HYDROLOGIC AND AQUATIC IMPACTS FROM A LANDSLIDE IN THE TENNESSEE COAL FIELDS[1]

Robert Liddle and Steve Bakaletz[2]

Abstract: The purpose of this paper is to describe practical methods used by the Office of Surface Mining to evaluate environmental impacts from a landslide and devise a mitigation strategy. On January 27, 2005, a 10-hectare (25-acre) landslide occurred on a steep mountainside at High Point Mountain in Scott County, TN. The landslide included spoil from a pre-law contour coalmine and a reclaimed cross-ridge coalmine. Sediments from the landslide washed into Smoky Creek, a tributary to New River, which flows into the Big South Fork of the Cumberland River. Initial suspended sediment concentrations below the landslide were about 5000 mg/L, while total sediment concentrations peaked at about 24,000 mg/L. After 4 months, the landslide had stabilized and suspended sediment concentrations fell to less than 10 mg/L. Sand and gravel sized particles settled out within 610 m (2000 ft) below the landslide tributary, while fine silts and clays were carried over 32 km (20 miles) downstream. Groundwater from the adjacent mine spoils was modeled using the USGS MODFLOW software; results indicated mine spoil discharges would reach equilibrium within 292 days. Acid-base accounting accurately predicted no acid mine drainage would occur. Stormwater was modeled using the TVA TENN-I double triangle model, and net sediment erosion was modeled using the ERODE-I model. Model results compared well with actual field data and should be useful in evaluating other landslides. Biological evaluations were conducted on the impacted stream and compared to adjacent streams to show area productivity. Steams were sampled for fish, benthic invertebrates, crayfish, and amphibians by biologists with the Tennessee Wildlife Resources Agency, National Park Service and Tennessee Valley Authority. Aquatic life, while initially smothered, had begun to recover after 22 months. The NRCS WEPP model was used to evaluate different mitigation strategies. Mitigation consisted of seeding the landslide with grasses, planting trees, and implementing vegetative filters. In conclusion, the landslide resulted in an intense short-term release of sediments similar to a construction site, which subsided in about 3 months. Models proved satisfactory in estimating impacts.

Additional Key Words: Erosion, modeling, MODFLOW, sedimentation, TVA, water quality, WEPP

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Introduction

On January 27, 2005, a landslide (High Point landslide) occurred on High Point Mountain in the upper Smoky Creek watershed, a tributary to New River basin in Scott County, Tennessee (Fig. 1). Sediments from the landslide were transported over 32 km (20 miles) to the Big South Fork National River and Recreation Area (BISO). Since there were several reclaimed coal mines within the affected area, the Office of Surface Mining Reclamation and Enforcement (OSM) conducted an investigation as to the causes of the landslide, the hydrologic impacts of the landslide, and whether corrective action was necessary. This report only addresses the physical, biological, and chemical impacts to the rivers downstream of the landslide. Separate investigations were conducted on the cause of the landslide and are not discussed here.

Citizens groups, and other State and Federal Agencies asked several key questions:

1) Will the landslide produce Acid Mine Drainage (AMD)
2) Will the sedimentation harm fish?
3) Will the streams recover?
4) Will the river remain muddy for an extended period?
5) Should OSM build a pond below the landslide?
6) What is OSM going to do to mitigate the impacts?
7) What are the impacts from other landslides in the region?

The objective of the study was to try to quickly answer these questions using whatever data, models, and literature was available.

Background

The landslide occurred in a remote area with no roads or dwellings (Fig. 2). In early February 2005, a citizen and the National Park Service informed the State of Tennessee that muddy conditions were seen in New River. Tennessee Department of Environment and Conservation (TDEC), Division of Water Pollution Control (DWPC) personnel initiated an investigation that identified the source. OSM sent a team of scientists from Knoxville, TN and Ashland, KY to the landslide on March 10, 2005 shortly after being notified by TDEC. From interviews with local citizens and seismograph records, OSM believes the landslide occurred January 27, 2005. Water and sediment samples were taken from March 10, 2005 until May 10, 2005. Very little flow or sedimentation occurred from the landslide after May 2005. The landslide has characteristics similar to a pre-law surface mine where spoil was dumped over the out-slope (Fig. 3). The landslide material was primarily natural soils and rocks but there was some coal spoil material and some coal fines.

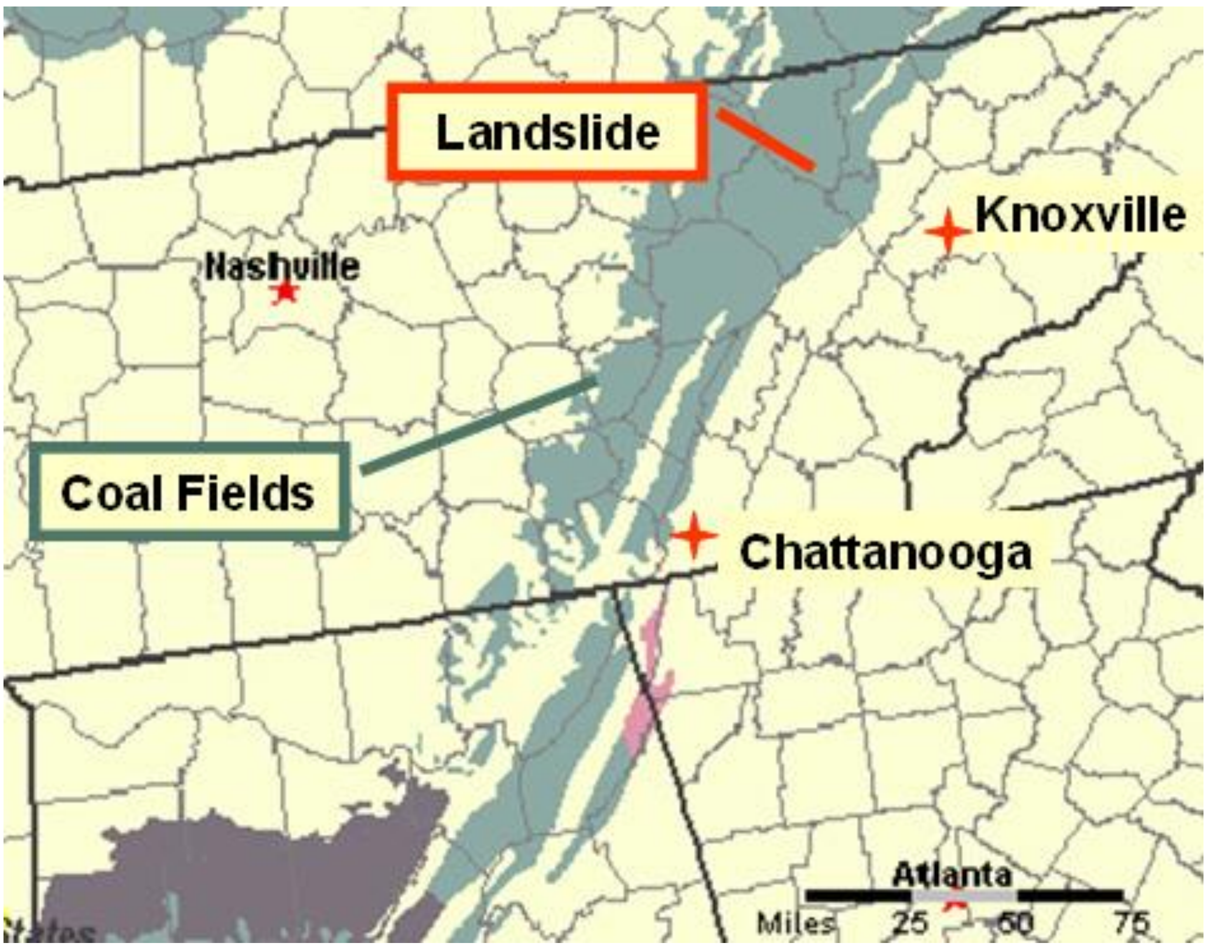

Figure 1. General Location Map (modified from USGS).

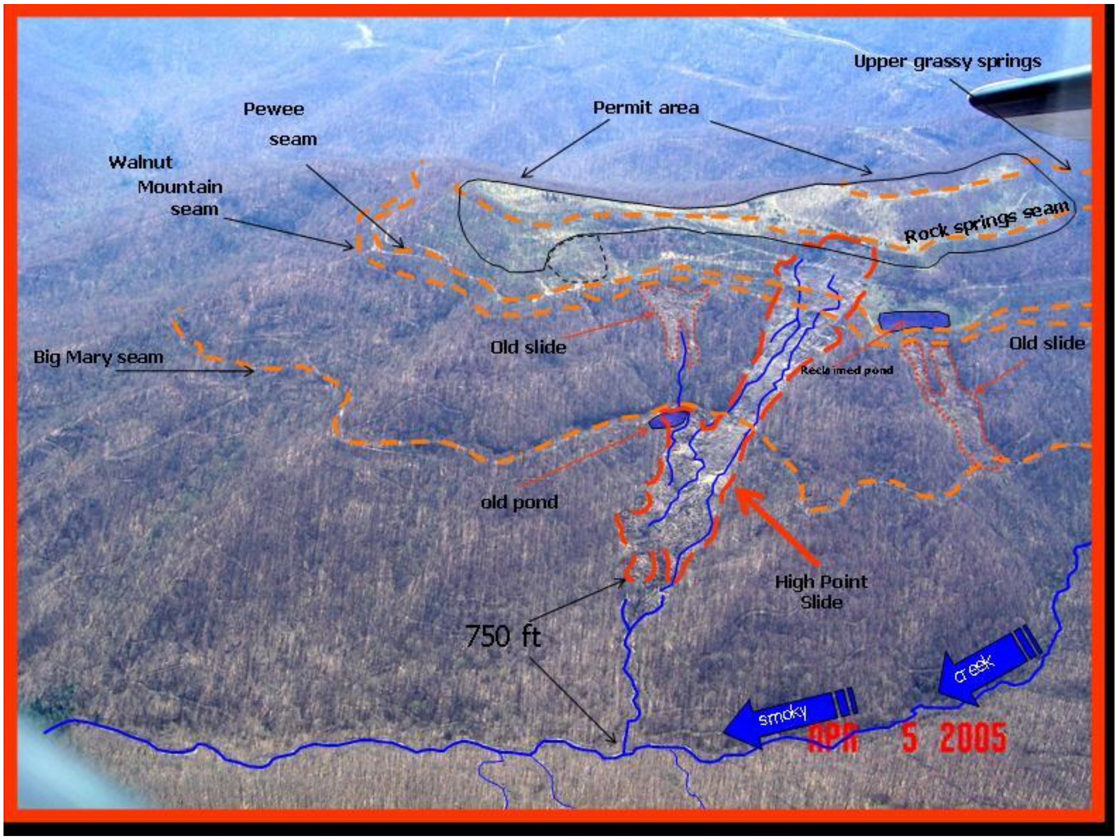

Figure 2. Overview of landslide region – photo from TDEC.

Figure 3. Arial Photo of Landslide (Source TDEC)

Location and description

The Big South Fork of the Cumberland River is a 3,522 square kilometer (1360 sq. mi) watershed. New River is the major sub-basin draining 989 square kilometers (382 sq. mi.). Smoky Creek is a sub-basin of New River with an 85 kilometer (32.8 sq. mi.) drainage area. The landslide affected about 10 hectares (25 acres) or 0.12% of the 8,495 hectare (20,992 acre) Smoky Creek watershed. The base or 'toe' of the landslide is in an un-named second order tributary about 239 m (750 ft) from Smoky Creek, 17.7 km (11 miles) upstream of New River, and 76 km (47 miles) from the BSF. The top (crown) of the landslide is 838 m (2,750 ft) above mean sea level (msl), whereas the bottom (mouth) of New River in the Big South Fork National River and Recreation Area (BSF) is 306 m (1004 ft) msl (Fig. 4).

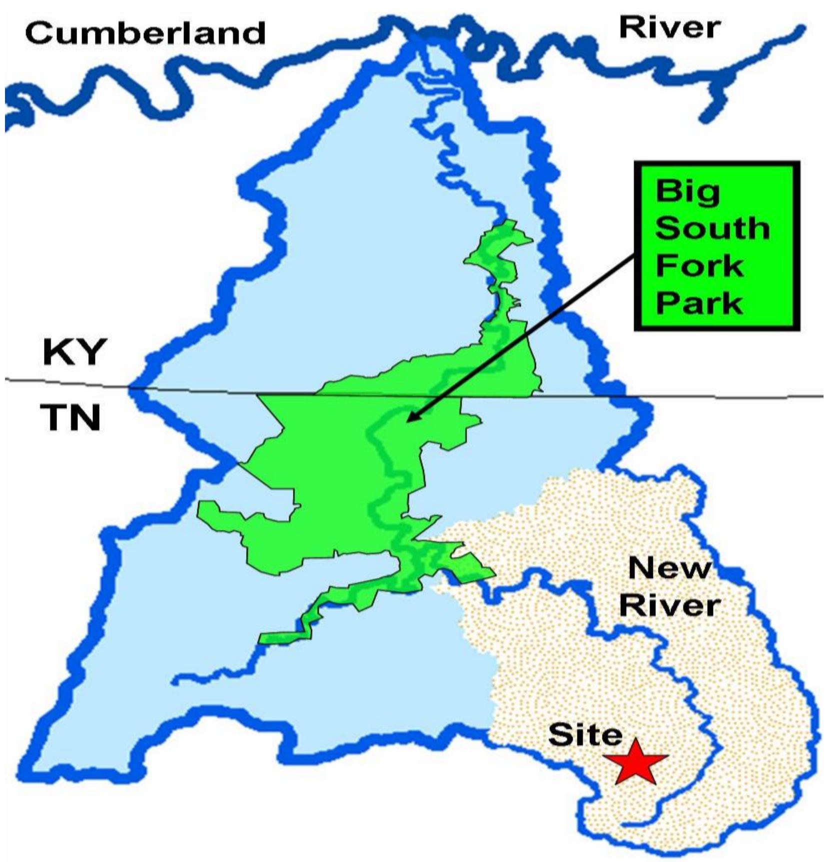

Figure 4. Watershed Map

Methodology

OSM's approach in this study was to:

1) Take water, sediment, and biological samples.

2) Conduct a literature search to identify projects, data, and models of the New River basins.

3) Inventory water users to evaluate the important resources downstream of the site.

4) Evaluate data using valid statistical methods.

5) Apply models to characterize the event and make predictions.

6) Compare landslide impacts to similar or historic events.

7) Draw conclusions and evaluate future actions.

8) Produce a final report on the landslide event.

9) Solicit peer review from other agencies.

Prior to the sediment study, OSM reviewed the concepts and procedures for evaluating fluvial sediments (Porterfield, 1972; EPA, 1976; Guy, 1978; Horowitz, 1991; Simons, 1992; Waters, 1995; Cohn, 1995; Radtke, 1997; Edwards, 1999; Stump, 2001, Runkel, 2004). Procedures were conducted according to the U.S. Geological Survey (USGS) National Field Manual for the collection of Water Quality Data, Book 9 A1 - A4 and A6 (USGS, 2004). Field parameters were taken with a Horuba model U-10 multi-probe meter, 0.45µ QED disposable pressure filters were used to separate solids. Stream flow measurements were taken using a Marsh-McBirney model 200 flow meter following the procedures of the USGS (Buchanan, 1976; Carter 1989). Suspended sediment in receiving streams were collected using a USGS DH-48 isokinetic glass bottle sampler (Edwards, 1999, p. 9) and bedload was collected using a cylinder pushed to 1 to 2 inches into the sediment or by collecting an entire discharge from a chute using a bucket. Settleable solids were measured in the field using an Imhoff Cone. Bulk bedload samples were put in plastic bags, frozen, and then sent to the lab.

Literature Review

A review of the literature showed many papers on the occurrence, causes, and repair of landslides; but little or no research on models to predict hydrologic impacts. OSM was able to obtain numerous references on erosion and sedimentation rates to use in comparing landslide impacts to other land uses. Perhaps the most useful result of the literature review was finding runoff, erosion, and sedimentation models to use in predicting hydrologic impacts from future landslides.

Inventory and Data Collection

There were no structures or water users for several kilometers downstream of the landslide. Therefore, the primary effects from the landslide would be felt by aquatic life within the stream. No access roads, limited time, manpower, and weather limited the amount of data that could be collected. Water quality could only be collected five times for the first three months (March through May of 2005). USGS and Tennessee Valley Authority (TVA) data on sedimentation rates in the watershed were obtained to use in comparing the impacts from the landslide.

Sampling Methodology

Composite grab samples were taken on the landslide and analyzed using the latest acid base accounting methods (siderite-peroxide method). Sediment samples were taken in the tributary drainage 240 m (730 ft) below the toe of the landslide; channel slope was 24%. Samples were taken in Smoky Creek below the mixing zone, near the mouth of Smoky Creek, and in New River above and below the confluence.

Sediment data were reported in several ways:

1) Settleable Solids (SS) is the volume of sediment that settles out in an Imhoff Cone in a one hour period; it is reported as volume per volume; milliliter sediment per liter sample (ml/L).

2) Total Suspended Solids (TSS) is the weight of sediment per volume of an aliquot sub-sample of the sample bottle. It is reported as mass/volume (mg/L). This method tends to under-estimate the sand size particles since these particles often settle out in the bottle or do not fit in the nozzle of the pipette (Gray, 2000).

3) Suspended Sediment Concentration (SSC) is the mass of sediment per volume sample; reported as mg/L. It differs from TSS in that the entire sample is measured, not just a sub-sample. The USGS considers this more representative than TSS (Gray, 2000).

4) The transition zone or zone of saltation (Fig. 5) was sampled in a chute on a few occasions to determine total sediment load.

5) Bedload transport was not seen to be occurring in the tributary drainage for the storm events that occurred during 2005, therefore none were reported. Most streams in the area are incised in bedrock.

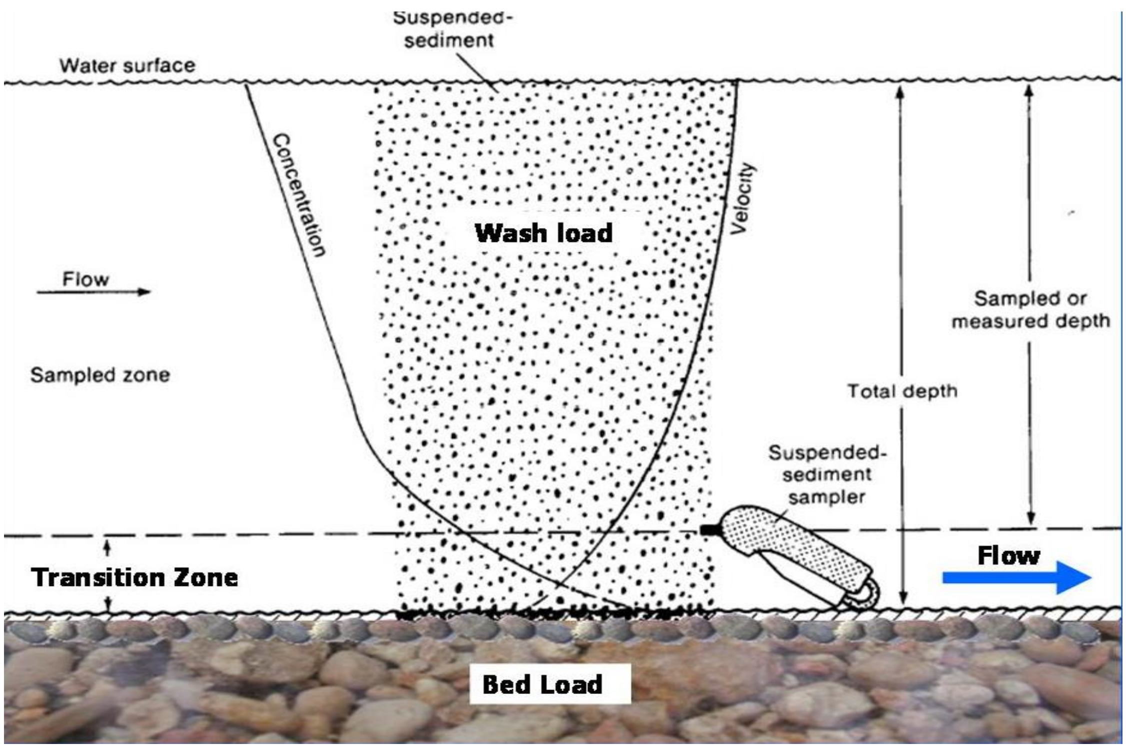

Figure 5. Conceptual model of sediment flow (After Guy, USGS)

Results

Water Quality Sampling

Sampling of the landslide material revealed that the material was non-acid forming and non-toxic. Composite rock samples were taken on the landslide and sent to the laboratory for standard Acid/Base accounting. Results showed the material is alkaline + 0.0044 kg $CaCO_3$ / 1 kg material or + 4.4 tons $CaCO_3$ per 1000 tons material, with paste pH 6.7, and < 0.1 % S. These values are typical from mines in this region.

The table below summarizes the general water quality of the drainages above and below the landslide. Discharges were alkaline with low levels of dissolved solids.

Table 1. Typical water quality of affected drainages.

Study Sites	% flow	pH	TDS mg/L	TDS load in kg or lbs/day	% load
Smoky above slide	6.1 %	7.45	121	92.5 / 204	7.6 %
Slide Tributary	2.5 %	7.6	180	56.7 / 125	4.7 %
Smoky below slide	8.5 %	7.6	139	150 / 331	12 %
Smoky at Mouth	100 %	7.2	96	1212 / 2671	100 %

Figure 6 below shows the time series of suspended sediment concentration (including the zone of transition) at the confluence of the landslide tributary and Smoky Creek. For the 3 month period sampled in 2005, the maximum total sediment concentration (wash load) was about 25,000 mg/L, settleable solids ranged from 4 to 14 ml/L, and total suspended solids ranged from 2 mg/L to 5,000 mg/L.

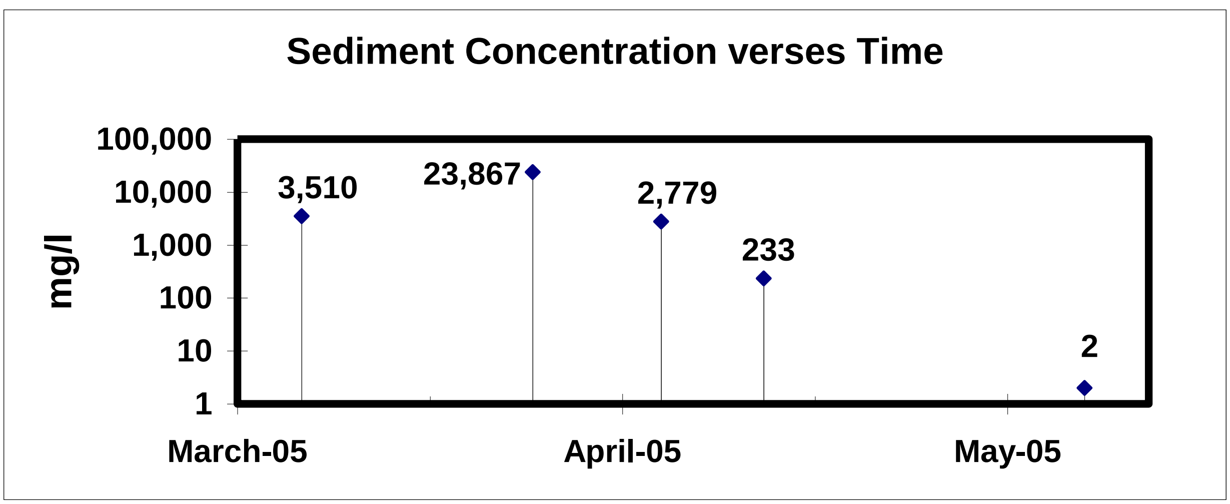

Figure 6. Total Suspended Sediment (Wash load) Concentration from Landslide.

Sampling was conducted regionally during a storm event (return interval approximately 2-yr) to compare the sediment concentrations in Smoky Creek to adjacent watersheds in the New River basin. Figure 7 shows the results of selected sampling in the area.

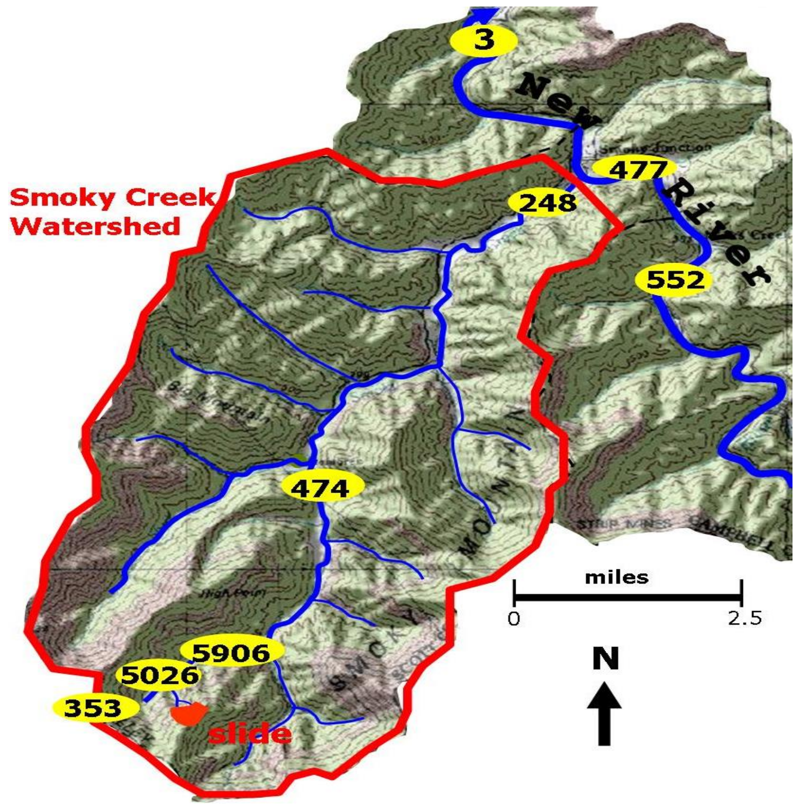

Figure7. Suspended Sediment Concentrations in mg/L during a 2-yr event.

Biological Sampling

Smokey Creek has had biological investigations conducted over a long period of time with different study objectives for each survey. These data show trends were variable with overall evidence that organisms are trying to re-populate areas that were formerly impacted and formerly had reduced species richness.

Invertebrates and Amphibians. Lokey (1977) reported 25 taxa for invertebrates in Smokey Creek during a New River study. In 2000 and 2004, the Tennessee Department of Environment and Conservation (TDEC) conducted biological assessments on Smoky Creek (prior to the 2005 landslide). The invertebrates were evaluated by TDEC using the EPA protocols for the Ecoregion reference site program. The TDEC scores showed Smoky Creek "fully supporting" the designated use as fishing, recreation, and livestock use prior to the landslide. Both invertebrate collections used similar techniques and identified taxa to the lowest possible level. A National

Park Service (NPS) biologist reviewed the raw data and prepared this report, the NPS intends to continue to participate with future data collections.

The scores for 2000 and 2004 were similar and reflect a creek that has good biodiversity and was recovering nicely from previous coal mining disturbances. We intended on collecting a similar data set immediately after the landslide, but rain events and scheduling crew members was a problem. Table 2 below shows the raw scores.

Table 2. Macroinvertebrate survey in Smoky Creek below landslide.

	1977	2000	2004
Taxa Richness	25	46	33
EPT Taxa	n/a	17	29.7
Intolerant Taxa	n/a	12	n/a
Tolerance Index	n/a	4.58	n/a

A biological survey was conducted in November 2006 to document the species richness in several streams in the impact area after the landslide occurred. Multiple agencies provided technical support for data collection. Species richness data indicated that at the time of the survey, streams were supporting the expected organisms that would occur in the area. However, the biological data was collected 22 months after the landslide event and this period of time was very likely a factor in allowing organisms to recover from the immediate impacts. The streams that were surveyed (Fig. 8) in November 2006 were: Smoky Creek below the landslide (Site A) and two adjacent streams; Asher Fork (Site B), and an un-named tributary to Asher Fork (Site C).

Species richness were collected for crayfish, amphibians, reptiles, fish, and aquatic invertebrates but not all of the data is available at this time. Mussels were searched for, but none were found, and they were last reported to occur in Smokey Creek in the mid-1950s by area residents. Crayfish were surveyed and 24 were found in Asher Fork, 26 in the un-named tributary and 22 were found in Smokey Creek, only one species of crayfish was found, the boxclaw crayfish, *Cambarus distans*. Surveys were conducted for reptiles and amphibians and the results included spring salamanders, two-lined salamander, and green frogs.

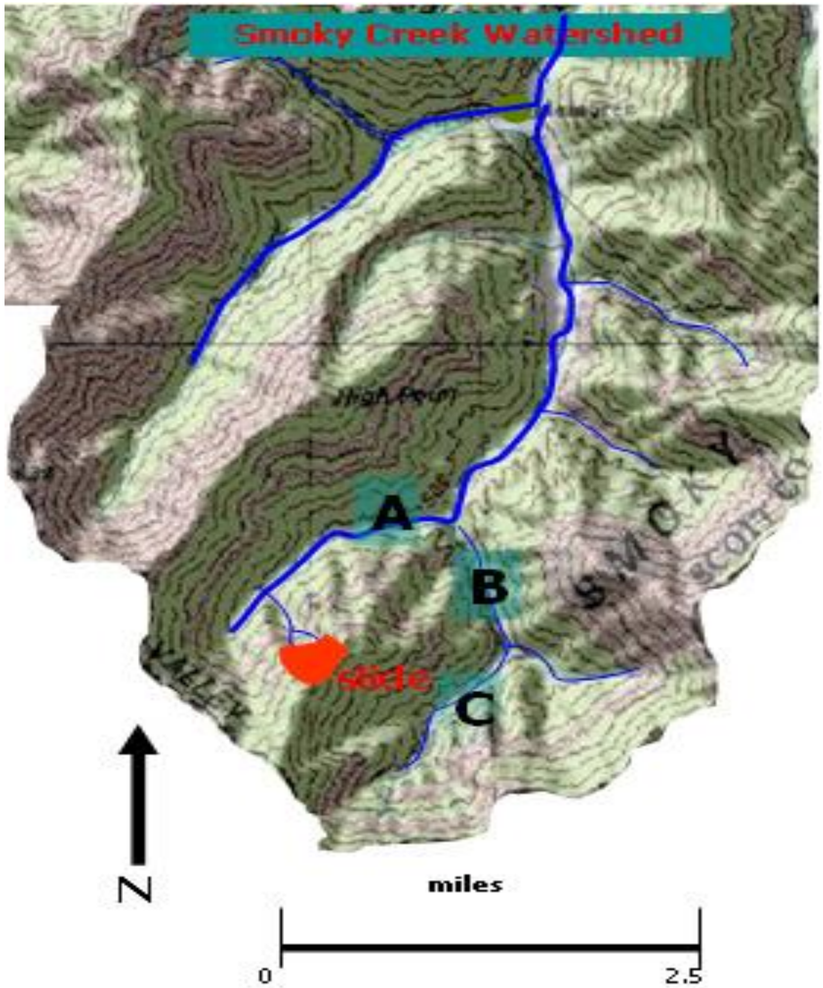

Figure 8. Biological sampling points in 2006.

<u>Fish Fauna.</u> Fish data are represented by studies that have occurred over a greater period of time and are summarized by Evans (1988). The NPS contracted with TVA to collect recent data from November 2006 and this data showed 10 species occurring in Smokey Creek. Table 3 shows these results.

Table 3. Smokey Creek Fish Species Richness

	1969	1978	1996	2006
Species Richness	14	15	20	10

The fish data shows an increasing trend for diversity as time increased from the period of intense mining activity in the 1950's and 1960's. The landslide may have set the recovery back, but data was not collected in a timely manner that would have reflected this condition due to weather and scheduling problems. Immediately after the landslide, Smokey Creek had visible signs of a heavy sediment load, which likely had impacts on the aquatic fauna. The data did reflect the species of fish had dropped by 50% at the time of sampling from the previous sampling in 1996. A 50% reduction in fish diversity 22 months after the event strongly indicates that a significant impact occurred, and that further monitoring is needed to document the recovery process. Asher Fork (Site B) had five species of fish, Smokey Creek (Site A) had nine species, and Smokey Creek below the landslide (above A) had ten species of fish. All sites were within a couple kilometers of each other, and located toward the headwaters.

Biological Assessment Conclusion. Biological diversity was likely affected by impacts due to the physical elements of the landslide increasing sedimentation to the creek and not by altering the water chemistry. Over time, the creek should return to previous levels of species richness and with implementation of practices that reduce sedimentation. Species richness should continue to increase to mimic levels that exist in recovered systems on the Cumberland Plateau. Additional monitoring is needed to report recovery status.

Modeling

Ground Water Modeling

The landslide disturbed about 10 hectare (25 acres) out of the 47 hectare (117 acre) tributary watershed. Unfortunately, there are very few stream-flow gaging stations in the area. Therefore, flows in the tributaries, Smoky Creek, and New River had to be calculated by various models. Groundwater discharge was calculated using the USGS hydrograph separation programs - RECESS, RORA, and PART (Rutledge, 1993). These programs take USGS daily stream-flow data and separate the baseflow component. Base flow percent for drainages near the landslide were calculated (Table 4); the median baseflow was 48 %.

During periods when there was no precipitation, water continued to flow from the landslide. Further examination revealed that much of the water was coming from springs at the escarpment of the landslide. These springs were draining from a reclaimed mine at the top of the mountain that the landslide had cut into. Concern was raised whether these springs might feed the slide year round, and therefore, cause muddy conditions during summer low flow season. OSM wanted to estimate how long it would take for the mountaintop spoils to drain and reach a new equilibrium. To answer this question the USGS Modular Ground-Water Model (MODFLOW 98, Harbaugh, 2000) was used. Groundwater Vistas ® numeric modeling software (Version 4.10) was used as a pre-model and post-model processor. Typical spoil properties from the literature were used in the model (Hawkins 1998). Storativity (specific yield) is @ 0.20 for surface mines with the unconfined storage coefficient about equal to porosity. Porosity is reported to be an average 20 % for this type of silty clay, hydraulic conductivity (k) ranges from 11.2 cm/day to 3048 cm/day (0.37 to 100 ft per day). The other input parameters for the model were: Kxy = 10, Kz = 0.1, leakage factor = 0.0001. The recharge taken from previous hydrograph separation calculations was 1.4 mm/day (0.0046 ft/day). Model grid was 2000-x by 2500-y and 3.71 sq. meter (40 sq. ft.) each.

Table 4. Water balance estimates using hydrograph separation programs.

Smoky Creek Tributaries	Area km^2 / mi^2	Years of record	Recharge in mm/in	Discharge in mm/in	GW Evapo-transpiration	Base flow index
Bills Branch	1.74 / 0.67	7	711 / 28	432 / 17	39 %	48 %
Bowling Branch	5.67 / 2.19	5	508 / 20	356 / 14	30 %	54 %
Shack Creek	13.1 / 5.08	2	559 / 22	635 / 25	-	48 %
Smoky at Hembree	44.5 / 17.2	7	635 / 25	381 / 15	40 %	41 %
New River at NR	989 / 382	56	356 / 14	279 / 11	21 %	40 %

The groundwater conditions at the site can be described as either quasi steady-state or transient. Initially when the landslide occurred, the backfilled mine spoil and outslope water table were at a dynamic steady-state condition where discharge was directly proportional to the past recharge rate and aquifer properties (Fig. 9A). However, when the slope failed, the flow became transient, that is, it immediately began to try to establish a new dynamic equilibrium (Fig. 9B). During this time, the groundwater discharge rate increased dramatically because the hydraulic gradient was steep due to the head-cutting into the saturated spoil. Eventually the landslide will re-establish a new steady state (Fig. 9C) and the groundwater discharge rate will return to near pre-landslide rates. Discharge measurements from 3/21/05 showed the landslide body was producing 16.9 cubic feet per second per square mile (CSM) while the adjacent Smoky Creek produced only 9.45 CSM. This data tends to support the concept that the groundwater (spoil aquifer) contributed significant water to the landslide in the spring of 2005.

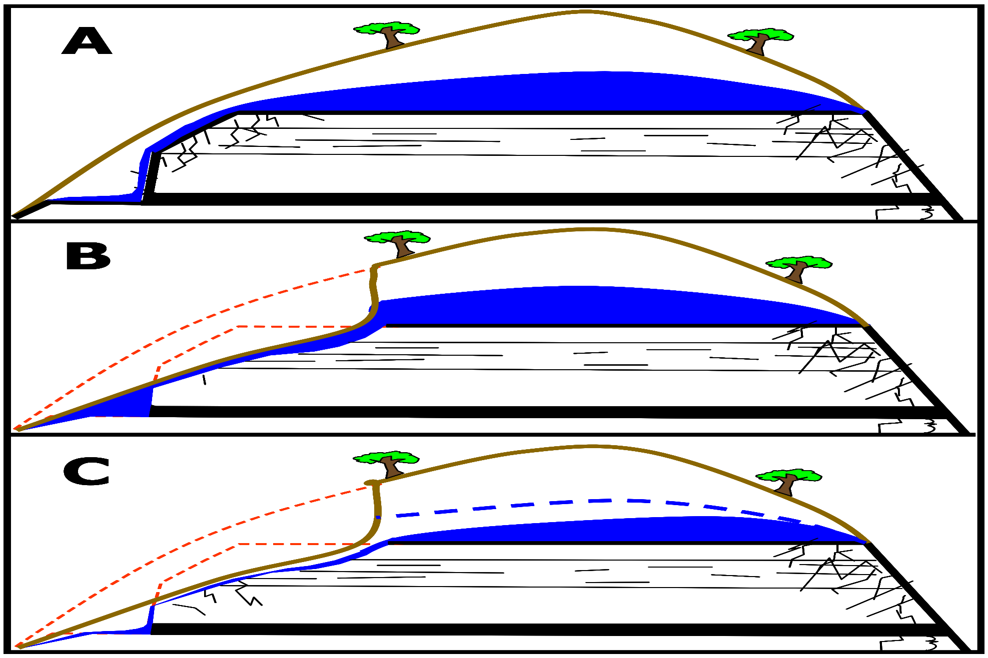

Figure 9. Conceptual model of spoil recharge to the landslide.

Since there are no monitoring wells at the site to obtain starting heads, MODFLOW was used to set up a steady state model of groundwater flow with conditions prior to the landslide. The boundary conditions were adjusted to obtain a reasonable simulation of what field conditions appeared to be. After the model was run, the resulting hydraulic gradients (heads) were saved in a separate file for use in the second model. For the second model, the boundary conditions were changed to reflect the landslide face cutting into the backfilled spoil at the top of High Point Mountain (Fig. 10). A transient model was then run to simulate the dewatering of the saturated spoil over a two-year period. A sensitivity analysis was run to establish the accuracy of the model. As expected, the hydraulic conductivity affected the hydraulic head of the model; however, the time it takes to establish equilibrium was not affected significantly.

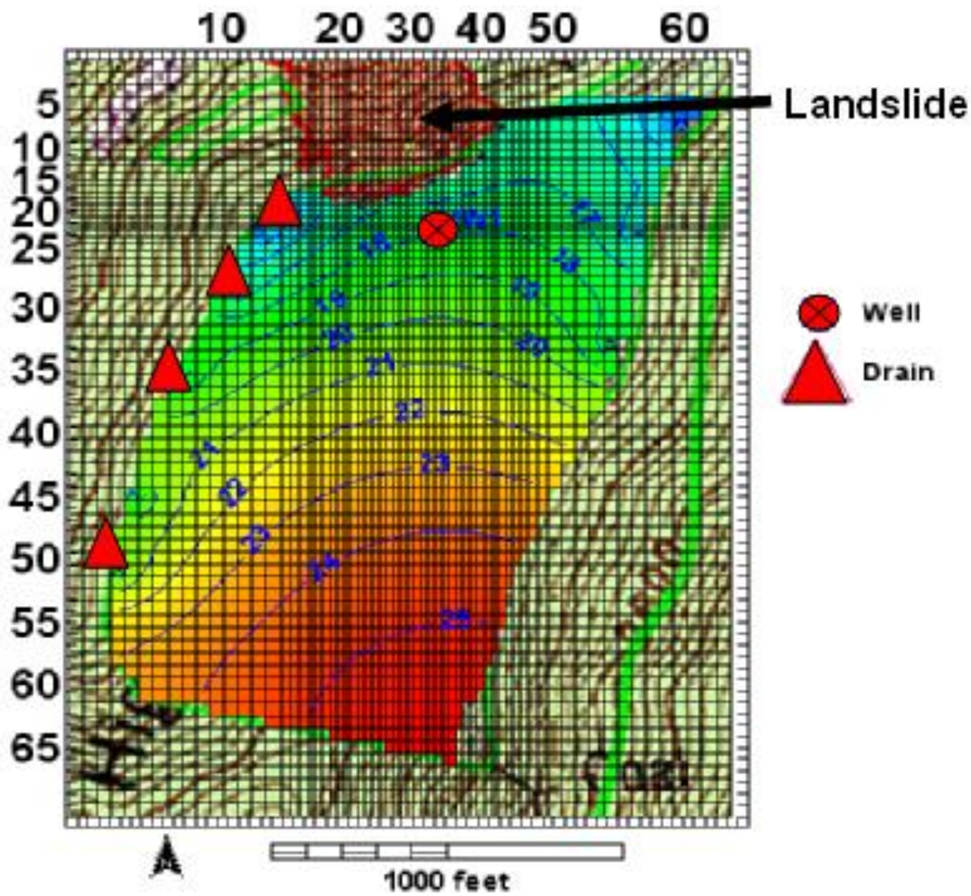

Figure 10. MODFLOW Grid Layout

The results (Fig. 11) show that most of the high groundwater flow occurred within the first month after the landslide event. By 146 days (4.8 months), the spoils were approaching equilibrium, and by 292 days (9.7 months), equilibrium was achieved. Since the landslide happened in late January 2005, the major groundwater flows would have subsided by mid June and normal flows would be observed by November 2005. OSM field measurements of the water flowing from the toe of the landslide were @ 1514 L/min (400 gpm) in March 2005 and @ 114 L/min (30 gpm) in March 2006 (47.6 in precipitation vs. 46.7 respectively). Most of the spoil springs dried up by fall of 2005.

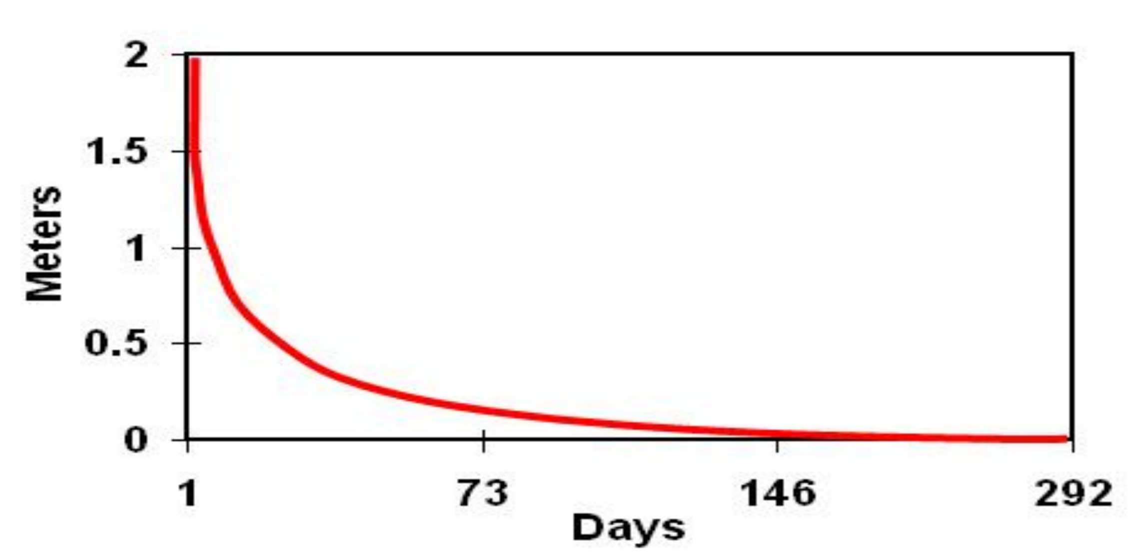

Figure 11. Drawdown verses Days

Surface Water Modeling

The difficulty in modeling the landslide occurs in the nature of runoff, non-Hortonian, and in the complexity of erosion and transport (rills, gullies, and sheet erosion). It was felt that the landslide closely resembled an un-reclaimed spoil bank at angle of repose, and therefore could be modeled using techniques developed in the 1970's for AML lands.

Synthetic hydrographs can be developed using techniques developed in the 1970's by TVA and others studying watersheds in the New River basin (Bowers, 1977; Troxler, 1978; Overton, 1978; Crosby, 1979; Betson, 1980). The characteristics of the basins can be regionalized to determine the particular basin characteristics that govern flow rate, thus eliminating the need to simulate the watershed as planes. Researchers collected field data in central and eastern Tennessee, including the New River basin. They determined the sensitivity of model parameters, and used regression to lump parameters. This allowed approximations of the algorithms and the use of simplifying regionalized parameters. The primary equations to model flow are summarized below.

TENN-I Stormwater Model

1) $Q_t = (t/t_e)^m$ where t is time from beginning of excess rainfall

t_e is time to equilibrium and

m is a function of the physical properties of the catchment basin

Q is discharge (volume per time)

2) $t_e = f(m) * \mu / (i_e)^n$ where μ is the lag modulus

i_e is the rainfall excess intensity (length per time)

n is related to Reynolds number

f(m) is related to the state of flow

3) $T_L = u\,(i_e{}^n)$ and can be linearized by $\ln(T_L) = \ln(u) + n * \ln(i_e)$ where T_L is Lag Time

Calculate lag modulus from basin characteristics.

4) $\mu = C_1(A) + C_2(PF) + C_3$

where μ is the lag modulus (time)

A is area of watershed (length squared)

PF is the percent forested (area / area * 100)

C_1, C_2, and C_3 are coefficients of optimization

Determine weighted rainfall excess (WRE) for entire watershed.

$WRE = 3i_e{}^2 / 3i_e$ where i_e is excess rainfall rate (length/time)

Simulate basin lag time from µ and WRE .

5) $\mu_L = T_L / (i_e)^n$

where μ_L is the lag modulus (time)

T_L is the Lag time

i_e is the weighted excess runoff intensity (length per time)

n is related to the type of flow (laminar, turbulent,) and

6) $n = (m-1)/m$

where $m \approx 5/3$ for Manning's kinematic flow in turbulent state for the stream

Simulate Unit Response Function (URF) where K is optimized constant.

7)	$T_1 = KT_1 * T_L$	where T_1 is time to peak
8)	$T_2 = KT_2 * T_L$	where T_2 is time to peak of delayed response
9)	$T_3 = KT_3 * T_L$	where T_3 is time end of delayed response
10)	$T_{23} = KT_{23} * T_L$	where T_{23} is time to end of initial response
11)	$UP_1 = K_{UP} * T_L$	where UP is peak ordinate of unit response function
12)	$UR_{0.2} = K_{UR} * T_L$	where UR is peak ordinate at unit response

T_L is from centroid of the unit hyetograph to the centroid of the unit hydrograph.

See Fig. 12 for ordinates.

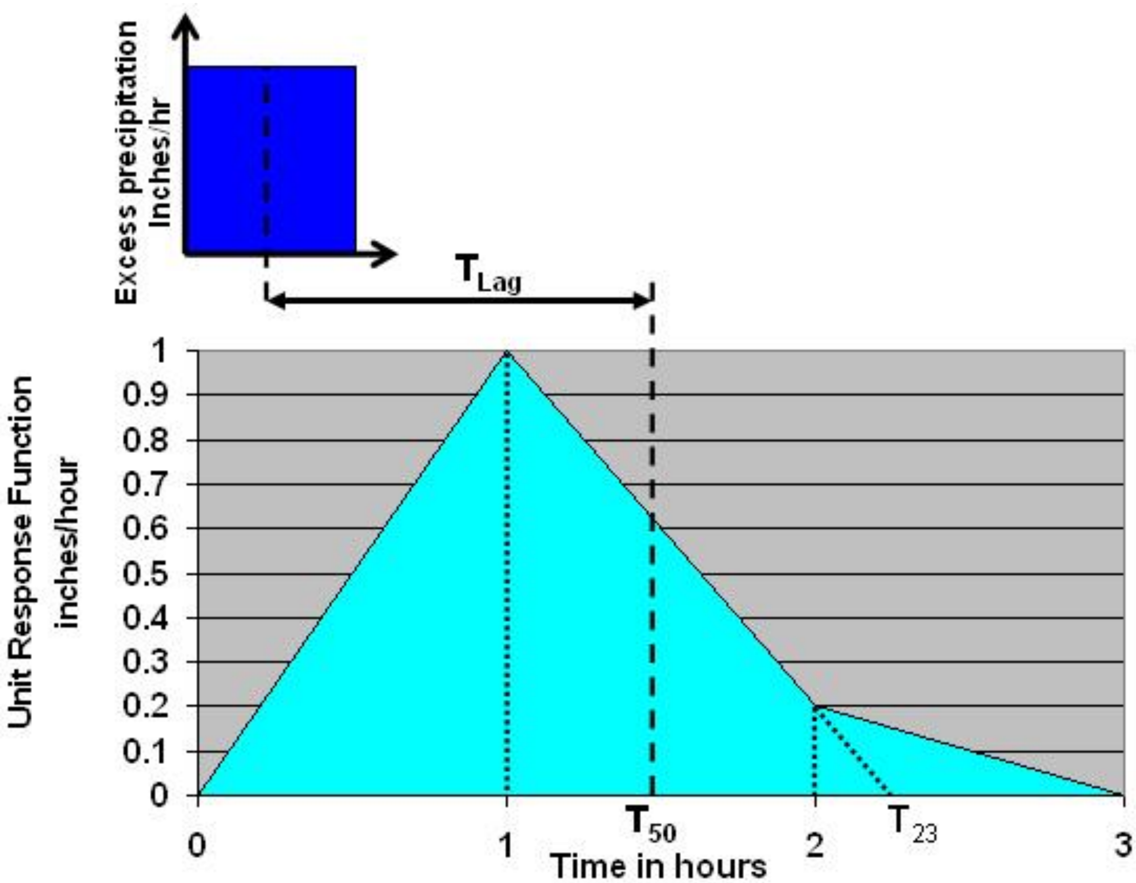

Figure 12. Ordinates of synthetic hydrograph.

For the Smoky Creek watershed the optimized coefficients for $k_1 \ldots k_{UR}$ is 0.253, 1.085, 1.541, 4.581, 0.740, and 0.215 respectively. The Lag modulus (μ_L) and Lag time (T_L) in hours calculated from the TENN-I model for the landslide watershed are:

Table 5. Flow model results for 2-yr event.

TENN-I Model	C_1	A	C_2	PF	C_3	μ_L
$\mu_L = C_1A + C_2(PF) + C_3$	0.64	0.183	0.0236	78	0.0251	1.98

	i_e	n	T_L
$T_L = \mu_L / i_e \exp n$	3.79	0.4	1.16

Where A is area in square miles, PF is percent forest, μ_L is lag modulus, ie is weighted rainfall excess, T_L is lag time in hours, and C are the coefficients found by regression.

Sediment loads from bare slopes can be estimated using a model developed for the New River Basin (Crosby, 1979). This model utilizes a lag modulus (see above) to characterize the watershed properties; this allows the calculation of a load modulus based on land use. Model coefficients used had been optimized using watersheds in Smoky Creek and other tributaries to New River. This model, called LOAD-I can be used for a watershed partly mined or for bare spoil banks (assume 100% mined). It predicts a sediment load (L_w) in tons. Results of this model for the landslide tributary are presented below:

Table 6. LOAD-I model results

LOAD-I Model	C_1	PS	C_2	PF	C_3	μ_w
$\mu_w = C_1(PS) - C_2(\mu)(PF) + C_3$	18.17	21	1.28	78	572	838

	RD_w	A_w	L_w
$L_w = \mu_w * RD_w * A_w$	0.316	117	30,966

Where PS is percent surface mined, μ is the lag modulus, L_W is the load, μ_w is the load modulus and the other coefficients are as above.

Mitigation

As expected, the sediment load from the landslide was very high. With limited funds, OSM desired to know what would be the most effective mitigation strategy. To answer this question, the USDA Water Erosion Protection Program (WEPP) version 2006.5 was used to look at different management practices on the landslide. This program may not be very accurate for the soils, slope, and length of the landslide as it is outside the range it has been calibrated and verified for. This is why the model was not used to predict sediment loads from the landslide. However, it was felt that this model could give *relative* rates of erosion for different management practices. In looking at the various management techniques it was found that employing several 15 m (50 ft) vegetative filter strips in addition to tree and grass seeding would be the most cost effective method to reduce sediment yields by 90 % over 6 years. Therefore, in 2005 OSM broadcast seeded 227 kg (500 lbs) of quick growing grass seed with an emphasis on establishing vegetative filter strips. Then in 2006, a contractor was hired to seed the entire landslide with native grass and shrub species at a rate of 227 kg (500 pounds) of seed over the 9.7 hectare (24 acres) area (20.8 lbs/ac). An additional 28,000 tree seedlings were planted by a contractor in the spring of 2007.

Summary

In Summary, this landslide resulted in a significant impact to Smoky Creek for a distance of 610 m (2000 ft) below the landslide tributary. The stream bottom was buried in sand and silts that appear to be non-toxic. The duration of the sedimentation event was about 3 months, after which loads decreased significantly. Monitoring data shows that the landslide did cause minor sedimentation from April 2005 to spring of 2006. Fine clays from the landslide were carried into Smoky Creek and caused visible discoloring (turbidity) to New River. It is not known what impacts occurred in the lower basin where these clays settle out. Impacts to aquatic life in the stream were severe the first year of the landslide. The monitoring data shows that within 22 months, aquatic life has recovered and is now better than the adjacent unaffected stream.

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