# Trends in Mining Fills and Associated Stream Loss in West Virginia 1984-2012

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**Abstract**— In steep slope regions of Appalachia, the volume of overburden material produced by surface mining often exceeds what can be utilized for reclamation. This condition results in the creation of permanent structures designed for the disposal of excess overburden material, which most commonly take the form of valley fills. Valley fills bury headwater streams, and have been linked with degraded water quality and biodiversity loss in several studies. However, federal regulation does not explicitly require the compilation of mining features on watershed or regional levels, making it difficult to visualize or quantify what is happening at these scales.

To address this problem, GIS was used to compile a comprehensive database of spoil and refuse fills constructed in West Virginia as of 2012. Fills initially were identified by analyzing differences between pre- and post-mining elevation models, and supplemented with aerial photography, mine maps, and LiDAR hillshade images. Satellite and aerial photography was used to identify construction status of each fill in 1984, 1990, 1996, 2003, 2009, and 2012. This allowed an analysis of trends in fill construction to be plotted over time. A 1:24,000 scale stream network was augmented to create consistent start points for intermittent and perennial streams, based on median drainage areas calculated from field research conducted by the USGS in the state's southern coalfield. The augmented stream network was used to estimate linear stream loss due to fill construction over time.

The analysis identified 1,935 spoil fills, and 392 refuse fills, occupying a combined area of over 62,600 acres, or nearly 98 square miles. It was estimated that these fills directly buried 766 miles of intermittent and perennial streams, with another 280 miles of disconnected streams isolated above a fill. The impact was relatively concentrated—the top 29 watersheds accounted for over half of the estimated statewide stream loss, but represented only slightly over 4% of the state's total land area

## Introduction

The impact of mining fills on water quality is a central issue in the debate over the long term impacts of surface mining in Appalachia. Yet until recently there has been a relative lack of geographical data on constructed fills that could be used to inform the debate. An Environmental Protection Agency (EPA) Report on the aquatic impacts of mountaintop mining and valley fills noted that that there was a significant 'data gap' in Geographical Information systems (GIS) inventories of valley fills (USEPA, 2011). This data gap makes it impossible to calculate accurate estimates of how many fills have been constructed or how many miles of streams have been buried. It also makes it difficult to know which watersheds are most heavily impacted by stream loss, or the time period when disturbance occurred. Previous attempts (USEPA, 2003) to characterize valley fill construction often relied on data for *permitted* fills, rather than *constructed* fills, even though many permitted fills were never built, and constructed fills did not always match their initial design. While this may have supported some conclusions about permitting activity, they were not able to characterize actual fill construction and stream loss.

This study partially addresses the data gap identified in the EPA report by creating a comprehensive inventory of constructed mining fills in West Virginia. The inventory was compiled by integrating data from a variety of sources, including permit maps, satellite and aerial photography, digital elevation models, and high resolution hillshade images. The study benefited from significant increases in data availability since initial mapping efforts in the late 1990's. The state now has five state-wide, high-resolution aerial photography datasets available, as well as a comprehensive inventory of Landsat TM satellite images dating to the early 1980s. Elevation data is orders of magnitude more detailed and accurate than what was available previously, and often is available for multiple dates. The availability of better data, combined with better information on the hydrologic characteristics of intermittent and perennial streams in the southern coalfields, provided the opportunity to produce a more accurate estimation of mining fill construction and stream loss than could be accomplished previously.

**Creating the Inventory**

The dataset used for calculating fill construction activity and stream loss was organized into two feature classes—one for spoil fills, and a second for refuse fills. Spoil fills are variously identified as valley fills, head of hollow fills, durable rock fills, or excess spoil fills, and are constructed primarily for the disposal of fractured overburden rock produced during mining operations. As it relates to West Virginia rules for optimizing excess spoil placement, the dataset makes no distinction between backfill areas, which occur within the mineral removal area, and excess spoil disposal areas, which lie outside the mineral removal area and are used primarily for spoil disposal. Individual fill polygons simply attempt to represent the extent of area exhibiting a net increase in elevation due to the placement of spoil material.

The second feature class delineated disposal areas for coarse and/or fine coal refuse produced during coal preparation. The refuse fill dataset was relatively comprehensive, in that it contained both impounding and non-impounding active sites, as well as reclaimed sites, and a significant number of fills that existed prior to federal regulation in 1977. The latter category was significantly aided by the acquisition of an atlas of refuse structures compiled in the early 1970's following the Buffalo Creek dam failure.

Fill polygons were compiled from four basic sources: 1. *IFSAR fills*. Fills were identified by analyzing differences between an IFSAR elevation model acquired in 2003, and hypsography data from USGS topographic maps. Since the hypsography pre-dated the construction of most mining fills, elevation differences between the two datasets could be exploited to extract mining fill areas (detailed in Shank, 2004). This analysis initially covered a 10-county region of southern West Virginia, and later was expanded to include the northern coal fields when a 1/9 arc second National Elevation Dataset (NED) became available. The NED dataset was created from aerial photography also flown in 2003. 2. *LiDAR fills.* LiDAR elevation data acquired in 2009-2010 was compared with the NED elevation dataset. This analysis identified fill construction activity in the southern coal region between 2003 and 2009. 3. *Permit maps*. Fills are routinely digitized from maps submitted to the WVDEP, and represent planned fills. 4. *Visual interpretation.* Fills not captured by other means were identified from multiple aerial photography sources that were collected between 1990 and 2011, as well as 1-meter hillshade images created from LiDAR data collected between 2009 and 2011. The hillshade images were particularly effective in revealing structures that are largely invisible in aerial photography and satellite images, and were responsible for locating many of the smaller, older spoil fills and refuse fills that were added to the inventory since the previous version of this report was completed in 2010.

With the exception of fills identified as 'under construction' in 2012, individual spoil fill polygons were edited to represent as-built conditions when they clearly differed from polygons obtained from other methods. This occurred primarily for fills digitized from permit maps due to subsequent permit modifications, or fills that were still under construction when the various elevation datasets were collected. Most editing involved modifying the downstream face of valley fills based on visual identification of lifts and ditches that comprised the face of a completed fill. Polygon boundaries were edited using aerial photography flown in the summer of 2011, or LiDAR hillshade images from 2009-2011. Only fills that were judged to be substantially complete were edited. Edits were not attempted on fills that were identified as 'under construction' in 2012, and all calculations involving these fills were based on the full original polygon digitized from the mining map. In addition, a conservative approach was taken toward editing the upstream fill boundaries, because this line often is not apparent from visual interpretation of aerial photography or hillshade data. In cases where this was necessary, reference was made to pre-mining contours as a guide to the probable extent of the fill area.

During the compilation process, it was discovered that spoil fill polygons occasionally overlapped due to activity occurring a different times. In these cases, the intersecting area of previously existing structures was removed before calculating area and stream length totals. Where spoil fills overlapped refuse fills, spoil fills were given precedence for calculating areas and stream length totals.

After identification, features in the spoil feature class were attributed to indicate their status at various times, based on the interpretation of aerial or satellite images. Landsat TM images were used for 1984 and 1990, aerial photography was used for 1996, 2003, and 2009, and a combination of SPOT and high resolution satellite images was used for 2012. A status of “not started”, “under construction”, or “complete” were given to each fill for the years 1984, 1990, 1996, 2003, 2009, 2012. Fills were considered complete when overburden deposition was not apparent and the fill area appeared to be re-graded. This determination was more difficult when using Landsat satellite images for 1984 and 1990 due to the relatively coarse resolution of the images. Determinations in these cases relied on analyst experience interpreting the presence of vegetation cover on the site. Most opportunities for misclassification centered on the transition from under construction to complete. However, these categories were grouped together when calculating area and stream loss statistics, so any potential errors did not impact the results of the study.

**Fill Area Analysis Results**

The data compilation effort identified 1,935 spoil fills either completed or under construction by 2012, occupying an area of nearly 48,000 acres (74.8 mi$^2$, 193.8 km$^2$). A total of 392 refuse fills contributed an additional 14,573 acres (23 mi$^2$, 59 km$^2$) for a total of 62,471 acres (97.6 mi$^2$, 252.8.km$^2$) for all types of fills (Table 1). The most apparent trend in fill construction was the significant decline in new area being utilized for fill following 2003 (Figure 1). In terms of trends in fill size (Figure 2), the apparent jump in mean fill size following 2009 is accompanied by a corresponding drop in standard deviation, when compared to the figures from 2003. Histograms of fill size and visual examination of the fill polygons from 2003 and 2012 suggest that the increase in mean fill size is due to fewer small fills being built, rather than more large fills.

| Year | fills complete or under construction | area (acres) | mean size (acres) | cumulative fill count | cumulative fill area (acres) |
|---|---|---|---|---|---|
| 1984 | 369 | 6,033.3 | 16.4 | 369 | 6,033.3 |
| 1990 | 438 | 9,024.6 | 20.6 | 807 | 15,057.9 |
| 1996 | 377 | 9,490.9 | 25.2 | 1,184 | 24,548.8 |
| 2003 | 437 | 13,013.5 | 29.8 | 1,621 | 37,562.3 |
| 2009 | 269 | 8,661.4 | 32.2 | 1,890 | 46,223.6 |
| 2012 | 42 | 1,673.5 | 39.8 | 1,932 | 47,897.2 |
| refuse fills | | | | 392 | 14,573.4 |
| spoil + refuse | | | | 2,324 | 62,471 |

Table 1. Fills completed or under construction between 1984 and 2012.

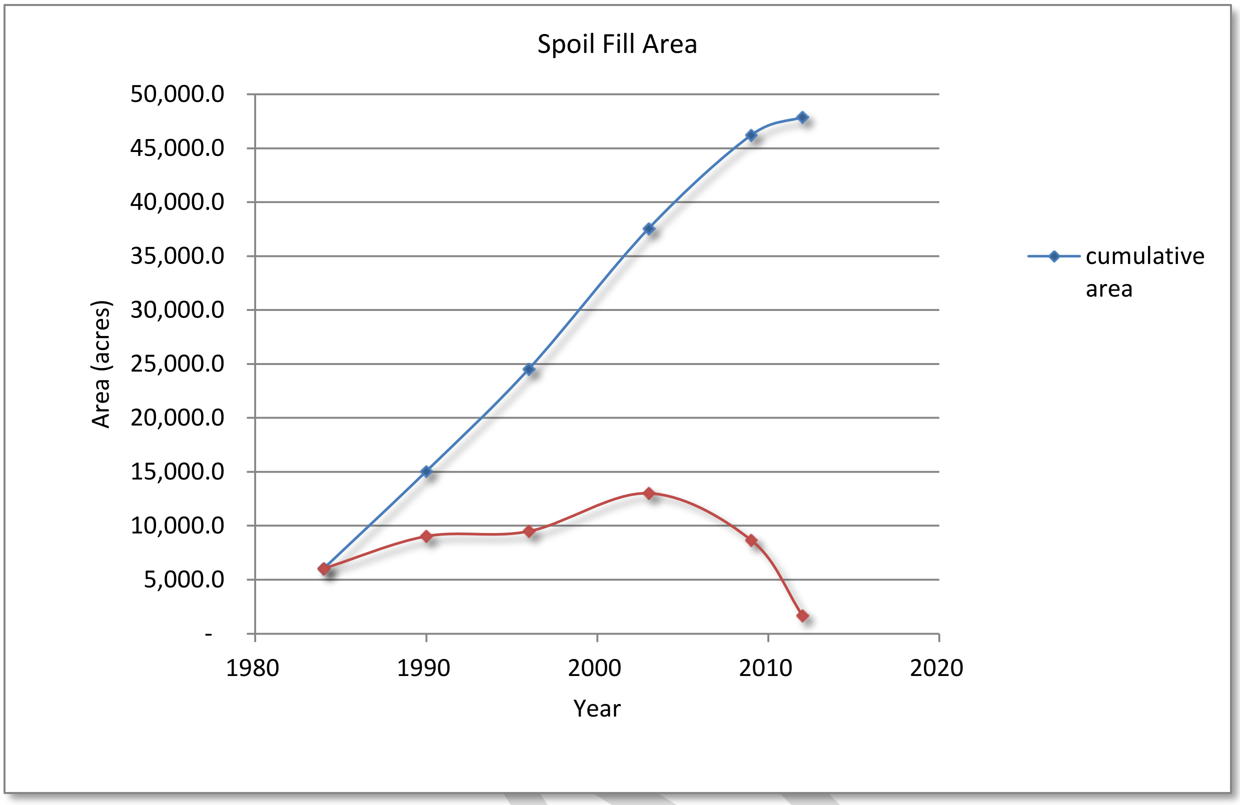


Figure1. Approximate rate of land surface utilization for spoil fill construction from 1984 to 2012, showing a declining trend after 2003.

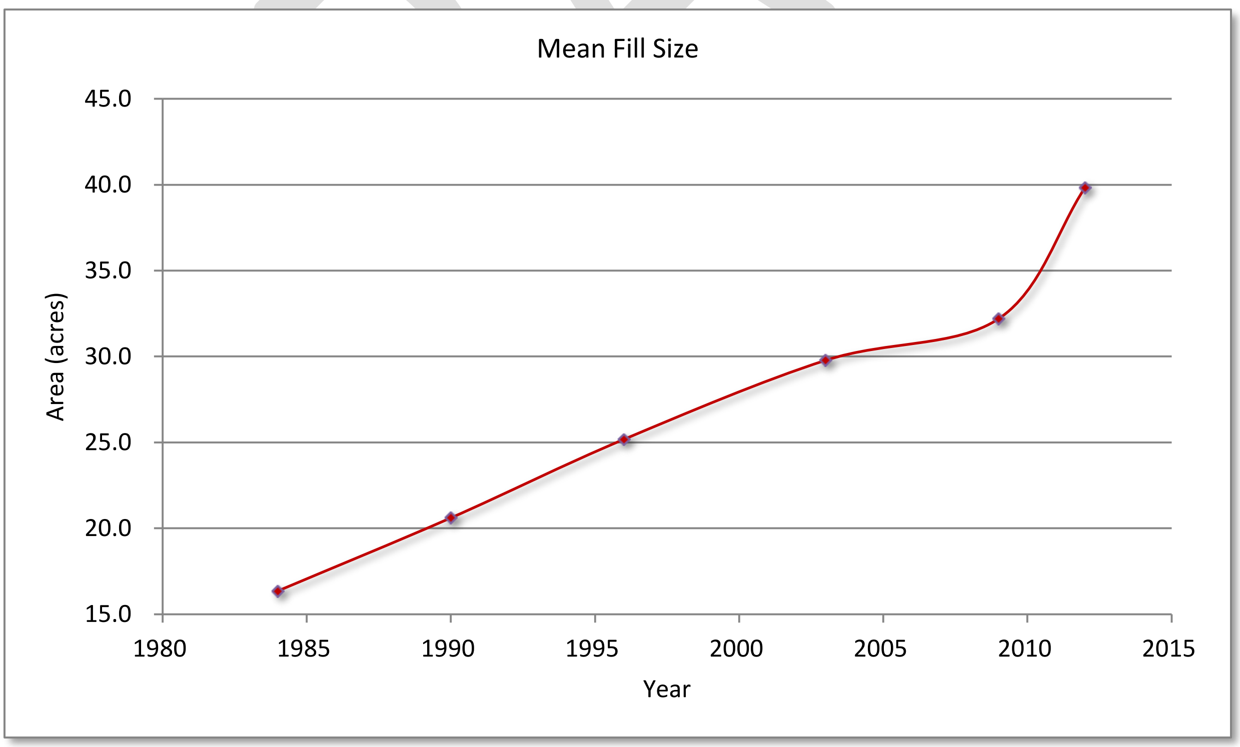


Figure 2. Trend in the mean size of new fills started or completed between 1984 and 2012. Note that the mean size estimate for 2012 is based on the planned extend of fills that were still under construction in 2012, not their actual size at that point in time.

**Direct Stream Loss—Analysis**

Estimating the total length of stream buried under fills required creating a consistent digital stream network that identified the start point of intermittent and perennial streams. This was accomplished using established GIS techniques. It involved embedding an existing 1:24,000 scale stream network in a 10-meter elevation grid, which then was processed to remove any sinks, calculate flow direction at each cell, and then calculate flow accumulation over the entire grid.

The value of any cell in a flow accumulation grid represents the total number of cells that flow into that location. Since each grid cell used in the analysis represents an area of $100m^2$, it is trivial to calculate the total area that drains to each cell. Paybins (2003) estimated the median drainage areas of intermittent and perennial streams in the mountaintop mining region of southern West Virginia, where over 95% of the fills identified by this study occur. By reclassifying the flow accumulation grid to match the median drainage of intermittent and perennial streams identified in the Paybins study, it was possible to extract a stream network with consistent start points for headwater segments. The reclassification scheme used for this study is presented in table 2. This approach is by no means perfect—variations in intermittent and perennial drainage points can vary significantly due to local conditions. However, adapting the results of actual field investigations is considered a major advance over relying on stream data derived from cartographic representations, or picking a number out of a hat.

After reclassification, the resulting grid was converted back to a vector line format that closely resembled the original 1:24,000 scale dataset, but with a more consistent representation of headwater stream segments. Figure 3 shows part of the study area with the original stream network that was based on USGS maps, while the modified stream network used to estimate stream loss is shown for the same area in figure 4. Line segments that fell within the boundaries of mining fill polygons were clipped at the polygon boundary, and the lengths of the clipped segments were summed to arrive at an estimation of the length of stream buried under fill.

The elevation grid used in the study was derived from USGS hypsography (contour) data depicted on USGS 1:24,000 scale maps. The grid proved to be a preferred source for creating the stream network for two reasons. First, the stream network that was embedded into the grid was derived from the same source—USGS 1:24,000 scale maps—so the two data sources were complementary. Second, attempts to utilize a more accurate, higher resolution grid created in 2003 could not reliably trace flow paths under existing fills that had been constructed by that date.

The elevation data and the stream lines were available in two disjoint areas that largely matched the northern and southern coal fields, with the exception of some mining in the Monongahela Group in Putnam County near Poca. However, for the most part the totals for the two regions can be used to compare the relative stream loss between the two mining regions within the state.

| Stream Classification | Upstream drainage area (acres) | Flow Accumulation Grid Value | Reclassified Grid Value |
|---|---|---|---|
| No stream | < 14.5 | < 587 | Null |
| Intermittent | 14.5 – 40.8 | 587 – 1651 | 1 |
| Perennial | 40.8 > | 1651 > | 2 |

Table 2. Relationship between stream type, drainage area, flow accumulation grid values, and reclassification output values used in creating the modified stream network. The reclassified grid was converted to a vector stream network and used to calculate the total length of streams buried by fill.

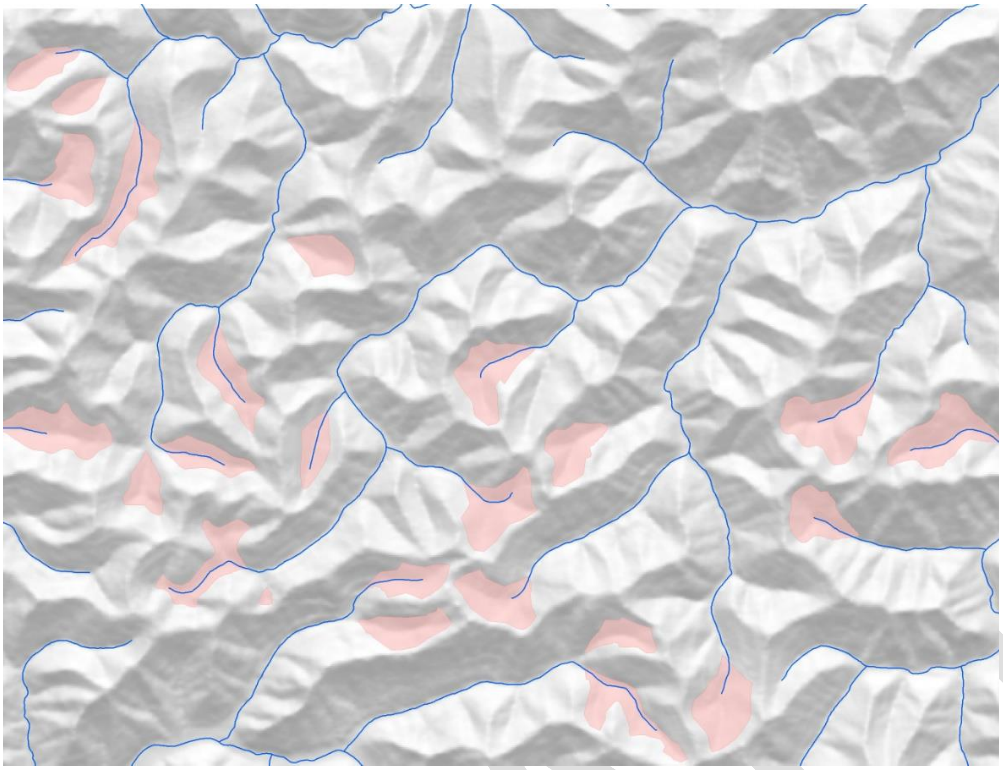

Figure 3. Streams from the original 1:24,000 scale data source. Constructed fills are shown in red.

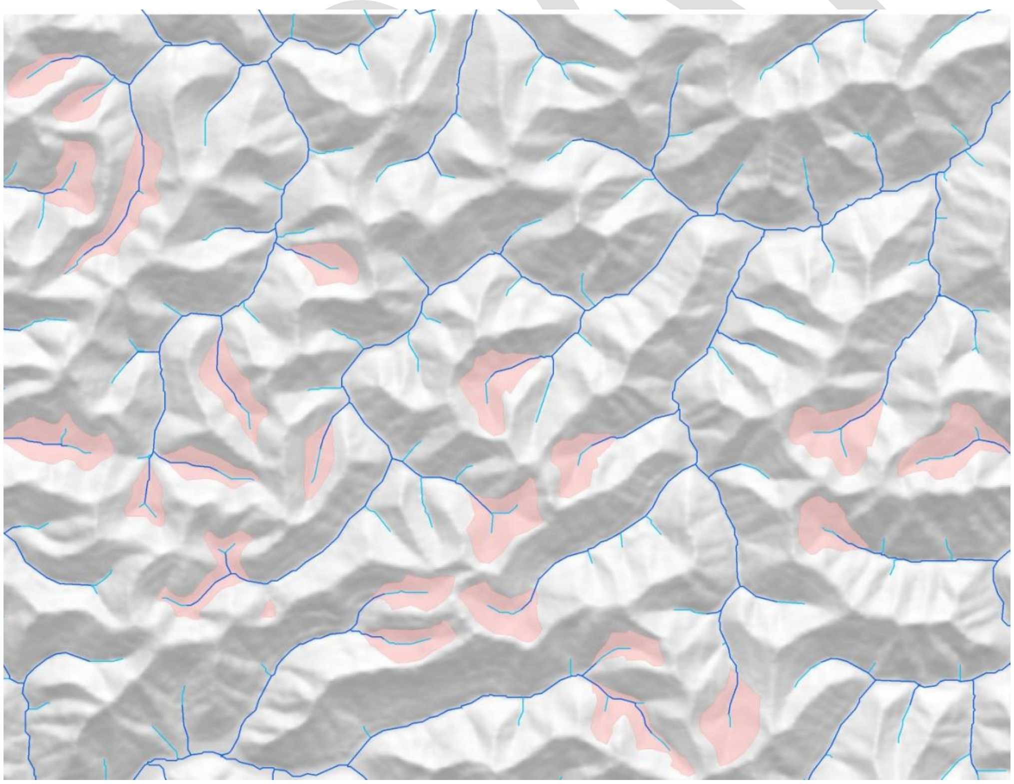

Figure 4. Modified stream network used for estimating stream loss, showing distinction between intermittent and perennial reaches.

**Direct Stream Loss--Results**

Figure 5 shows part of the study area and how streams were clipped to calculate direct and upstream losses for spoil and refuse fills. Note that for overlap areas between refuse fills and spoil fills, the loss is added to the spoil fill total.

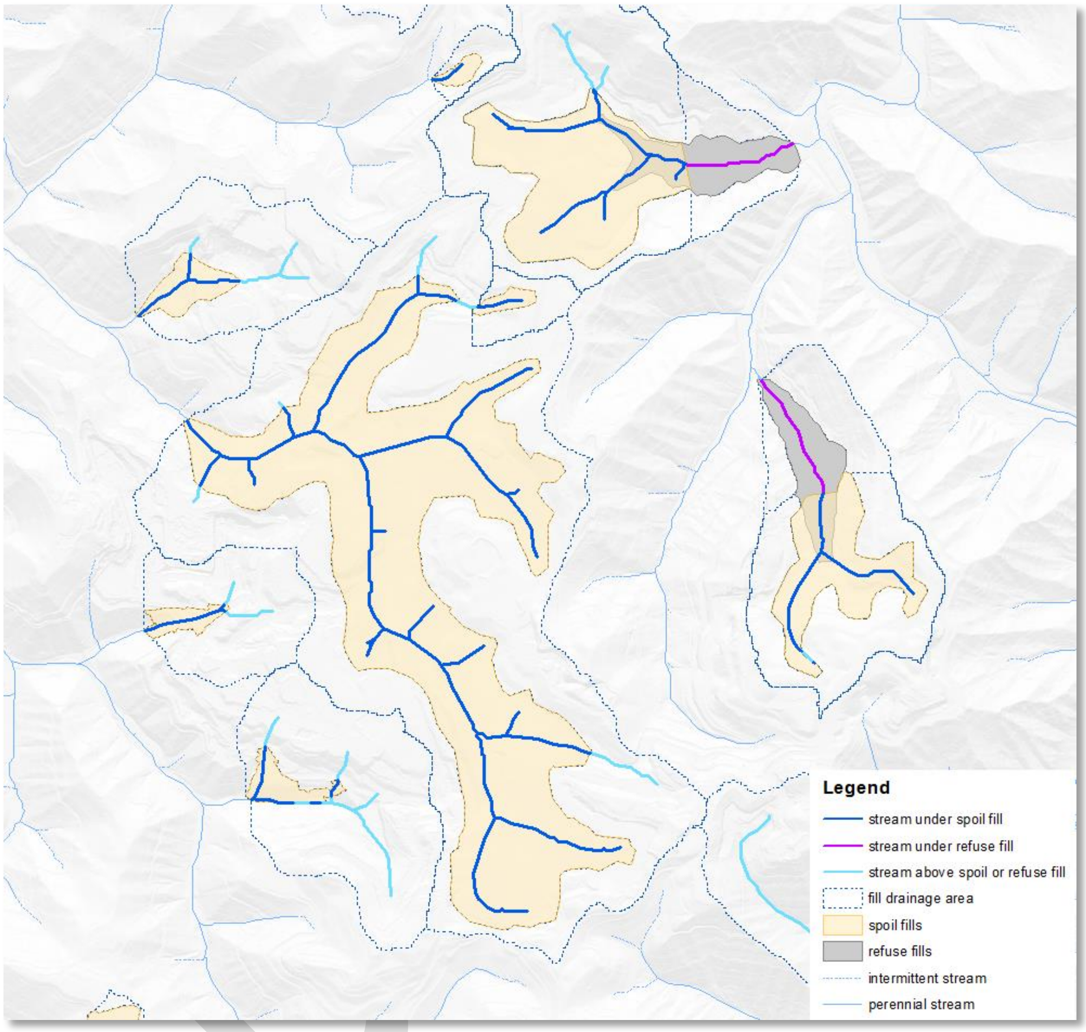


Figure 5. Data sources used to calculate various stream loss totals.

Stream loss statistics are presented in table 3. Direct stream loss for all types of mining fills totaled 764.3 miles, comprised of 297.5 miles of intermittent, and 466.8 miles of perennial streams. 95% of the stream loss occurred in the southern coal field. Table 3 also includes estimates for isolated stream segments that occur above existing fills. It is arguable that these stream fragments should be included in estimates of stream loss because they may no longer perform the same ecological functions as they did previously. The estimates in table 3 were derived from examining sections of stream that fell within the drainage area of an existing fill, but not within the boundary of the fill itself. While this analysis is not definitive, it suggests that as many as 279.5 miles additional miles of streams may fit within this category.

Figure 6 depicts stream loss due to spoil fills from 1984-2012. By 2012, spoil fills had buried nearly 8 times the total estimated loss for 1984. The trend in direct stream loss from spoil fills is presented in figure 7. The rate of stream loss increased for each sample period until 2003, before beginning a significant decline. In the period 1996-2003, stream loss reached a peak of over 158 miles, or a rate of about 22.5 miles/year, before falling dramatically.

| | south | | | north | | | combined | | |
|---|---|---|---|---|---|---|---|---|---|
| | Intermittent | perennial | total | Intermittent | perennial | total | Intermittent | perennial | total |
| spoil fills, 1984 | 33.2 | 35.7 | 68.9 | 2.1 | 1.3 | 3.4 | 35.3 | 37.0 | 72.3 |
| spoil fills, 1990 | 45.8 | 57.9 | 103.6 | 0.4 | 1.0 | 1.5 | 46.2 | 58.9 | 105.1 |
| spoil fills, 1996 | 45.5 | 66.5 | 112.0 | 1.2 | 0.6 | 1.8 | 46.7 | 67.1 | 113.8 |
| spoil fills, 2003 | 64.5 | 92.1 | 156.7 | 0.5 | 1.2 | 1.7 | 65.0 | 93.3 | 158.4 |
| spoil fills, 2009 | 42.3 | 61.0 | 103.3 | 0.1 | 0.0 | 0.1 | 42.4 | 61.0 | 103.3 |
| spoil fills, 2012 | 7.0 | 10.2 | 17.1 | 0.0 | 0.0 | 0.0 | 7.0 | 10.2 | 17.1 |
| spoil fills, total | 238.2 | 323.3 | 561.5 | 4.3 | 4.2 | 8.5 | 242.5 | 327.5 | 570.0 |
| all refuse fills | 43.3 | 120.7 | 164.1 | 11.7 | 18.6 | 30.3 | 55.0 | 139.3 | 194.4 |
| total streams under fills | 281.5 | 444.0 | 725.6 | 16.0 | 22.8 | 38.8 | 297.5 | 466.8 | 764.3 |
| disconnected above fills | *143.1* | *112.8* | *255.8* | *12.6* | *11.1* | *23.7* | *155.7* | *123.9* | *279.5* |
| total loss, including above all fills | ***424.6*** | ***556.8*** | ***981.4*** | ***28.6*** | ***33.9*** | ***62.5*** | ***453.2*** | ***590.7*** | ***1043.9*** |

Table 3. Stream length buried under mining fills (in miles) 1984-2012. An overlap adjustment accounts for overlapping fills built at different times on the same location. Calculations for streams above a fill include stream segments within the drainage area of an existing fill.

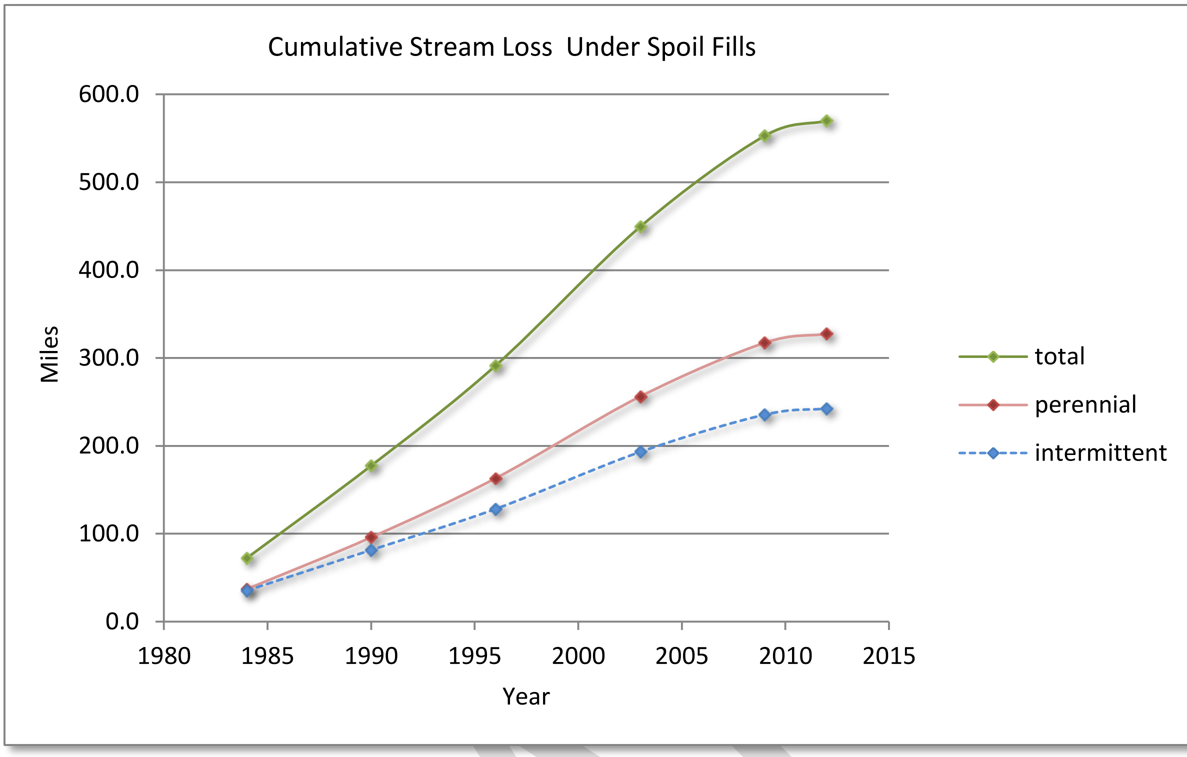


Figure 6. Cumulative stream loss due to spoil fill construction reached 572 miles by 2012. This does not include refuse fills, which contributed an additional 194 miles.

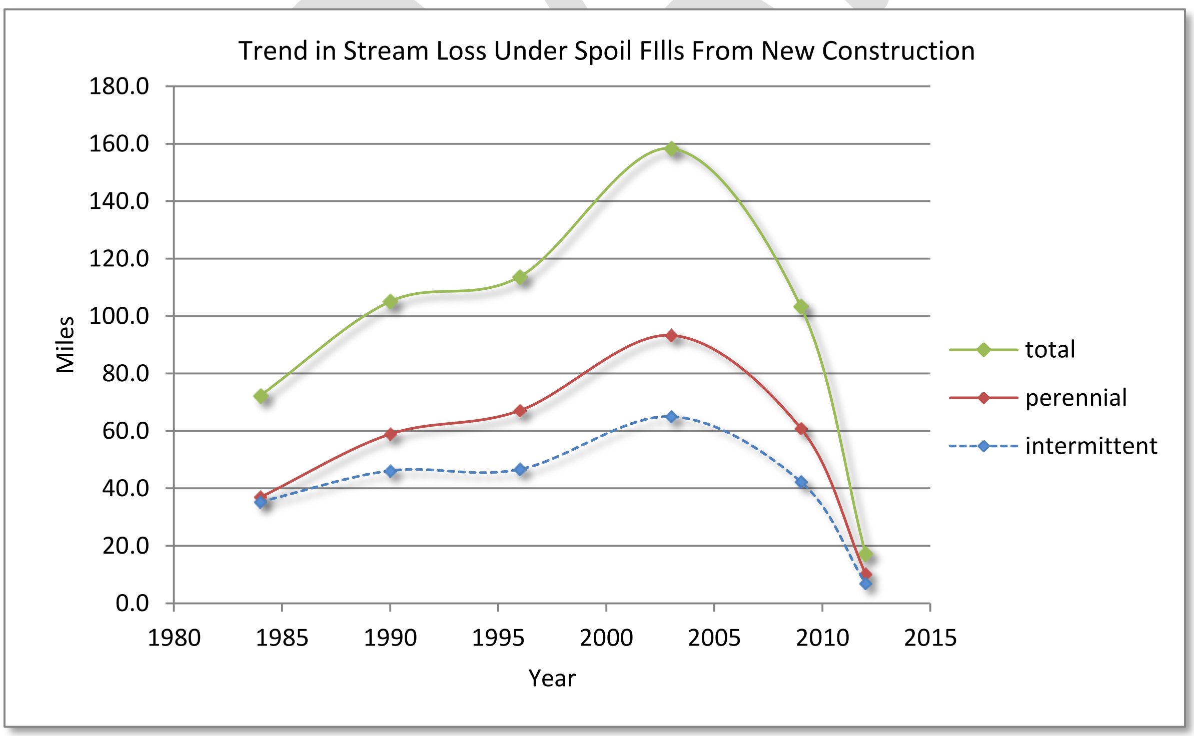


Figure 7. Direct stream loss from new fills started since the previous sample year. Stream loss began a significant decline after 2003.

Stream losses also were calculated for every 12-digit watershed in the state. The totals included direct losses under both spoil and refuse fills, as well as disconnected segments above the fill. It was found that 60 watersheds had total stream losses that exceeded 5% of the total linear stream length within the watershed. Thirty watersheds had losses that exceeded 10% (table 4). The losses were relatively concentrated within the state—the top 28 watersheds accounted for over half of the estimated statewide stream loss, but represented only 4% of the state's total land area.

Figure 8 maps the locations of watersheds with more than 5% stream loss in the southern part of the state where most of the losses are concentrated. White Oak Creek, with over 30% loss, is associated with a large complex of permits near Kayford, which occupy over 55% of the total watershed area. The second highest impacted watershed, Twentymile Creek, also contains large surface operations by Fola Coal, Alex Energy, and others, which have permitted over 47% of the watershed area.

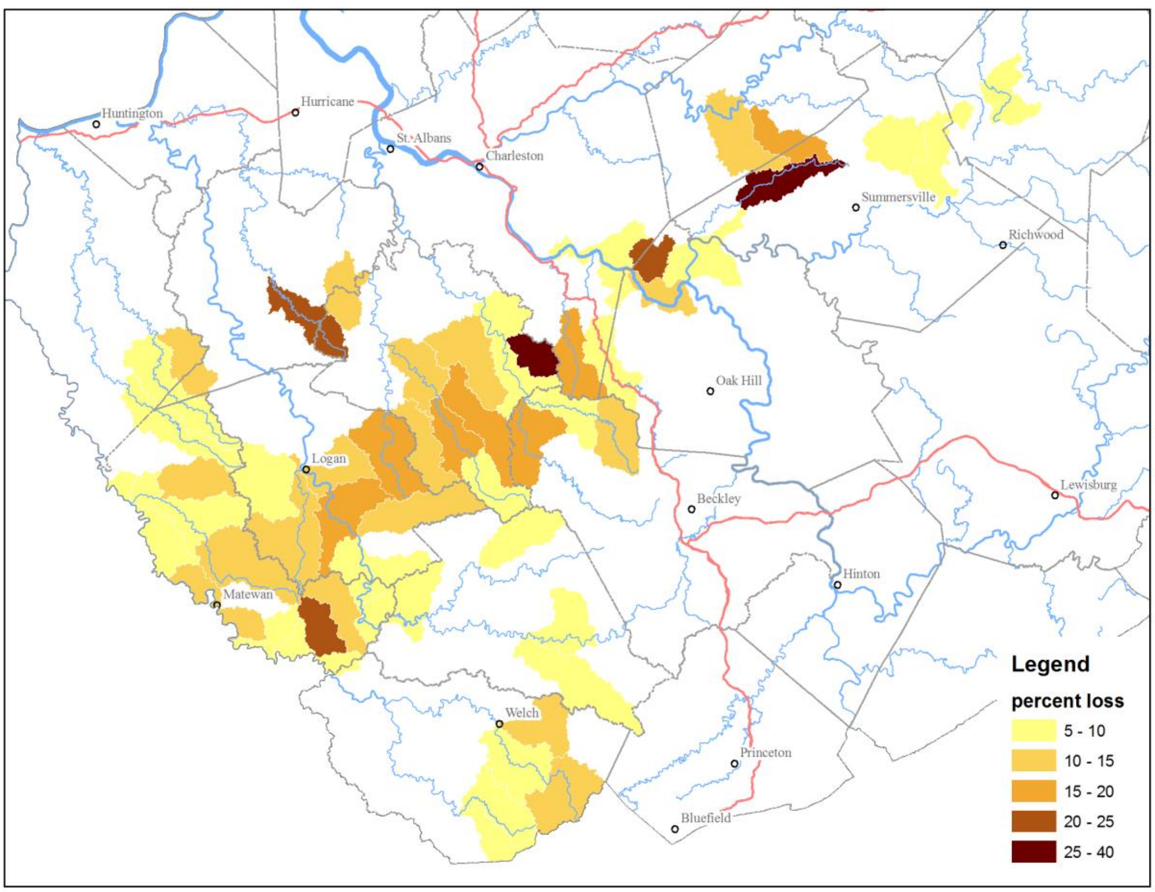


Figure 8. Watersheds most impacted by stream loss from mining fills. Stream loss totals include streams under and above all types of mining fills.

| | HUC 12 | NAME | total miles of stream | | | total miles lost | | | percentage lost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | int | per | total | int | per | total | int | per | total |
| 1 | 050500090601 | White Oak Creek | 16.7 | 47.8 | 64.4 | 7.2 | 14.9 | 22.0 | 43.0% | 31.1% | 34.2% |
| 2 | 050500050701 | Headwaters Twentymile Creek | 34.8 | 81.8 | 116.6 | 12.1 | 18.4 | 30.4 | 34.7% | 22.5% | 26.1% |
| 3 | 050702010302 | Ben Creek | 27.5 | 54.6 | 82.1 | 9.8 | 10.0 | 19.8 | 35.8% | 18.3% | 24.2% |
| 4 | 050701020302 | Ballard Fork-Mud River | 46.3 | 95.0 | 141.4 | 13.3 | 17.7 | 31.0 | 28.7% | 18.6% | 21.9% |
| 5 | 050500060303 | Smithers Creek | 19.9 | 43.5 | 63.5 | 6.9 | 6.6 | 13.5 | 34.8% | 15.2% | 21.3% |
| 6 | 050500060201 | Headwaters Cabin Creek | 32.8 | 79.7 | 112.6 | 8.0 | 14.2 | 22.2 | 24.3% | 17.9% | 19.8% |
| 7 | 050500090204 | Lower Marsh Fork | 37.3 | 89.3 | 126.6 | 6.9 | 18.0 | 24.9 | 18.6% | 20.1% | 19.7% |
| 8 | 050500090302 | Headwaters Spruce Fork | 49.3 | 124.4 | 173.7 | 12.1 | 20.1 | 32.1 | 24.5% | 16.1% | 18.5% |
| 9 | 050500090402 | West Fork | 41.4 | 99.6 | 140.9 | 9.5 | 16.5 | 26.0 | 22.9% | 16.6% | 18.4% |
| 10 | 050500090403 | Middle Pond Fork | 27.4 | 66.9 | 94.3 | 6.0 | 11.2 | 17.2 | 22.1% | 16.7% | 18.2% |
| 11 | 050701010507 | Rum Creek-Guyandotte River | 44.3 | 104.7 | 149.1 | 8.9 | 16.1 | 25.0 | 20.0% | 15.4% | 16.8% |
| 12 | 050500070502 | Lilly Fork | 34.4 | 68.4 | 102.8 | 7.2 | 9.7 | 16.9 | 21.0% | 14.2% | 16.5% |
| 13 | 050702010203 | Outlet Elkhorn Creek | 46.1 | 81.7 | 127.9 | 8.5 | 10.4 | 18.8 | 18.4% | 12.7% | 14.7% |
| 14 | 050901020201 | Kiah Creek | 33.4 | 77.7 | 111.2 | 8.5 | 7.3 | 15.9 | 25.4% | 9.4% | 14.3% |
| 15 | 050500090501 | Big Horse Creek | 34.4 | 78.2 | 112.7 | 7.0 | 9.0 | 16.0 | 20.3% | 11.5% | 14.2% |
| 16 | 050500090101 | Headwaters Clear Fork | 62.9 | 84.9 | 147.8 | 11.2 | 9.6 | 20.8 | 17.8% | 11.3% | 14.1% |
| 17 | 050500090404 | Lower Pond Fork | 36.2 | 82.6 | 118.7 | 5.5 | 9.0 | 14.5 | 15.3% | 10.9% | 12.2% |
| 18 | 050500090602 | Laurel Creek | 46.4 | 124.5 | 170.9 | 8.9 | 11.5 | 20.4 | 19.1% | 9.3% | 11.9% |
| 19 | 050701010505 | Buffalo Creek | 42.9 | 106.6 | 149.6 | 6.2 | 11.5 | 17.7 | 14.4% | 10.8% | 11.8% |
| 20 | 050500070901 | Leatherwood Creek-Elk River | 54.4 | 114.5 | 169.0 | 8.7 | 11.2 | 19.9 | 15.9% | 9.8% | 11.8% |
| 21 | 050701010402 | Island Creek | 63.6 | 141.5 | 205.0 | 9.7 | 14.3 | 24.0 | 15.2% | 10.1% | 11.7% |
| 22 | 050702010312 | Sycamore Creek-Tug Fork | 16.9 | 41.5 | 58.4 | 3.3 | 3.2 | 6.6 | 19.7% | 7.8% | 11.2% |
| 23 | 050301061205 | Boggs Run-Ohio River | 12.7 | 27.8 | 40.5 | 1.5 | 3.0 | 4.5 | 11.9% | 10.7% | 11.1% |
| 24 | 050702010401 | Headwaters Pigeon Creek | 58.8 | 135.6 | 194.5 | 8.1 | 13.2 | 21.3 | 13.8% | 9.7% | 11.0% |
| 25 | 050500060304 | Boomer Branch-Kanawha River | 27.9 | 49.6 | 77.5 | 3.4 | 5.1 | 8.4 | 12.0% | 10.2% | 10.9% |
| 26 | 050701010502 | Gilbert Creek | 33.2 | 70.1 | 103.3 | 4.2 | 7.1 | 11.2 | 12.6% | 10.1% | 10.9% |
| 27 | 050702010310 | Blackberry Creek-Tug Fork | 14.6 | 34.0 | 48.6 | 2.3 | 2.9 | 5.3 | 16.0% | 8.6% | 10.8% |
| 28 | 050702010201 | South Fork Tug Fork-Tug Fork | 63.3 | 100.8 | 164.1 | 8.0 | 9.6 | 17.6 | 12.7% | 9.5% | 10.7% |
| 29 | 050500090301 | Spruce Laurel Fork | 28.2 | 80.2 | 108.4 | 4.6 | 6.9 | 11.6 | 16.4% | 8.7% | 10.7% |
| 30 | 050702010402 | Laurel Fork | 31.1 | 79.2 | 110.2 | 4.9 | 6.6 | 11.5 | 15.6% | 8.4% | 10.4% |

Table 4. Watersheds with more than 10% total stream loss by mining fills as of 2009.

**Data Quality**

The fill inventory used for this analysis represents the best available source. Its constituent parts were built from countless hours of digitizing and analysis. Compiling and cross checking the final inventory required over 120 hours to complete, before any analysis could be conducted. Even so, the data on which this analysis is permeated with errors of many different kinds, a legacy of the lineage from which it was derived. Individual fill polygons are intended to capture general locations and extents of features on the ground; they are not produced using survey methods and are of limited usefulness for investigations of individual structures. The scale of error is appropriately measured in meters, not centimeters. In the author's judgment, these error sources do not significantly impact regional analyses such as the one presented here, but could lead to problems if the data were used in inappropriate ways. With this in mind, some of the recognized error sources associated with the dataset are enumerated below:

1) Some small number of fills may have been omitted. These fills likely are old and small, associated with operations for which a map is not available, and not easily picked up by airphoto interpretation. In some cases, visual evidence was not conclusive enough to warrant inclusion in the database.

2) Fills delineated from the analysis of elevation models may have imperfect boundaries arising from errors in the elevation models from which they were derived.

3) The boundaries of fills digitized from aerial photographs or hillshade images could be subject to interpretation, and often relied on pre-mining contours to suggest the extent of a valley fill above the toe.

4) Fills digitized from permit maps can contain errors that include: 1) error in the map source itself, 2) error introduced by scanning and georeferencing, 3) error contributed by imperfect digitizing.

5) Fills digitized from permit maps can be subject to interpretation when their extent was not clearly indicated. In these cases, contours or drainage ditches were sometimes used to interpret the fill extent.

6) Fills in adjacent valleys sometimes converge to a single point downstream, or sometimes diverge into opposite drainages. While technically a single connected fill, these structures usually were split into two fill polygons. This affects the total fill count by a small amount, but does not affect area or length of stream calculations.

7) The status of fills depicted on satellite images in 1984 and 1990 could be difficult to determine due to the limited resolution of the images. This problem was minimized by examining images from other

dates, and examining the issue date of the associated permit, where available. Also, the status of each fill was compared across all dates to ensure logical consistency.

8) Calculations of total area at various dates include fills under construction. However, the area used in the calculation represents the area of the completed fill. In some cases, a fill under construction at a particular date may not have reached its terminal point downstream, resulting in an overestimate of the total area estimated for a particular date.

9) Calculations of stream loss only include stream segments directly under (and above) the fill, though it could be argued that stream loss should be extended to the downstream pond below the toe of a valley fill.

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Appendix A. Notes on revised valley fill numbers and stream loss totals

This report is an update to a report first released in 2009. In comparing the revised numbers of fills and stream loss calculations, some categories show an increase over the previous version. Increases in totals representing the loss of streams directly under fills can be attributed to additional fills discovered using 1-meter resolution hillshade images derived from LiDAR elevation data that were acquired since the initial report. This resource also was used to delineate additional refuse fills, which could be verified using a recently obtained atlas of refuse structures that was compiled by an aerial survey conducted in the early 1970's.

The significant increase in stream loss totals for disconnected stream segments above fills resulted from a combination of additional fills identified since the original analysis, and a change in the way that totals were calculated. For the revised study, all stream segments upstream of a fill were used in the total, whereas the original study only counted stream segments that were verified to fall within a mining permit boundary.

# Appendix B. 12-digit watersheds with over 1 percent direct stream loss from mining fill construction

| | HUC 12 | NAME | total miles of stream | | | total miles lost | | | percentage lost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | int | per | total | int | per | total | int | per | total |
| 1 | 050500090601 | White Oak Creek | 16.7 | 47.8 | 64.4 | 7.2 | 14.9 | 22.0 | 43.0% | 31.1% | 34.2% |
| 2 | 050500050701 | Headwaters Twentymile Creek | 34.8 | 81.8 | 116.6 | 12.1 | 18.4 | 30.4 | 34.7% | 22.5% | 26.1% |
| 3 | 050702010302 | Ben Creek | 27.5 | 54.6 | 82.1 | 9.8 | 10.0 | 19.8 | 35.8% | 18.3% | 24.2% |
| 4 | 050701020302 | Ballard Fork-Mud River | 46.3 | 95.0 | 141.4 | 13.3 | 17.7 | 31.0 | 28.7% | 18.6% | 21.9% |
| 5 | 050500060303 | Smithers Creek | 19.9 | 43.5 | 63.5 | 6.9 | 6.6 | 13.5 | 34.8% | 15.2% | 21.3% |
| 6 | 050500060201 | Headwaters Cabin Creek | 32.8 | 79.7 | 112.6 | 8.0 | 14.2 | 22.2 | 24.3% | 17.9% | 19.8% |
| 7 | 050500090204 | Lower Marsh Fork | 37.3 | 89.3 | 126.6 | 6.9 | 18.0 | 24.9 | 18.6% | 20.1% | 19.7% |
| 8 | 050500090302 | Headwaters Spruce Fork | 49.3 | 124.4 | 173.7 | 12.1 | 20.1 | 32.1 | 24.5% | 16.1% | 18.5% |
| 9 | 050500090402 | West Fork | 41.4 | 99.6 | 140.9 | 9.5 | 16.5 | 26.0 | 22.9% | 16.6% | 18.4% |
| 10 | 050500090403 | Middle Pond Fork | 27.4 | 66.9 | 94.3 | 6.0 | 11.2 | 17.2 | 22.1% | 16.7% | 18.2% |
| 11 | 050701010507 | Rum Creek-Guyandotte River | 44.3 | 104.7 | 149.1 | 8.9 | 16.1 | 25.0 | 20.0% | 15.4% | 16.8% |
| 12 | 050500070502 | Lilly Fork | 34.4 | 68.4 | 102.8 | 7.2 | 9.7 | 16.9 | 21.0% | 14.2% | 16.5% |
| 13 | 050702010203 | Outlet Elkhorn Creek | 46.1 | 81.7 | 127.9 | 8.5 | 10.4 | 18.8 | 18.4% | 12.7% | 14.7% |
| 14 | 050901020201 | Kiah Creek | 33.4 | 77.7 | 111.2 | 8.5 | 7.3 | 15.9 | 25.4% | 9.4% | 14.3% |
| 15 | 050500090501 | Big Horse Creek | 34.4 | 78.2 | 112.7 | 7.0 | 9.0 | 16.0 | 20.3% | 11.5% | 14.2% |
| 16 | 050500090101 | Headwaters Clear Fork | 62.9 | 84.9 | 147.8 | 11.2 | 9.6 | 20.8 | 17.8% | 11.3% | 14.1% |
| 17 | 050500090404 | Lower Pond Fork | 36.2 | 82.6 | 118.7 | 5.5 | 9.0 | 14.5 | 15.3% | 10.9% | 12.2% |
| 18 | 050500090602 | Laurel Creek | 46.4 | 124.5 | 170.9 | 8.9 | 11.5 | 20.4 | 19.1% | 9.3% | 11.9% |
| 19 | 050701010505 | Buffalo Creek | 42.9 | 106.6 | 149.6 | 6.2 | 11.5 | 17.7 | 14.4% | 10.8% | 11.8% |
| 20 | 050500070901 | Leatherwood Creek-Elk River | 54.4 | 114.5 | 169.0 | 8.7 | 11.2 | 19.9 | 15.9% | 9.8% | 11.8% |
| 21 | 050701010402 | Island Creek | 63.6 | 141.5 | 205.0 | 9.7 | 14.3 | 24.0 | 15.2% | 10.1% | 11.7% |
| 22 | 050702010312 | Sycamore Creek-Tug Fork | 16.9 | 41.5 | 58.4 | 3.3 | 3.2 | 6.6 | 19.7% | 7.8% | 11.2% |
| 23 | 050301061205 | Boggs Run-Ohio River | 12.7 | 27.8 | 40.5 | 1.5 | 3.0 | 4.5 | 11.9% | 10.7% | 11.1% |
| 24 | 050702010401 | Headwaters Pigeon Creek | 58.8 | 135.6 | 194.5 | 8.1 | 13.2 | 21.3 | 13.8% | 9.7% | 11.0% |
| 25 | 050500060304 | Boomer Branch-Kanawha River | 27.9 | 49.6 | 77.5 | 3.4 | 5.1 | 8.4 | 12.0% | 10.2% | 10.9% |
| 26 | 050701010502 | Gilbert Creek | 33.2 | 70.1 | 103.3 | 4.2 | 7.1 | 11.2 | 12.6% | 10.1% | 10.9% |
| 27 | 050702010310 | Blackberry Creek-Tug Fork | 14.6 | 34.0 | 48.6 | 2.3 | 2.9 | 5.3 | 16.0% | 8.6% | 10.8% |
| 28 | 050702010201 | South Fork Tug Fork-Tug Fork | 63.3 | 100.8 | 164.1 | 8.0 | 9.6 | 17.6 | 12.7% | 9.5% | 10.7% |
| 29 | 050500090301 | Spruce Laurel Fork | 28.2 | 80.2 | 108.4 | 4.6 | 6.9 | 11.6 | 16.4% | 8.7% | 10.7% |
| 30 | 050702010402 | Laurel Fork | 31.1 | 79.2 | 110.2 | 4.9 | 6.6 | 11.5 | 15.6% | 8.4% | 10.4% |
| 31 | 050500060103 | Long Branch-Paint Creek | 38.3 | 80.8 | 119.1 | 4.0 | 7.4 | 11.4 | 10.5% | 9.2% | 9.6% |
| 32 | 050701010508 | Dingess Run-Guyandotte River | 31.2 | 75.7 | 106.9 | 4.1 | 6.1 | 10.2 | 13.2% | 8.0% | 9.5% |
| 33 | 050500090401 | Upper Pond Fork | 32.4 | 71.8 | 104.3 | 2.4 | 7.3 | 9.7 | 7.5% | 10.2% | 9.3% |
| 34 | 050301061208 | Big Run-Ohio River | 4.4 | 10.7 | 15.1 | 0.4 | 0.9 | 1.4 | 10.1% | 8.7% | 9.1% |
| 35 | 050701010401 | Copperas Mine Fork | 46.2 | 110.3 | 156.5 | 7.5 | 6.7 | 14.2 | 16.3% | 6.1% | 9.1% |
| 36 | 050500050802 | Headwaters Muddlety Creek | 46.2 | 88.3 | 134.5 | 4.7 | 7.4 | 12.0 | 10.1% | 8.4% | 9.0% |
| 37 | 050701010303 | Cabin Creek-Guyandotte River | 40.3 | 88.3 | 128.6 | 3.5 | 8.0 | 11.5 | 8.6% | 9.1% | 8.9% |
| 38 | 050702010102 | Jacobs Fork | 31.1 | 51.9 | 83.1 | 3.4 | 4.0 | 7.4 | 10.9% | 7.7% | 8.9% |
| 39 | 050500060306 | Hughes Creek-Kanawha River | 44.5 | 94.0 | 138.4 | 5.3 | 7.1 | 12.3 | 11.9% | 7.5% | 8.9% |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 050301061105 | Lower Fish Creek | 26.1 | 59.2 | 85.3 | 2.7 | 4.8 | 7.5 | 10.3% | 8.1% | 8.8% |
| 41 | 050500050809 | Rich Creek-Gauley River | 38.5 | 89.6 | 128.1 | 4.1 | 6.7 | 10.8 | 10.7% | 7.4% | 8.4% |
| 42 | 050500070201 | Headwaters Laurel Creek | 33.3 | 71.9 | 105.2 | 4.1 | 4.3 | 8.4 | 12.2% | 6.0% | 8.0% |
| 43 | 050702010506 | Miller Creek-Tug Fork | 34.8 | 90.9 | 125.7 | 4.6 | 5.0 | 9.6 | 13.2% | 5.5% | 7.6% |
| 44 | 050701010506 | Elk Creek-Guyandotte River | 53.2 | 102.4 | 155.6 | 4.8 | 6.6 | 11.4 | 9.1% | 6.4% | 7.3% |
| 45 | 050702010403 | Outlet Pigeon Creek | 46.2 | 125.0 | 171.2 | 4.6 | 7.8 | 12.4 | 9.8% | 6.3% | 7.2% |
| 46 | 050702010308 | Beech Creek-Tug Fork | 23.1 | 42.4 | 65.6 | 2.2 | 2.5 | 4.7 | 9.5% | 5.8% | 7.1% |
| 47 | 050500090603 | Joes Creek-Big Coal River | 53.9 | 128.9 | 182.8 | 4.7 | 8.0 | 12.7 | 8.6% | 6.2% | 6.9% |
| 48 | 050301061202 | Salt Run-Ohio River | 7.2 | 14.0 | 21.1 | 1.0 | 0.4 | 1.4 | 13.8% | 3.0% | 6.6% |
| 49 | 050901020101 | Upper West Fork Twelvepole Creek | 45.5 | 114.3 | 159.8 | 5.7 | 3.9 | 9.7 | 12.6% | 3.4% | 6.1% |
| 50 | 050701010202 | Headwaters Clear Fork | 50.1 | 88.1 | 138.1 | 3.0 | 5.2 | 8.2 | 6.0% | 5.9% | 5.9% |
| 51 | 050500090102 | Outlet Clear Fork | 38.6 | 62.6 | 101.2 | 2.3 | 3.7 | 6.0 | 5.9% | 6.0% | 5.9% |
| 52 | 050701010302 | Pinnacle Creek | 69.6 | 143.6 | 213.2 | 5.6 | 6.0 | 11.6 | 8.1% | 4.2% | 5.5% |
| 53 | 050200030308 | Scotts Run-Monongahela River | 43.2 | 84.2 | 127.4 | 3.4 | 3.6 | 7.1 | 7.9% | 4.3% | 5.5% |
| 54 | 050702010204 | Sandlick Creek-Tug Fork | 60.7 | 99.0 | 159.7 | 4.9 | 3.9 | 8.8 | 8.0% | 4.0% | 5.5% |
| 55 | 050500050801 | Big Beaver Creek | 61.9 | 99.6 | 161.5 | 5.5 | 3.2 | 8.7 | 8.9% | 3.3% | 5.4% |
| 56 | 050702010101 | Big Creek | 46.7 | 79.5 | 126.1 | 2.9 | 3.8 | 6.7 | 6.2% | 4.8% | 5.3% |
| 57 | 050701010503 | Big Cub Creek-Guyandotte River | 57.8 | 115.4 | 173.2 | 4.5 | 4.7 | 9.1 | 7.7% | 4.0% | 5.3% |
| 58 | 050702010303 | Long Branch-Tug Fork | 24.1 | 55.6 | 79.7 | 2.4 | 1.8 | 4.2 | 9.9% | 3.2% | 5.3% |
| 59 | 050901020202 | Upper East Fork Twelvepole Creek | 60.4 | 136.4 | 196.7 | 5.5 | 4.8 | 10.3 | 9.2% | 3.5% | 5.3% |
| 60 | 050500060404 | Campbells Creek | 45.4 | 95.3 | 140.7 | 3.6 | 3.4 | 7.0 | 7.9% | 3.5% | 5.0% |
| 61 | 050500060305 | Kellys Creek | 29.7 | 56.8 | 86.5 | 1.9 | 2.1 | 4.1 | 6.5% | 3.7% | 4.7% |
| 62 | 050500050807 | Outlet Peters Creek | 34.7 | 54.5 | 89.2 | 2.3 | 1.9 | 4.2 | 6.6% | 3.4% | 4.7% |
| 63 | 050500070401 | Upper Birch River | 53.9 | 113.2 | 167.1 | 3.2 | 4.1 | 7.3 | 6.0% | 3.6% | 4.4% |
| 64 | 050702010601 | Marrowbone Creek | 23.0 | 55.1 | 78.1 | 2.0 | 1.4 | 3.4 | 8.7% | 2.5% | 4.3% |
| 65 | 050500070202 | Outlet Laurel Creek | 36.9 | 87.4 | 124.3 | 2.5 | 2.8 | 5.2 | 6.7% | 3.2% | 4.2% |
| 66 | 050500050702 | Outlet Twentymile Creek | 56.8 | 130.7 | 187.5 | 3.9 | 4.0 | 7.9 | 6.9% | 3.1% | 4.2% |
| 67 | 050500060403 | Fields Creek-Kanawha River | 31.3 | 80.7 | 112.1 | 2.1 | 2.6 | 4.6 | 6.6% | 3.2% | 4.1% |
| 68 | 050500090606 | Fork Creek-Big Coal River | 34.3 | 86.7 | 121.1 | 2.2 | 2.8 | 5.0 | 6.4% | 3.2% | 4.1% |
| 69 | 050500060104 | Fourmile Fork-Paint Creek | 18.6 | 46.5 | 65.1 | 0.8 | 1.9 | 2.6 | 4.1% | 4.0% | 4.0% |
| 70 | 050701010203 | Outlet Clear Fork | 51.5 | 82.7 | 134.2 | 2.6 | 2.5 | 5.1 | 5.0% | 3.0% | 3.8% |
| 71 | 050500090503 | Lower Little Coal River | 27.1 | 62.5 | 89.6 | 1.7 | 1.7 | 3.3 | 6.2% | 2.7% | 3.7% |
| 72 | 050702010311 | Mate Creek | 19.9 | 37.1 | 57.0 | 1.0 | 1.1 | 2.1 | 5.0% | 3.0% | 3.7% |
| 73 | 050500020904 | Widemouth Creek-Bluestone River | 63.4 | 107.4 | 170.8 | 2.0 | 4.3 | 6.3 | 3.1% | 4.0% | 3.7% |
| 74 | 050500090604 | Drawdy Creek-Big Coal River | 39.7 | 112.6 | 152.2 | 2.4 | 3.2 | 5.6 | 6.0% | 2.8% | 3.7% |
| 75 | 050500060302 | Armstrong Creek | 22.5 | 49.7 | 72.2 | 0.7 | 2.0 | 2.6 | 3.0% | 3.9% | 3.6% |
| 76 | 050701010101 | Tommy Creek | 71.1 | 135.5 | 206.6 | 3.7 | 3.9 | 7.5 | 5.2% | 2.8% | 3.6% |
| 77 | 050500060202 | Outlet Cabin Creek | 36.9 | 91.0 | 127.9 | 2.2 | 2.5 | 4.6 | 5.8% | 2.7% | 3.6% |
| 78 | 050701010201 | Laurel Fork | 81.8 | 135.4 | 217.2 | 3.6 | 3.7 | 7.3 | 4.4% | 2.7% | 3.4% |
| 79 | 050701010305 | Indian Creek | 50.5 | 107.5 | 158.0 | 3.8 | 1.3 | 5.1 | 7.5% | 1.2% | 3.2% |
| 80 | 050701010301 | Barkers Creek | 42.0 | 91.8 | 133.8 | 2.3 | 1.9 | 4.2 | 5.6% | 2.0% | 3.1% |
| 81 | 050701010504 | Huff Creek | 56.3 | 121.5 | 177.8 | 2.6 | 2.9 | 5.5 | 4.7% | 2.4% | 3.1% |
| 82 | 050500070601 | Big Run-Elk River | 38.9 | 59.6 | 98.5 | 1.5 | 1.4 | 3.0 | 3.9% | 2.4% | 3.0% |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 83 | 050500060402 | Lens Creek | 18.7 | 46.3 | 65.0 | 1.1 | 0.8 | 1.9 | 5.9% | 1.7% | 2.9% |
| 84 | 050702010208 | Horse Creek-Tug Fork | 47.8 | 90.9 | 138.7 | 1.4 | 2.6 | 4.1 | 3.0% | 2.9% | 2.9% |
| 85 | 050500090502 | Upper Little Coal River | 69.1 | 160.3 | 229.4 | 3.2 | 3.4 | 6.6 | 4.6% | 2.1% | 2.9% |
| 86 | 050200010705 | Hackers Creek-Tygart Valley River | 39.7 | 78.5 | 118.2 | 1.4 | 1.8 | 3.1 | 3.5% | 2.2% | 2.7% |
| 87 | 050702010202 | Headwaters Elkhorn Creek | 54.3 | 97.3 | 151.6 | 1.8 | 2.1 | 4.0 | 3.3% | 2.2% | 2.6% |
| 88 | 050500050804 | Panther Creek-Gauley River | 63.0 | 113.4 | 176.3 | 2.4 | 2.2 | 4.6 | 3.8% | 1.9% | 2.6% |
| 89 | 050200030301 | Paw Paw Creek | 40.2 | 103.5 | 143.7 | 1.3 | 2.3 | 3.7 | 3.3% | 2.3% | 2.5% |
| 90 | 050500070501 | Headwaters Buffalo Creek | 40.1 | 97.3 | 137.4 | 2.0 | 1.4 | 3.4 | 5.1% | 1.4% | 2.5% |
| 91 | 050200050104 | Miracle Run | 23.3 | 57.8 | 81.1 | 0.5 | 1.6 | 2.0 | 1.9% | 2.7% | 2.5% |
| 92 | 050500060101 | Packs Branch-Paint Creek | 81.3 | 110.3 | 191.5 | 3.2 | 1.5 | 4.7 | 4.0% | 1.3% | 2.5% |
| 93 | 050500060401 | Witcher Creek | 23.8 | 50.5 | 74.3 | 1.1 | 0.7 | 1.8 | 4.6% | 1.4% | 2.4% |
| 94 | 020700020203 | Buffalo Creek-North Branch Potomac River | 25.7 | 42.8 | 68.5 | 1.1 | 0.5 | 1.6 | 4.1% | 1.2% | 2.3% |
| 95 | 050702010104 | Middle Dry Fork | 73.0 | 121.7 | 194.7 | 2.0 | 2.5 | 4.5 | 2.7% | 2.0% | 2.3% |
| 96 | 050901020204 | Lower East Fork Twelvepole Creek | 18.2 | 42.9 | 61.1 | 0.5 | 0.7 | 1.2 | 2.6% | 1.7% | 1.9% |
| 97 | 050200030309 | West Run-Monongahela River | 36.2 | 72.9 | 109.2 | 1.0 | 1.0 | 2.0 | 2.8% | 1.4% | 1.9% |
| 98 | 050500060301 | Loop Creek | 74.8 | 117.3 | 192.2 | 1.5 | 1.9 | 3.4 | 2.0% | 1.6% | 1.7% |
| 99 | 050200010601 | Headwaters Three Fork Creek | 71.4 | 151.3 | 222.7 | 1.4 | 2.5 | 3.9 | 1.9% | 1.7% | 1.7% |
| 100 | 020700020201 | Shields Run-North Branch Potomac River | 22.8 | 42.3 | 65.2 | 0.3 | 0.9 | 1.1 | 1.1% | 2.0% | 1.7% |
| 101 | 020700020202 | Mount Storm Lake-Stony River | 72.5 | 107.8 | 180.4 | 1.7 | 1.4 | 3.1 | 2.3% | 1.3% | 1.7% |
| 102 | 050500060405 | Rush Creek-Kanawha River | 36.2 | 84.0 | 120.2 | 1.0 | 1.1 | 2.1 | 2.7% | 1.3% | 1.7% |
| 103 | 050701010306 | Turkey Creek-Guyandotte River | 48.5 | 114.2 | 162.6 | 1.2 | 1.5 | 2.7 | 2.4% | 1.3% | 1.6% |
| 104 | 050500090201 | Stephens Lake | 39.5 | 61.0 | 100.5 | 1.0 | 0.6 | 1.6 | 2.5% | 1.0% | 1.6% |
| 105 | 050702010301 | Bull Creek-Tug Fork | 29.3 | 52.2 | 81.5 | 0.8 | 0.4 | 1.2 | 2.7% | 0.8% | 1.5% |
| 106 | 050701020102 | Crawley Creek-Guyandotte River | 63.2 | 130.7 | 193.9 | 1.0 | 1.9 | 2.9 | 1.6% | 1.5% | 1.5% |
| 107 | 050500060102 | Plum Orchard Lake-Paint Creek | 44.8 | 54.8 | 99.5 | 1.1 | 0.4 | 1.4 | 2.4% | 0.7% | 1.5% |
| 108 | 050702010205 | Spice Creek-Tug Fork | 77.0 | 144.7 | 221.7 | 1.9 | 1.2 | 3.1 | 2.4% | 0.8% | 1.4% |
| 109 | 050200020202 | Headwaters Elk Creek | 43.0 | 89.1 | 132.1 | 0.9 | 0.8 | 1.7 | 2.2% | 0.9% | 1.3% |
| 110 | 050702010103 | Upper Dry Fork | 34.8 | 61.7 | 96.5 | 0.6 | 0.6 | 1.2 | 1.8% | 1.0% | 1.3% |
| 111 | 050702010105 | Lower Dry Fork | 69.4 | 123.8 | 193.2 | 1.3 | 1.1 | 2.4 | 1.8% | 0.9% | 1.2% |
| 112 | 050500070603 | Lower Sutton Lake-Elk River | 10.1 | 22.2 | 32.4 | 0.3 | 0.1 | 0.4 | 3.0% | 0.4% | 1.2% |
| 113 | 050200010304 | Tenmile Creek-Buckhannon River | 72.3 | 162.1 | 234.5 | 1.1 | 1.6 | 2.7 | 1.5% | 1.0% | 1.2% |
| 114 | 050200020201 | Gnatty Creek | 35.9 | 80.5 | 116.4 | 0.7 | 0.5 | 1.2 | 1.8% | 0.6% | 1.0% |
| 115 | 050701010102 | Slab Fork | 46.1 | 85.1 | 131.3 | 0.6 | 0.7 | 1.3 | 1.3% | 0.8% | 1.0% |
| 116 | 050200030303 | Indian Creek | 22.3 | 53.7 | 76.0 | 0.6 | 0.2 | 0.7 | 2.6% | 0.3% | 1.0% |
| 117 | 050500050806 | Headwaters Peters Creek | 52.6 | 62.8 | 115.5 | 0.7 | 0.4 | 1.1 | 1.4% | 0.6% | 1.0% |