
Cowbell Member, Borden Formation	siltstone and shale	113.16	38.39	$55,947	$208	93
Tyrone Limestone	limestone, fine-grained	12.28	10.96	$7,790	$197	24

Appendix 2: Cost and Frequency of Rockfall Repairs by Geologic Formation (Sorted by Cost per Mile per Year).

Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
Conemaugh Formation	reddish green shale	114.38	50.21	$35,092	$195	178
Pikeville and Grundy Formations, undifferentiated	shale, siltstone, sandstone, minor coal	46.87	19.26	$25,077	$186	25
Caseyville Formation	quartzose sandstone	321.40	172.28	$105,584	$183	32
Waltersburg Sandstone	siltstone and shale	17.53	13.75	$479	$180	2
lower part, Lexington Limestone	limestone and shale	426.23	419.03	$32,558	$161	127
Chattanooga Shale	black shale	44.44	16.22	$8,797	$150	38
Crab Orchard Formation and Brassfield Dolomite	shale and minor dolomite	83.81	61.79	$18,918	$139	35
Paragon Formation	sandstone, siltstone, shale, minor coal	207.94	66.05	$29,896	$126	151
Rockcastle Conglomerate	quartzose sandstone	46.28	5.29	$1,505	$124	19
Bisher Limestone	dolomite	11.24	3.91	$460	$119	2
lower shale member, Borden Formation	gray shale	7.69	4.38	$3,636	$119	4
Louisville Limestone and Waldron Shale	dolomite and limestone	17.88	24.42	$16,674	$113	12
Hardinsburg Sandstone	sandstone and minor shale	395.60	298.65	$49,146	$111	157
Bull Fork Formation	limestone and shale	461.73	472.31	$72,478	$110	97
Leipers Limestone	limestone, fine-grained	28.43	43.05	$21,252	$98	95
Nada Member, Borden Formation	siltstone and shale	5.10	2.28	$1,566	$98	1
Cumberland Formation	limestone, fine-grained	48.22	42.94	$21,921	$97	122
siltstone member, Borden Formation	siltstone and shale	69.05	16.23	$9,999	$88	19
Salem Limestone	limestone, coarse-grained	90.74	30.15	$18,222	$87	27
lacustrine deposits (Wisconsinan)	clay and silt	29.63	67.30	$3,151	$83	11
Tanglewood Limestone Member No. 4 (upper tongue), Lexington Limestone	limestone and minor shale	108.13	81.07	$7,168	$82	40
New Albany Shale	black shale	311.74	303.19	$38,907	$81	137
Ste. Genevieve Limestone Member, Monteagle Limestone	limestone, coarse-grained	74.63	80.19	$45,593	$81	178
Beaver Bend Limestone, Mooretown Formation, and Paoli Limestone	limestone, fine-grained	10.41	3.62	$1,920	$78	14
Ohio Shale	black shale	86.35	33.91	$6,141	$77	32
coarse clastic limestone member, Clays Ferry Formation	limestone, coarse-grained	1.38	0.84	$450	$76	1

Appendix 2: Cost and Frequency of Rockfall Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
lower part, Breathitt Group	sandstone, shale, siltstone, coal	4.66	3.92	$770	$75	3
Nancy Member, Borden Formation	gray shale	182.17	50.31	$19,015	$72	26
Farmers Member, Borden Formation	sandstone and minor shale	115.18	45.31	$21,091	$67	27
Grainger Formation	siltstone and shale	6.35	2.46	$544	$65	4
Four Corners and Hyden Formations, undifferentiated	sandstone, shale, siltstone, coal	5.35	6.22	$2,806	$64	7
Fort Payne Formation	siltstone and shale	1,139.25	489.67	$90,352	$64	368
older alluvium	mixed sediments	19.62	15.72	$6,796	$62	24
upper part, Grant Lake Limestone	limestone and minor shale	21.48	12.34	$5,126	$59	8
upper part, Newman Limestone	limestone and minor shale	3.84	0.62	$120	$55	1
river area	river	262.66	10.26	$856	$55	3
Tradewater Formation	shale, siltstone, sandstone, limestone, coal	517.11	358.08	$45,897	$53	210
Tanglewood Limestone Member No. 3, Lexington Limestone	limestone and minor shale	78.79	87.04	$5,950	$48	31
St. Louis Limestone	limestone, fine-grained	1,852.01	1,883.25	$177,613	$48	1,280
alluvial fan deposits	mixed sediments	1.01	2.36	$763	$48	14
Pennington Group	sandstone, siltstone, shale, limestone	21.76	38.59	$4,792	$47	26
Grant Lake Limestone	limestone and minor shale	476.53	450.09	$30,311	$45	90
Ste. Genevieve Limestone Member, Slade Formation	limestone, coarse-grained	32.16	37.00	$11,126	$44	30
Buffalo Wallow Formation	sandstone, siltstone, shale, limestone	110.21	70.22	$14,004	$43	30
Bangor Limestone and Hartselle Formation	sandstone and minor shale	21.64	7.90	$2,370	$43	29
Girkin Formation	limestone, fine-grained	226.02	118.38	$26,990	$40	38
Clays Ferry Formation	limestone and shale	1,350.72	758.81	$39,508	$40	186
upper part, Slade Formation	limestone and minor shale	52.52	36.14	$7,124	$39	63
Salem and Warsaw Limestones	limestone, coarse-grained	976.14	854.20	$80,158	$38	568
reef limestone, Fort Payne Formation	limestone, coarse-grained	149.98	108.37	$17,595	$38	55
Naese Sandstone Member, upper part of Bee Rock Sandstone	quartzose sandstone	11.00	19.31	$4,994	$37	16
Tanglewood Limestone Member, Lexington Limestone	limestone and minor shale	0.62	1.40	$326	$36	4
high-level fluvial deposits	mixed sediments	65.30	61.97	$5,101	$35	60

Appendix 2: Cost and Frequency of Rockfall Repairs by Geologic Formation (Sorted by Cost per Mile per Year).

Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
Muldraugh Member, Borden Formation	siltstone and shale	264.86	81.93	$11,936	$34	58
Kidder Limestone Member, Monteagle Limestone	limestone, fine-grained	129.09	63.62	$15,277	$34	87
Glen Dean Limestone	limestone and minor shale	187.57	126.48	$13,311	$33	53
lacustrine and terrace deposits	mixed sediments	9.84	7.51	$1,730	$33	10
Tar Springs Sandstone	shale and sandstone	152.65	120.53	$6,867	$33	35
landslide deposits and colluvium	mixed sediments	1.45	5.18	$1,108	$32	12
Drakes Formation	dolomite and limestone	614.25	384.40	$11,891	$31	49
upper part, Borden Formation	siltstone and shale	128.09	15.36	$274	$30	4
glacial outwash (Wisconsinan)	sand and gravel	92.77	204.10	$12,848	$30	47
Tanglewood Limestone Member No. 2, Lexington Limestone	limestone and minor shale	342.21	418.12	$12,585	$29	107
Waldron Shale	gray shale	13.99	18.73	$84	$26	1
Lexington Limestone	limestone and shale	15.70	23.42	$1,035	$26	24
Kope Formation	shale and limestone	835.91	537.67	$48,449	$26	347
glacial outwash (Illinoian)	sand and gravel	1.60	3.76	$682	$26	9
Tanglewood Limestone Member No. 1 (lower tongue), Lexington Limestone	limestone and minor shale	81.57	93.36	$2,752	$25	14
Calloway Creek Limestone	limestone and minor shale	448.56	418.39	$16,588	$23	58
Carter Caves Sandstone	quartzose sandstone	5.59	5.25	$825	$22	7
upper part, Lexington Limestone	limestone and shale	389.65	389.52	$6,986	$22	51
Burnside Member, Slade Formation	limestone, coarse-grained	36.24	41.54	$5,983	$21	43
Paoli Limestone	limestone, fine-grained	45.24	15.54	$2,194	$20	13
Kope and Clays Ferry Formations	shale and limestone	470.96	246.30	$5,399	$20	63
Haney Limestone Member, Golconda Formation	limestone and minor shale	120.38	62.44	$4,433	$19	21
alluvium and lacustrine deposits	sand, silt, clay	270.88	165.50	$4,805	$18	22
Point Pleasant Tongue, Clays Ferry Formation	limestone and shale	36.31	65.66	$7,511	$16	172
Haney Limestone Member, Golconda Formation	limestone and minor shale	56.46	24.35	$1,275	$16	7
Breathitt Group, intensely deformed	sandstone, shale, siltstone, coal	5.00	5.76	$649	$16	2
lower member, Grant Lake Limestone	limestone and minor shale	39.47	38.35	$4,048	$15	9

Appendix 2: Cost and Frequency of Rockfall Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
Big Clifty Sandstone Member, Golconda Formation	sandstone and minor shale	105.56	45.90	$3,345	$15	25
lower part, Calloway Creek Limestone	limestone and minor shale	16.14	15.43	$1,606	$15	2
Hardinsburg Sandstone, Golconda Formation, and Cypress Sandstone	sandstone, siltstone, shale, limestone	7.43	2.09	$78	$15	2
sandstone member, Mooretown Formation	quartzose sandstone	5.20	5.53	$566	$15	1
Big Clifty Sandstone Member, Golconda Formation	sandstone and minor shale	293.12	163.04	$7,647	$14	47
Ste. Genevieve Limestone	limestone, fine-grained	1,174.75	1,106.32	$45,987	$14	403
Livingston Conglomerate Member, Alvy Creek Formation	quartzose sandstone	3.17	1.55	$149	$14	1
Beech Creek Limestone Member, Golconda Formation	limestone and minor shale	44.33	15.20	$1,328	$14	6
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	0.90	2.20	$195	$13	2
Boyle Dolomite	dolomite	41.01	33.51	$497	$12	5
Menard Limestone	limestone and shale	72.98	36.64	$925	$11	4
landslide deposits	mixed sediments	2.06	7.57	$384	$11	6
Estill Shale, Crab Orchard Group	gray shale	81.86	67.05	$4,951	$11	15
Brannon Member, Lexington Limestone	limestone and shale	64.60	71.37	$4,920	$10	15
Paragon and Slade Formations, undifferentiated	sandstone, siltstone, shale, minor coal	15.63	9.74	$655	$10	7
sand of Quaternary alluvium	sand, silt, clay	14.83	5.70	$406	$10	5
Renfro Member, Slade Formation	dolomite and limestone	75.81	73.99	$5,236	$10	24
Tradewater and Caseyville Formations	shale, siltstone, sandstone, limestone, coal	896.46	585.69	$13,552	$10	179
Garrard Siltstone	siltstone and shale	80.66	52.72	$3,371	$10	3
Ashlock Formation	limestone and shale	220.46	218.44	$4,027	$9	23
loess	eolian loess	1,709.06	1,843.75	$33,138	$8	178
Sunbury Shale, Berea Sandstone, and Bedford Shale, undivided	shale, sandstone	2.22	1.40	$65	$8	1
Degonia Sandstone, Clore Limestone, and Palestine Sandstone	sandstone, siltstone, shale, limestone	24.44	6.73	$347	$8	2
lower part of Renfro Member, Slade Formation	dolomite	6.26	4.01	$207	$7	10

Appendix 2: Cost and Frequency of Rockfall Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
Hensley Member, Alvy Creek Formation	sandstone, shale, siltstone, coal	27.33	3.72	$158	$7	2
New Albany Shale and Beechwood Limestone Member, Sellersburg Limestone	shale and limestone	89.59	93.57	$2,805	$7	13
Muldraugh Member, Borden Formation	siltstone and shale	6.25	0.67	$31	$7	2
Shelburn Formation	sandstone, shale, siltstone, coal, limestone	221.17	197.31	$8,957	$6	60
lower member, St. Louis Limestone	limestone, fine-grained	15.37	17.98	$300	$6	1
Sellersburg and Jeffersonville Limestones	limestone, coarse-grained	70.97	159.43	$6,563	$6	8
unnamed sandstone bed, Grundy Formation	quartzose sandstone	7.08	5.38	$211	$6	4
Nancy and Farmers Members, Borden Formation	gray shale and sandstone	3.31	0.81	$31	$5	2
Waco Member and Lulbegrud Shale Member, Alger Shale	shale and minor dolomite	2.05	1.46	$52	$5	3
Brassfield Dolomite	dolomite	22.60	17.67	$533	$5	3
Bethel Sandstone	sandstone and minor shale	52.91	51.92	$1,441	$5	12
Laurel Dolomite	dolomite	120.86	147.59	$2,565	$5	26
Mattoon Formation	sandstone, shale, siltstone, coal, limestone	34.63	28.21	$956	$5	1
lower part, Grant Lake Limestone	limestone and minor shale	13.45	22.30	$742	$5	4
lacustrine deposits (Illinoian)	clay and silt	2.59	8.68	$273	$4	2
upper part of Renfro Member, Slade Formation	dolomitic limestone, siltstone, shale, sandstone	34.96	25.38	$705	$4	25
glacial drift (Illinoian)	sand and gravel	3.00	5.66	$138	$3	2
Tate Member, Grant Lake Limestone	limestone and minor dolomite	3.62	3.32	$52	$3	3
Renault Limestone	limestone and minor shale	109.08	126.75	$1,363	$3	12
Fairview Formation	limestone and shale	485.46	532.29	$4,782	$3	74
Waltersburg Sandstone and Vienna Limestone	sandstone, siltstone, shale, limestone	34.62	35.13	$598	$3	10
Harrodsburg Limestone	limestone, coarse-grained	78.69	47.08	$373	$3	8
Leitchfield Formation	shale and sandstone	78.16	51.03	$328	$3	18
Carbondale Formation	sandstone, shale, siltstone, coal, limestone	293.47	259.14	$4,530	$3	44

Appendix 2: Cost and Frequency of Rockfall Repairs by Geologic Formation (Sorted by Cost per Mile per Year).						
Geologic Formation	*Dominant Lithology*	*Area (mi^2)*	*Miles*	*Landslide Total Cost*	*Landslide Cost per Mile per Year*	*Landslide Frequency*
Cypress Sandstone, Paint Creek Shale, and Bethel Sandstone	sandstone, siltstone, shale, limestone	78.97	33.59	$566	$2	1
Ste. Genevieve Limestone	limestone, fine-grained	290.89	313.14	$4,543	$2	28
Ste. Genevieve Limestone and upper member, St. Louis Limestone	limestone, fine-grained	117.35	142.88	$1,004	$2	5
lacustrine and fluvial deposits	mixed sediments	212.52	153.67	$1,889	$2	7
Paint Creek Limestone	limestone and shale	57.06	35.04	$227	$2	8
Preachersville and Rowland Members, Drakes Formation	shale and minor dolomite	14.52	7.26	$42	$2	4
Alger Shale	gray shale	16.52	19.89	$212	$2	12
Estill Shale Member, Alger Shale	gray shale	9.79	6.09	$63	$1	3
St. Louis and Salem Limestones	limestone, fine-grained	189.33	155.99	$1,576	$1	12
Tazewell Outwash	sand and gravel	110.27	130.71	$1,203	$1	5
Tyrone Limestone and Oregon Formation	dolomite and limestone	36.04	20.76	$173	$1	2
brecciated sandstone	shale and limestone	1.21	1.15	$9	$1	1
Osgood Formation	shale and minor dolomite	28.77	25.79	$168	$1	2
Kinkaid Limestone, Degonia Sandstone, and Clore Limestone, undivided	sandstone, siltstone, shale, limestone	20.59	12.27	$68	$1	1
Drowning Creek Formation	shale and minor dolomite	72.31	46.72	$281	$1	21
Preachersville Member, Drakes Formation	dolomite and limestone	43.90	28.75	$173	$1	9
unnamed sandstone bed in lower Breathitt Group	quartzose sandstone	5.36	2.81	$15	$1	1
New Albany Shale and Beechwood Limestone Member, Sellersburg Limestone	shale and limestone	2.34	7.48	$39	$1	3
Bond Formation	sandstone, shale, siltstone, coal, limestone	98.64	93.01	$473	$1	1
Louisville Limestone	dolomite and limestone	142.15	228.30	$1,095	$1	24
Claiborne Formation	sand, silt, clay	26.07	15.43	$67	$1	2
Big Clifty Sandstone Member of Golconda Formation and Cypress Sandstone	sandstone and minor shale	12.00	5.74	$23	$1	1
Sample Sandstone	sandstone and minor shale	79.36	32.03	$126	$1	7
Sunset Member, Bull Fork Formation	limestone and minor shale	8.50	5.55	$21	$1	1

Appendix 3: Frequency of Work-Order Miles for Landslides.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
alluvium	mixed sediments	7,905	4,354
Pikeville Formation	sandstone, shale, siltstone, coal	6,496	2,149
Hyden Formation	sandstone, shale, siltstone, coal	3,985	916
Grundy Formation	sandstone, siltstone, shale, minor coal	2,210	922
Kope Formation	shale and limestone	1,994	538
Four Corners Formation	sandstone, shale, siltstone, coal	1,270	278
St. Louis Limestone	limestone, fine-grained	1,228	1,883
Fairview Formation	limestone and shale	934	532
Borden Formation	siltstone and shale	843	385
glacial outwash (Wisconsinan)	sand and gravel	781	204
Ste. Genevieve Limestone	limestone, fine-grained	662	1,106
Clays Ferry Formation	limestone and shale	637	759
artificial fill	artificial fill	619	497
Hardinsburg Sandstone	sandstone and minor shale	590	299
Kope and Clays Ferry Formations	shale and limestone	573	246
Bull Fork Formation	limestone and shale	561	472
Point Pleasant Tongue, Clays Ferry Formation	limestone and shale	541	66
loess	eolian loess	493	1,844
Princess Formation	sandstone, shale, siltstone, coal	444	191
Grant Lake Limestone	limestone and minor shale	416	450
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	358	243
Calloway Creek Limestone	limestone and minor shale	332	418
terrace deposits	mixed sediments	279	157
Salem and Warsaw Limestones	dolomitic limestone, siltstone, shale, sandstone	273	854
Salem and Warsaw Limestones	limestone, coarse-grained	273	854
Paragon Formation	sandstone, siltstone, shale, minor coal	264	66
Tazewell Outwash	sand and gravel	240	131
lower part, Lexington Limestone	limestone and shale	208	419
Conemaugh Formation	reddish green shale	192	50

Appendix 3: Frequency of Work-Order Miles for Landslides.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Drakes Formation	dolomite and limestone	189	384
New Albany Shale	black shale	171	303
Tar Springs Sandstone	shale and sandstone	149	121
Big Clifty Sandstone Member, Golconda Formation	sandstone and minor shale	146	163
Tradewater and Caseyville Formations	quartzose sandstone	137	586
Tradewater and Caseyville Formations	shale, siltstone, sandstone, limestone, coal	137	586
Slade Formation	limestone and minor dolomite	131	53
Louisville Limestone	dolomite and limestone	114	228
Buffalo Wallow Formation	sandstone, siltstone, shale, limestone	111	70
Tradewater Formation	sandstone, shale, siltstone, coal, limestone	111	358
Tradewater Formation	shale, siltstone, sandstone, limestone, coal	111	358
alluvium and lacustrine deposits	sand, silt, clay	110	166
Carbondale Formation	sandstone, shale, siltstone, coal, limestone	108	259
Carbondale Formation	shale, siltstone, sandstone, limestone, coal	108	259
high-level fluvial deposits	mixed sediments	106	62
Fort Payne Formation	siltstone and shale	100	490
glacial drift (pre-Illinoian)	sand and gravel	97	29
Haney Limestone Member, Golconda Formation	limestone and minor shale	97	62
Newman Limestone	limestone and minor shale	95	0
glacial outwash (Illinoian)	sand and gravel	91	4
Alvy Creek Formation	sandstone, siltstone, shale, minor coal	90	36
upper part, Slade Formation	limestone and minor shale	89	36
upper part, Lexington Limestone	limestone and shale	87	390
Louisville Limestone and Waldron Shale	dolomite and limestone	85	24
Lexington Limestone	limestone and shale	84	23
Estill Shale, Crab Orchard Group	gray shale	79	67
middle part of Breathitt Group, undifferentiated	sandstone, shale, siltstone, coal	79	70
middle part of Breathitt Group, undifferentiated	shale, siltstone, sandstone, minor coal	79	70
Muldraugh Member, Borden Formation	dolomitic limestone, siltstone, shale, sandstone	79	82

Appendix 3: Frequency of Work-Order Miles for Landslides.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Muldraugh Member, Borden Formation	siltstone and shale	79	82
lacustrine deposits (Wisconsinan)	clay and silt	76	67
Tanglewood Limestone Member No. 3, Lexington Limestone	limestone and minor shale	70	87
Tanglewood Limestone Member No. 2, Lexington Limestone	limestone and minor shale	69	418
Glen Dean Limestone	limestone and minor shale	68	126
Laurel Dolomite	dolomite	66	148
Ste. Genevieve Limestone	limestone, fine-grained	66	313
Shelburne Formation	sandstone, shale, siltstone, coal, limestone	63	197
Sellersburg and Jeffersonville Limestones	limestone, coarse-grained	59	159
Pennington Group	sandstone, siltstone, shale, limestone	57	39
river area	river	57	10
Girkin Formation	limestone, fine-grained	52	118
Alger Shale	gray shale	50	20
lacustrine and terrace deposits	mixed sediments	49	8
Ohio Shale	black shale	47	34
Cowbell Member, Borden Formation	siltstone and shale	46	38
Drowning Creek Formation	shale and minor dolomite	42	47
Leipers Limestone	limestone, fine-grained	40	43
Ashlock Formation	limestone and shale	38	218
Beech Creek Limestone Member, Golconda Formation	limestone and minor shale	38	15
lacustrine and fluvial deposits (pre-Illinoian)	mixed sediments	36	16
glacial drift (Illinoian)	sand and gravel	34	6
Boyle Dolomite	dolomite	31	34
eolian sand, dune sand	eolian sand	30	9
Tanglewood Limestone Member No. 4 (upper tongue), Lexington Limestone	limestone and minor shale	29	81
Millersburg Member, Lexington Limestone	limestone and shale	28	1
Nancy Member, Borden Formation	gray shale	28	50
continental deposits	mixed sediments	27	374

Appendix 3: Frequency of Work-Order Miles for Landslides.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Paragon and Slade Formations, undifferentiated	sandstone, siltstone, shale, minor coal	26	10
lower member, Grant Lake Limestone	limestone and minor shale	25	38
Brannon Member, Lexington Limestone	limestone and shale	24	71
Farmers Member, Borden Formation	sandstone and minor shale	23	45
Preachersville and Rowland Members, Drakes Formation	shale and minor dolomite	23	7
Ste. Genevieve Limestone Member, Monteagle Limestone	limestone, coarse-grained	22	80
upper part, Borden Formation	siltstone and shale	22	15
alluvium of valley sides, meander cores, cut-off meanders, and abandoned channels	mixed sediments	21	8
Leitchfield Formation	shale and sandstone	21	51
Paoli Limestone	limestone, fine-grained	21	16
Caseyville Formation	quartzose sandstone	20	172
older alluvium	mixed sediments	20	16
siltstone member, Borden Formation	siltstone and shale	20	16
Beaver Bend Limestone and Mooretown Formation	limestone and shale	19	7
lower part, Breathitt Group	sandstone, shale, siltstone, coal	19	4
Renfro Member, Slade Formation	dolomite and limestone	19	74
Renfro Member, Slade Formation	dolomitic limestone, siltstone, shale, sandstone	19	74
Big Clifty Sandstone Member, Golconda Formation	sandstone and minor shale	18	46
Grier Limestone Member, Lexington Limestone	limestone and minor shale	18	1
Mattoon Formation	sandstone, shale, siltstone, coal, limestone	18	28
Pikeville and Grundy Formations, undifferentiated	sandstone, shale, siltstone, coal	18	19
Pikeville and Grundy Formations, undifferentiated	shale, siltstone, sandstone, minor coal	18	19
Reelsville Limestone	limestone and minor shale	18	15
Ste. Genevieve Limestone Member, Slade Formation	limestone, coarse-grained	18	37
lower member, Newman Limestone	limestone, fine-grained	17	3
Rockcastle Conglomerate	quartzose sandstone	17	5
Salem Limestone	limestone, coarse-grained	17	30
Sample Sandstone	sandstone and minor shale	17	32

Appendix 3: Frequency of Work-Order Miles for Landslides.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Tanglewood Limestone Member No. 1 (lower tongue), Lexington Limestone	limestone and minor shale	17	93
Harrodsburg Limestone	limestone, coarse-grained	16	47
Kidder Limestone Member, Monteagle Limestone	limestone, fine-grained	16	64
lacustrine and fluvial deposits	mixed sediments	16	154
Patoka Formation	sandstone, shale, siltstone, coal, limestone	16	118
Beaver Bend, Mooretown Formation, and Paoli Limestone, undifferentiated	limestone, fine-grained	14	9
Haney Limestone Member, Golconda Formation	limestone and minor shale	14	24
Jackson Formation	sand, silt, clay	14	3
Renault Limestone	limestone and minor shale	14	127
Tate Member, Ashlock Formation	shale and limestone	14	20
Bee Rock Sandstone	quartzose sandstone	13	8
Crab Orchard Formation and Brassfield Dolomite	shale and minor dolomite	13	62
unnamed sandstone bed, Grundy Formation	quartzose sandstone	13	5
Burnside Member, Slade Formation	limestone, coarse-grained	12	42
Ste. Genevieve Limestone and upper member, St. Louis Limestone	limestone, fine-grained	12	143
Beaver Bend Limestone, Mooretown Formation, and Paoli Limestone	limestone, fine-grained	11	4
Camp Nelson Limestone	limestone and minor dolomite	11	6
Monongahela Formation and upper part, Conemaugh Formation	shale, siltstone, sandstone, minor coal	11	9
New Albany Shale and Beechwood Limestone Member, Sellersburg Limestone	shale and limestone	11	7
Preachersville Member, Drakes Formation	dolomite and limestone	11	29
Tanglewood Limestone Member, Lexington Limestone	limestone and minor shale	11	1
Cary Outwash	sand and gravel	10	14
Tyrone Limestone	limestone, fine-grained	10	11
upper member, Grant Lake Limestone	limestone and minor shale	10	38
Bedford Shale	shale and sandstone	9	5
Bond Formation	sandstone, shale, siltstone, coal, limestone	9	93
coarse clastic limestone member, Clays Ferry Formation	limestone, coarse-grained	9	1

Appendix 3: Frequency of Work-Order Miles for Landslides.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
outwash deposits (pre-Illinoian)	sand and gravel	9	4
Beaver Bend and Paoli Limestones	limestone, fine-grained	8	19
Berea Sandstone and Bedford Shale	shale, sandstone	8	0
Bethel Sandstone	sandstone and minor shale	8	52
Claiborne Formation	sand, silt, clay	8	15
colluvium	mixed sediments	8	15
lower shale member, Borden Formation	gray shale	8	4
Naese Sandstone Member, upper part of Bee Rock Sandstone	quartzose sandstone	8	19
Grant Lake Member, Ashlock Formation	limestone, fine-grained	7	26
Osgood and Brassfield Formations	shale and minor dolomite	7	35
Beech Creek Limestone Member, Golconda Formation	limestone and minor shale	6	1
Kinkaid Limestone	limestone, fine-grained	6	8
lacustrine deposits (Illinoian)	clay and silt	6	9
New Albany Shale and Beechwood Limestone Member, Sellersburg Limestone	shale and limestone	6	94
sand of Quaternary alluvium	sand, silt, clay	6	6
Berea Sandstone	quartzose sandstone	5	9
Four Corners and Hyden Formations, undifferentiated	sandstone, shale, siltstone, coal	5	6
Menard Limestone	limestone and shale	5	37
Muldraugh Member, Borden Formation	siltstone and shale	5	1
older Ohio River alluvium	mixed sediments	5	5
Reelsville Limestone and Sample Sandstone	sandstone, siltstone, shale, limestone	5	4
Waltersburg Sandstone and Vienna Limestone	sandstone, siltstone, shale, limestone	5	35
Bisher Limestone	dolomite	4	4
Cumberland Formation	limestone, fine-grained	4	43
landslide deposits	mixed sediments	4	8
Paint Creek Limestone	limestone and shale	4	35
Renfro Member, Slade Formation, and Nada Member, Borden Formation	sandstone, siltstone, shale, minor coal	4	4

Appendix 3: Frequency of Work-Order Miles for Landslides.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
sandstone member, Mooretown Formation	quartzose sandstone	4	6
Sewanee and Warren Point Sandstones	quartzose sandstone	4	5
Tyrone Limestone and Oregon Formation	dolomite and limestone	4	21
Chattanooga Shale	black shale	3	16
Estill Shale Member, Alger Shale	gray shale	3	6
lower member, St. Louis Limestone	limestone, fine-grained	3	18
Sunbury Shale	black shale	3	2
Carter Caves Sandstone	quartzose sandstone	2	5
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	2	2
Livingston Conglomerate Member, Alvy Creek Formation	quartzose sandstone	2	2
Louisville Limestone, Waldron Shale, and Laurel Dolomite	dolomite and limestone	2	36
lower part, Calloway Creek Limestone	limestone and minor shale	2	15
Palestine Sandstone	sandstone and minor shale	2	22
unnamed sandstone bed, Princess Formation	quartzose sandstone	2	0
Vienna Limestone	limestone, coarse-grained	2	8
Big Clifty Sandstone Member, Golconda Formation, and Cypress Sandstone	sandstone and minor shale	1	6
Garrard Siltstone	siltstone and shale	1	53
Hartselle Formation	shale and sandstone	1	1
Hensley Member, Alvy Creek Formation	sandstone, shale, siltstone, coal	1	4
landslide deposits and colluvium	mixed sediments	1	5
Renault Limestone, Ste. Genevieve Limestone, St. Louis Limestone, and Salem Limestone	limestone and minor shale	1	3
Rockcastle Sandstone Member, Bee Rock Formation	quartzose sandstone	1	1
St. Louis and Salem Limestones	limestone, fine-grained	1	156
lower member, St. Louis Limestone, and Salem Limestone	limestone, fine-grained	1	2
St. Louis Limestone	limestone, fine-grained	1	3
upper part, Calloway Creek Limestone	limestone and minor shale	1	10

Appendix 4: Frequency of Work-Order Miles for Rockfalls.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
alluvium	mixed sediments	8,776	4,354
Pikeville Formation	sandstone, shale, siltstone, coal	8,132	2,149
Hyden Formation	sandstone, shale, siltstone, coal	6,201	916
Grundy Formation	sandstone, siltstone, shale, minor coal	4,214	922
Four Corners Formation	sandstone, shale, siltstone, coal	2,035	278
St. Louis Limestone	limestone, fine-grained	1,280	1,883
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	839	243
Salem and Warsaw Limestones	dolomitic limestone, siltstone, shale, sandstone	568	854
Salem and Warsaw Limestones	limestone, coarse-grained	568	854
Borden Formation	siltstone and shale	561	385
Princess Formation	sandstone, shale, siltstone, coal	513	191
Ste. Genevieve Limestone	limestone, fine-grained	403	1,106
Fort Payne Formation	siltstone and shale	368	490
Kope Formation	shale and limestone	347	538
artificial fill	artificial fill	341	497
Tradewater Formation	sandstone, shale, siltstone, coal, limestone	210	358
Tradewater Formation	shale, siltstone, sandstone, limestone, coal	210	358
Clays Ferry Formation	limestone and shale	186	759
Tradewater and Caseyville Formations	quartzose sandstone	179	586
Tradewater and Caseyville Formations	shale, siltstone, sandstone, limestone, coal	179	586
Conemaugh Formation	reddish green shale	178	50
loess	eolian loess	178	1,844
Ste. Genevieve Limestone Member, Monteagle Limestone	limestone, coarse-grained	178	80
Point Pleasant Tongue, Clays Ferry Formation	limestone and shale	172	66
Hardinsburg Sandstone	sandstone and minor shale	157	299
middle part of Breathitt Group, undifferentiated	sandstone, shale, siltstone, coal	154	70
middle part of Breathitt Group, undifferentiated	shale, siltstone, sandstone, minor coal	154	70
Paragon Formation	sandstone, siltstone, shale, minor coal	151	66
Slade Formation	limestone and minor dolomite	151	53

Appendix 4: Frequency of Work-Order Miles for Rockfalls.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Alvy Creek Formation	sandstone, siltstone, shale, minor coal	142	36
New Albany Shale	black shale	137	303
lower part, Lexington Limestone	limestone and shale	127	419
Cumberland Formation	limestone, fine-grained	122	43
terrace deposits	mixed sediments	114	157
Tanglewood Limestone Member No. 2, Lexington Limestone	limestone and minor shale	107	418
Bull Fork Formation	limestone and shale	97	472
Leipers Limestone	limestone, fine-grained	95	43
Cowbell Member, Borden Formation	siltstone and shale	93	38
Grant Lake Limestone	limestone and minor shale	90	450
Kidder Limestone Member, Monteagle Limestone	limestone, fine-grained	87	64
Fairview Formation	limestone and shale	74	532
Kope and Clays Ferry Formations	shale and limestone	63	246
upper part, Slade Formation	limestone and minor shale	63	36
high-level fluvial deposits	mixed sediments	60	62
Shelburn Formation	sandstone, shale, siltstone, coal, limestone	60	197
Calloway Creek Limestone	limestone and minor shale	58	418
Muldraugh Member, Borden Formation	dolomitic limestone, siltstone, shale, sandstone	58	82
Muldraugh Member, Borden Formation	siltstone and shale	58	82
reef limestone, Fort Payne Formation	limestone, coarse-grained	55	108
Glen Dean Limestone	limestone and minor shale	53	126
upper part, Lexington Limestone	limestone and shale	51	390
Drakes Formation	dolomite and limestone	49	384
upper member, Grant Lake Limestone	limestone and minor shale	48	38
Big Clifty Sandstone Member, Golconda Formation	sandstone and minor shale	47	163
glacial outwash (Wisconsinan)	sand and gravel	47	204
lower member, Newman Limestone	limestone, fine-grained	46	3
Carbondale Formation	sandstone, shale, siltstone, coal, limestone	44	259
Carbondale Formation	shale, siltstone, sandstone, limestone, coal	44	259

Appendix 4: Frequency of Work-Order Miles for Rockfalls.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Burnside Member, Slade Formation	limestone, coarse-grained	43	42
Tanglewood Limestone Member No. 4 (upper tongue), Lexington Limestone	limestone and minor shale	40	81
Chattanooga Shale	black shale	38	16
Girkin Formation	limestone, fine-grained	38	118
Crab Orchard Formation and Brassfield Dolomite	shale and minor dolomite	35	62
Tar Springs Sandstone	shale and sandstone	35	121
Bee Rock Sandstone	quartzose sandstone	32	8
Caseyville Formation	quartzose sandstone	32	172
Ohio Shale	black shale	32	34
Tanglewood Limestone Member No. 3, Lexington Limestone	limestone and minor shale	31	87
Buffalo Wallow Formation	sandstone, siltstone, shale, limestone	30	70
Ste. Genevieve Limestone Member, Slade Formation	limestone, coarse-grained	30	37
Bangor Limestone and Hartselle Formation	sandstone and minor shale	29	8
Ste. Genevieve Limestone	limestone, fine-grained	28	313
Farmers Member, Borden Formation	sandstone and minor shale	27	45
Monongahela Formation and upper part, Conemaugh Formation	shale, siltstone, sandstone, minor coal	27	9
Salem Limestone	limestone, coarse-grained	27	30
Laurel Dolomite	dolomite	26	148
Nancy Member, Borden Formation	gray shale	26	50
Pennington Group	sandstone, siltstone, shale, limestone	26	39
Berea Sandstone	quartzose sandstone	25	9
Big Clifty Sandstone Member, Golconda Formation	sandstone and minor shale	25	46
Pikeville and Grundy Formations, undifferentiated	sandstone, shale, siltstone, coal	25	19
Pikeville and Grundy Formations, undifferentiated	shale,siltstone, sandstone, minor coal	25	19
upper part of Renfro Member, Slade Formation	dolomitic limestone, siltstone, shale, sandstone	25	25
Lexington Limestone	limestone and shale	24	23
Louisville Limestone	dolomite and limestone	24	228
older alluvium	mixed sediments	24	16

Appendix 4: Frequency of Work-Order Miles for Rockfalls.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Renfro Member, Slade Formation	dolomite and limestone	24	74
Renfro Member, Slade Formation	dolomitic limestone, siltstone, shale, sandstone	24	74
Tyrone Limestone	limestone, fine-grained	24	11
Ashlock Formation	limestone and shale	23	218
alluvium and lacustrine deposits	sand, silt, clay	22	166
Drowning Creek Formation	shale and minor dolomite	21	47
Haney Limestone Member, Golconda Formation	limestone and minor shale	21	62
colluvium	mixed sediments	20	15
Rockcastle Conglomerate	quartzose sandstone	19	5
siltstone member, Borden Formation	siltstone and shale	19	16
lake area	lake	18	3
Leitchfield Formation	shale and sandstone	18	51
Rockcastle Sandstone Member, Bee Rock Formation	quartzose sandstone	18	1
continental deposits	mixed sediments	16	374
Naese Sandstone Member, upper part of Bee Rock Sandstone	quartzose sandstone	16	19
Patoka Formation	sandstone, shale, siltstone, coal, limestone	16	118
alluvium of valley sides, meander cores, cut-off meanders, and abandoned channels	mixed sediments	15	8
Brannon Member, Lexington Limestone	limestone and shale	15	71
Estill Shale, Crab Orchard Group	gray shale	15	67
alluvial fan deposits	mixed sediments	14	2
Beaver Bend Limestone, Mooretown Formation, and Paoli Limestone	limestone, fine-grained	14	4
Tanglewood Limestone Member No. 1 (lower tongue), Lexington Limestone	limestone and minor shale	14	93
New Albany Shale and Beechwood Limestone Member, Sellersburg Limestone	shale and limestone	13	94
Paoli Limestone	limestone, fine-grained	13	16
Alger Shale	gray shale	12	20
Bethel Sandstone	sandstone and minor shale	12	52
landslide deposits and colluvium	mixed sediments	12	5

Appendix 4: Frequency of Work-Order Miles for Rockfalls.

Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Louisville Limestone and Waldron Shale	dolomite and limestone	12	24
Renault Limestone	limestone and minor shale	12	127
St. Louis and Salem Limestones	limestone, fine-grained	12	156
lacustrine deposits (Wisconsinan)	clay and silt	11	67
lacustrine and terrace deposits	mixed sediments	10	8
lower part of Renfro Member, Slade Formation	dolomite	10	4
Waltersburg Sandstone and Vienna Limestone	sandstone, siltstone, shale, limestone	10	35
glacial outwash (Illinoian)	sand and gravel	9	4
lower member, Grant Lake Limestone	limestone and minor shale	9	38
Preachersville Member, Drakes Formation	dolomite and limestone	9	29
Harrodsburg Limestone	limestone, coarse-grained	8	47
Newman Limestone	limestone and minor shale	8	0
Paint Creek Limestone	limestone and shale	8	35
Sellersburg and Jeffersonville Limestones	limestone, coarse-grained	8	159
shale member, Fort Payne Formation	siltstone and shale	8	1
upper part, Grant Lake Limestone	limestone and minor shale	8	12
Carter Caves Sandstone	quartzose sandstone	7	5
Four Corners and Hyden Formations, undifferentiated	sandstone, shale, siltstone, coal	7	6
Haney Limestone Member, Golconda Formation	limestone and minor shale	7	24
Hartselle Formation	shale and sandstone	7	1
lacustrine and fluvial deposits	mixed sediments	7	154
Paragon and Slade Formations, undifferentiated	sandstone, siltstone, shale, minor coal	7	10
Sample Sandstone	sandstone and minor shale	7	32
Beech Creek Limestone Member, Golconda Formation	limestone and minor shale	6	15
landslide deposits	mixed sediments	6	8
Boyle Dolomite	dolomite	5	34
sand of Quaternary alluvium	sand, silt, clay	5	6
Ste. Genevieve Limestone and upper member, St. Louis Limestone	limestone, fine-grained	5	143
Tazewell Outwash	sand and gravel	5	131

Appendix 4: Frequency of Work-Order Miles for Rockfalls.

Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
Grainger Formation	siltstone and shale	4	2
lower part, Grant Lake Limestone	limestone and minor shale	4	22
lower shale member, Borden Formation	gray shale	4	4
Menard Limestone	limestone and shale	4	37
Preachersville and Rowland Members, Drakes Formation	shale and minor dolomite	4	7
Tanglewood Limestone Member, Lexington Limestone	limestone and minor shale	4	1
unnamed sandstone bed, Grundy Formation	quartzose sandstone	4	5
upper part, Borden Formation	siltstone and shale	4	15
Bedford Shale	shale and sandstone	3	5
Brassfield Dolomite	dolomite	3	18
Estill Shale Member, Alger Shale	gray shale	3	6
Garrard Siltstone	siltstone and shale	3	53
lower part, Breathitt Group	sandstone, shale, siltstone, coal	3	4
New Albany Shale and Beechwood Limestone Member, Sellersburg Limestone	shale and limestone	3	7
river area	river	3	10
Tate Member, Grant Lake Limestone	limestone and minor dolomite	3	3
Waco Member and Lulbegrud Shale Member, Alger Shale	shale and minor dolomite	3	1
Beaver Bend Limestone and Mooretown Formation	limestone and shale	2	7
Bisher Limestone	dolomite	2	4
Breathitt Group, intensely deformed	sandstone, shale, siltstone, coal	2	6
Claiborne Formation	sand, silt, clay	2	15
Corbin Sandstone Member, Grundy Formation	quartzose sandstone	2	2
Degonia Sandstone, Clore Limestone, and Palestine Sandstone	sandstone, siltstone, shale, limestone	2	7
glacial drift (Illinoian)	sand and gravel	2	6
Hardinsburg Sandstone, Golconda Formation, and Cypress Sandstone	sandstone, siltstone, shale, limestone	2	2
Hensley Member, Alvy Creek Formation	sandstone, shale, siltstone, coal	2	4
lacustrine deposits (Illinoian)	clay and silt	2	9

Appendix 4: Frequency of Work-Order Miles for Rockfalls.			
Geologic Formation	*Dominant Lithology*	*Frequency of Work-Order Miles*	*Road Miles*
lower part, Calloway Creek Limestone	limestone and minor shale	2	15
mine dump or mine spoil	mine spoil	2	1
Muldraugh Member, Borden Formation	siltstone and shale	2	1
Nancy and Farmers Members, Borden Formation	gray shale and sandstone	2	1
Osgood Formation	shale and minor dolomite	2	26
Reelsville Limestone	limestone and minor shale	2	15
Tyrone Limestone and Oregon Formation	dolomite and limestone	2	21
Waltersburg Sandstone	siltstone and shale	2	14
Big Clifty Sandstone Member, Golconda Formation, and Cypress Sandstone	sandstone and minor shale	1	6
Bond Formation	sandstone, shale, siltstone, coal, limestone	1	93
brecciated sandstone	shale and limestone	1	1
coarse clastic limestone member, Clays Ferry Formation	limestone, coarse-grained	1	1
Cypress Sandstone, Paint Creek Shale, and Bethel Sandstone	sandstone, siltstone, shale, limestone	1	34
Jackson Formation	sand, silt, clay	1	3
Kinkaid Limestone, Degonia Sandstone, and Clore Limestone, undivided	sandstone, siltstone, shale, limestone	1	12
Livingston Conglomerate Member, Alvy Creek Formation	quartzose sandstone	1	2
Louisville Limestone, Waldron Shale, and Laurel Dolomite	dolomite and limestone	1	36
Mattoon Formation	sandstone, shale, siltstone, coal, limestone	1	28
Nada Member, Borden Formation	siltstone and shale	1	2
Osgood and Brassfield Formations	shale and minor dolomite	1	35
sandstone member, Mooretown Formation	quartzose sandstone	1	6
lower member, St. Louis Limestone	limestone, fine-grained	1	18
Sunbury Shale, Berea Sandstone, and Bedford Shale, undivided	shale, sandstone	1	1
Sunset Member, Bull Fork Formation	limestone and minor shale	1	6
unnamed sandstone bed, lower Breathitt Group	quartzose sandstone	1	3
upper part, Newman Limestone	limestone and minor shale	1	1
Waldron Shale	gray shale	1	19