

**West Virginia Water Research Institute
Annual Technical Report
FY 2013**

Introduction

The West Virginia Water Research Institute is dedicated to the preservation and restoration of the natural environment through research and outreach with industry, government agencies, academia and the public.

Water is one of West Virginia's most precious resources. It is essential for life and our economic prosperity, yet so many of the activities that keep our economy alive, and growing, also threaten our water resources. Energy generation, mineral extraction, agricultural production and other industrial activities all impact our water, making it increasingly necessary to find new ways to protect and restore this vital commodity as our economic activity accelerates. For over 40 years, the West Virginia Water Research Institute (WVWRI) has been leading the important work of addressing these issues and is the go-to organization for solving West Virginia's water-related problems.

While much of the work we do is focused on exploring and implementing technologies to improve and protect the quality of our State's water resources, we are also dedicated to expanding the understanding of threats and opportunities related to this critically important resource. We strive to bring together a diverse cross section of stakeholders to participate in water-related research throughout West Virginia. We encourage a constructive and respectful dialog about the future of our lakes, rivers and streams as well as our groundwater supplies.

Today, the WVWRI continues to grow its established programs and develop new initiatives to address emerging problems affecting the State's environmental and economic health. With financial support from State and Federal partners, private foundations and industry, and through the efforts of our staff and collaborating researchers, the WVWRI continues to work for real improvements to West Virginia's water resources.

Water Research for West Virginia: A Team Approach

In 1967, under Federal legislation, the United States Geological Survey established the West Virginia Water Research Institute (WVWRI) to conduct research related to water issues in the State. Today, the WVWRI develops state water research priorities with oversight and guidance from the West Virginia Advisory Committee for Water Research, a committee represented by members of Federal and State agencies, academia and industry. Our programs and projects develop strong, multi-disciplinary research teams through collaboration with West Virginia University colleges and divisions, higher education institutions across the country and industry professionals. This team approach offers the best expertise available to address West Virginia's water issues and allows the WVWRI to perform research in a number of areas at any given time. More information on WVWRI programs, research, projects, initiatives and publications can be found at www.wvwri.org.

West Virginia Advisory Committee for Water Research

Our research program is guided by the West Virginia Advisory Committee for Water Research. It includes representatives from the following:

West Virginia Department of Natural Resources West Virginia Bureau for Public Health West Virginia Coal Association West Virginia Department of Environmental Protection West Virginia Oil and Natural Gas Association GenPower Services, LLC U.S. Federal Bureau of Investigation U.S. Geological Survey U.S. Environmental Protection Agency Region III U.S. Department of Energy - National Energy Technology Laboratory U.S. Army Corps of Engineers - Huntington, WV District West Virginia University Extension and Public Service

The Advisory Committee develops the Institute's research priority list, reviews its progress and selects startup projects at its annual meeting. With this direction, the Institute recruits new researchers to study emerging water research issues. Because the Advisory Committee understands future regulatory and economic driving factors, these issues tend to grow in importance and have often led to follow-on funding from their agencies.

Funding Strategy

The Institute uses funding received from the U.S. Geological Survey Clean Water Act section 104b program and State funding to develop research capabilities in priority areas and to provide service to State agencies, industry and citizen groups. Our strategy relies on using the USGS section 104b funding to develop competitive capabilities that, in turn, translate into successful proposals funded by a broad spectrum of Federal and State agencies.

Our strategy also relies on maintaining a broad cadre of researchers within WVU and other institutions within the state. We also work with faculty from institutions across the country to form competitive research partnerships. As West Virginia University is the State's flagship research institution, its researchers have played the dominant role. Our funding strategy relies on successful competition for Federal dollars while teaming with State agency and industry partners. They later provide test sites, in-kind support and invaluable background data. The institute has 13 full time staff. The institute also supports numerous students (6 within the WVWRI) and more through other departmental projects. All but two positions are supported entirely on grant funds. Roughly two-thirds of the Institute staff is directly engaged in research projects; the remaining is engaged in community economic redevelopment, outreach, and administration.

Research Program Introduction

This year's report includes results on four 104b projects, one 104g project, and one flow-through project.

Identifying Geomorphic Design Parameters to Improve Flood Control and Water Quality

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Abstract

Fluvial geomorphic landform design has the potential to improve water quality while restoring productive stream channels in the reclaimed landscape. The technique is difficult to apply in the southern West Virginia coal fields in part due to the absence of unaltered landform data to serve as reference design values. This research examined the application of geomorphic landform design principles to valley fills. The objectives of this research were to quantify mature landform features in an undisturbed watershed in southern West Virginia and compare these characteristics to default parameters utilized in a current design tool. Reference landform characteristics were quantified in the Whetstone and Oldhouse watersheds located in the Panther Wildlife Management Area in southern West Virginia. A topographic survey was completed to quantify ridge to head of channel distance, channel slope, and hillslope profile. Channel grain size distributions were quantified in both head of channel and watershed outlet locations. Findings suggest that the slope at the head of channel ranges between 16 and 43 percent, with the slope at the mouth remaining at 8-14 percent. Drainage density was calculated as 5.3 km^{-1} , and sinuosity remained close to one (≤ 1.12). These design parameters substantially differ from design inputs of current design tools. The practicality to Appalachian valley fill stream construction is that the stream lengths are shorter and the land slopes are steeper with straighter head water channels compared with other areas of the United States. While the application of geomorphic landform design to surface mine sites presents challenges, this work provides support for the future application.

Table of Contents

Abstract.....	ii
List of Figures	iv
List of Tables.....	iv
Executive Summary	5
Introduction	5
Experimental Methods	6
Study Area and Site characteristics	6
Data Collection and Analysis.....	9
Geomorphic Valley-fill Design Calibration	10
Results and Discussion.....	10
Stream Pattern and Profile	10
Channel Material and Hillslope.....	11
Comparison and Analysis of Design Parameters.....	14
Geomorphic Valley-fill Design Comparison	15
Default Design	15
RHC 150	16
RHC 150-Reconfiguration.....	16
RHC 220	17
Conclusions	18
References.....	19
Appendix A: Geomorphic Data	21

List of Figures

Figure 1. Location of experimental watershed, Whetstone Branch, in Panther Wildlife Management Area, West Virginia	7
Figure 2. Head of channels surveyed in Whetstone Branch watershed	7
Figure 3. Experimental field sites for the head of channel sampling stations (I, II, III, IV, V, VI, VII) and the watershed outlet (M) Whetstone Branch watershed	8
Figure 4. Head of channels surveyed in Oldhouse watershed	8
Figure 5. Experimental field sites for the head of channel locations in the Oldhouse watershed (I, II, III, IV, V) and outlet (M).....	9
Figure 6. Slope map of Whetstone Branch	12
Figure 7. Slope map of Oldhouse Branch	13
Figure 8. Aspect map of Whetstone Branch	13
Figure 9. Aspect map of Oldhouse Branch	14
Figure 10. Comparison of four design iterations: a) default design; b) RHC 150; c) RHC 150-R; and, d) RHC 220	16
Figure 11. Drainage density for channels included in the four geomorphic landform designs; channels are named from the headwater location of the main channel moving downstream: R is right, L is left. Main considers the entire subwatershed	17
Figure 12. Valley length for channels included in the four geomorphic landform designs; channels are named from the headwater location of the main channel moving downstream: R is right, L is left. Main considers the entire subwatershed	17
Figure 13. Watershed area for channels included in the four geomorphic landform designs; channels are named from the headwater location of the main channel moving downstream: R is right, L is left.....	18

List of Tables

Table 1. Ridge to head of channel distance, sinuosity, and channel slope for each field site	11
Table 2. Grain size distributions for each field site	11
Table 3. Channel width, bank material, and bank slope for each field site	12
Table 4. Comparison of default design parameters to measurements taken from experimental watersheds.....	15
Table 5. Design parameters for subwatershed 1	15
Table 6. Geomorphic data for Whetstone Branch watershed	22
Table 7. Geomorphic data for Oldhouse Branch watershed.....	23

Executive Summary

This project examined the application of geomorphic landform design principles to valley fills. The work was intended to help determine if geomorphic landform design is a viable reclamation option for Central Appalachia. Geomorphic data were collected to quantify undisturbed landforms. These data were used to calibrate a conceptual geomorphic landform design of a valley fill in southern West Virginia.

Introduction

Approximately 2,000 km of headwater streams were lost by 2002 due to surfacing mining disturbance in the central Appalachian region (USEPA 2011). Typically, the horizontally bedded seams are removed sequentially as overburden is placed both on the pit floor and in external valley fill dumps. Conventional valley fills under West Virginia regulations are designed to meet minimum design requirements to achieve geotechnical stability and to control surface runoff. State regulations (WVDEP 1993) require:

- i. A long-term static factor of safety of 1.5;
- ii. 2:1 slopes with minimum 20-ft wide benches installed within every 50 vertical feet;
- iii. Internal drainage provided by a vertical rock chimney (minimum width of 16 ft); and,
- iv. Surface drainage for a 100-yr, 24-hr precipitation event.

The resulting surfaces often have planar slope profiles which contrast with the surrounding landscape, and their increasing size has resulted in an increasing loss of headwater streams. Studies have shown that streams below valley fills often have elevated dissolved ion concentrations resulting from water contact with the overburden (Hartman et al. 2005; Pond et al. 2008; Petty et al. 2010). Additionally, research has documented that surface mining and reclamation increase stormflow response compared to the undisturbed condition (Bonta et al. 1997; Messinger 2003; Messinger and Paybins 2003; Negley and Eshleman 2006), and selenium leaching from spoil related to coal mining is of increasing concern (e.g. Ziemkiewicz et al. 2011).

Fluvial geomorphic landform design has the potential to improve water quality while restoring productive stream channels in the reclaimed landscape. Under natural conditions, landforms develop a balance between erosive and resistance forces, resulting in a system in dynamic equilibrium with low erosion rates. The fluvial geomorphic landform design approach attempts to design landforms in this steady-state condition, considering long-term climatic conditions, soil types, slopes, and vegetation types (Toy and Chuse 2005; Bugosh 2009). Relative to traditional reclaimed landforms, fluvial geomorphic landform design appears natural, reduces long-term maintenance, requires fewer artificial elements, and supports long-term stability (Martin-Duque et al. 2009).

This design approach has been used with success (e.g. Toy and Chuse 2005; Measles and Bugosh 2007; Martin-Moreno et al. 2008; Bugosh 2009; Robson et al. 2009; Marin-Duque et al. 2009) but has not been utilized in Appalachian surface mining reclamation. The complexity of mature landform design in steep terrain presents challenges. In addition, current regulations do not support the utilization of the design technique (Michael et al. 2010).

Geomorphic landform design uses a reference landform approach which requires pre-development geomorphic data. The data needed for design are similar to those needed for stream classification systems (e.g. Schumm and Mosley 1977; Rosgen 1994, 1996; Montgomery

and Buffington 1997) and stream assessments (e.g. Kaufmann and Robison 1998; VANR 2004):

- i. main channel slope;
- ii. drainage density;
- iii. longitudinal profile shape;
- iv. channel characteristics (bankfull width, width to depth ratio, sinuosity, meander belt width, "A" channel length); and,
- v. ridge to head of channel distance.

Limited geomorphic data are available in West Virginia, especially in the southern coal fields (e.g. Wiley et al. 2001). This region has a history of surface mining and logging, often requiring changes of the steep terrain for site access, which has rendered limited unaltered land profiles.

The overall goal of this research was to quantify geomorphic features in an undisturbed watershed in southern West Virginia. The data were used to inform geomorphic landform design for valley fills in Central Appalachia. Specifically, this research quantified geomorphic characteristics in Whetstone and Oldhouse watersheds located in the Panther Wildlife Management Area (WMA). These characteristics were then compared to design inputs used in a recent alternative valley fill design developed by Sears (2012). Lastly, the conceptual valley-fill design was calibrated using the measured regional design characteristics.

Experimental Methods

Study Area and Site characteristics

Two watersheds were chosen as the study areas for this project: Whetstone Branch and Oldhouse Branch. Both watersheds are located in the Panther Wildlife Management Area in McDowell County, near the southern border of West Virginia (Figure 1). The study locations were identified using aerial photography, topographic maps, and communication with area officials. The Panther WMA site is managed by the West Virginia Division of Natural Resources and has had only minor terrain impacts, mostly due to road construction. The study area receives an average of 100-122 cm of precipitation annually with a strong seasonal pattern (NRCS-NWCC 2012).

Whetstone Branch watershed (0.75 km²) and Oldhouse Branch watershed (0.64 km²) are characterized by a mixed mesophytic forest. Invasive species are also common to the area, including *Elaeagnus umbellate* (autumn olive), *Ailanthus altissima* (tree of heaven), *Pueraria lobata* (kudzu), and *Rosa multiflora* (multiflora rose). The Whetstone Branch watershed consists mainly of an extremely steep and stony soil (Pineville-Berks), with a small portion fine sandy loam (Yeager) located around the mouth of the stream.

The Whetstone Branch watershed includes nine major unnamed tributaries. Seven of these tributaries were selected for study based on accessibility. Field data collection was completed June-July 2012. Geomorphic characteristics were quantified at the seven head of channel locations (I, II, III, IV, V, VI, and VII) as well as the watershed outlet (M for main channel outlet; Figures 2-3). The characteristics were determined through a combination of field surveys and existing GIS data as described in the following sections. Five tributaries were studied in Oldhouse Branch watershed (I, II, III, IV, and V) as well as the watershed outlet (M); Figures 4-5).



Figure 1. Location of experimental watershed, Whetstone Branch, in Panther Wildlife Management Area, West Virginia

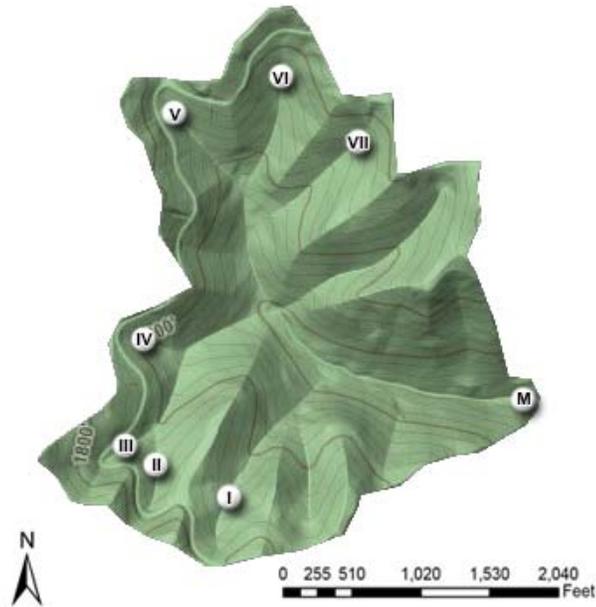


Figure 2. Head of channels surveyed in Whetstone Branch watershed



Figure 3. Experimental field sites for the head of channel sampling stations (I, II, III, IV, V, VI, VII) and the watershed outlet (M) Whetstone Branch watershed

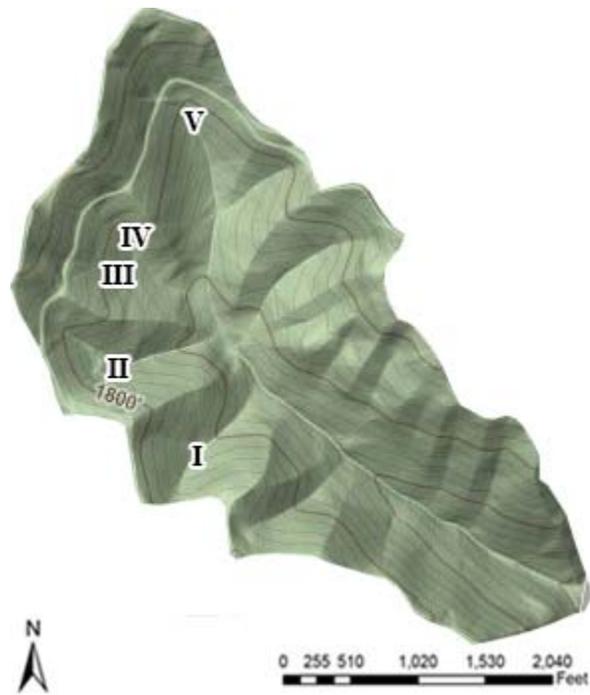


Figure 4. Head of channels surveyed in Oldhouse watershed

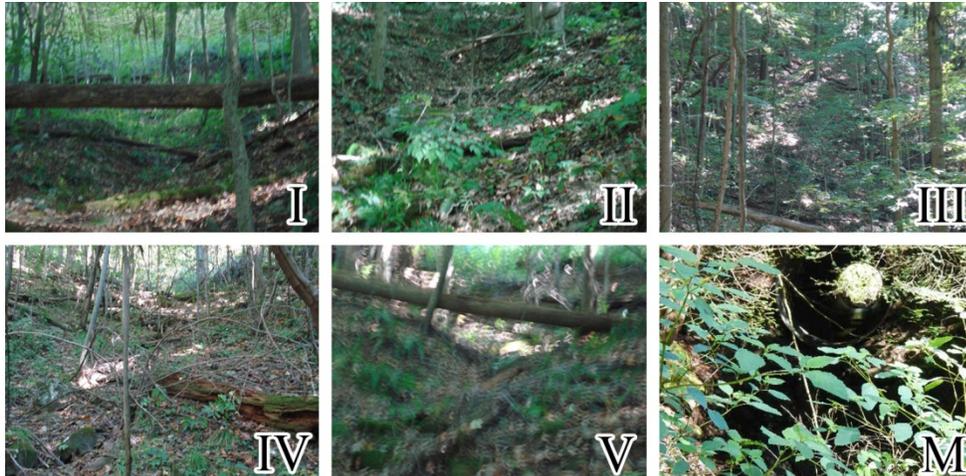


Figure 5. Experimental field sites for the head of channel locations in the Oldhouse watershed (I, II, III, IV, V) and outlet (M)

Data Collection and Analysis

Field data needed to quantify grain size distribution, hillslopes, ridge to head of channel distance, channel slope, and cross-sectional geometry were collected in head of channel and watershed outlet locations (Figure 2). A field survey was completed using a Topcon FC-100 and Hyperlite+ receivers (Topcon, Paramus, New Jersey) using a 0.6 m horizontal error and a 1.5 m vertical accuracy; this error represented the minimum allowable error to complete measurements within the dense vegetation cover. Study reaches were surveyed to quantify slopes, sinuosity, ridges, and channel head locations. The location of the watershed ridge and head of channel locations were identified and recorded as points; these data were used to calculate ridge to head of channel distance. Roads that altered the natural topography were also recorded. A minimum of five points were taken downslope from the start of channel to identify the channel slope and sinuosity (i.e. channel length/valley length). Bank slopes were determined through points taken a minimum of 7.5 m from the start of channel on either side of the channel. A clinometer was used to verify slope measurements. Channel dimensions were measured at the head of each channel as well as the mouth of the watershed. These sections were taken by placing an adjustable measuring rod horizontally and perpendicular to the stream; the distance from the rod to the streambed were measured and recorded at 0.3 m intervals.

Particle size distributions of bed material were quantified at each sampling locations using modified Wolman (1954) pebble count (Harrelson et al. 1994). Bank materials were also observed and recorded. Riparian trees, shrubs, and herbaceous plants were characterized at each head of channel location through sketching sections, highlighting plant types and observations of plant cover. Additionally, a percentage of each type of cover (trees, shrubs, low lying plants) was estimated based on observation.

ArcMap was used in conjunction with digital spatial datasets for elevation (U.S. Geological Survey, WV SAMB), hydrology (U.S. Geological Survey, WV SAMB), and soils (NRCS). The field measurements were downloaded into a GIS desktop application and georeferenced with the field data. GIS was used to verify slope and sinuosity measurements. Slope and aspect maps were created and drainage density (i.e. valley length/watershed area) was calculated. Ridge to head of channel distances were calculated using survey data.

Geomorphic Valley-fill Design Calibration

The regional data were used to improve a previously created valley-fill design. Three iterations were completed. The redesigned watersheds (designated as “RHC 150”, “RHC 150-R”, and “RHC 220”) were compared to the default design as well as to the regional design data.

Results and Discussion

Stream Pattern and Profile

Sinuosity, a measure of channel curvature, was calculated as nearly one when using both survey data (average sinuosity = 1.02) and GIS data (average sinuosity = 1.05) (Table 1). Channels with a sinuosity greater than 1.3 are considered meandering (FISRWG 1998); therefore, no meandering channels were observed in the steep, headwater watersheds. The sinuosity measurements calculated with field measurements were slightly smaller than those derived from GIS. This is expected because the survey only accounted for a small stretch at the beginning of the stream (where slopes are greater) while the GIS measurements represented the entire branch.

The ridge to head of channel distance represents the distance required to form channelized flow and is essential to understand watershed runoff processes (Hancock and Evans 2006). The head of channel was determined by identifying the location where soil began to give way to gravel and there was an apparent change in slope. An apparent v-notch began to form at the head of each channel as well. The mean ridge to head-of-channel distance was 121 m and 178 m for Whetstone and Oldhouse watersheds, respectively (Table 1).

For the headwater tributary locations, channel slope was greater than 16%. At the watershed outlet, the main channel had a slope of 8-14%, which is characteristic of a non-meandering stream.

Table 1. Ridge to head of channel distance, sinuosity, and channel slope for each field site

Watershed	Site	Ridge to channel head distance (m)	Sinuosity (from survey)	Sinuosity (from GIS)	Channel Slope (%)
W	I	112	1.05	1.08	16
W	II	113	1.01	1.12	18
W	III	163	1.00	1.05	21
W	IV	108	1.00	1.02	27
W	V	106	1.00	1.00	42
W	VI	136	1.01	1.06	34
W	VII	110	1.01	1.02	36
W	M	NA [‡]	1.01	1.03	8
O	I	104	1.02	1.02	35
O	II	171	1.00	1.07	32
O	III	220	1.06	1.09	43
O	IV	218	1.04	1.06	41
O	V	177	1.01	1.05	39
O	M	NA [‡]	1.01	1.04	14

‡NA=not applicable

Channel Material and Hillslope

Median particle size (D50) ranged from 18 to 43 mm for all headwater locations (W I-VII, W I-V; Table 2), representing gravel bed channels. The median particle size for the watershed outlet was also in the gravel size range (D50=20 and 45 mm). The head of channel bed material was colluvial according to the Montgomery-Buffington classification (Montgomery and Buffington 1993); it originated from hillslope debris and was formed by gravity.

Table 2. Grain size distributions for each field site

Watershed	Site	D16 (mm)	D50 (mm)	D84 (mm)
W	I	9.1	31	72
W	II	9.4	21	59
W	III	11	33	66
W	IV	9.4	22	62
W	V	8.7	19	51
W	VI	8.3	27	76
W	VII	8.4	34	63
W	M	10	20	32
O	I	9.6	43	79
O	II	9.3	30	61
O	III	8.6	26	64
O	IV	6.4	18	54
O	V	7.6	20	54
O	M	11	45	120

Banks primarily consisted of sand and tended to have slopes from 9%-25%. The heads of the channels tended to start out broad (1.8-3 m) and narrowed as they traveled down the slope

(Table 3). Channel slopes were also very steep, reaching as high as 43% grade (Table 1). The steep valley slopes are also presented in Figures 7 and 8. Much of the watershed has greater than a 50% incline, with very few areas less than 30% (Figures 7-8). The complexity of the watershed arrangement is apparent through the aspect distribution; the Whetstone Branch watershed had 40%, 30%, 20%, and 10% of south (south, southwest, southeast), north (north, northwest, northeast), east, and west facing slopes, respectively (Figure 9); Oldhouse Branch had a similar distribution (Figure 10).

Table 3. Channel width, bank material, and bank slope for each field site

	Site	Channel Width	Left Bank		Right Bank	
			Slope	Texture	Slope	Texture
W	I	SC	VS	Sand/Silt	VS	Sand/Silt
W	II	B	S	Sand	S	Sand
W	III	B	S	Sand	S	Sand
W	IV	B	H	Sand	H	Sand
W	V	B	VS	Sand	VS	Sand
W	VI	B	H	Sand	VS	Sand
W	VII	N	S	Sand	S	Sand
W	M	B	ES	Sand	S	Sand
O	I	VB	H	Sand	H	Sand
O	II	B	S	Sand	S	Sand
O	III	VB	H	Sand	H	Sand
O	IV	B	S	Sand	S	Sand
O	V	N	S	Sand	S	Sand
O	M	B	ES	Sand	ES	Sand

*SC is semi-confined (0.6-1.2 m), B is broad (1.8-3 m), N is Narrow (1.2-1.8 m), VS is very steep (16%-25%), S is steep (9%-15%), H is hilly (4-8%), and ES is extremely steep (>25%); notation adapted from (VANR, 2004).

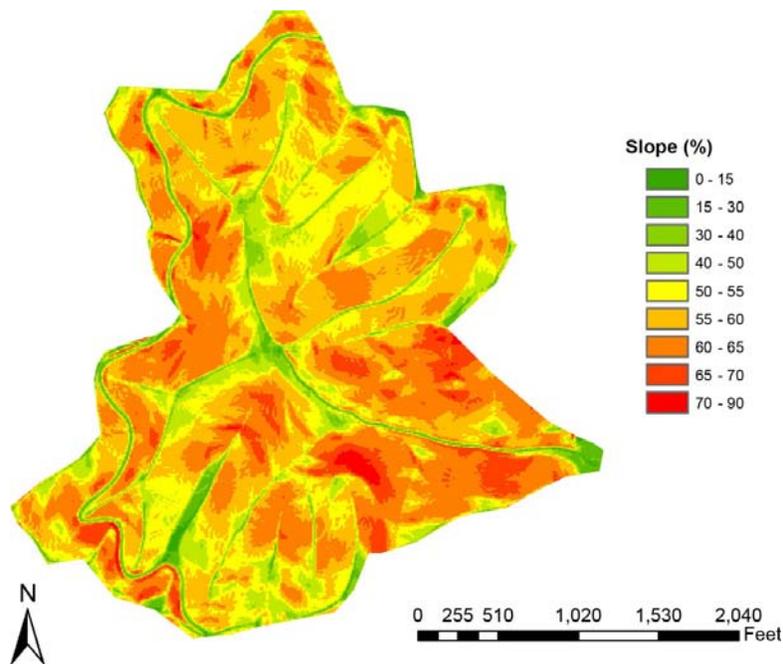


Figure 6. Slope map of Whetstone Branch

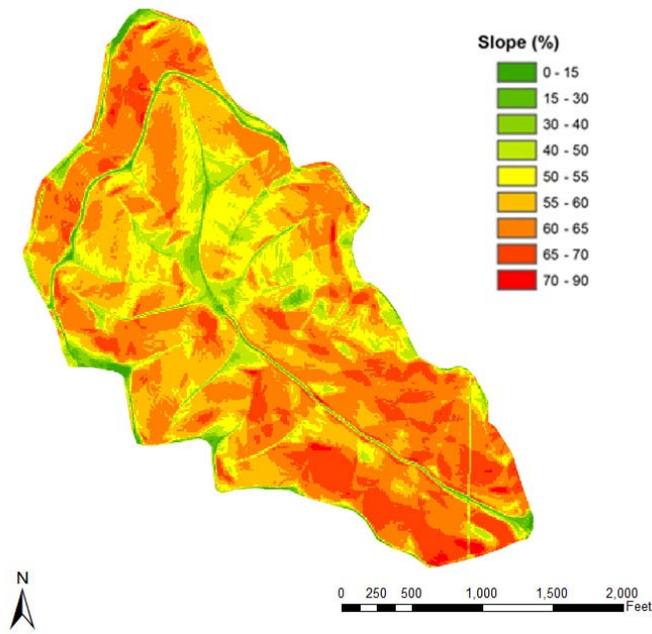


Figure 7. Slope map of Oldhouse Branch

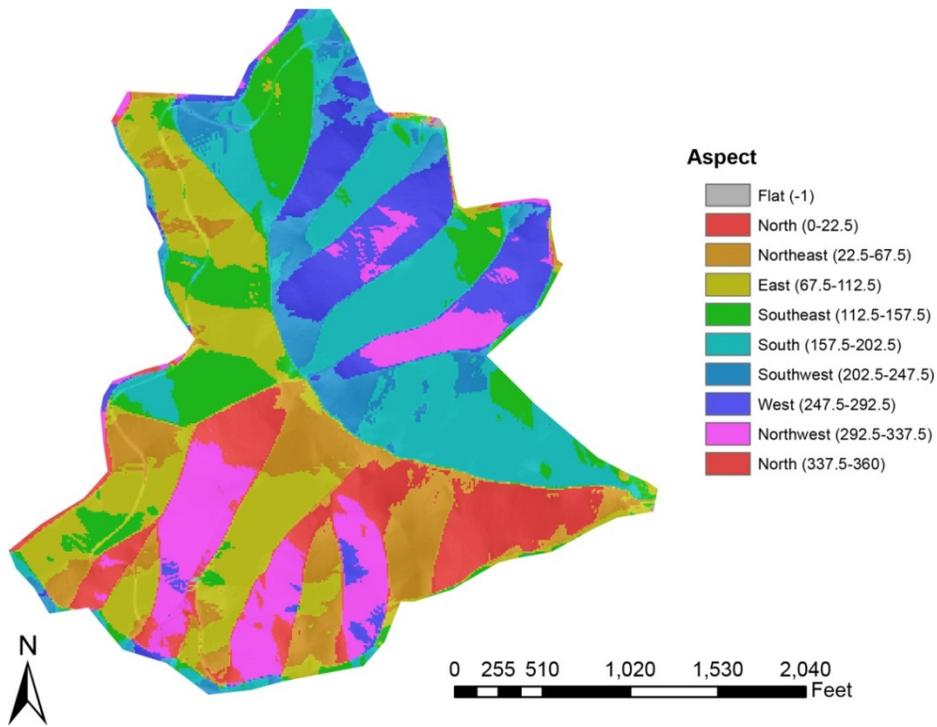


Figure 8. Aspect map of Whetstone Branch

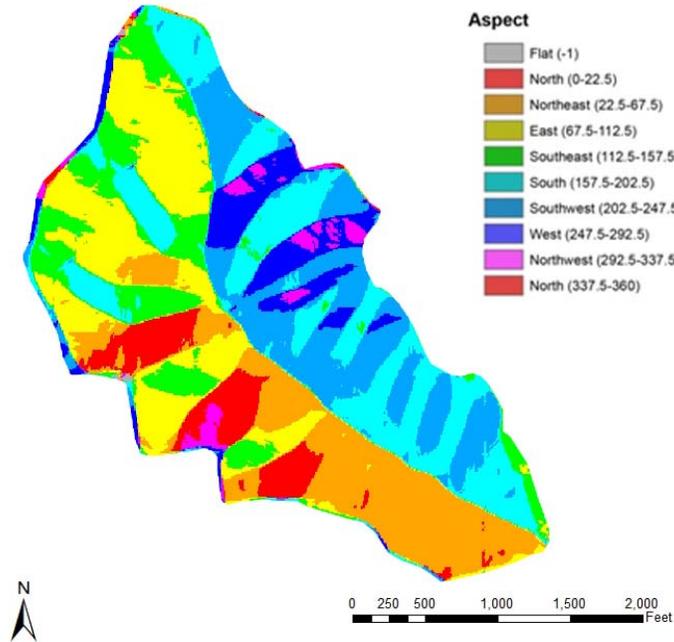


Figure 9. Aspect map of Oldhouse Branch

Comparison and Analysis of Design Parameters

Sears (2012) recently designed an alternative valley fill for a site under construction in southern West Virginia. The design applied the geomorphic landform technique and used the design tool Carlson Natural Regrade with GeoFluv™. Default design parameters that were not specific to West Virginia were utilized in the design process (Table 4).

The measured values quantified in this research varied significantly from the default settings. All observed channels were characterized as colluvial as described by the Montgomery and Buffington (1993) classification system. All channel slopes were greater than 4% for this study and all measured sinuosity values were near one. The measured ridge to head of channel distances were at least four times greater than the value utilized in the Sears (2012) design. The default drainage area was less than the measured value; however Sears (2012) allowed a 20% error ($6-9 \text{ km}^{-1}$). The experimental watershed value ($5.0-5.3 \text{ km}^{-1}$) fell outside of this range (Table 4).

Table 4. Comparison of default design parameters to measurements taken from experimental watersheds

	Default**	Whetstone	Oldhouse
Max ridge to head of channel distance, m (ft)	24 (80)	163 (534)	220 (723)
Slope at mouth of main valley channel (%)	2	8	14
Drainage density, km⁻¹ (ft/ac)	7.5 (100)	5.3 (70)	5.0 (67)
Upstream slope (%)	12	28*	34*
Downstream slope (%)	2	8*	14*
Sinuosity (> -4%)	1.15	1.03*	1.06*
Sinuosity (< -4%)	1.48	NA [‡]	NA [‡]

*represents an average value

**default values incorporated in the design software

‡NA=not applicable

Geomorphic Valley-fill Design Comparison

The regional data were used to improve the previously created valley-fill design (designated as “Default Design”). First, the ridge to head-of-channel distance (RHC) was increased to 150 m and the drainage density (DD) was decreased to 5.3 km⁻¹, allowing a 20% variance for DD. In the second design, the stream channels were reconfigured to obtain the targeted DD while the design parameters of the first iteration remained unchanged. In the final design, the RHC was increased to 220 m (720 ft) while the DD remained at 5.3±20% km⁻¹ (Table 5).

Table 5. Design parameters for subwatershed 1

	Default	RHC 150	RHC 150-R	RHC 220
Ridge to head-of-channel distance, m (ft)	24 (80)	150 (500)	150 (500)	220 (720)
Drainage density*, km⁻¹ (ft/ac)	7.5 (100)	5.3 (70)	5.3 (70)	5.3 (70)
Channel reconfiguration	NA [‡]	No	Yes	No

*±20%

‡NA=not applicable

Default Design

The default design utilized criteria assigned by the software and included six subwatersheds. The DD for the channels within the entire boundary was within 0.32% - 18.9% the default design criteria, respectively, and the RHC distance was less than 24 m (mean = 10.1 m, range = 2.1 - 16.8 m). The main subwatershed (area = 0.98 km²) represented 70% of the area within the permit boundary. This subwatershed had the largest channel network with 13 channels, totaling 6.7 km in length. The channels were arranged in a dendritic pattern (1st-3rd order; Strahler, 1957). The 12 tributaries were classified as Aa+ channels (Rosgen, 1994) due to the steep slopes (>4%) and low sinuosity (1.13-1.16). A portion of the main channel near the watershed outlet was classified as a Rosgen type C channel, a meandering channel with reduced slopes (< 2%). The area of the remaining five subwatersheds ranged from 0.016 to 0.146 km² (4 to 36 ac) and had 1-2 channels also classified as Rosgen type Aa+ and C. The default design accounted for 58x10⁶ m³ of overburden which was balanced with the volume of cut material to create a comprehensive design. (See Sears (2012) for a description of the default design).

The design in the default form needed to be improved for erosion stability. Based on the regional RHC data (Table 5), all of the subwatersheds except for the main subwatershed would have only sheet flow due to the small watershed areas. The main subwatershed (Figure 10 a) was re-designed to consider the regional design parameters. The following sections describe the three design iterations.

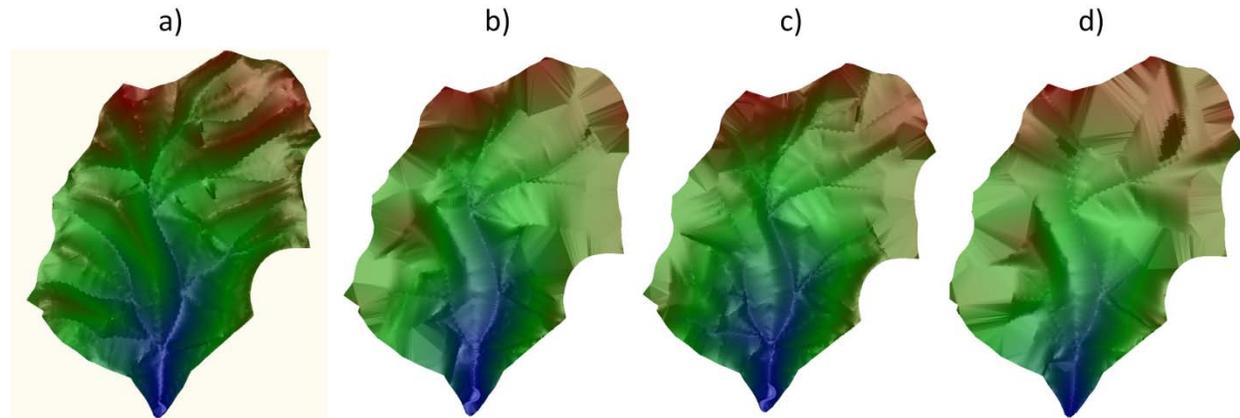


Figure 10. Comparison of four design iterations: a) default design; b) RHC 150; c) RHC 150-R; and, d) RHC 220

RHC 150

All of the channels that were in the default GLD were truncated at a distance of 150 m from the subwatershed boundary (Table 5). The channel pattern remained constant as compared to the default design; therefore, multiple channels in the default design were shortened or eliminated (Figures 10b, 12-13). The RHC 150 design had eight tributaries on the main channel, while the default design had 12. The DD exceeded suitable range for six of the eight tributaries (31.5%-81.7%) (Figure 11). This result suggests that altering the stream length alone was not sufficient to develop a design meeting regional criteria. Because the DD is less than desired in some locations and greater in others, in practice both erosion and aggradation would be expected to occur until equilibrium is reached.

RHC 150-Reconfiguration

The design criteria of the first iteration remained unchanged ($DD=5.3\pm 20\% \text{ km}^{-1}$; max RHC =150 m) for the RHC 150-Reconfiguration design (Table 5, Figure 10 c). Stream channel pattern of the RHC 150 design was altered to obtain the target drainage density. This design had 12 tributaries and a main channel, similar to the default design; however, the design met regional design criteria. The RHC distance less than 150 m (mean=85.6 m, range=40.2-130.8 m) and the DD was within the acceptable design range ($4.2\text{-}5.9 \text{ km}^{-1}$); six of the thirteen created channels were within 5% of 5.3 km^{-1} (Figure 11). The valley length was up to 45% less than in the default GLD due to the increased RCH length (Figure 12). The watershed area between the two designs varied up to 10% (Figure 13). Like the default design, the channels were primarily Rosgen type Aa+. Since the design used drainage concepts which emulated natural processes, it is expected to be in dynamic equilibrium in terms of erosion by creating the proper drainage density.

RHC 220

In the final design, the RHC was increased to 220 m, reducing the number of stream channels to seven tributaries and a main channel (Figs. 10d, 12, 13). The target drainage density remained at $5.3 \pm 20\% \text{ km}^{-1}$, but DD criteria were not achieved, even with altering the channel pattern. For all channels, DD was less than the optimal range, up to 74% for one channel, suggesting that erosion would occur until the drainage areas reached equilibrium (Fig. 11).

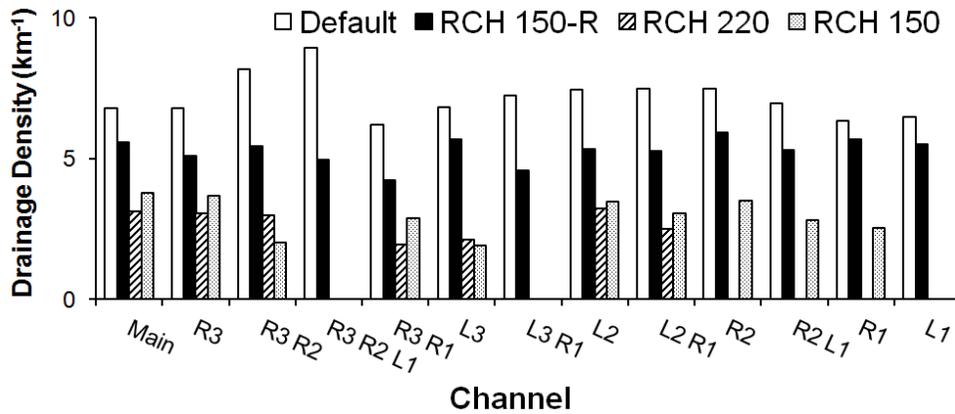


Figure 11. Drainage density for channels included in the four geomorphic landform designs; channels are named from the headwater location of the main channel moving downstream: R is right, L is left. Main considers the entire subwatershed.

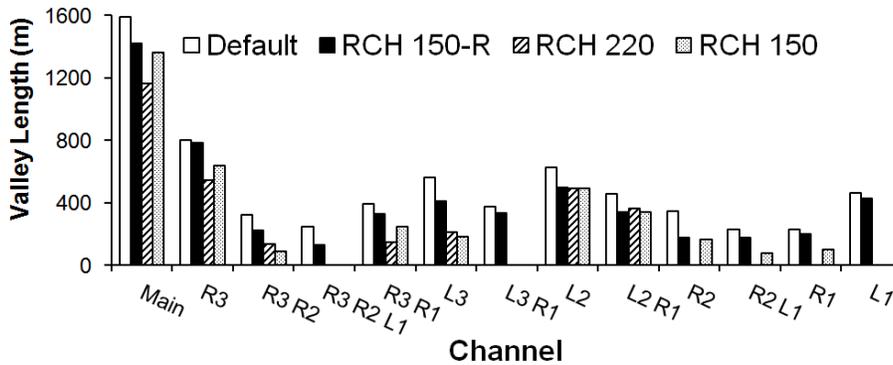


Figure 12. Valley length for channels included in the four geomorphic landform designs; channels are named from the headwater location of the main channel moving downstream: R is right, L is left. Main considers the entire subwatershed.

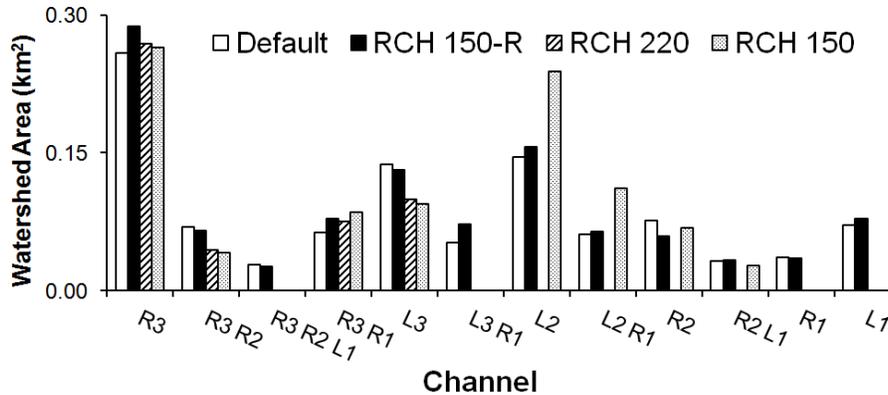


Figure 13. Watershed area for channels included in the four geomorphic landform designs; channels are named from the headwater location of the main channel moving downstream: R is right, L is left

Conclusions

These reference landform design values are critical to design a system with low erosion rates. Systems designed with a lower than optimum drainage density will likely promote sediment deposition, and systems designed with a greater than optimum drainage density will likely promote erosion, leading to instability. Difference between default and measured parameters noted in this study were somewhat expected. The default design parameters incorporated into the design software were based on semi-arid regions. The geomorphic characteristics in southern West Virginia are a result of the steep slopes, consolidated soil, vegetation, and climatic influences of the region. These characteristics need to be considered for future designs.

Because the geomorphic landform approach utilizes a reference landform design method, region specific design parameters are crucial to inform design. This research quantified the complex, steep terrain in southern West Virginia. Results from this study suggest that incorporation of GLD principles into surface mining reclamation is feasible and practical for Central Appalachia. This works illustrates the importance of field determination of the RHC input parameter. Published values previously used in design were consistently one order of magnitude less than values measured in this study, Default = 24 m versus Field = 220 m. Similarly for the DD parameter, the published range is 7.5 km^{-1} with $\pm 20\%$ error; 6.0 to 9.0 km^{-1} , respectively. The field measurements for Central Appalachia quantified the DD to range from 5.0 to 5.3 km^{-1} . The geomorphic characteristics in southern West Virginia are a result of the steep slopes, consolidated soil, vegetation, and climatic influences of the region. The practicality to Appalachian valley fill stream construction is that the stream lengths are shorter and the land slopes are steeper with straighter head water channels compared with other areas of the United States. These reference landform design values are critical to design a system with low erosion rates. Systems designed with a lower than optimum drainage density will likely promote sediment deposition, and systems designed with a greater than optimum drainage density will likely promote erosion, leading to instability.

Future work will quantify geomorphic characteristics in additional watersheds in the mining region of southern West Virginia. In addition, surveys of reclaimed sites of varying ages will also provide insight into generating successful designs. Designs will then be created using region specific design values and the differences in each design will be quantified. Ultimately, the research will provide the coal industry and regulators with data to advance watershed reclamation in Central Appalachia.

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Appendix A: Geomorphic Data

Table 6. Geomorphic data for Whetstone Branch watershed

Site	Whetstone 1	Whetstone 2	Whetstone 3	Whetstone 4	Whetstone 5	Whetstone 6	Whetstone 7	Whetstone Mouth
#	I	II	III	IV	V	VI	VII	M
Lat	37° 24' 54.9"	37° 24' 56.0"	37° 24' 59.3"	37° 25' 6.9"	37° 25' 23.5"	37° 25' 27.0"	37° 25' 21.2"	37° 25' 2.4"
Long	81° 53' 15.7"	81° 53' 21.0"	81° 53' 24.1"	81° 53' 22.8"	81° 53' 19.8"	81° 53' 9.7"	81° 53' 2.8"	81° 52' 45.1"
Slope	16%	18%	21%	27%	42%	34%	36%	8%
Channel Width	Semi-Confined (2-4 ft)	Broad (6-10 ft)	Broad (6-10 ft)	Broad (6-10 ft)	Broad (6-10 ft)	Broad (6-10 ft)	Narrow (4-6 ft)	Broad (6-10 ft)
Left Bank Slope	Very Steep (16-25%)	Steep (9-15%)	Steep (9-15%)	Hilly (4-8%)	Very Steep (16-25%)	Hilly (4-8%)	Steep (9-15%)	Extremely Steep (>25%)
Texture of Exposed Left Bank	Sand/Silt	Sand	Sand	Sand	Sand	Sand	Sand	Sand
Right Bank Slope	Very Steep (16-25%)	Steep (9-15%)	Steep (9-15%)	Hilly (4-8%)	Very Steep (16-25%)	Very Steep (16-25%)	Steep (9-15%)	Steep (9-15%)
Texture of Exposed Right Bank	Sand/Silt	Sand	Sand	Sand	Sand	Sand	Sand	Sand
Ridge-Head Dist on Map (m)	106.4	107.8	152.6	74.9	101.1	124.2	102.3	N/A
Elevation Change (m)	33.8	32.9	56.7	25.9	31.4	55.4	40.2	N/A
Adjusted Ridge-Head Distance (m)	111.6	112.7	162.8	79.3	105.9	136.0	109.9	N/A
Sinuosity (Field)	1.050	1.005	1.004	1.002	1.003	1.010	1.007	N/A
Sinuosity (GIS)	1.075	1.122	1.054	1.022	1.002	1.060	1.016	N/A
D16 (mm)	9.1	9.4	11	9.4	8.7	8.3	8.4	19
D50 (mm)	31	21	33	22	19	27	34	38
D84 (mm)	72	59	66	62	51	76	63	81

Table 7. Geomorphic data for Oldhouse Branch watershed

Site	Oldhouse 1	Oldhouse 2	Oldhouse 3	Oldhouse 4	Oldhouse 5	Oldhouse Mouth
#	I	II	III	IV	V	M
Lat	37° 25' 32.6"	37° 25' 34.0"	37° 25' 43.9"	37° 25' 28.7"	37° 25' 21.7"	37° 25' 13.3"
Long	81° 53' 00.2"	81° 52' 59.7"	81° 52' 55.6"	81° 53' 02.9"	81° 52' 55.7"	81° 52' 25.2"
Slope	35%	32%	43%	41%	39%	14%
Channel Width	Very Broad (>10 ft)	Broad (6-10 ft)	Very Broad (>10 ft)	Broad (6-10 ft)	Narrow (4-6 ft)	Broad (6-10 ft)
Left Bank Slope	Hilly (4-8%)	Steep (9-15%)	Hilly (4-8%)	Steep (9-15%)	Steep (9-15%)	Extremely Steep (>25%)
Texture of Exposed Left Bank	Sand	Sand	Sand	Sand	Sand	Sand
Right Bank Slope	Hilly (4-8%)	Steep (9-15%)	Hilly (4-8%)	Steep (9-15%)	Steep (9-15%)	Extremely Steep (>25%)
Texture of Exposed Right Bank	Sand	Sand	Sand	Sand	Sand	Sand
Ridge-Head Dist on Map (m)	96.5	155.6	204.2	199.9	161.2	N/A
Elevation Change (m)	38.4	70.7	82.6	87.8	72.4	N/A
Adjusted Ridge-Head Distance (m)	103.9	170.9	220.3	218.3	176.7	N/A
Sinuosity (Field)	1.019	1.002	1.057	1.041	1.012	N/A
Sinuosity (GIS)	1.019	1.071	1.086	1.064	1.045	N/A
D16 (mm)	9.6	9.3	8.6	6.4	7.6	11
D50 (mm)	43	30	26	18	20	45
D84 (mm)	79	61	64	54	54	120

1. Publications:

Buckley, C., L. Hopkinson, J. Quaranta, B. Mack, and P. Ziemkiewicz. 2013. Investigating design parameters in the design of West Virginia valley fills to support application of geomorphic landform design principles. In *Environmental Considerations in Energy Production*, (book chapter submitted for review 10/2012; reviews submitted 01/2012; expected publication 04/2013.)

2. Information Transfer Program:

- A text description of the project was added to the WV Water Research Institute (WVWRI) website (<http://www.wvri.org/project-listing/>).
- Preliminary results were presented at the West Virginia Water Research conference as a poster (abstract published in program).

Buckley, C., L.C. Hopkinson, B. Mack, and J.D. Quaranta. 2012. Quantifying mature landform characteristics for geomorphic design in the coal-mining region of southern West Virginia. West Virginia Water Research Conference, October 30-31. Waterfront Place Hotel: Morgantown, WV. *Poster*.

- Abstract submitted and accepted to present an oral presentation at the Environmental Considerations in Energy Production Symposium:

Buckley, C., L. Hopkinson, J. Quaranta, B. Mack, and P. Ziemkiewicz. 2013. Investigating design parameters in the design of West Virginia valley fills to support application of geomorphic landform design principles. In *Environmental Considerations in Energy Production*, April 14-18, 2013.

3. Student Support:

Category	Number of students supported with 104b base grant	\$ Value of students supported with 104b base grant	Number of students supported with matching funds	\$ Value of student support with matching funds	Total number of students supported	Total \$ value of student support
Undergraduate	1				1	
Masters	1				1	
Ph.D.						
Post-Doc						
Total	2				2	

4. Notable Achievements and Awards: Provide a brief description of any especially notable achievements and awards resulting from work supported with section 104b and required matching funds and by supplemental grants during the reporting period.

- One book chapter was submitted for review with a graduate student as the lead author. A manuscript is in preparation to submit to a refereed journal.

Development of a Drinking Water Well Sampling Protocol to Establish Baseline Data Prior to Horizontal Drilling of Gas Wells

Basic Information

Title:	Development of a Drinking Water Well Sampling Protocol to Establish Baseline Data Prior to Horizontal Drilling of Gas Wells
Project Number:	2012WV178B
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Focus Category:	Water Quality, Groundwater, Water Supply
Descriptors:	
Principal Investigators:	Jennifer Hause, Melissa J. O'Neal, Tamara Vandivort, Paul Ziemkiewicz

Publications

There are no publications.

*Development of a Drinking Water Well Sampling Protocol to Establish Baseline
Data Prior to Horizontal Drilling of Gas Wells*

Annual Status Report
March 1, 2013 – February 28, 2014

Principal Authors:
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Abstract

Increased use of horizontal drilling and hydraulic fracturing methods to produce natural gas from deep shale beds has raised environmental impact concerns from the general public. Although hydraulic fracturing is not a new technique to release deep deposits of natural gas, the rate of which it has been recently used within the Marcellus Shale Formation has greatly escalated. Of most concern to the general public are potential contamination threats to nearby private drinking water wells during shale gas development activities. In areas with a high level of shale gas drilling in the Marcellus Shale Formation, many homeowners claim their drinking water wells have been negatively impacted by the activities associated with gas well development. However, most homeowners have no baseline data to show the quality of their drinking water has changed since initiation of shale gas development near their property. State agencies provide recommendations for pre-drilling baseline water quality testing. Industry usually takes the recommendations further by testing a more comprehensive suite of parameters. However, the question remains as to whether or not these tests are monitoring the right parameters to identify if nearby drinking water wells are being intruded by drilling or hydraulic fracturing fluids from shale gas well development.

This study proposes to respond to this question by:

1. Characterizing the make-up of drilling muds and cuttings, hydraulic fracturing fluids, and flowback waters of Marcellus Shale gas wells in northern West Virginia,
2. Determining parameters of concern (health-based concerns) found in water and waste streams produced from shale gas development with the greatest potential to be found in nearby groundwater resources,
3. Sampling nearby private drinking water wells for identified parameters of concern, and
4. Finalizing a sampling protocol for private drinking water well owners to follow that provides a level of health protection in a cost-effective and efficient manner.

Table of Contents

Abstract	2
Table of Contents	3
List of Tables	3
Executive Summary	4
Introduction	5
Study Methods	5
Results and Discussion.....	6
Task 1: Characterize shale gas well water and waste streams.....	6
Task 2: Identify Parameters of Concern	7
Task 3: Sample Drinking Water Wells.....	8
Task 4: Finalize Sampling Protocol	8
Publications	8
Information Transfer Program	8
Student Support	8
Notable Achievements and Awards	9

List of Tables

Table 1: Horizontal gas well water and waste stream analytical results (ranges presented)	7
Table 2: Drinking water well sampling parameters.....	7

Executive Summary

As pressure for fossil fuel production grows, exploration and extraction operations tapping the gas reserves of the Devonian-aged Marcellus Shale Formation are moving closer to residential increasing the concern for human exposure to potential hazards and pollution. The general public is specifically concerned with potential contamination threats to nearby private drinking water wells during shale gas development activities. Horizontal wells in the Marcellus differ from vertical wells due to the large amount of water used and thus wastewater produced; therefore, these shale gas extraction activities pose an increased potential to impact nearby water resources. In areas of active shale gas drilling, many homeowners claim their drinking water wells have been negatively impacted by the activities associated with developing a well site. However, most homeowners have no baseline data to show the quality or quantity of their drinking water has changed since nearby shale gas development started.

Many homeowners living in rural areas depend upon individual (private) groundwater wells as their source of drinking water. When drinking water wells are drilled, flow rates are measured to determine adequate yield and water sampling is conducted to determine if treatment prior to use is necessary. In most cases, homeowners may never have their well water tested again unless they notice a change in color, smell, taste, or if industrial development begins to sprout up around them. State agencies provide recommendations for pre-drilling baseline water quality testing. Natural gas companies usually take those recommendations further by testing a more comprehensive suite of parameters. However, the question remains as to whether or not these tests are monitoring the right parameters to identify if nearby drinking water wells are being intruded by drilling or hydraulic fracturing fluids from gas well development.

This study proposes to respond to this question by characterizing drilling muds and cuttings, hydraulic fracturing and flowback waters of Marcellus Shale gas wells and determining those parameters with the greatest potential to be found in groundwater sources and thus nearby drinking water wells. The need exists to narrow the list of contaminants to potential indicator parameters that are characteristic of water and waste streams associated with horizontal gas well development activities and serve as the basis to develop a sampling protocol for private drinking water wells that is:

- Valid, reliable, and affordable to the homeowner offering a level of protection in the event their water well becomes compromised,
- Identifies adequate baseline water quality,
- Provides a monitoring mechanism to identify upsets in water quality potentially caused by nearby gas well development by monitoring the correct water quality parameters and therefore shortens mitigation response time, and
- Develops a mechanism for the general public, industry, and regulatory agencies to work together.

Introduction

Development of the extensive natural gas reserves contained in the Marcellus Shale Formation promises to be an important opportunity for the United States. Extraction from shale gas reservoirs like the Marcellus Shale Formation requires either vertical or horizontal drilling coupled with hydraulic fracturing to access and release the gas. Rapid application of these technological advancements has increased concern about potential environmental impacts from the general public. Drilling fluids and muds may consist of water, mineral oil or synthetic-based oil compound, weighing agents such as barite or bentonite clay, biocides, lubricants and corrosion inhibitors. The drilling process, through the use of the drilling fluids and cuttings created, increases the threat to groundwater contamination because they also have the potential to include radioactive materials. Flowback and produced water contains salts, metals and organic compounds along with the compounds introduced into the fracturing supply water such as friction reducers, surfactants, gelling agents, scale inhibitors, acids, corrosion inhibitors, antibacterial agents and clay stabilizers.

Efficient management of water streams associated with the development of a shale gas well requires knowing the characteristics of those waters. This study has focused on sampling and analyzing drilling fluids, muds and cuttings along with hydraulic fracturing and flowback waters of Marcellus Shale gas wells in northern West Virginia and determining which of these compounds if they were to reach groundwater resources are of concern for potential contamination that may affect human health. A draft sampling protocol for monitoring nearby individual drinking water wells has been developed taking into account other sampling protocols in existence from various sources such as state agencies, private analytical service providers, and industry (energy companies). The draft sampling protocol has been compared to research studies that have sampled and monitored drinking water wells located in close proximity to planned and active Marcellus Shale gas wells. The next step is to “field-test” the sampling protocol to determine if the sampling protocol will provide a cost-effective and efficient tool for homeowners to monitor water quality of their drinking water wells and detect contaminant intrusion.

Study Methods

This study proposes to begin to address public concern of private drinking water well contamination by nearby shale gas well development activities. Tasks 1 and 2 have been completed and efforts are underway to complete Tasks 3 and 4 - identify a study area to test and finalize the sampling protocol over the next year.

1. Characterizing the make-up of drilling muds and cuttings, hydraulic fracturing fluids, and flowback waters of Marcellus Shale gas wells in northern West Virginia,
2. Determining parameters of concern (health-based concerns) found in water and waste streams produced from shale gas development with the greatest potential to be found in nearby groundwater resources,
3. Sampling nearby private drinking water wells for identified parameters of concern, and

- Finalizing a sampling protocol for private drinking water well owners to follow that provides a level of health protection in a cost-effective and efficient manner.

Results and Discussion

Task 1: Characterize shale gas well water and waste streams

Marcellus Shale gas wells located in northern West Virginia were identified and samples were collected of water and waste streams. WVVRI developed an initial list of analytes for sampling and characterizing water and waste streams associated with the various stages of horizontal gas well development. The list was based on the literature review efforts to identify commonalities among the parameters measured and previous monitoring studies conducted by WVVRI of Marcellus Shale gas wells in West Virginia and Ohio. **Table 1** details the parameter list and analytical results.

Parameter	Units	Freshwater Impoundment	HF Fluids	Drilling Muds	Drill Cuttings	Flowback	Waste Storage
Aluminum	mg/l	ND – 0.0236	ND – 0.335	0.969 – 4550	4740 – 12100	ND – 13.3	ND – 2.78
Arsenic	mg/l	ND	ND	ND – 30.6	2.35 – 19.2	ND	ND
Barium	mg/l	0.032 – 0.0565	0.61 – 12.4	2.13 – 4910	23.9 – 5920	23.1 – 2580	10.2 – 572
Bromide	mg/l	ND – 0.11	2.3 – 126	8.4 – 37.5	ND – 10.8	370 – 970	52.5 – 675
Calcium	mg/l	20.8 – 44.4	49 – 1260	1090 – 47900	781 – 152000	2310 – 19900	1010 – 8670
Chloride	mg/l	12.8- 26.5	219 – 9500	1180 – 131000	876 – 20000	27500 – 79000	4700 – 56000
Chromium	mg/l	ND	ND	0.268 – 16.2	6.367 – 32.8	ND – 0.068	ND – 0.144
Iron	mg/l	ND – 0.0244	0.174 – 30.9	1.09 – 13600	6670 – 30400	14.7 – 149	19.3 – 57
Lead	mg/l	ND	ND	ND – 84.9	3.5 – 31.5	ND – 0.102	ND
Magnesium	mg/l	4.04 – 8.24	6.85 – 171	2.84 – 2410	1920 – 7090	436 – 2260	107 – 944
Manganese	mg/l	0.0025 – 0.022	0.147 – 1.76	0.064 – 435	91.9 – 714	1.74 – 10.2	1.38 – 7.56
Mercury	mg/l	ND	ND	ND – 0.196	ND – 0.173	ND	ND
Nickel	mg/l	ND	ND	ND – 37.7	10.3 – 41.4	ND	ND
Phosphorus	mg/l	ND – 0.04	0.09 – 11.2	0.6 – 235	100 – 349	ND – 2.36	0.75 – 90
Potassium	mg/l	1.61 – 2.92	2.32 – 63.6	465 – 24900	1930 – 12000	211 – 488	44.2 – 315
Selenium	mg/l	ND	ND	ND – 3.34	ND – 3.14	ND – 0.335	ND
Silver	mg/l	ND	ND	ND – 0.509	ND – 0.397	ND	ND
Sodium	mg/l	8.46 – 27.1	110 – 3990	364 – 44900	543 – 12400	15900 – 119000	2440 – 20800
Strontium	mg/l	0.122 – 0.239	3.92 – 136	10.6 – 839	4.22 – 508	657 – 4660	117 – 1460
Sulfides	mg/l	4.19 – 30.3	4.47 – 33	638 – 9450	1410 – 12800	ND – 303	ND – 38.7
Zinc	mg/l	ND – 0.0075	ND – 1.74	ND – 94.8	2.22 – 89.7	ND – 0.288	0.06 – 0.352
Conductivity	µmhos/cm	315 – 483	1030 – 33100	13200 – 222000	1150 – 77000	74900 – 225000	16800 – 132000
pH		8.09 – 8.75	6.63 – 7.96	7.35 – 12.71	NM	6.49 – 7.07	6.16 – 7.82
Hardness (total)	mg/l	68.4 – 142	150 – 3840	2740 – 6550	NM	196 – 59000	2950 – 25500
Alkalinity (total)	mg/l	48.2 – 188	49.3 – 188	220 – 11100	209 – 54700	139 – 255	118 – 234
TDS	mg/l	170 – 277	568 – 20400	6600 – 119000	NM	45400 – 154000	8840 – 93700
TSS	mg/l	ND – 6	14 – 260	18300 – 162000	NM	ND – 348	143 – 420
Methane	µg/l	ND	ND – 265	ND	NM	1.81 – 8310	187 – 10500
Ethane	µg/l	ND	ND	ND	NM	ND – 2730	ND – 1760
Propane	µg/l	ND	ND	ND	ND	ND – 1130	ND
TOC	mg/l	0.72 – 5.4	4.55 – 217	1050 – 60000	26700 – 82100	3.36 – 588	25.8 – 309
COD	mg/l	12 – 19	31 – 1110	3290 – 11200	526 – 5290	743 – 2660	568 – 2280
Oil & Grease	mg/l	ND	ND – 20.4	ND – 196	ND – 5.13	ND – 39.1	4.6 – 594
Benzene	µg/l	ND	ND – 29.4	ND – 300	ND – 294	ND – 716	ND – 372
Toluene	µg/l	ND	ND – 76.9	ND – 2160	ND – 1640	ND – 2470	ND – 2070
Ethylbenzene	µg/l	ND	ND – 8.7	ND – 513	ND – 404	ND – 220	ND – 235
Xylene (o,m,p)	µg/l	ND	ND – 165.5	ND – 5610	ND – 3164	ND – 4053	ND – 3097

Styrene	µg/l	ND	ND	ND – 9.5	ND	ND	ND – 141
Tetrachloroethylene	µg/l	ND	ND	ND	ND – 63.3	ND	ND
MBAS	mg/l	ND – 0.177	ND	ND – 262	NM	ND – 0.605	ND – 0.473
TPH (diesel)	mg/l	ND	ND – 119	23.1 - 237000	115 - 55900	0.57 – 114	1.9 – 285
Gross Alpha	pCi/l	NM	1.2 – 9.43	3.78 – 173	8.93 – 28.3	18.9 – 20920	8.69 – 5304
Gross Beta	pCi/l	1.48 – 2.25	9.89 – 83	14.9 – 23770	17.3 – 30.1	168 – 4664	34 – 1349
Radium-226	pCi/l	0 - .725	NM	6.45	0.95 – 3.114	178 – 685	15.4 – 1194
Radium-228	pCi/l	0.189 – 0.354	NM	4.95	0.715 – 1.929	49.1 – 85.5	53.5 - 216

ND = not detected NM = not measured

Table 1: Horizontal gas well water and waste stream analytical results (ranges presented)

Task 2: Identify Parameters of Concern

A review of drinking water supply studies and various state guidelines for water well testing yielded a fairly comprehensive water quality list of inorganic, organic, and radioactive parameters. Water and waste stream characterization results allowed WVVRI to eliminate parameters that were not detected and thus would not appear in drinking water well sampling results. WVVRI staff enlisted public health professionals to evaluate the shale gas water and waste stream characterization sampling results and identify potential pollutant markers. This exercise led to the development of list of parameters for analysis when sampling drinking water wells located near shale gas development activities, see **Table 2**.

Parameter				
Inorganics	Alkalinity	Specific Conductance	Total Dissolved Solids	Total Suspended Solids
	pH	Aluminum	Barium	Beryllium
	Bromide	Calcium	Chloride	Iron
	Lithium	Magnesium	Manganese	Potassium
	Sulfates	Strontium		
Organics	Benzene	Toluene	Ethylbenzene	Xylene
	MBAS*			
Radionuclides	Gross alpha	Gross beta	Radium-226	Radium-228

*MBAS = methylene-blue active substances

Table 2: Drinking water well sampling parameters

Task 3: Sample Drinking Water Wells

With the assistance of public health professionals at the WVU School of Public Health, WVVRI has obtained information on nearly 40 individual private drinking water wells located various distances from active shale gas well development in northern West Virginia. WVVRI will be meeting with county health officials and members of the general public to discuss project objectives, obtain additional information on current drinking water wells identified, and identify drinking water well owners living in areas of no active gas well development interested in having their wells monitored. These additional wells will allow WVVRI researchers to compare wells in active and non-active shale gas development areas.

Task 4: Finalize Sampling Protocol

WVVRI will continue to work with public health officials to refine the monitoring recommendations including sampling procedures and water quality parameters. The results of the collaboration with public health officials, regulatory official, and industry representatives will yield a concise list of parameters with the greatest potential to be found in nearby groundwater resources and potential health-related concerns associated with each of the parameters

Publications

No articles have been submitted for publication consideration to date.

Information Transfer Program

Work is ongoing. Once the drinking water well sampling and monitoring protocol has been finalized, WVVRI will submit abstracts and/or papers to relevant publications and conferences for consideration.

WVVRI will explore options available to include the sampling results of drinking water wells as an additional layer to the 3 Rivers QUEST (originally MonRiver Quest) GIS platform. 3 Rivers QUEST is a water quality monitoring and reporting project for the Monongahela, Allegheny, and Upper Ohio River Basins. It provides the public, researchers, federal and state agencies, and industry with timely and accurate information as it pertains to the overall health of our local rivers and streams. WVVRI anticipates the drinking water well monitoring protocol exercise will begin to build the 3 Rivers Quest platform to eventually include groundwater data of the three river basins.

Student Support

Two graduate students have assisted with project activities on a part-time basis. Currently, one graduate student is obtaining background information on private drinking water well owners who will be participating in the “field-testing” of the draft monitoring protocol. Two graduate students will assist the WVVRI field technician with collection of samples and data analysis. Based on the

results, the protocol will be adjusted to provide a plan for private drinking water well owners to follow that offers health protection in a cost-efficient and effective manner.

Notable Achievements and Awards

No awards to report at this time.

Stable isotope fingerprinting of waters in area of accelerating Marcellus shale gas development

Basic Information

Title:	Stable isotope fingerprinting of waters in area of accelerating Marcellus shale gas development
Project Number:	2012WV197B
Start Date:	3/1/2012
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Groundwater, Surface Water, Water Quality
Descriptors:	
Principal Investigators:	Shikha Sharma, Shikha Sharma

Publications

1. Sharma, S., M. Mulder, A. Sack, K. Schroeder, R. Hammack. 2013. Isotope approach to assess hydrologic connections during Marcellus Shale drilling. Groundwater. (Under review.)
2. Pelak, A. and S. Sharma. Stable isotopic and geochemical analysis of surface waters in an area of Marcellus Shale development in north-central West Virginia. Hydrologic Processes. Hydrologic Sciences. (In preparation.)

Project Report title: Stable isotope fingerprinting of waters in an area of accelerating Marcellus shale gas development

Type of report: Final

Reporting period: February 2012-March 2013

Summary

The main concern associated with Marcellus shale gas development is that water quality of surface waters and fresh water aquifers can be compromised during gas well drilling, stimulation, and improper disposal practices. Under natural conditions the highly saline groundwater occurring within Marcellus shale and other deep formations does not mix with shallow fresh water aquifers due to the barrier provided by several thousand feet of impermeable rocks present between the two end-members. However, during well drilling casing or grouting failures, existing subsurface fractures, and fractures created during hydraulic fracking can generate or augment hydraulic pathways between previously isolated formations. These pathways can allow frack water, deep saline water or methane to contaminate shallow fresh water sources. In addition, improper management and disposal of frack flowback water can deteriorate the water quality of surface water bodies and shallow groundwater aquifers in the area. In order to effectively assess the effect of Marcellus shale development on water quality there is a need to establish the background or ambient geochemical signatures of different water sources. In addition, there is need to develop a suite of natural geochemical tracers that can track the flowback waters and dissolved methane in the groundwaters or surface waters of the area.

The aim of this project is to test the applicability of isotopic composition of water ($\delta^{18}\text{O}_{\text{H}_2\text{O}}$, $\delta\text{D}_{\text{H}_2\text{O}}$) dissolved inorganic carbon ($\delta^{13}\text{C}_{\text{DIC}}$), and dissolved sulfate ($\delta^{34}\text{S}_{\text{SO}_4}$, $\delta^{18}\text{O}_{\text{SO}_4}$) as natural tracers to identify any potential water quality deterioration associated with Marcellus Shale drilling in North Central West Virginia. The main tasks undertaken in collaboration with WV Water Science Center during this year of this grant were:

- 1) Characterization of O,H,C, and S isotope composition as well as major, minor, and trace metal geochemistry of surface waters (sampled by 50 streams) overlying the Marcellus shale in north central West Virginia
- 2) Evaluation and comparison of 5 categories of Marcellus Shale production of surface water samples.

Preliminary data indicates that O,H and C stable isotope compositions of produced/flowback water from wells drilled in Upper Devonian sands and Marcellus Shale can be used to distinguish different water sources indicating the promise of this approach to identify potential contamination ensuing from shale gas drilling activities in future. The preliminary paper summarizing this approach has been accepted with minor revisions.

Experimental Methods

Water samples were collected from 50 streams in the Monongahela River basin of north-central West Virginia. Sample locations were chosen by analyzing all of the HUC-12 watersheds that comprise the Monongahela River basin and determining the extent of Marcellus Shale production that has occurred to date. 5 categories were created to represent the differing amounts of production present in the basin. The number of samples for each category was chosen by analyzing the production status for all HUC-12's in the basin, and then determining a representative number of samples for each category out of a total of 50 samples. Table 1 shows the ideal number of sites, available number of sites, and the actual number of sites chosen for the study. Figure 1 shows the study area and sample locations.

	Ideal # of Sites	# of Sites Available	Number of sites chosen
High Prod.	9	18	12
Low Prod.	7	7	5
No Production	15	13	9
Near HP	7	9	12
Near LP	12	12	12

Table 1: Ideal numbers of sites, available sites, and actual number of sites chosen

The production categories are defined as follows:

- **High production** -> HUC-12 that contains Marcellus shale development that produces greater than 1,000 MCF/mi²/year
- **Low production**, ->HUC-12 that contains Marcellus shale development that produces less than 1,000 MCF/mi²/year
- **Near high production** -> adjacent to high production HUC-12
- **Near low production**, -> adjacent to low production HUC-12
- **No Production** -> Underlain by Marcellus shale greater than 50 feet thick, no Marcellus Shale production in or adjacent to HUC-12.

Water samples were collected from 50 surface water samples sites in the Monongahela River basin of north-central West Virginia. All samples were collected when streams were at base flow to ensure that all streamflow contributions were from groundwater discharge. The width and depth of each stream

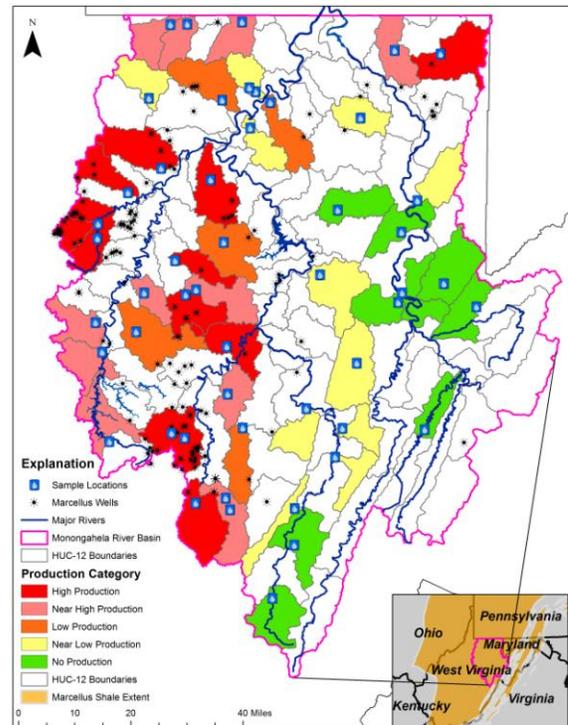


Figure 1 – Study area and sample locations

sample site was first measured, and then a width integrated sample was collected in an open mouth hand-held bottle and placed in a churn carrier. The churn carrier was filled with approximately 8 liters of water from the sample location so that all of the water in the churn was representative of all of the water in the stream. Width integrated collection of field parameters (pH, specific conductance, Eh, temperature, total dissolved solids, dissolved oxygen, and turbidity) were collected with an YSI 6820 V2 Sonde at each stream. Average field conditions of each stream were calculated using the width collected field parameters. Field alkalinity was calculated at each sample site using a standard titration with nitric acid. All geochemical and isotope samples were pulled from the width integrated sample in the churn carrier. One isotope sample was collected for $\delta^2\text{H}$ and $\delta^{18}\text{O}$ of water, one sample for $\delta^{13}\text{C}_{\text{DIC}}$ of dissolved inorganic carbon, and one sample for $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$ of dissolved sulfate. All isotope samples were refrigerated until analysis was performed.

Samples for $\delta^2\text{H}_{\text{H}_2\text{O}}$ and $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ were pulled from the width integrated sample in the churn carrier and placed in an 8 mL pre-rinsed glass threaded vial with no headspace. Random duplicate samples were taken for quality control purposes. Vials were wrapped with parafilm to ensure no leakage took place. Samples for $\delta^{13}\text{C}_{\text{DIC}}$ were pulled from the width integrated sample in the churn carrier and collected in a triple pre-rinsed 60 mL syringe. Samples were then filtered through Cameo 0.45 μm nylon pre-filter into a 10 mL Wheaton serum vial with no headspace. 1-2 drops of benzalkonium chloride (17% w/w) were then added to the 10mL vial before the filtered water was added to halt any metabolic activity. $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$ samples for dissolved sulfate were collected in a 1L pre-rinsed high density polyethylene bottle. Water samples were then filtered using a vacuum pump through a 45mm 0.4 μm PCM filter and placed back in the original bottle. During filtration a glass petri dish was placed over the water to prevent oxidation of sulfide to sulfate. Prior to placing water back in to the original bottle, the bottle was triple rinsed with DI. Filtered water samples were then shipped to IsoTech Laboratories where further sample prep will be done, which includes precipitation of BaSO_4 powder for isotopic analysis.

The O,H and C isotopic composition were analyzed at the Stable Isotope Laboratory at WVU (WVSIL) using a Finnigan Delta Advantage continuous flow isotope ratio mass spectrometer (IRMS) with the ThermoQuest Finnigan GasBench II device. Each sample is flushed using the PAL autosampler system, equilibrated for 24 hours, and then sampled with PAL system. The headspace is analyzed using a double-needle; while the carrier gas is being injected continuously into the sample vial through one slit, the other removes headspace evacuated by the gas. Duplicate samples of 10.0 μL are taken over the course of 60 seconds with a total 10 replications for each sample. From there, the head space sample is carried through the components of the IRMS via the carrier gas through the GasBench. Internal lab standards are incorporated in triplicates in the beginning, middle (if a high number of samples), and end of each run sequence for QA/QC checks. These internal standards are calibrated against the respective IAEA international standard. Samples for C and H isotope of methane and S isotope of sulfate were shipped to IsoTech Laboratories for analysis.

Samples for analysis of major ions, and trace elements were shipped to the National Water Quality Laboratory. Sodium, calcium, magnesium, strontium, potassium, iron, manganese, boron, and silica are analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-EAS). Sulfate, chloride, and bromide are analyzed by ion chromatography (IC). Fluoride is analyzed by inhibited spontaneous emission (ISE) and TDS by residue on evaporation (ROE). Trace elements of aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, lead, molybdenum, nickel, selenium, silver, uranium, and zinc are analyzed by inductively coupled plasma mass spectroscopy (ICP-MS) or cICP-MS. Samples for radiochemistry were shipped to Eberline Services.

Results and Discussion

Water geochemistry and isotopic composition

Results from major ion hydrochemistry show wide variations in the surface water samples. Analyses were grouped by production category to determine if there were any significant differences between the categories. There were no clear differences between the categories, while there were 4 distinct water facies present. The water facies were Ca-SO₄, Ca-HCO₃, Na-HCO₃, & Na-SO₄. The main processes affecting the hydrochemistry of the samples are hypothesized to be carbonate dissolution, silicate weather, and pyrite oxidation.

Oxygen and hydrogen isotopes in the samples fall along the LWML. The higher *d*-excess values in the surface waters are interpreted to be a result of dominant recharge being sourced by recycled moisture in air masses originating above the Great Lakes area. The original air masses are subjected to high rates of evaporation over the water bodies, of which the evaporative vapor is mixed with atmospheric. In conjunction with local processes such as altitude and latitude, the isotopic signatures of $\delta^2\text{H}_{\text{H}_2\text{O}}$ and $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ plot above the GMWL in the area of an arid vapor mass.

Carbon isotopes of DIC show deviation from the range of natural waters. Enriched values of $\delta^{13}\text{C}_{\text{DIC}}$ are predominantly the result of carbonate and carbonaceous shale weathering, evident through hydrochemical relationships. Sulfur isotope compositions in dissolved sulfate can indicate the source of sulfur, shown to be ranging from coals, shales, and pyrite. The depleted carbon signatures may be indicative of sulfate reduction, but was not confirmed through the isotopic analysis of $\delta^{34}\text{S}_{\text{SO}_4}$ with $\delta^{18}\text{O}_{\text{SO}_4}$ or $\delta^{13}\text{C}_{\text{DIC}}$ due to the origin of the oxygen atom and variations in carbon input in DIC. The depletion seen in $\delta^{34}\text{S}_{\text{SO}_4}$ is a preliminary indication of sulfide oxidation. Overall variation, both in hydrochemistry and isotopic signatures, differed widely between and within each production category. Seasonal sampling should be done in order to understand the variations that are naturally present in surface waters.

The hydrochemical and isotopic variations in the area surface waters in this study in addition to a previous study of groundwater done last year provide the basis for prospective studies regarding the water quality of north-central West Virginia as shale gas exploration is expanding. If surface waters are exposed to significant contributions of flowback/produced water from natural gas drilling, the established baseline isotopic signatures will dramatically change. This occurrence will distinctly shift the ambient signatures and hence serve as a

natural fingerprint to determine if aquifers are receiving significant contribution from flowback waters. Accordingly, this study provides the foundation for geochemical assessment of water quality issues related to Marcellus Formation gas development in the study area.

Conclusions

The O, H, and C isotope composition of waters collected from streams during base-flow conditions in areas of different stages of Marcellus Shale production show no prominent differences. The hydrochemical analyses also indicates no significant contribution from flowback waters associated with Marcellus Shale operations in the area. This indicates that these surface waters are not receiving any significant input from produced waters associated with Marcellus Shale drilling or the contribution is so small that it cannot be detected using this isotopic approach.

Publications, Posters, and Talks

1. Sharma S., Mulder M., Sack A., Schroeder K., Hammack R. 2013. Isotope approach to assess hydrologic connections during Marcellus Shale drilling. Groundwater (acceptance stage)
2. Pelak A. and Sharma S. Stable isotopic and geochemical analysis of surface waters in an area of Marcellus Shale development in north-central West Virginia. Hydrologic Processes. Hydrologic Sciences (in prep)
3. Sharma S., 2012. Use of stable isotopes in shale gas research: examples from the Appalachian Region of eastern USA. International Workshop on Exploration and Exploitation of Shale Gas, National Geophysical Research Institute, Hyderabad, 19-20 December, Hyderabad, India.
4. Sharma S., Mulder M.L. Sack A., Carr T., Schroeder K., Hammack, R., White, J., Chambers D., 2012. Isotopic fingerprinting of stray gas in area of accelerating shale gas development in the Appalachians. WV Water Conference, 30-31 October , Morgantown, WV.
5. Sharma S., Mulder M.L. Sack A. , Bowman, L. , Carr T., Schroeder K., Hammack, R., White, J., Chambers D. 2012. Understanding natural variations of dissolved methane in areas of accelerating Marcellus Shale gas development. GSA National Annual Meeting 4-7 November, Charlotte, NC.
6. Pelak A., Sharma S., Chambers D., White J., 2012. Spatial analysis of stable isotopic variations in surface waters of an area of accelerating Marcellus shale development in north-central West Virginia. GSA National Annual Meeting 4-7 November, 2012 Charlotte, NC.
7. Pelak, A., and Sharma S., 2012. Comparison of stable isotopic variations in surface waters in five stages of Marcellus shale development in the Monongahela River basin of north-central West Virginia. WV Water Research Conference, October, 30, 2012. Morgantown, WV.

Student Support

1 MS student Michon Mulder graduated in May 2012

MS thesis: “ *Ambient Geochemical and Isotopic Variations in Groundwaters Across an Area of Accelerating Shale Gas Development*”

1 MS student: Adam Pelak - graduating Summer 2013

MS thesis : “*Stable isotopic and geochemical analysis of surface waters in an area of Marcellus Shale development in north-central West Virginia*”

Notable Achievements and Awards

- 2 MS Thesis supported by 2 year funding (1 student graduated and other to graduate this summer)
- 1 research paper in final acceptance stage in journal Groundwater and one paper in preparation
- Results presented in several regional/national/international conferences
- Research highlighted in several university and regional magazines and articles

Modeling the hydrologic response in surface mining watersheds with redesigned reclamation practices

Basic Information

Title:	Modeling the hydrologic response in surface mining watersheds with redesigned reclamation practices
Project Number:	2012WV200G
Start Date:	9/1/2012
End Date:	8/31/2015
Funding Source:	104G
Congressional District:	First
Research Category:	Engineering
Focus Category:	Hydrology, Models, Management and Planning
Descriptors:	None
Principal Investigators:	Leslie Hopkinson, Ben Mack, John D. Quaranta

Publication

1. Snyder, M.W. 2013. Hydrologic response of alternative valley fill reclamation design. MS Thesis. Civil and Environmental Engineering Department, West Virginia University.

Annual Report

Title: Modeling the hydrologic response in surface mining watersheds with redesigned reclamation practices

Reporting Period Start Date: 03/01/2013

Reporting Period End Date: 02/28/2014

Principal Authors: L. Hopkinson, J. Quaranta, B. Mack

Date Report Issued: May 2014

USGS Award Number: G12AP20156

Table of Contents

List of Figures	2
List of Tables.....	3
1. Research.....	4
Obj. 1. Generate geomorphic valley fill designs	4
Bench pond design	4
Retrofit design.....	4
Obj. 2. Determine the hydrologic function of a redesigned valley fill site in southern WV.....	5
Runoff	5
Erosion.....	11
Obj. 3: Predict differences in floodplain mapping downstream of redesigned reclamation, resulting from extreme meteorological events.....	15
Preliminary Methods	15
Preliminary Results.....	17
Obj. 4: Predict the hydrologic response of watersheds with redesigned reclamation at the landscape scale.....	21
2. Publications.....	22
3. Information Transfer Program.....	22
4. Student Support	22
5. Student Internship Program	23
6. Notable Achievements and Awards.....	23

List of Figures

Figure 1. Created bench pond design.....5
Figure 2. Retrofit design of permitted valley fill in (a) 2D and (b) 3D.5
Figure 3. Landforms for hydrologic response comparison: a) undisturbed topography, b) conventional valley fill, c) geomorphic landform design, d) pond design, and e) retrofit design...6
Figure 4. Undisturbed topography: 1. Transect 1, 2. Transect 2, 3. Transect 3..... 12
Figure 5. Transect 1 hillslope profile of undisturbed topography 12
Figure 6. Transect 2 hillslope profile of undisturbed topography 12
Figure 7. Transect 3 hillslope profile of undisturbed topography 13
Figure 8. GLD Design; 1. Transect 1, 2. Transect 2, 3. Transect 3 13
Figure 9. Transect 1 hillslope profile of GLD design 13
Figure 10. Transect 2 hillslope profile of GLD design 14
Figure 11. Transect 3 hillslope profile of GLD design 14
Figure 12. Study Site Map 16
Figure 13. Estimated stream centerline and bank locations 16
Figure 14. Cut lines for extracted cross sections 17
Figure 15: Depth (m) legend for flood maps 18
Figure 16: Pre-Mining 2-year flood extents and depth 18
Figure 17: Pre-Mining 100-year 18
Figure 18: Pre-Mining 500-year flood extents and depth 19
Figure 19: Conventional 2-year flood extents and depth 19
Figure 20: Conventional 100-year flood extents and depth 19
Figure 21: Conventional 500-year flood extents and depth 19
Figure 22: GLD (During Mining) 2-year flood extents and depth 19
Figure 23: GLD (During Mining) 100-year flood extents and depth 20
Figure 24: GLD (During Mining) 500-year flood extents and depth 20
Figure 25: GLD (Post Mining) 2-year flood extents and depth..... 20
Figure 26: GLD (Post Mining) 100-year flood extents and depth..... 20
Figure 27: GLD (Post Mining) 500-year flood extents and depth..... 20

List of Tables

Table 1. Comparison between the hydrologic response of the GLD watershed and the original topography for during mining conditions6

Table 2: Comparison between the hydrologic response of the GLD watershed and the original topography for post-mining conditions7

Table 3. Comparison between the hydrologic response of the designed watershed and original topography for during mining conditions7

Table 4: Comparison between the hydrologic response of the designed watershed and original topography for short-term, post-mining conditions.....8

Table 5: Comparison between the hydrologic response of the designed watershed and original topography for long-term, post-mining conditions8

Table 6. Comparison between the hydrologic response of 2B of the retrofit watershed and original topography for during mining conditions9

Table 7. Comparison between the hydrologic response of 2B of the retrofit watershed and original topography for post-mining, short-term conditions9

Table 8. Comparison between the hydrologic response of 2B of the retrofit watershed and original topography for post-mining, long-term conditions 10

Table 9. Average percent difference between original topography at CN=66 and various reclamation designs for peak discharge, time of peak, and total runoff averaged over all rainfall return periods..... 10

Table 10. Percent difference of peak discharge in comparison with the conventional reclamation 11

Table 11. Undisturbed topography results 15

Table 12. GLD results utilizing the same C-factor and K-factor as the undisturbed topography 15

Table 13. GLD results utilizing the same C-factor as the undisturbed topography while altering the K-factor 15

Table 14. Peak Discharges (obtained from Snyder, 2013) 17

Table 15. Flood extents and maximum depth of study reach for steady analysis 18

1. Research

The goal of this research is to evaluate the potential application of geomorphic design in surface mining reclamation, focusing on the water supply in Central Appalachia. Specific objectives include the following:

- Obj. 1: Generate geomorphic valley fill designs.
- Obj. 2: Determine the hydrologic function of a redesigned valley fill site in southern West Virginia.
- Obj. 3: Predict differences in floodplain mapping downstream of redesigned reclamation, resulting from extreme meteorological events.
- Obj. 4: Predict the hydrologic response of watersheds with redesigned reclamation at the landscape scale.

In this reporting period, there was technical progress for objectives 1, 2, 3 and 4. Tasks related to objectives 3 and 4 were initiated within this reporting period. Specific technical progress is outlined in the following sections.

Obj. 1. Generate geomorphic valley fill designs

Two additional geomorphic valley fill designs for a permitted valley fill were created during the reporting period. One design included bench ponds as created wetlands with the intention to improve wildlife and vegetation habitat. The second design is termed a retrofit design. Geomorphic landform principles were applied to the crown of the traditional valley fill. Results from this work were presented at the 2013 American Geophysical Union Fall Meeting.

Bench pond design

The bench ponds were created on the geomorphic landform designed valley fill and were designed by creating a top of dam of a specified width, and then projecting inward to model the pond, and outward to model the slopes to match to the target surface. The bench pond structures mimic wetlands and are located beside stream channels that were created on the valley fill site. Three bench ponds were spaced over the 241 acre area (1.4 km²) (Figure 1).

Retrofit design

The valley fill surface design was complete using geomorphic landform principles (Figure 2). The original surface of the valley fill was level at an elevation of 1693 ft (516 m) and the land-use was specified as pastureland. The GLD surface of the valley fill includes stream channels, ridges, and valleys. The GLD corresponds with government regulations including no flow over the valley-fill face. Features of the GLD included complex slope profiles and a dendritic drainage pattern potentially resulting in improved surface water control and topography creating a natural appearance. The design resulted in 6.7 x 10⁷ m³ of cut volume and 5.7 x 10⁷ m³ of fill volume and approximately 8.4 km of stream length.

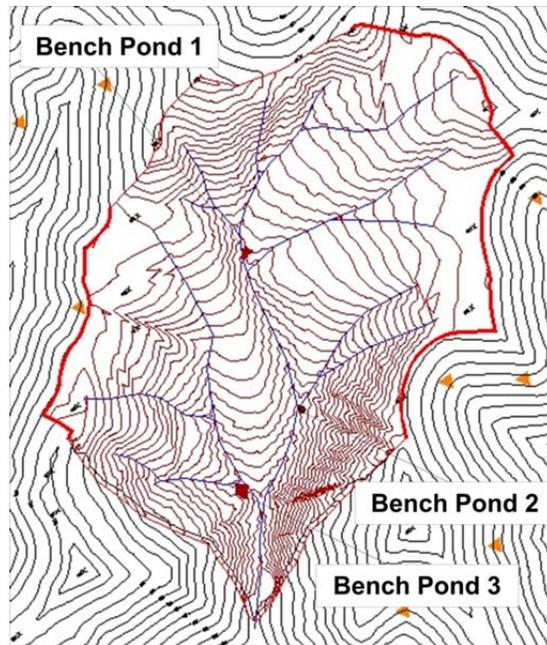


Figure 1. Created bench pond design

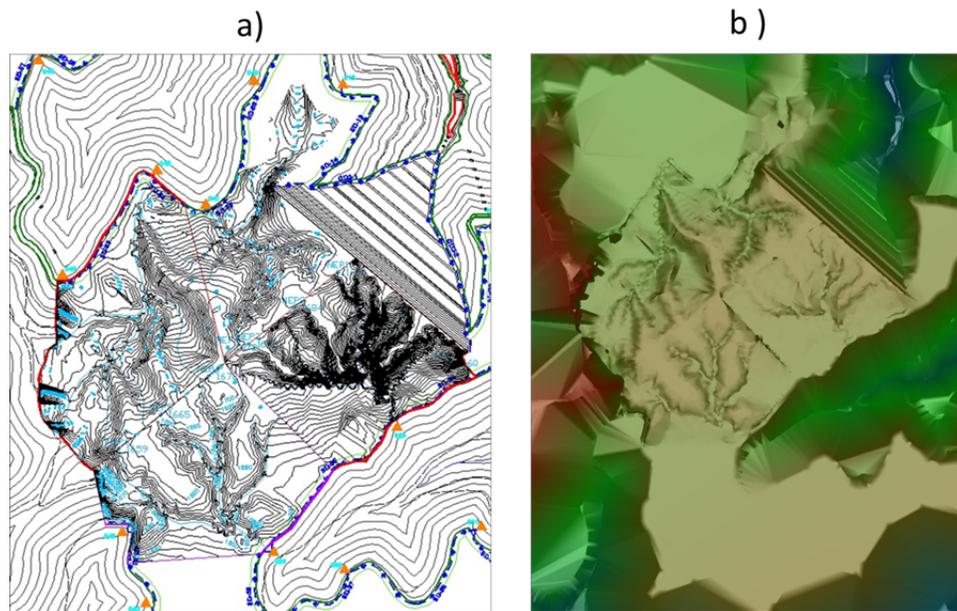


Figure 2. Retrofit design of permitted valley fill in (a) 2D and (b) 3D.

Obj. 2. Determine the hydrologic function of a redesigned valley fill site in southern WV

Runoff

The objective of this research was to predict the hydrologic response of a mine site reclaimed using geomorphic methods for a location in southern West Virginia. This work was completed during the reporting period and is reported in a student thesis (Snyder, 2013). Results were also presented at a professional meeting. The results are summarized in the following sections.

Methods. Three alternative geomorphic reclamation designs were modeled using Aquaveo’s Watershed Modeling System: i) a geomorphic reclamation of the valley fill (“GLD”); ii) a geomorphic reclamation of the valley fill with three detention ponds (“Pond design”; and, iii) a geomorphic retrofit design (“Retrofit”). Results were compared to the response of both the original, undisturbed topography and a conventional valley fill (Figure 3). The peak flowrate, time to peak, and runoff volumes were evaluated at three stages of reclamation (during mining, post-mining (< 5 years), and post-mining (> 5 years)) for a range of storm events (1- through 500-year, 24-hour).

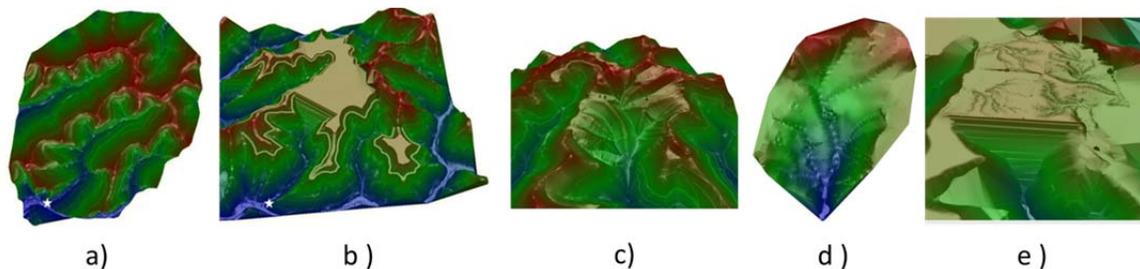


Figure 3. Landforms for hydrologic response comparison: a) undisturbed topography, b) conventional valley fill, c) geomorphic landform design, d) pond design, and e) retrofit design.

Comparison of reclamation designs to the original topography. The GLD for during mining conditions generated higher peak discharge and runoff volume values and lower time of peak values when compared to the original topography (Table 1). During mining conditions resulted in peak discharge values on average 340% higher, average time of peak values 1% lower, and average runoff volume values 140% higher than the original topography (Table 9).

Table 1. Comparison between the hydrologic response of the GLD watershed and the original topography for during mining conditions

Return Period	Peak Discharge (cfs)		Time of Peak (min)		Volume (ft ³)	
	GLD	Original	GLD	Original	GLD	Original
1-year	521	54	732	738	1.82×10 ⁶	4.69×10 ⁵
2-year	686	104	732	738	2.34×10 ⁶	7.34×10 ⁵
5-year	1037	246	732	738	3.43×10 ⁶	1.38×10 ⁶
10-year	1369	398	732	738	4.45×10 ⁶	2.04×10 ⁶
25-year	1725	580	732	738	5.53×10 ⁶	2.79×10 ⁶
50-year	1904	678	732	738	6.08×10 ⁶	3.19×10 ⁶
100-year	2205	849	732	738	6.98×10 ⁶	3.87×10 ⁶
500-year	3,225	1,256	726	738	9.07×10 ⁶	5.45×10 ⁶

The GLD for post-mining conditions generated peak discharge and runoff volume values that closely resembled the values generated by the original watershed (Table 2). When compared to the original, undisturbed watershed, the GLD post-mining values most closely matched the peak discharge values of the original topography with an average peak discharge 2% lower and runoff volume 7% higher than those produced by the original topography (Table 9). Average time of peak values were no different than the values for the original watershed (Table 9).

Table 2: Comparison between the hydrologic response of the GLD watershed and the original topography for post-mining conditions

Return Period	Peak Discharge (cfs)		Time of Peak (min)		Volume (ft ³)	
	GLD	Original	GLD	Original	GLD	Original
1-year	56.7	54	750	738	5.20×10 ⁵	4.69×10 ⁵
2-year	105	104	744	738	8.02×10 ⁵	7.34×10 ⁵
5-year	238	246	744	738	1.47×10 ⁶	1.38×10 ⁶
10-year	372	398	744	738	2.16×10 ⁶	2.04×10 ⁶
25-year	542	580	738	738	2.94×10 ⁶	2.79×10 ⁶
50-year	634	678	738	738	3.35×10 ⁶	3.19×10 ⁶
100-year	795	849	738	738	4.05×10 ⁶	3.87×10 ⁶
500-year	1,383	1,256	732	738	5.71×10 ⁶	5.45×10 ⁶

The detention pond reclamation design generated peak discharge values that more closely resembled the original watershed values than the GLD for during mining conditions (Table 3). Average peak discharge values were 250% higher than the peak discharge values generated by the original watershed for all rainfall return periods (Table 9). The GLD and detention pond design produced similar average runoff values. Both reclamation designs generated 140% more runoff volume than the original topography (Table 9). Average time of peak values were 2% lower for the detention pond design than the original topography (Table 9).

Table 3. Comparison between the hydrologic response of the designed watershed and original topography for during mining conditions

Return Period	Peak Discharge (cfs)		Time of Peak (min)		Volume (ft ³)	
	Detention Pond	Original	Detention Pond	Original	Detention Pond	Original
1-year	440	54	726	738	1.85×10 ⁶	4.69×10 ⁵
2-year	572	104	726	738	2.39×10 ⁶	7.34×10 ⁵
5-year	850	246	726	738	3.52×10 ⁶	1.38×10 ⁶
10-year	1,104	398	726	738	4.58×10 ⁶	2.04×10 ⁶
25-year	1,370	580	726	738	5.69×10 ⁶	2.79×10 ⁶
50-year	1,498	678	726	738	6.25×10 ⁶	3.19×10 ⁶
100-year	1,725	849	726	738	7.19×10 ⁶	3.87×10 ⁶
500-year	2,188	1,256	720	738	9.21×10 ⁶	5.45×10 ⁶

The detention pond design produced lower peak discharge and total runoff volume and higher time of peak values than the original watershed for short-term (< 5 years) post-mining conditions (Table 4). Peak discharge values were, on average, 45% lower than values generated by the original watershed (Table 9). Average time of peak values were 1% higher and total runoff volume was 15% lower than the original watershed (Table 9).

Table 4: Comparison between the hydrologic response of the designed watershed and original topography for short-term, post-mining conditions

Return Period	Peak Discharge (cfs)		Time of Peak (min)		Volume (ft ³)	
	Detention Pond	Original	Detention Pond	Original	Detention Pond	Original
	1-year	36	54	756	738	4.54×10 ⁵
2-year	63	104	750	738	6.72×10 ⁵	7.34×10 ⁵
5-year	136	246	747	738	1.17×10 ⁶	1.38×10 ⁶
10-year	216	398	747	738	1.70×10 ⁶	2.04×10 ⁶
25-year	308	580	747	738	2.29×10 ⁶	2.79×10 ⁶
50-year	356	678	747	738	2.60×10 ⁶	3.19×10 ⁶
100-year	439	849	747	738	3.13×10 ⁶	3.87×10 ⁶
500-year	625	1,256	744	738	4.32×10 ⁶	5.45×10 ⁶

The detention pond design generated even lower peak discharge and total runoff volume values than those generated by the original watershed for long-term (> 5 years), post-mining conditions (Table 5). Average peak discharge and total runoff volume values were 73% and 44% lower respectively (Table 9). Average time of peak values were 3% greater than time of peak values generated by the original topography (Table 9).

Table 5: Comparison between the hydrologic response of the designed watershed and original topography for long-term, post-mining conditions

Return Period	Peak Discharge (cfs)		Time of Peak (min)		Volume (ft ³)	
	Detention Pond	Original	Detention Pond	Original	Detention Pond	Original
	1-year	9	54	777	738	2.35×10 ⁵
2-year	20	104	762	738	3.77×10 ⁵	7.34×10 ⁵
5-year	59	246	759	738	7.43×10 ⁵	1.38×10 ⁶
10-year	109	398	756	738	1.15×10 ⁶	2.04×10 ⁶
25-year	173	580	756	738	1.63×10 ⁶	2.79×10 ⁶
50-year	207	678	756	738	1.88×10 ⁶	3.19×10 ⁶
100-year	269	849	753	738	2.33×10 ⁶	3.87×10 ⁶
500-year	412	1,256	753	738	3.37×10 ⁶	5.45×10 ⁶

For during mining conditions the retrofit reclamation design generated peak discharge, time of peak, and total runoff volume values lower than those generated by the GLD or detention pond design at during mining conditions, but greater than those generated by the original watershed (Table 6). Average peak discharge and total runoff volume values were 117% and 58% greater respectively (Table 9). Average time of peak values were 1% higher than those generated by the original topography.

Table 6. Comparison between the hydrologic response of 2B of the retrofit watershed and original topography for during mining conditions

Return Period	Peak Discharge (cfs)		Time of Peak (min)		Volume (ft ³)	
	Retrofit	Original	Retrofit	Original	Retrofit	Original
1-year	262	54	744	738	1.20×10 ⁶	4.69×10 ⁵
2-year	345	104	744	738	1.55×10 ⁶	7.34×10 ⁵
5-year	521	246	744	738	2.27×10 ⁶	1.38×10 ⁶
10-year	688	398	744	738	2.94×10 ⁶	2.04×10 ⁶
25-year	867	580	744	738	3.66×10 ⁶	2.79×10 ⁶
50-year	957	678	744	738	4.02×10 ⁶	3.19×10 ⁶
100-year	1,108	849	744	738	4.62×10 ⁶	3.87×10 ⁶
500-year	1,434	1,256	744	738	5.91×10 ⁶	5.45×10 ⁶

The short-term (< 5 years), post-mining conditions of the retrofit design produced peak discharge and runoff volume values lower and time of peak values higher than those generated by the original watershed (Table 7). Average peak discharge and total runoff volumes were 46% and 30% lower respectively while average time of peak values were 4% higher than those generated by the original watershed (Table 9).

Table 7. Comparison between the hydrologic response of 2B of the retrofit watershed and original topography for post-mining, short-term conditions

Return Period	Peak Discharge (cfs)		Time of Peak (min)		Volume (ft ³)	
	Retrofit	Original	Retrofit	Original	Retrofit	Original
1-year	33.9	54	780	738	3.40×10 ⁵	4.69×10 ⁵
2-year	61.7	104	768	738	5.25×10 ⁵	7.34×10 ⁵
5-year	141	246	768	738	9.69×10 ⁵	1.38×10 ⁶
10-year	214	398	768	738	1.42×10 ⁶	2.04×10 ⁶
25-year	300	580	768	738	1.94×10 ⁶	2.79×10 ⁶
50-year	346	678	768	738	2.22×10 ⁶	3.19×10 ⁶
100-year	425	849	768	738	2.68×10 ⁶	3.87×10 ⁶
500-year	620	1,256	762	738	3.74×10 ⁶	5.45×10 ⁶

Under long-term (> 5 years), post-mining conditions the retrofit design generated peak discharge and runoff volume values lower than the both the short-term conditions and the original watershed (Table 8). Time of peak values increased with respect to the short-term conditions (Table 8). Average peak discharge and total runoff volume values were 74% and 55% lower respectively and average time of peak values were 4% higher (Table 9).

Table 8. Comparison between the hydrologic response of 2B of the retrofit watershed and original topography for post-mining, long-term conditions

Return Period	Peak Discharge (cfs)		Time of Peak (min)		Volume (ft ³)	
	Retrofit	Original	Retrofit	Original	Retrofit	Original
1-year	8.35	54	792	738	1.48×10 ⁵	4.69×10 ⁵
2-year	19.1	104	780	738	2.69×10 ⁵	7.34×10 ⁵
5-year	59.6	246	780	738	5.90×10 ⁵	1.38×10 ⁶
10-year	112	398	780	738	9.50×10 ⁵	2.04×10 ⁶
25-year	177	580	780	738	1.38×10 ⁶	2.79×10 ⁶
50-year	207	678	780	738	1.60×10 ⁶	3.19×10 ⁶
100-year	261	849	780	738	2.00×10 ⁶	3.87×10 ⁶
500-year	404	1,256	768	738	2.93×10 ⁶	5.45×10 ⁶

Table 9. Average percent difference between original topography at CN=66 and various reclamation designs for peak discharge, time of peak, and total runoff averaged over all rainfall return periods

	Condition	GLD	Detention Pond	Retrofit*
Average Peak Discharge Difference	DM	340%	250%	120%
	SR	-2%	-45%	-46%
	LR	-2%	-73%	-74%
Average Time of Peak Difference	DM	-1%	-2%	1%
	SR	0%	1%	4%
	LR	0%	3%	6%
Average Total Runoff Difference	DM	140%	140%	58%
	SR	7%	-15%	-30%
	LR	7%	-44%	-55%

Note: DM=during mining; SR = short-term reclaimed (< 5 years); LR = long-term reclaimed (>5 years). The retrofit reclamation design has a smaller drainage basin discharging to outlet 1C than the other two reclamation designs.

These results indicate that the GLD may be the most suitable design for the reclamation of the mountaintop removal mine site being investigated. The detention pond and retrofit design appear to perform better than the GLD for during-mining conditions in regards to peak discharge, however for post-mining conditions the two designs generate both peak discharge and total runoff volumes considerably lower than the original topography.

Comparison of GLD reclamation to conventional reclamation. The during-mining peak discharge values of every reclamation design were much higher than the peak discharge values generated by the conventional design. The GLD generated peak discharge values as much as 3,240% higher than the discharge values generated by the conventional design (Table 10). The retrofit and detention pond designs yielded similar results with peak discharge values 1,579% and 2,721% respectively higher at the 1-year return period (Table 10). The during-mining peak discharge values generated by the alternative reclamation designs more closely resembled the values generated by the conventional design as the rainfall return period increased. Post-mining peak discharge values were closer to the conventional design peak discharge values for each reclamation design. The GLD generated peak discharge values larger than the conventional design for the 1-, 2-, and 5-year return period rainfall event, but at the 10-year and greater return period the GLD generated lower peak discharge values (Table 10). The retrofit and detention pond designs followed similar patterns for the short-term reclamation though they generated lower peak discharge values than the GLD reclamation design (Table 10). Long-term

peak discharge values for the retrofit and detention pond design were lower than the conventional design peak discharges for all return periods (Table 10).

Table 10. Percent difference of peak discharge in comparison with the conventional reclamation

Return period (yrs)	Time of Reclamation	GLD (%)	Retrofit (%)	Detention (%)
1	DM	3,240	1,579	2,721
	SR	263	117	131
	LR	263	-46	-42
2	DM	2,274	1,094	1,879
	SR	263	113	118
	LR	263	-34	-31
5	DM	810	357	646
	SR	109	24	19
	LR	109	-48	-48
10	DM	220	61	158
	SR	-13	-50	-50
	LR	-13	-74	-75
25	DM	119	10	74
	SR	-31	-62	-61
	LR	-31	-78	-78
50	DM	103	2	59
	SR	-33	-63	-62
	LR	-33	-78	-78
100	DM	89	-5	48
	SR	-32	-64	-62
	LR	-32	-78	-77
500	DM	98	-12	34
	SR	-15	-62	-62
	LR	-15	-75	-75

Note: DM=during mining; SR = short-term reclaimed (< 5 years); LR = long-term reclaimed (>5 years). The retrofit reclamation design has a smaller drainage basin discharging to outlet 1C than the other two reclamation designs.

Erosion

As part of an Undergraduate Research Class (CE 497 497 Civil Engineering Research Projects for Undergraduates), one student examined erosion from on GLD reclamation using the Revised Universal Soil Loss Equation. Preliminary results will be presented at a professional meeting and a course report will be submitted. These preliminary methods and results are described in the following sections. The methods will be improved and the research will be expanded in the next reporting period.

Site Characteristics. Two sites were compared: undisturbed topography and one GLD reclamation. Three hillslope transects were selected within each landform type to calculate erosion potential at each region of the site (Figures 4-11).

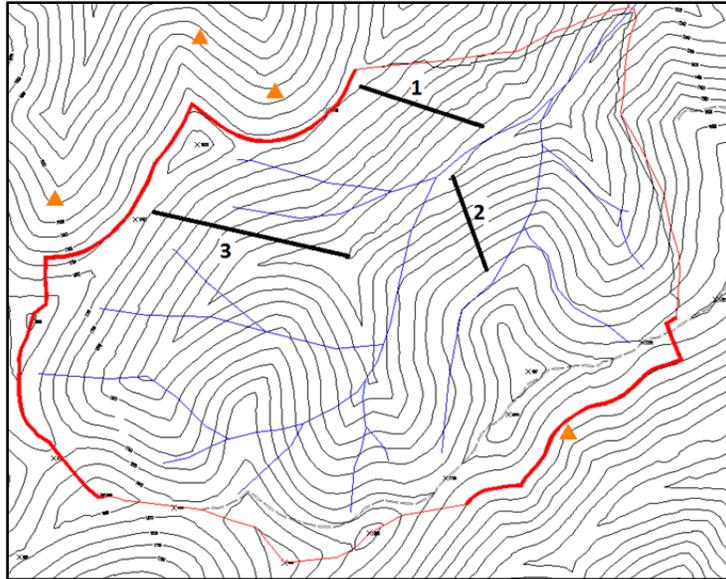


Figure 4. Undisturbed topography: 1. Transect 1, 2. Transect 2, 3. Transect 3.

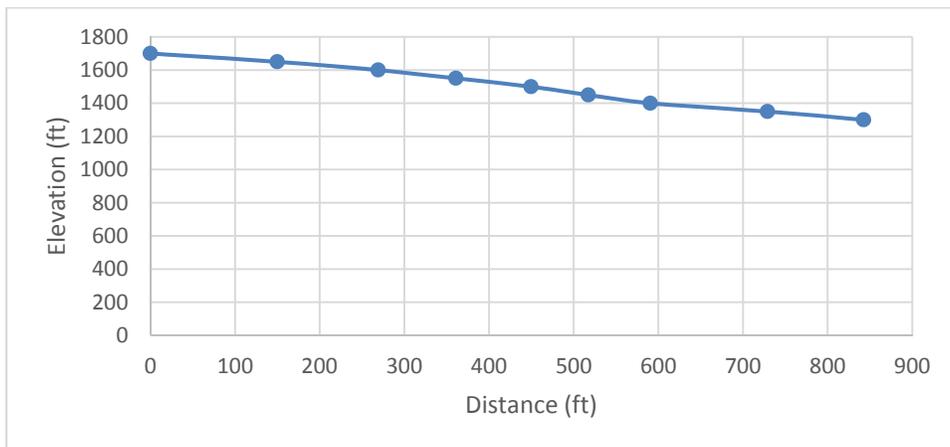


Figure 5. Transect 1 hillslope profile of undisturbed topography

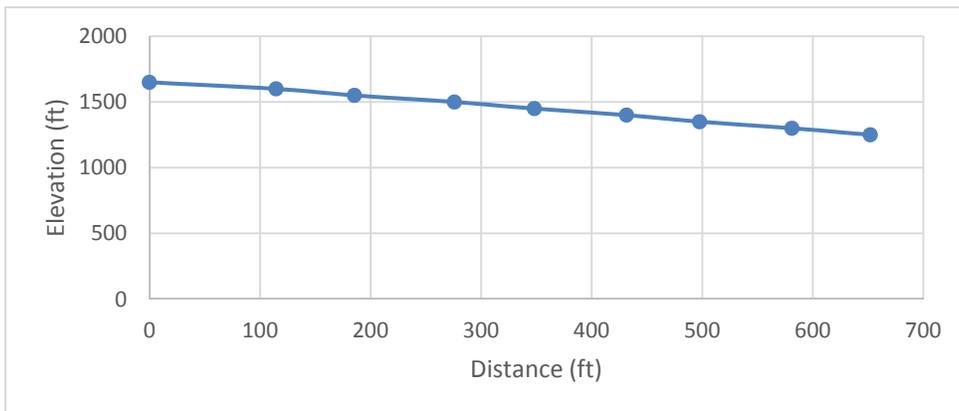


Figure 6. Transect 2 hillslope profile of undisturbed topography

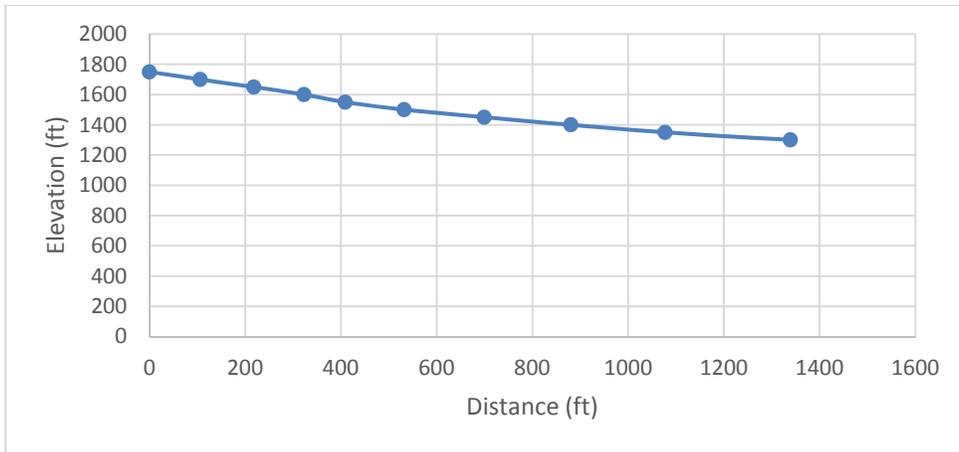


Figure 7. Transect 3 hillslope profile of undisturbed topography

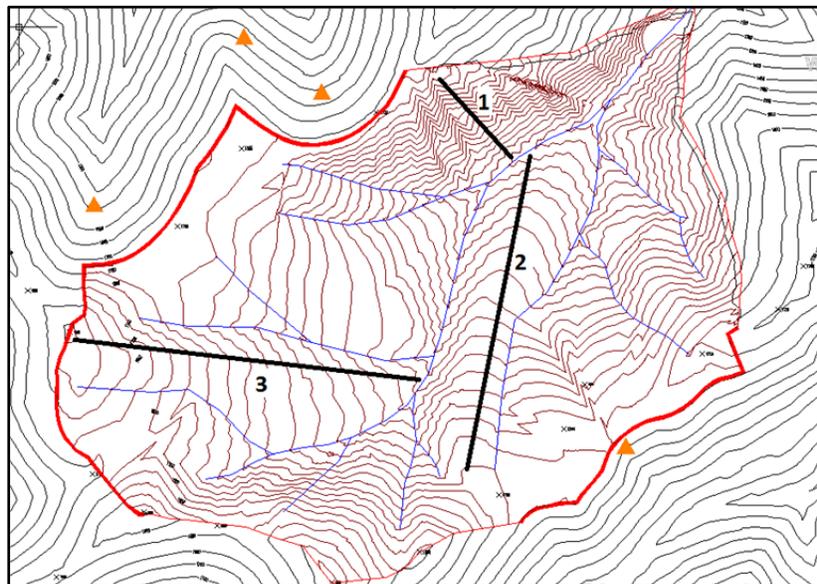


Figure 8. GLD Design; 1. Transect 1, 2. Transect 2, 3. Transect 3

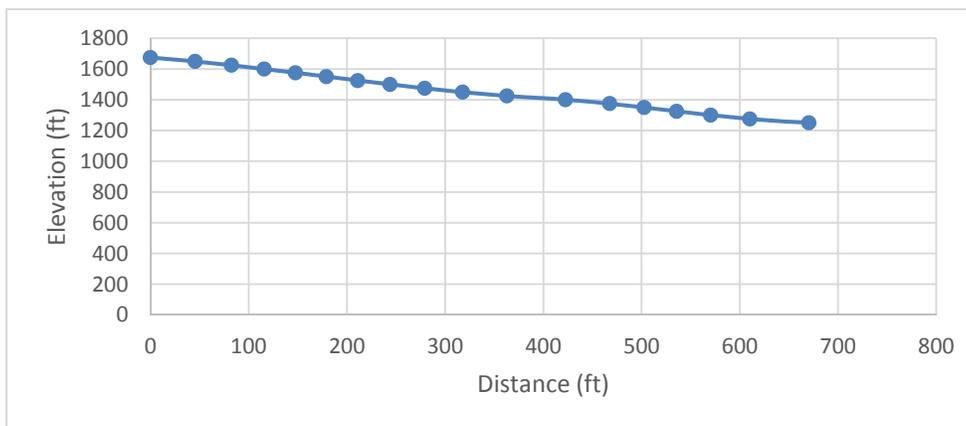


Figure 9. Transect 1 hillslope profile of GLD design

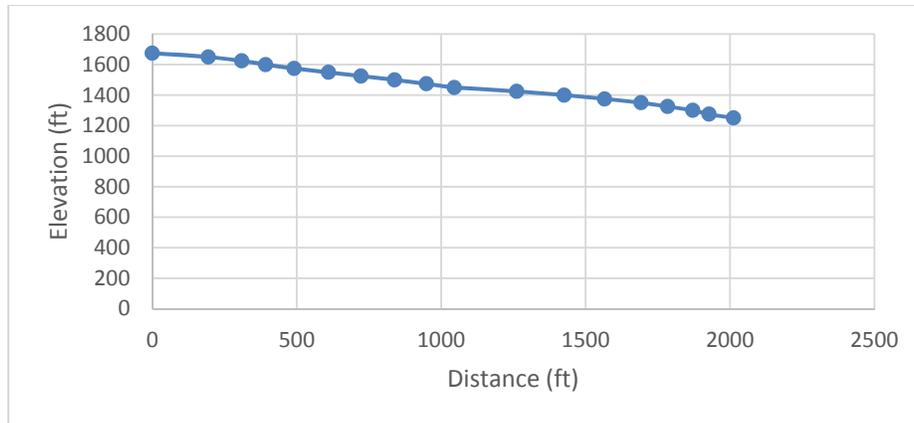


Figure 10. Transect 2 hillslope profile of GLD design

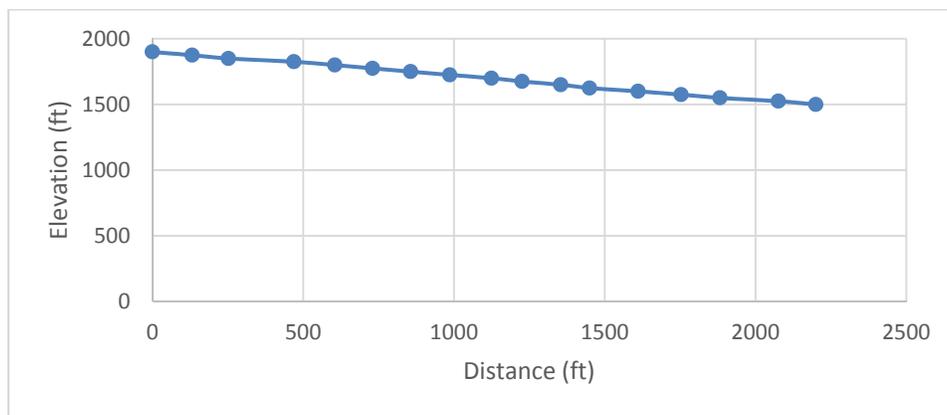


Figure 11. Transect 3 hillslope profile of GLD design

Preliminary RUSLE methods. The R factor, erosivity, was based on rainfall data for Charleston, WV. A value for K in the RUSLE was calculated based on the soil survey results in the surrounding region. Slopes and slope lengths from the site topography (Figures 5-7, 9-11) were utilized to define the LS values. The cover and management factor (C) alters the RUSLE to the circumstances where vegetative cover is existing on the site (Evans and Loch, 1996). For the undisturbed topography, dense grass was chosen to represent a more mature vegetation within the site, and a bare coverage with weeds was chosen for the GLD Design to represent a younger vegetation. (These methods to define the C-factor will be improved). Values for P were determined to be equal to 1 for both the undisturbed topography and the GLD design since no conservation practices were in effect and the transects represent undisturbed lands (Renard et al., 1991).

Two trials were conducted using different C-Factors and K-Factors for the GLD Design to develop an idea of which factor has the most influence over the site's sediment delivery. The first trial utilized the same cover and erodibility factors between the two sites; this trial would indicate how much slope length and steepness control interrill and rill erosion while leaving all other factors constant. The second trial consisted of the same erodibility factor, but a different cover factor was used for the GLD (Bare, cut, smooth, weeds) to see how the vegetation, or cover, effects sediment delivery.

Preliminary Results. The two trials conducted were based upon the different management practices and soil types present at each site. The undisturbed topography was used as a control

group throughout each trial (Table 11). Trial 1 represents the same management and soil type at each location (Table 12). Trial 2 represents different management practices at each site with the same soil coverage (Table 13).

For Trial 1, in which all factors remained constant aside from the LS-Factor, the sediment delivery between the two sites was comparable. The cover and management practices (C-factor) had the highest influence on erosion rates; this can be observed through Trial 2; interrill erosion and sediment delivery were highly correlated to the amount of vegetation, and this can be observed as the sediment delivery of the site was greatly increased when the cover of the GLD was changed to younger vegetation. Foliage and residue cover protects the soil from the impact of rain, and it tends to slow down the movement of runoff water and allows excess surface water to infiltrate (Loch and Roswell, 1992). This C-factor will better defined in future work.

Table 11. Undisturbed topography results

Transect No.	Sediment Delivery (t/ac/yr.)	Management	Soil Type
1	0.5	Dense Grass	loam (l-m OM, m perm)
2	0.59	Dense Grass	loam (l-m OM, m perm)
3	0.36	Dense Grass	loam (l-m OM, m perm)

Table 12. GLD results utilizing the same C-factor and K-factor as the undisturbed topography (Trial 1)

Transect No.	Sediment Delivery (t/ac/yr.)	Management	Soil Type
1	0.59	Dense Grass	loam (l-m OM, m perm)
2	0.25	Dense Grass	loam (l-m OM, m perm)
3	0.21	Dense Grass	loam (l-m OM, m perm)

Table 13. GLD results utilizing the same C-factor as the undisturbed topography while altering the K-factor (Trial 2)

Transect No.	Sediment Delivery (t/ac/yr.)	Management	Soil Type
1	110	Bare, cut, smooth, weeds	loam (l-m OM, m perm)
2	59	Bare, cut, smooth, weeds	loam (l-m OM, m perm)
3	43	Bare, cut, smooth, weeds	loam (l-m OM, m perm)

Obj. 3: Predict differences in floodplain mapping downstream of redesigned reclamation, resulting from extreme meteorological events.

This work will result in a MS thesis and preliminary results were presented at an international meeting. Preliminary, steady modeling results are presented; we are currently working on unsteady modeling.

Preliminary Methods

Study site. The study site was an approximately 2.1 kilometer stream section, located in Logan County, West Virginia. The study reach began at the outlet of the unnamed mountain stream carrying the runoff from the mine site, and ended at a downstream confluence (Figure 12).



Figure 12. Study Site Map

Geometric data were not available for the study area. Data were extracted from high quality elevation data (Alho and Asltonen, 2008; Owusu et al., 2013; Shellberg et al., 2013; Yochum et al., 2008) (Figure 3). Samuel's equation was used to assist in determining cross section spacing (Samuels, 1989).

$$\Delta x \leq \frac{0.15D}{S_0}$$

where, Δx = cross section spacing; D = bankful depth; and S_0 = stream slope.

Flood depths for the largest storm (500-year) and smallest storm (2-year) were input into the equation as "D" instead of bankful depth, due to the modeling of larger storm events. This resulted in a cross sectional spacing range of 32 m to 83 m. This range was used as a starting point, and cross sections were added and altered as needed. The final model resulted in 44 cross sections (Figure 14).



Figure 13. Estimated stream centerline and bank locations

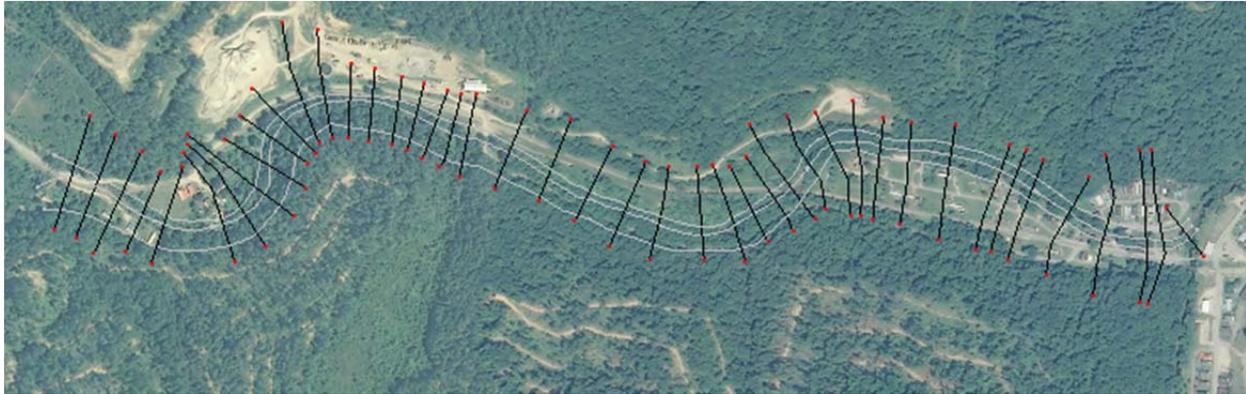


Figure 14. Cut lines for extracted cross sections

Hydraulic Modeling. Four reclamation conditions were used for analysis: Pre-mining, Conventional, GLD (During Mining), and GLD (Post-mining). The pre-mining condition analyzed the effects of runoff from the undisturbed topography at the mine site location.

Three storms were used for the steady analysis of each reclamation condition: 2-year, 100-year, and 500-year. Necessary data for a steady hydraulic model are geometric data, steady flow data, and boundary conditions (USACE, 2010). Geometric data was extracted from GIS data, as described in the previous section. Peak discharges from the hydrologic model created in a previous study (Snyder, 2013) were used for the steady flow data (Table 14).

Table 14. Peak Discharges (obtained from Snyder, 2013)

	Peak Discharge, m/s (cfs)		
	2-year	100-year	500-year
Pre-mining	2.94 (104)	24.04 (849)	35.57 (1256)
Conventional	0.82 (28.9)	33.07 (1168)	46.10 (1628)
GLD (During mining)	19.43 (686)	62.44 (2205)	91.32 (3225)
GLD (Post mining)	2.97 (105)	22.51 (795)	36.16 (1383)

Normal depth was used as the downstream boundary condition, which required entering the downstream slope for normal depth computation. A slope of 0.0144 that was measured from GIS was used for this input.

A steady flow analysis with a supercritical flow regime was performed. The resulting water surface elevations were imported into the conceptual model. The water surface elevation data was delineated to display the resulting flood extents for each storm event.

Preliminary Results

The greatest flooding extents and depths for each storm event resulted from the GLD (During Mining) reclamation condition. Conventional reclamation resulted in the least flooding impacts for the 2-year storm event. Of the reclamation treatments, GLD (Post-mining) caused the least flooding impacts for the 100-year and 500-year storm events. The results from the GLD (Post Mining) reclamation condition were comparable to Pre-mining results (Table 15 and Figures 15-27).

Table 15. Flood extents and maximum depth of study reach for steady analysis

Return Period (yr)	Pre-Mining		Conventional		GLD-DM		GLD-PM	
	Flood Extents (m)	D_{max} (m)						
2	5.2-19.7	0.5	4.1-16.6	0.3	8.5-31.3	1.2	5.2-19.7	0.5
100	9.03-33.9	1.4	9.7-42.0	1.57	12.1-52.2	2.2	8.9-33.1	1.3
500	10.3-40.4	1.6	11.0-44.5	1.84	13.5-57.5	2.7	10.3-43.4	1.7

Note: D_{max} = maximum flow depth; GLD-DM = Geomorphic Landform Design (During Mining); and, GLD-PM = Geomorphic Landform Design (Post-Mining)

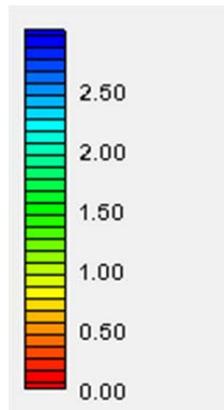


Figure 15: Depth (m) legend for flood maps



Figure 16: Pre-Mining 2-year flood extents and depth



Figure 17: Pre-Mining 100-year



Figure 18: Pre-Mining 500-year flood extents and depth



Figure 19: Conventional 2-year flood extents and depth



Figure 20: Conventional 100-year flood extents and depth



Figure 21: Conventional 500-year flood extents and depth



Figure 22: GLD (During Mining) 2-year flood extents and depth



Figure 23: GLD (During Mining) 100-year flood extents and depth

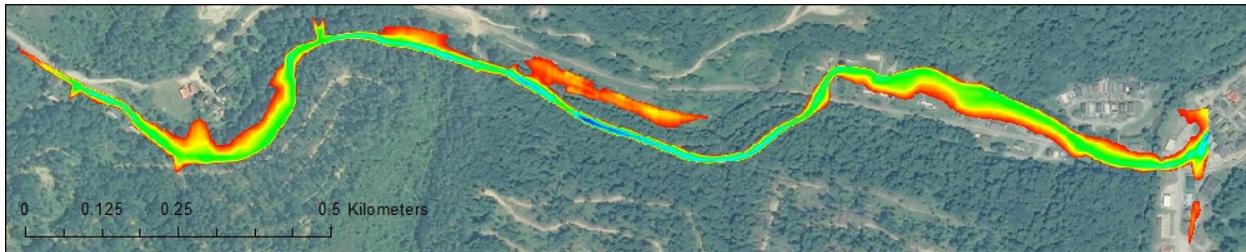


Figure 24: GLD (During Mining) 500-year flood extents and depth



Figure 25: GLD (Post Mining) 2-year flood extents and depth



Figure 26: GLD (Post Mining) 100-year flood extents and depth



Figure 27: GLD (Post Mining) 500-year flood extents and depth

Obj. 4: Predict the hydrologic response of watersheds with redesigned reclamation at the landscape scale.

The objective of this part of the project is to predict the hydrologic response of watersheds with redesigned reclamation at the landscape scale. Work has been initiated on this research. An extensive literature review of the subject matter, including hydraulic simulation programs and their mining related uses, has been completed. This literature review will be updated throughout the project to include recent works. A watershed in southern West Virginia was chosen on which to perform the modeling to achieve our research goal. Data necessary to complete the Hydrological Simulation Program-FORTRAN (HSPF) modeling has been acquired from sources including the USGS, the WV GIS Technical Center, and the National Climate Data Center. These data are currently being imported into HSPF for calibration. Then, simulation in land use and land cover change will be completed by altering the land area attributed to reclaimed mine land to predict the hydrologic response of the watersheds with redesigned reclamation.

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2. Publications

Thesis

Snyder, M.W. 2013. Hydrologic response of alternative valley fill reclamation design. MS Thesis. Civil and Environmental Engineering Department: West Virginia University.

3. Information Transfer Program

Oral Presentations (*Graduate student, presenter in bold)

Snyder, M.*, and L. Hopkinson. 2013. The hydrologic response of valley fills with alternative reclamation methods. 88th Annual West Virginia Academy of Science Meeting, April 6. Canaan Valley Institute: Davis, WV. (published abstract)

Poster Presentations (*Graduate student, **Undergraduate student, presenter in bold)

O’Leary, E.*, Hopkinson, L. 2014. Floodplain mapping in response to surface mine reclamation. Environmental Connection 2014. International Erosion Control Association Annual Conference, Nashville, TN. Feb. 23-28, 2014. *poster*

Sears, A.*, Hopkinson, L., Quaranta, J., and Bise, C. 2013. Enhanced surface mine reclamation using geomorphic landform principles. American Geophysical Union Fall Meeting. December 9-13. Moscone Center: San Francisco, CA. (published abstract)

Accepted Abstracts (*Graduate student, **Undergraduate student, presenter in bold)

Billian, H.**, Sears, A.*, and Hopkinson, L. 2014. Evaluating the effects of geomorphic landform design on erosion potential. 89th Annual West Virginia Academy of Science Meeting, April 12. Shepherd University: Shepherdstown, WV. (poster)

Snyder, C.**, DePriest, N.*, and Hopkinson, L. 2014. Sizing ponds for a surface mine reclamation valley fill. 89th Annual West Virginia Academy of Science Meeting, April 12. Shepherd University: Shepherdstown, WV. (poster)

Project listed on WVWRI website (<http://wvwri.org>)

4. Student Support

- Three graduate students have worked on research related to this project: Alison Sears (PhD, continuing), Mike Snyder (MS, graduated December 2013), Erin O’Leary (MS, continuing).
- Two undergraduate students completed a research course for three hours of credit (CE 497 Civil Engineering Research Projects for Undergraduates). The semester-long research projects were related to this work.

CE 497, Students Supervised:

	Name	Major	Semester	Topic
1	H. Billian	CEE	S14	Erosion on reclaimed surface mine sites
2	C. Snyder	CEE	S14	Pond design for stormwater control

5. Student Internship Program

NA

6. Notable Achievements and Awards.

The following achievements were completed in this reporting period:

- One graduate student graduated with a MS in December 2013.
- Two graduate students presented results at professional meetings.
- Two abstracts were accepted to present at professional meetings.
- MS student, Erin O'Leary, was selected as a student moderator for an international conference:
 - Erin O'Leary, Student Moderator, International Erosion Control Association (IECA) 2014 Environmental Connection Conference, February 25-28, 2014, Nashville, TN. (awarded travel and registration costs)
- PhD student, Alison Sears, won a Student Research Enhancement Award to present at an international meeting:
 - Alison Sears, 2013. Student Research Enhancement Award, "Improvement of Water Supply on Reclaimed Appalachian Surface Mine Sites", 2013-2014 Student Research Enhancement Award, WVU Women in Science and Engineering (WiSE), \$1,250.
- Two undergraduate students complete a research course.
- Technical progress has been initiated for all objectives.

Understanding variations in isotopic and molecular compositions of stray gas in areas of accelerating shale gas development

Basic Information

Title:	Understanding variations in isotopic and molecular compositions of stray gas in areas of accelerating shale gas development
Project Number:	2013WV205B
Start Date:	3/1/2013
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Water Quality, Geochemical Processes, Hydrogeochemistry
Descriptors:	
Principal Investigators:	Shikha Sharma

Publications

1. Sharma, S., M. Mulder, A. Sack, K. Schroeder, and R. Hammack. 2013. Isotope approach to assess hydrologic connections during Marcellus Shale drilling. Groundwater. DOI: 10.1111/gwat.12083.
2. Soeder, D.J., S. Sharma, N. Pekney, L. Hopkinson, R. Dilmore, B. Kutchko, B. Stewart, K. Carter, A. Hakala, and R. Capo. 2014. An approach for assessing engineering risk from shale gas wells in the United States. International Journal of Coal Geology. DOI: 10.1016/j.coal.2014.01.004.

Understanding variations in isotopic and molecular compositions of stray gas in
areas of accelerating shale gas development

Annual Report

Reporting period: March 1, 2013-February 28, 2014

Principal Author: Dr. Shikha Sharma

Report Issue Date: May 15, 2014

USGS Award: 104b grant

Submitted by: West Virginia University Department of Geology and Geography

330 Brooks Hall, 98 Beechurst Ave.

Morgantown, WV 26505

Research

Abstract

Accurate spatial and geochemical characterization of stray gas is imperative as shale gas production rapidly increases in basins around the world, including the Appalachian basin. To achieve economic gas production from shale, a technique known as hydraulic fracturing, or “fracking” is adopted. During the hydraulic fracturing process a mixture of water, proppant and chemicals is injected thousands of feet underground at high pressure which induces fractures in the source rock to release trapped gas. Under natural conditions, the water and gases occurring within the shale and other deep formations do not mix with shallow fresh water aquifers due to the barrier provided by several thousand feet of impermeable rocks. However, there are concerns that the hydraulic fracturing process can create new fracture networks or connect existing fracture networks which could augment hydraulic pathways between previously isolated formations. Additionally, well casing or grouting failures intersecting with pre-existing faults can allow dissolved gases and brine waters to contaminate shallow fresh water sources. Gas migrating into shallow aquifers, particularly methane, is a concern because the corresponding explosion risks, suffocation potential, and the negative impact on air quality. The preliminary data collected by the WVU Stable Isotope Lab and USGS collaborators at WV Water Science Center indicate that dissolved methane concentrations can be naturally high in some fresh water sources in North central West Virginia. The isotopic and molecular composition of dissolved methane, concentration of dissolved CO₂ and the carbon isotope signature of dissolved inorganic carbon suggest that methane in these groundwaters is not produced by biogenic processes at shallow depths but instead produced by CO₂ reduction and thermogenic processes in deeper geological formations. There is no prior or recent oil/gas drilling or coal mining activity in the study area. Hence, we propose that methane in these aquifers could be naturally migrating along natural faults and fractures from deeper coalbeds, Marcellus Shale and/or deeper Silurian and Ordovician oil and gas reservoirs over geological time scales. It is important to note that concentration, isotopic, and molecular composition of dissolved gas in water can also be significantly affected by changes in sampling methodologies and environmental conditions at time of sampling. With public awareness and concern about stray gas incidents on the rise, a complete understanding of spatial baseline stray gas concentrations and their relationships with natural faults and fractures is a necessity.

Table of Contents

RESEARCH	
Abstract	2
Executive Summary	4
Introduction	4
Experimental Method	7
Results and Discussion	9
Conclusions	12
References	13
PUBLICATIONS, POSTERS AND TALKS	14
INFORMATION TRANSFER PROGRAM	15
STUDENT SUPPORT	15
NOTABLE ACHIEVEMENTS AND AWARDS	15

Executive Summary

One of the primary concerns associated with shale gas development is stray gas migration into shallow aquifers during gas well drilling and stimulation through the creation of new hydrologic connections or the reactivation of ancient fracture networks. Under natural conditions, the fluids occurring within the shale and other deep formations do not mix with shallow fresh water aquifers due to the barrier provided by several thousand feet of impermeable rocks present between the two end-members. However, during well drilling, casing or grouting failures, existing subsurface fractures, and fractures created during hydraulic fracturing can generate or augment hydraulic pathways between previously isolated formations. While stray gas may migrate from gas wells, other sources of stray gas include coalbeds, storage gas fields, abandoned oil and gas wells, and coalbed methane wells. In addition to these sources of stray gas, methane may also be produced through biogenic pathways within the aquifer. Isotopic and geochemical analyses can be used to aid in the determination of stray gas sources in shallow groundwater. This study is a deeper exploration of results from a project completed in the summer of 2011 where 4 out of 41 groundwater wells sampled had methane concentrations >10 mg/L. Results from this study also indicated that the stray gas in these shallow aquifers is not produced by biogenic processes in shallow aquifers but is probably sourced from deeper oil/gas containing geological formations. However, high methane concentrations could not be related to old oil/gas/coalbed methane drilling activities or recent shale gas drilling in the study area.

The aim of this study is to determine the source of the stray gas present in these shallow aquifers by targeting the area around the high dissolved methane wells (Mulder, 2012) and attempt to isolate potential pathways for this fluid migration. This will be accomplished by completing the following objectives:

- 1) Understand the isotopic and molecular composition of natural gas in major coalbed and oil and gas reservoirs in the study area to assess the potential sources for the stray gas in this area.
- 2) Understand the relationship between dissolved methane, water quality parameters and stable isotope (C, O and H) signatures of ground waters sampled for this study. The results will help in the development of robust isotopic models to evaluate stray gas incidents in areas of active shale gas drilling.
- 3) Determine potential source of stray gas through isotopic and geochemical analyses as well as mapping of potential migration pathways.

Preliminary results indicate that dissolved methane present in groundwater wells is likely sourced from deeper rocks in the region, and is present in high concentrations in 4 of the 27 wells sampled. Further correlation of results with both geochemical results and structural geology analysis will be undertaken.

Introduction

Previous Work: Previous groundwater sampling was completed in 2011 before active shale gas drilling occurred throughout north central West Virginia (Sharma et al., 2013, Mulder, 2012). This project highlighted that methane concentrations in groundwater are extremely variable throughout north central West Virginia and several relationships were considered to explain occurrences of high methane. These included; topographic lows (as described by Molofsky et al., 2012), structural faults, gas storage fields, landfills and marshes, abandoned oil and gas wells and abandoned/active coal mining activity. Mulder (2012) identified two locations in Randolph County, WV (Ran-0276 and Ran-0278) that had high methane concentrations and no relationship with prior energy development. However, both Ran-0276 and Ran-0278 are located within a river valley and are in proximity to a Precambrian fault (figure 1). From these results, it is hypothesized that high concentrations of stray gas occur naturally in proximity to faults or areas with dense underlying fracture networks.

Purpose: The purpose of this study is to complete targeted, high-density sampling in an area with extensive faulting and naturally high concentrations of stray gas unrelated to previous energy development. Geochemical and isotopic data will be used to determine potential source as well as post-formation mixing and migration trends of stray gas.

Study Location and Geology: The study site for this project is a section of the Tygart River valley located in central Randolph county and extending south into northern Pocahontas county, West Virginia (figure 1).

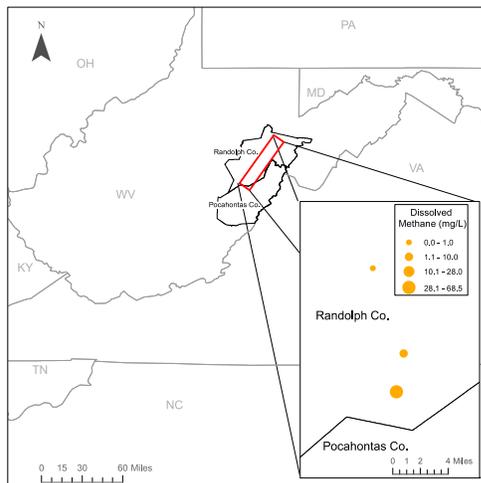


Figure 1: Study location spanning northern Pocahontas and Randolph counties, West Virginia. Inset shows locations and corresponding concentrations of dissolved methane from study by Mulder, 2012.

The extent of the study area is approximately 35 miles in length and 5 miles in width. Land use is generally residential with some agricultural activity (predominantly cattle grazing). The study area lies within the Tygart and Cheat watersheds with the southern section extending into the Elk watershed. The three main rivers are the Tygart Valley river which essentially bisects the study area, the Elk river in the southern section of the study area and Shaver's fork to the east.

The majority of the study area is located along the Deer Park anticline (also called the Elkins Valley anticline) which runs South 12° West through Randolph county and extends into Pocahontas county (Reger, 1931). The Elkins Valley anticline lies within the Allegheny plateau province and is located approximately 20 miles to the east of the Allegheny structural front (Ryder et al., 2008). The anticline was formed as a result of

the Alleghenian orogeny which resulted in dramatic deformation in the Valley and Ridge province with less deformational impact in central and eastern West Virginia. While less deformationally dramatic, the Appalachian High plateau is distinguished by high-amplitude folds with thrust faults sometimes occurring within the anticlinal cores. The thrust faults occurring

within the folds increases the overall fold amplitudes which results in the topographic variation observed in Randolph and Pocahontas counties (Renton, 2004). The Elkins Valley anticline has experienced multiple thrust faults originating from the Harrell shale acting as the zone of detachment.

A common feature of the Appalachian high plateau, the axis of the Elkins Valley anticline has eroded and the units exposed at the surface in Randolph County primarily consist of the Upper Devonian-age Portage and Chemung series. The Genesee series and Catskill Series also outcrop along the anticline in shorter intervals. To the east of the anticline the Pennsylvanian-age Pottsville series is the dominant rock type (Reger, 1931). Also occurring in

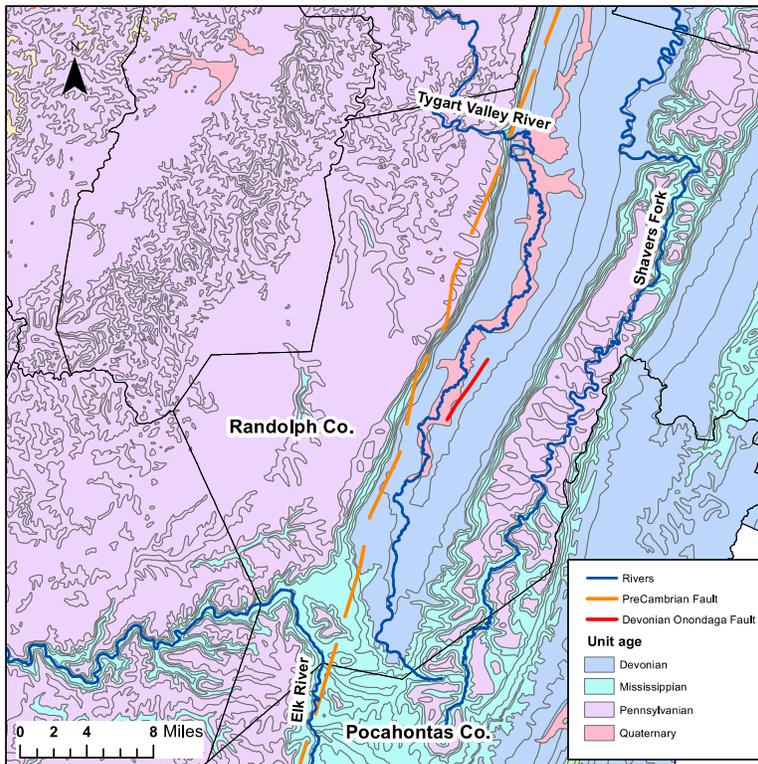


Figure 2: Age of rock units in study area with previously mapped Precambrian fault, Devonian fault and major rivers.

the center of the valley are deposits of Quaternary alluvium (figure 2).

Closer to the Pocahontas border the outcrops become Mississippian in age which includes the Pocono, Maccrady, Greenbrier and Mauch Chunk series. In Pocahontas County the surface geology within the study area is definitively Mississippian with the Greenbrier and Mauch Chunk series dominating (Reger, 1931) (figure 2).

The aquifers in the study area generally occur within the rock that composes the surface geology of the particular location due to the thickness of units compared to an average groundwater well depth. This potentiates that the likely aquifers in the study area are Tygart valley

alluvium, Devonian sands, and in the southern part of the study area Mississippian limestones (figure 2). The alluvium, while high in productivity, likely contains high amounts of clay and silt which may impact potability of the groundwater. However, some shallow wells that were sampled may be accessing water from this unit. The Devonian aquifers make up a majority of the study area and are a clastic fractured bedrock type aquifer with characteristically high transmissivity. The Greenbrier limestone to the south of the study area could potentially have conduit flow within the aquifer which complicates the understanding of localized aquifer characteristics but is overall understood to be a productive aquifer. Complicating the understanding of groundwater flow in the study area are the thrust faults cutting through the anticlinal hinge as these can create major pathways for groundwater flow (Kozar and Mathes, 2001).

Natural gas production hasn't to date been successful or intensive in Randolph or Pocahontas county. Interest in drilling for natural gas and oil in Randolph county began in the early 1900s but the anticline limbs complicated the driller's ability to complete a straight well and the wells weren't as productive as other locations in the state (Reger, 1931). Vertical wells continued to be drilled in the mid-1900s but the current status of most wells within the study area is abandoned or plugged. However, with vertical wells permitted in the study area and horizontal Marcellus wells encroaching from the west the timing of this study becomes apropos (WVDEP Office of Oil and Gas permit locations, accessed February, 2014).

Experimental Method

For this study, business and homeowners are contacted that are within the desired area and state that they have groundwater wells or spring water supplying their property. The well/spring owners also must confirm that the water is not exposed to air (i.e. headspace in a spring box) before coming out of the sampling port, experiences no treatment (i.e. chlorinators, softeners etc.) and that there is a working pump in the well. Attaining representative groundwater well samples is difficult due to complications such as pump variability and sample flow rates (Gorody, 2012) but efforts were made to limit varied environmental conditions and collect samples in a consistent and deliberate fashion. A total of 27 private and public groundwater wells and springs were sampled between October, 2013 and December, 2013.

Field Parameters: The purpose of monitoring field parameters is two-fold; firstly, parameters such as pH, temperature and conductivity are important for calculations that describe the water geochemistry. Secondly, monitoring relative differences in field parameters over the pre-collection and sample collection time period is important in understanding whether changes are occurring that may impact sample quality. For example, if a spike in dissolved oxygen is observed, it is assumed that drawdown has occurred to the point where water is cascading from a fracture above the water level in the well, and time should be allowed for the well to recover so as to prevent degassing. For this study, field parameters are monitored constantly from when water began to flow from the well to the completion of sampling.

A YSI Professional Plus handheld multiparameter meter is used in conjunction with a Professional Series pH/ORP combo sensor inserted into a 203 mL standard flow cell. The YSI is calibrated for pH and conductivity in the field to ensure accurate measurement. Parameters are logged every 30 seconds from when water begins flowing through the cell until every sample is collected (figure 7).

When possible, depth to water is also measured using a Solinst 101 P2 water level meter to determine initial water level and change in water level throughout the pumping period (figure 8). This is to ensure that drawdown doesn't occur too quickly; this could result in damage to the pump if it were to start drawing in air or sediment. At sites where monitoring water level wasn't possible, the owner was interviewed about the recharge to the well, depth of the well, and perceived initial water level so that flow rate could be adjusted appropriately.

Geochemistry: Alkalinity is measured in the field using a Hanna Instruments handheld colorimeter and replicated in the lab with a Metrohm 848 Titrino plus autotitrator using 0.1 normal Hydrochloric acid. The Hanna meter has a precision of ± 5 ppm and replication occurs in the field until consecutive samples are within 5 ppm of each other. Samples for titration are collected in the field in pre-rinsed 125 mL narrow mouth HDPE bottles. The bottle is filled from a 60 mL Luer-lock syringe fitted with a .45 μm Whatman nylon filter until a positive meniscus is

observed so that no headspace occurs within the sample. To confirm precision of methods, field alkalinity measurements and autotitrations are compared with manual titrations (table 2). From this comparison, it was determined that using the Hanna meter in the field followed by a measurement done in the lab within 48 hours after collection using the autotitrator is an accurate characterization of alkalinity for the purposes of this study.

Samples are collected for cation and anion analysis using a pre-rinsed 60 mL Luer-lock syringe and .45 μm Whatman nylon filter. Cation samples are collected in pre-rinsed 60 mL HDPE narrow mouth bottles and are acidified with approximately 1 mL of 65% Omni Trace Nitric acid (figure 9). Anion samples are collected in pre-rinsed 30 mL narrow mouth HDPE bottles. Both cation and anion samples are collected with no headspace. The samples are then shipped to a geochemical lab for analysis.

Water Isotopes: Isotope samples are collected for measuring $\delta^{13}\text{C}_{\text{DIC}}$, $\delta\text{D}_{\text{H}_2\text{O}}$, and $\delta^{18}\text{O}_{\text{H}_2\text{O}}$. Samples for $\delta\text{D}_{\text{H}_2\text{O}}$ and $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ are collected in a 8 mL glass screw-top vial using a pre-rinsed 60 mL Luer-lock syringe with no headspace. The vials are then wrapped in parafilm to prevent leaking or contamination. For $\delta^{13}\text{C}_{\text{DIC}}$, the same syringe is fitted with a .45 μm glass/nylon filter and water is filtered into a 10 mL glass bottle and topped with 3 drops of benzalkonium chloride as a preservative. The bottle is then crimped shut with a 20 mm Teflon septa and aluminum cap with no headspace.

The three stable isotopes are analyzed at the WVU Stable Isotope lab using a Finnigan Delta Advantage continuous flow isotope ratio mass spectrometer connected with a ThermoQuest Finnigan GasBench II. $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ and $\delta\text{D}_{\text{H}_2\text{O}}$ are measured from the same aliquot of sample water, but different flushing gases and equilibration methods are used. A platinum catalyst is used to enhance equilibration for $\delta\text{D}_{\text{H}_2\text{O}}$ samples. The precision rate for $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ is $\pm 0.02\%$ and the precision rate for $\delta\text{D}_{\text{H}_2\text{O}}$ is $\pm 1\%$. The $\delta^{13}\text{C}_{\text{DIC}}$ samples are run in different vials separately from O and H and are acidified to enhance equilibration. The precision rate for $\delta^{13}\text{C}_{\text{DIC}}$ is $\pm 0.02\%$.

Dissolved gases and methane isotopes: Gas samples are collected in a 1 liter plastic Isotech dissolved gas bottle with a Teflon septa cap and a benzalkonium chloride capsule that releases into the water after sample collection to prevent microbial activity. The bottle is submerged into a clean 5-gallon bucket without the cap and the sample water tube is submerged at the bottom of the bottle (figure 10). The water flows at a rate of approximately 1 liter/min (control on flow velocity was varied at each site) into the bottle and sample water is cycled into the bottle until 3 sample volumes are exchanged. The bottle is then capped quickly underwater. The cap is wrapped in parafilm and samples are stored upside down to prevent gas from escaping.

Dissolved gas compositions and isotopes of methane and ethane are analyzed at Isotech laboratory. The gas analysis is performed using a headspace equilibration method. Water is removed through the septum at the top of the bottle and then an equivalent amount of helium is added to create between 30-60 mL of headspace at a dilution factor of 0.68. The bottle is then shaken for two hours to allow equilibrium of gases between the water and headspace. Gas composition is measured using a Shimadzu 2010 GC system and then concentrations of dissolved gas are calculated using Henry's Law. Gas composition analyses have a precision rate of $\pm 5\%$ for C_{1-4} and $\pm 10\%$ for C_{5-6+} .

For isotopes of methane and ethane, both an online and offline prep system are used depending on the concentrations of methane or ethane. When the concentrations are higher, an offline prep system is used that combines a Finnigan MAT Delta S Isotope Ratio Mass Spectrometer for carbon measurement and a Finnigan Delta Plus XL Isotope Ratio Mass Spectrometer for hydrogen. When concentrations are lower, a HP6890 GC connected to a ThermoFinnigan Delta Plus Advantage is used for measuring carbon, and a HP6890/7890 is connected with a Thermo Scientific Delta V Plus for measuring hydrogen. When the concentrations of methane are below 0.5% and the ethane concentrations are below 0.3% the analysis is performed with the online system. Higher concentrations of methane are required relative to ethane due to the increased number of carbons in the ethane molecule. The precision rate for offline preparation of gas isotopes is $\delta^{13}\text{C}_{\text{C1-2}}$ is $\pm 0.2\%$ and $\pm 2.0\%$ for $\delta\text{D}_{\text{C1-2}}$. The precision rate for online preparation of the gas isotopes is $\delta^{13}\text{C}_{\text{C1-2}}$ is $\pm 0.3\%$ and $\pm 5.0\%$ for $\delta\text{D}_{\text{C1-2}}$.

Results and Discussion

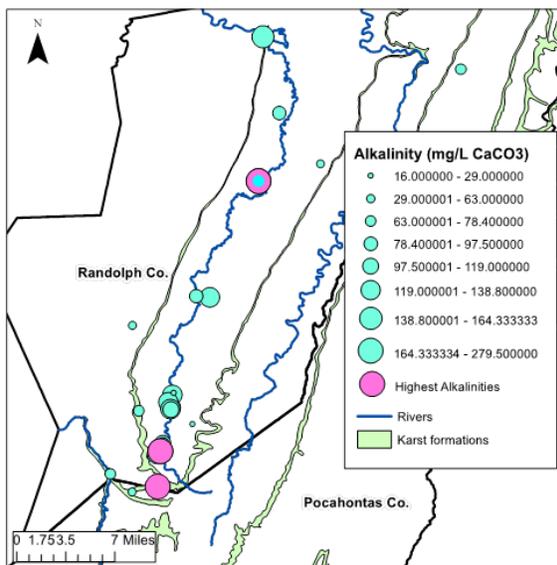


Figure 3: Alkalinity concentrations in sampled wells

positive linear correlation. While there is some indication that the Ca and Mg may be a source of ions in some of the wells (shallow positive linear correlation at low alkalinities) there is also a negative linear correlation between specific conductance values of 400-800 uS/cm (figure 4). This indicates that in these wells (Ran-19, Ran-21 and Ran-25) there are ions present that have little contribution to alkalinity. Again, further geochemical analysis will contribute to the understanding of this particular trend.

Field Parameters: Alkalinity and specific conductance were the two field parameters that showed variability throughout the study area. It is presumed that due to the occurrence of carbonate rock in the study area, this is the predominant source of alkalinity (figure 3). However, alkalinity shows no spatial trends related to limestone/karst occurrence. This indicates that there could either be another source of alkalinity in the study area (i.e. iron or phosphate) or there are more localized/well specific controls on alkalinity. Further geochemical analysis of the samples will help illuminate this trend. Alkalinity and specific conductance were plotted to understand whether Ca and Mg (potential sources of alkalinity) would show a

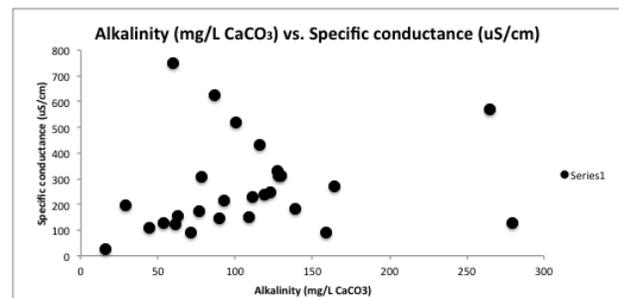
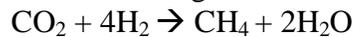


Figure 4: Plot of Alkalinity (mg/L CaCO_3) vs. Specific Conductance (uS/cm)

Dissolved Gas: Proper end member characterization of natural gas in situ is the most effective way to understand gas signatures occurring out of geologic context (Breen et al., 2005, Gorody, 2012). Methane occurring in groundwater can be produced in a variety of settings through numerous processes. The production of methane can generally be subdivided into three different categories; microbial, thermogenic and abiogenic methane (Coleman, 1995, Gorody, 2012). Microbial methane can be further divided into two different production methods: the CO₂ reduction process and acetate fermentation process (Baldassare and Laughrey, 1997, Breen et al., 2005, Coleman 1995, Martini et al., 1998, Révész et al, 2010, Whiticar, 1999, Whiticar et al., 1986). Each of these gas production categories results in methane with distinct signatures that can help us identify the potential source of stray occurring within wells in the study area.

$\delta^{13}\text{C-CH}_4$ and $\delta^2\text{H-CH}_4$: Carbon and hydrogen isotopes of methane are the most defining and widely used characteristic to determine the source of stray gas. Methane produced thermogenically is influenced by the pressure and temperature conditions at the time of gas formation as well as the type of organic material that the gas was produced from (Coleman, 1995). Potential sources of thermogenic gases in the study area include the Devonian Harell and Marcellus shales. Thermogenic gases native to the Appalachian basin have $\delta^{13}\text{C}_{\text{CH}_4}$ values that range from -55.1‰ to -27.2‰ and $\delta^2\text{H}_{\text{CH}_4}$ values that range from -303‰ to -150‰ (Baldassare and Laughrey, 1997). Maturity of thermogenic gases can also be assessed using gas isotopes with $\delta^{13}\text{C}_{\text{CH}_4}$ values becoming increasingly enriched with increasing thermal maturity (Whiticar, 1999).

Microbial gas can be produced by either CO₂ reduction or acetate fermentation (Baldassare and Laughrey, 1997, Coleman 1995, Martini et al., 1998, Révész et al, 2010, Whiticar, 1999, Whiticar et al., 1986). CO₂ reduction occurs when microbes use CO₂ and H₂ present in formation water to create methane in the following reaction:



This process generally occurs in a marine setting and results in more depleted $\delta^{13}\text{C}_{\text{CH}_4}$ and $\delta^2\text{H}_{\text{CH}_4}$ values than observed in thermogenic gas (Martini et al., 1998, Révész et al., 2010). CO₂ reduction methane produces gases with $\delta^{13}\text{C}_{\text{CH}_4}$ signatures of approximately -62‰ to -90‰ and $\delta^2\text{H}_{\text{CH}_4}$ signatures of about -180‰ to -240‰ (Breen et al., 2005). Relative to methane produced by acetate fermentation, CO₂ reduction methane $\delta^{13}\text{C}_{\text{CH}_4}$ tends to be more depleted and the $\delta^2\text{H}_{\text{CH}_4}$ tends to be slightly more enriched. Acetate fermentation occurs when methanogens, generally in a freshwater system, breakdown an

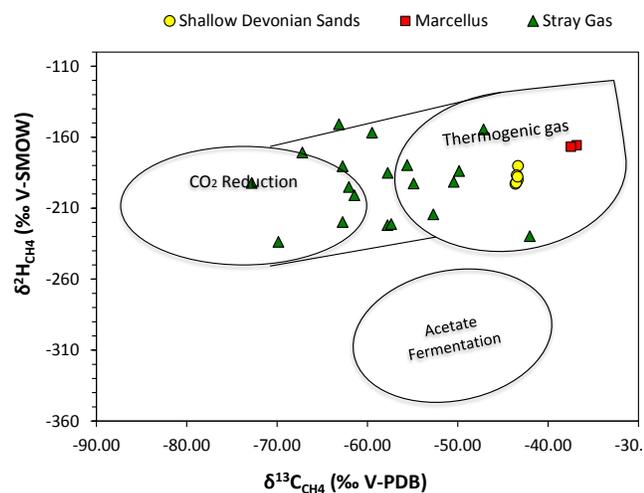
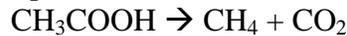


Figure 5: General classification of natural gas sources based on isotope compositions. Though carbon and hydrogen isotopes are somewhat diagnostic, more geochemical evidence must be integrated before defining source (Coleman, 1995). Plotted for comparison are GW sites (Mulder, 2012), Shallow Devonian sands gases and Marcellus shale gases.

organic compound that results in the production of CO₂ and CH₄ in the following reaction:



(Révész et al., 2010, Whiticar, 1999). In the acetate fermentation process, the hydrogen is slightly more depleted than during CO₂ reduction because the majority of the hydrogen atoms in the CH₄ molecules are derived from organic matter. In comparison, hydrogen is derived from formation water in the CO₂ reduction process (Révész et al., 2010, Whiticar, 1999, Whiticar et al., 1986). Acetate fermentation produced methane results in a δ¹³C_{CH₄} signature of approximately -40‰ to -62‰ and a δ²H_{CH₄} signature of -270‰ to -350‰ (Breen et al., 2005). Abiogenic, or mantle gas, is very uncommon and therefore is unlikely to be a source of stray gas (Coleman, 1995). The carbon and hydrogen isotopes are frequently used to distinguish between the thermogenic and biogenic origin of gases.

When stray gas samples from the study area are plotted on the dual carbon and hydrogen isotope plot the samples fall in the CO₂ reduction, thermogenic and mixed regions (figure 5). None of the sample fall in acetate fermentation category which is prominent pathway of biogenic methane formation in shallow freshwater aquifers. However, it's important to note that post genetic processes like migration, mixing and microbial oxidation can alter/modify these signatures. Further determination of whether the methane in specific wells is microbial in origin will be aided by results of additional geochemical analysis including CO₂ and δ¹³C_{DIC} analysis.

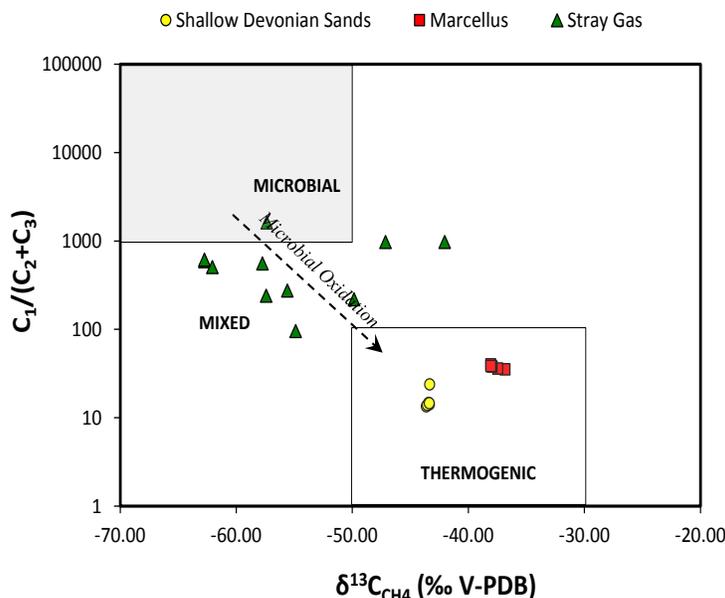


Figure 6: Plot of δ¹³C_{CH₄} vs. concentration of C₁/C₂+ hydrocarbons. Stray gas samples fall into the microbial and mixed areas of the plot which could indicate either the oxidation of microbial gas or the migration of thermogenic gas.

to distinguish the origin of gas occurring within wells in the study area (figure 6). Though initial isotopic and compositional results of dissolved methane in the study area indicate either oxidized microbial gas or migrated thermogenic gas, continuing isotopic analysis of the samples will further constrain the likely sources of stray gas.

Natural gas

compositions: Chemical compositions of natural gas can also be used as an indicator of whether the stray gas in the study area has a thermogenic or microbial origin. Thermogenic natural gas generally produces a larger volume of higher chain hydrocarbons such as ethane, propane and butane. Microbial processes generate a higher percentage of methane, with lower percentages of C₂+ hydrocarbons (Coleman, 1995, Osborn et al, 2011, Whiticar, 1999). A plot that combines δ¹³C_{CH₄} values with natural gas compositions is another way

Conclusions

Initial results show extreme variability in the geochemical and isotopic composition of dissolved gases and waters throughout the study area. The isotopic and molecular compositional analyses indicate that the stray gas is either of thermogenic and/or CO₂ reduction origin probably produced in deeper geological formations. There is no old/recent oil, gas, coalbed methane or shale gas drilling activity in the region. Therefore, it appears that gas has migrated into the shallow freshwater aquifers from the deeper formations through natural faults and fractures probably over geological time scales. Further geochemical and isotopic analyses will help clarify the effect of migration/mixing and microbial oxidation on isotopic and molecular composition of stray gas. Additionally, a more extensive fault/fracture dataset will be created to help determine potential natural migration pathways.

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Publications, Posters, and Talks

Publications:

- 1) Sharma S., Mulder M., Sack A., Schroeder K. and Hammack, R. 2013. Isotope approach to assess hydrologic connections during Marcellus Shale drilling. *Groundwater*. DOI: 10.1111/gwat.12083
- 2) Soeder D.J., Sharma S , Pekney N, Hopkinson L, Dilmore R., Kutcho B., Stewart B., Carter K., Hakala A., and Capo R. An approach for assessing engineering risk from shale gas wells in the United States. *International Journal of Coal Geology*. DOI: 10.1016/j.coal.2014.01.004

Conference Proceedings

- 1) Bowman, L., Sharma, S., Carr, T., and Sharma, M., 2014. Understanding Stray gas occurrences in Shallow aquifers in Randolph Co., West Virginia. GSA Southeastern Section Annual meeting 10-11 April, Blacksburg, VA.
- 2) Bowman, L., Sharma, S., Carr, T., and Sharma, M., 2013. A Geochemical and Isotopic study of Stray gas related to Structural and Topographic features in the Southern Appalachian basin. GSA Annual meeting 27-30 October, Denver, CO.
- 3) Sharma S., 2012. Use of stable isotopes in shale gas research: examples from the Appalachian Region of eastern USA. International Workshop on Exploration and Exploitation of Shale Gas, National Geophysical Research Institute, Hyderabad, 19-20 December, Hyderabad, India.
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- 5) Sharma S., Mulder M.L. Sack A. , Bowman, L. , Carr T., Schroeder K., Hammack, R., White, J., Chambers D. 2012. Understanding natural variations of dissolved methane in areas of accelerating Marcellus Shale gas development. GSA National Annual Meeting 4-7 November, Charlotte, NC.

Information Transfer Program

Student Support

Category	Number of students supported with 104b base grant	\$ Value of students supported with 104b base grant	Number of students supported with matching funds	\$ Value of student support with matching funds	Total number of students supported	Total \$ value of student support
Undergraduate	1					
Masters	1					
Ph.D.	0					
Post-Doc	0					
Total	2					

NOTABLE ACHIEVEMENTS AND AWARDS

- Two publications in peer-review international journals and one in process
- \$2 M collaborative research funding award from NSF to understand microbial methanogenesis in geological formations
- \$ 250K funding award from DOE-NETL to better understand gas migration pathways

Using geomorphic landform design principles to reduce selenium loads from West Virginia valley fills

Using geomorphic landform design principles to reduce selenium loads from West Virginia valley fills

Basic Information

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Congressional District:	First
Research Category:	Water Quality
Focus Category:	Water Quality, None, None
Descriptors:	
Principal Investigators:	Ben Mack, Leslie Hopkinson, John D. Quaranta

Publications

There are no publications.

Report title: Using geomorphic landform design principles to reduce selenium loads from West Virginia Valley fills

Type of report (annual or final): Annual

Reporting Period Start Date: March 1, 2013

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Principal Author(s): Leslie Hopkinson, John Quaranta, Ben Mack

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Name and address of submitting department(s):

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Abstract

Selenium is found in southern West Virginia coal seams and overburden. This selenium is leached into watersheds and is toxic in excessive concentrations. The objective of this study is to characterize leaching of mobile selenium for two WV valley fills. Unsaturated column leaching tests were performed on coal overburden samples from two southern WV surface mines. Duplicate 15.2 cm diameter columns containing each soil were periodically leached with simulated rain water (1,010 mL) similar in pH (~5.2) to southern WV rainfall. Leachate water was tested for dissolved selenium, dissolved metals, pH, specific conductance, sulfate, acidity, and alkalinity. Saturated tests were performed by filling a series of 3.8 L jars with each soil, saturating the jars, and collecting water samples after certain time intervals. The samples were tested for the same parameters as the unsaturated test. The desorption coefficients were calculated for each soil. Preliminary results indicate that conductivity ranges were 100-1132 $\mu\text{S}/\text{cm}$ and 503-2940 $\mu\text{S}/\text{cm}$ for the unsaturated and saturated tests, respectively. Maximum selenium concentrations occurred in the unsaturated tests during the first two samples (0.071-0.185 mg/L). The desorption coefficient varied by soil type but was consistent between replicated samples. Results from this work will be used in groundwater modeling.

Table of Contents

List of Figures.....	iv
List of Tables.....	iv
Research.....	1
Introduction	1
Experimental Methods	1
Site Description	1
Sampling Methods	2
Soil Testing.....	3
Testing Procedure	3
Unsaturated tests.....	3
Saturated tests.....	5
Results and Discussion.....	7
Soil.....	7
Unsaturated tests	7
Saturated tests	10
Conclusions.....	12
References.....	13
Appendix: Concentration Data	14

List of Figures

Figure 1. Area where overburden sample was obtained from Mine A	1
Figure 2. Overburden pile sample was obtained from Mine A	2
Figure 3. Area where overburden sample was obtained from Mine B	2
Figure 4. Overburden pile sample was obtained from Mine B	2
Figure 5. Two inch sieve being held over overburden collection tubs	3
Figure 6. Schematic of unsaturated testing column	4
Figure 7. Unsaturated column setup	4
Figure 8. Saturated jars being filled with soil	6
Figure 9. Soil being put through a 1 in sieve	6
Figure 10. Soil filled jar saturated with simulated rain water	6
Figure 11. Selenium concentrations (unsaturated tests)	8
Figure 12. Distribution of pH values (unsaturated tests)	9
Figure 13. Distribution of conductivity (unsaturated tests)	9
Figure 14. Distribution of total dissolved solids (unsaturated tests)	10
Figure 15. Selenium concentrations (saturated tests)	11
Figure 16. Distribution of pH values (saturated tests)	11
Figure 17. Distribution of conductivity (saturated tests)	12
Figure 18. Distribution of total dissolved solids (saturated tests)	12

List of Tables

Table 1. Unsaturated leaching schedule of 1,010 mL of simulated rainwater	5
Table 2. Saturated sampling schedule	7
Table 3. Unsaturated data for Mine A, sample 1; detection limit in italics	14
Table 4. Unsaturated data for Mine A, sample 2; detection limit in italics	14
Table 5. Unsaturated data for Mine B, sample 1; detection limit in italics; detection limit in italics	15
Table 6. Unsaturated data for Mine B, sample 2; detection limit in italics	15
Table 7. Saturated data for Mine A, sample 1; detection limit in italics	16
Table 8. Saturated data for Mine A, sample 2; detection limit in italics	16
Table 9. Saturated data for Mine B, sample 1; detection limit in italics	17
Table 10. Saturated data for Mine B, sample 2; detection limit in italics	17

Research

Introduction

Selenium is a water quality concern because it can be toxic in excessive concentrations. It is a naturally occurring element in the sedimentary rock and coal seams in Central Appalachia and can be released through mining practices (Vesper et al., 2008; Ziemkiewicz and Lovett, 2012). Overburden rock composed of organic shale (4.10 mg/kg) has selenium concentrations four times that of sandstone (Vesper et al., 2008). Approximately 25% of the total selenium found in overburden is mobile (Roy, 2005).

For WV coal mines, selenium discharges must meet the chronic aquatic life standard of 5 $\mu\text{g/L}$ (WVDEP, 2011). Many surface mines and tailings facilities require treatment to meet this value. Ziemkiewicz and Lovett (2012) proposed that selenium concentrations will reach this level within 25 years after initial mining.

The objective of this study is to characterize leaching of mobile selenium for two WV valley fills. Results will be used to determine if the selenium concentrations resulting from valley fill effluent can be controlled through geomorphic landform design principles.

Experimental Methods

Site Description

Overburden samples were collected from two active surface mines in southern West Virginia (July 9, 2013). Both samples had been relatively recently uncovered from their natural geological locations at the time of collection.



Figure 1. Area where overburden sample was obtained: Mine A



Figure 2. Overburden pile where sample was obtained: Mine A



Figure 3. Area where overburden sample was obtained: Mine B



Figure 4. Overburden pile where sample was obtained: Mine B

Sampling Methods

When collecting the material, caution was taken to obtain as high a portion of shale as possible. The shale was passed through a 2 in (5 cm) metal sieve prior to collection (Figure 5). The pieces of rock that did not pass the sieve were broken by hand as much as possible while using little effort. Large particles were removed from the sample.



Figure 5. Two inch sieve being held over overburden collection tubs

Soil Testing

The following tests will be performed on the two soil samples to determine their physical and engineering properties: Soil Classification-USCS (D-2487), Sieve/hydrometer (D-422), and Specific Gravity (D-854).

Testing Procedure

Unsaturated tests

A 1.5 ft. long (0.46 m), 6 in (15.2 cm) inside diameter PVC pipe was used for this leaching study as suggested by ASTM E2242. A 0.5 in (1.3 cm) hole was drilled through the center of the PVC end cap to allow drainage of the effluent from the bottom of the column setup. An Oatey 5 in (12.7 cm) stainless steel drainage grate with 0.375 in (0.95 cm) square openings was placed inside the end cap followed by a 6 in (15.2 cm) diameter piece of HB Wick Drains MD-88 wick drain filter fabric with US Sieve #170 pore size. The fabric was secured and the edge was sealed by applying a bead of silicone caulk between its edge and the side of the end cap. The stainless steel grate served to hold the weight of the soil above the drainage hole and allow free drainage of the soil. The filter fabric kept any soil particles from draining with the effluent and clogging the drain. The pipe was inserted into the end cap until secure. A 4 in (10.2 cm) long, 0.5 in (1.3 cm) outside diameter piece of flexible vinyl tubing was inserted to the bottom of the end cap and water sealed with grease sealant. A 6 in (15.2 cm) diameter piece of the wick drain filter fabric was placed on top of the soil once it was added. Four columns were setup in this configuration for the unsaturated leaching tests: two for each of the mine site soils (Figures 6 and 7).

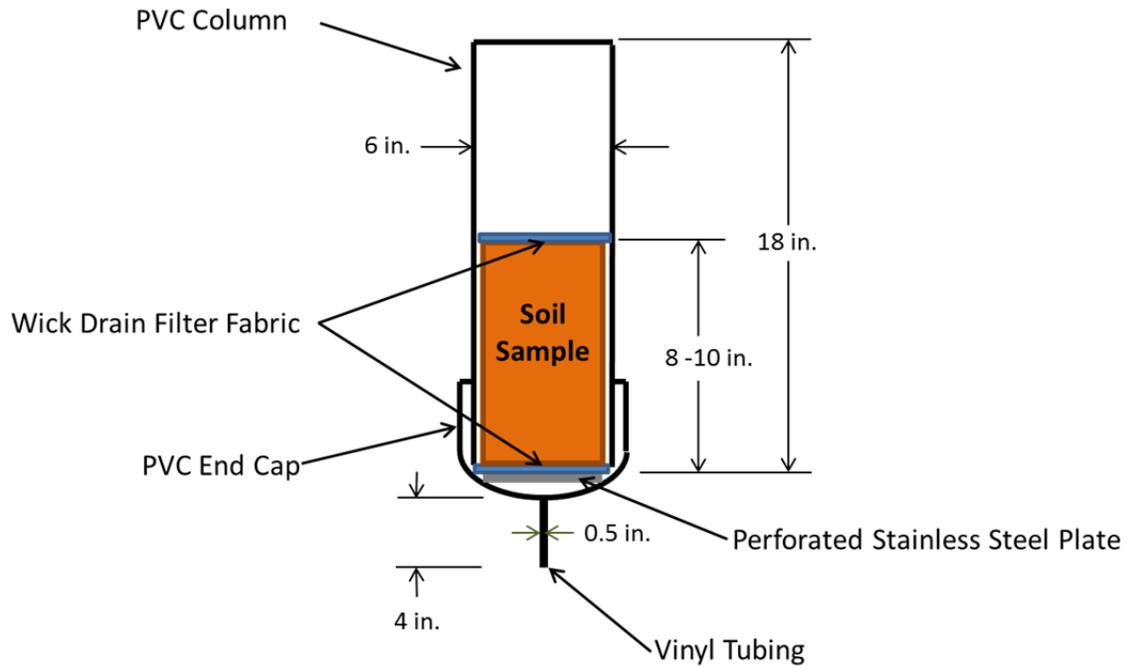


Figure 6. Schematic of unsaturated testing column.



Figure 7. Unsaturated column setup

A test sample was obtained from the overburden material collected from the mine site. To follow ASTM E2242, only the material that passed through a 2 in. sieve by hand-breaking was brought back to the lab. Five kilograms of overburden by dry weight were used for each unsaturated test. To obtain the actual weight (W_T) needed for 5 kilograms by dry weight (W_s), the following relationships were utilized:

$$W_w = w \times W_s \quad (1)$$

$$W_T = W_s + W_w \quad (2)$$

where W_w = weight of water;
 W_s = weight of solids;
 W_T = total weight; and,
 w = moisture content (Punmia et al. 2005).

The overburden sample was transferred to the column on top of the drainage plate and filter fabric at the bottom. Caution was used to prevent and excessive compaction or breaking of the soil particles by dropping the soil in diagonally or from a low drop (less than 20 cm). Once the soil was in place, a 6 in (15.2 cm) diameter piece of wick drain filter fabric was placed above the sample.

A series of pours was performed on two columns of each sample. Simulated rainwater was utilized for the testing to match the acidity of typical Appalachian precipitation (~5.2). A 2-yr, 12-hr storm of 5.5 cm for Madison, WV (NOAA Station 46-5563) was chosen for rainfall simulation. The weather station is close to both of the mine sites due to proximity (both within 16 km). Also, this volume of pour ensured sufficient effluent was collected to perform the lab testing. This pour of 1,010 mL was performed twice per week for each column (Table 1). The effluent was then filtered and sent to the WVU National Research Center for Coal and Energy Analytical Laboratory where it was analyzed for pH (EPA Method 150.1), alkalinity (SM2310A), acidity (SM2310B), sulfate (EPA Method 375.4), specific conductance (SM2510B), and dissolved Fe, Al, Ca, Mg, and Mn (EPA Method 200.7). REIC Consultants (Beaver, WV) analyzed the effluent for selenium (SM3114B). Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

Table 1. Unsaturated leaching schedule of 1,010 mL of simulated rainwater

AU1*	AU2*	BU1*	BU2*
8/13/13	8/13/13	8/13/13	8/13/13
8/15/13	8/15/13	8/15/13	8/15/13
8/20/13	8/20/13	8/20/13	8/20/13
8/27/13	8/27/13	8/27/13	8/27/13
9/3/13	9/3/13	9/3/13	9/3/13
9/10/13	9/10/13	9/10/13	9/10/13
9/12/13	9/12/13	9/12/13	9/12/13
9/17/13	9/17/13	9/17/13	9/17/13
9/19/13	9/19/13	9/19/13	9/19/13
9/25/13	9/25/13	9/25/13	9/25/13
9/27/13	9/27/13	9/27/13	9/27/13
10/1/13	10/1/13	10/1/13	10/1/13
10/8/13	10/8/13	10/8/13	10/8/13
10/11/13	10/11/13	10/11/13	10/11/13

*AU1=Mine A, unsaturated, replication 1; AU2=Mine A, unsaturated, replication 2; BU1=Mine B, unsaturated, replication 1; and, BU2=Mine B, unsaturated, replication 2.

Saturated tests

For the saturated tests, 3.8 L jars were filled with soil, starting with the largest rocks (Figure 8). The remaining soil was passed through a large 1 in (2.54 cm) sieve in order to obtain the rest of the largest particles (Figure 9). The portion retained was divided into the jars. This process was repeated with a 0.5 in (1.27 cm) sieve. The rest of the available soil was placed on top of the already added soil in the jars. The large pieces were added first to make sure that the top surfaces of the soil horizons in the jars were as flat and uniform as possible. This allowed for a more definite saturation volume when filling the jars with the simulated rain water. Mine A jars contained approximately 3.7 kg of soil, and Mine B jars contained approximately 4.4 kg of soil.

Jars were filled to the observed saturation point with simulated rainwater (pH~5.2). As the jars were being filled, the sides were lightly tapped and shaken to remove any air bubbles that remained. After saturation, jars containing the samples were sealed (Figure 10). Water samples were collected at predetermined intervals with one replicate per soil type (Table 2).



Figure 8. Saturated jars being filled with soil



Figure 9. Soil being put through a 1 in sieve



Figure 10. Soil filled jar saturated with simulated rain water

Table 2. Saturated sampling schedule

Sample IDs				Date of Fill	Date of Sampling	Number of Days Saturated
AS1-1	AS2-1	BS1-1	BS2-1	12/19/13	12/19/13	0.083 (2 hrs)
AS1-2	AS2-2	BS1-2	BS2-2	12/19/13	12/19/13	0.25 (6 hrs)
AS1-3	AS2-3	BS1-3	BS2-3	1/16/14	1/17/14	0.5 (12 hrs)
AS1-4	AS2-4	BS1-4	BS2-4	12/9/13	12/10/13	1
AS1-5	AS2-5	BS1-5	BS2-5	12/9/13	12/11/13	2
AS1-6	AS2-6	BS1-6	BS2-6	12/9/13	12/12/13	3
AS1-7	AS2-7	BS1-7	BS2-7	12/9/13	12/13/13	4
AS1-8	AS2-8	BS1-8	BS2-8	12/9/13	12/16/13	7
AS1-9	AS2-9	BS1-9	BS2-9	12/9/13	12/19/13	10
AS1-10	AS2-10	BS1-10	BS2-10	12/23/13	1/6/14	14
AS1-11	AS2-11	BS1-11	BS2-11	12/23/13	1/10/14	18
AS1-12	AS2-12	BS1-12	BS2-12	12/17/13	1/8/14	22
AS1-13	AS2-13	BS1-13	BS2-13	12/9/13	1/8/14	30
AS1-14	AS2-14	BS1-14	BS2-14	11/22/13	1/8/14	47

*AS1=Mine A, saturated, replication 1; AS2=Mine A, saturated, replication 2; BS1=Mine B, saturated, replication 1; and, BS2=Mine B, saturated, replication 2.

To collect the sample, mesh strainers with a coffee filter were used to minimize the amount of larger particles getting into the lab sampling bottles. Like the unsaturated experiment, WVU National Research Center for Coal and Energy Analytical Laboratory analyzed the samples for pH (EPA Method 150.1), alkalinity (SM2310A), acidity (SM2310B), sulfate (EPA Method 375.4), specific conductance (SM2510B), and dissolved Fe, Al, Ca, Mg, and Mn (EPA Method 200.7). REIC Consultants (Beaver, WV) analyzed the second sample for selenium (SM3114B). Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

Results and Discussion

Soil

Acid digestion of Mine A soil produced a total selenium concentration of 4.84 mg/kg. Acid digestion of Mine B soil produced a total selenium concentration of 1.26 mg/kg.

Unsaturated tests

For parameters selenium, pH, conductivity and total dissolved solids, equilibrium was reached by a leached volume of 10.1 L (Figures 11-14). Selenium concentrations (0.0038-0.18 mg/L) were on the same order of magnitude for each of the mine sites, AU and BU. Concentrations of Se were greater than the chronic aquatic life standard of 5 µg/L. Three outliers occurred for BU2 (samples 6-8) that were exactly one order of magnitude less than expected (Figure 13).

The pH values followed similar trends for both mine sites; the only variation occurred during the first two samples. The pH values reached an equilibrium value of 6.9 after the tenth sample (i.e. 10.1 L) (Figure 12).

Conductivity values for BU samples (240-1131 $\mu\text{S}/\text{cm}$) were on average approximately two times the values for AU (100-418 $\mu\text{S}/\text{cm}$) (Figure 13). TDS values were also greater for BU than AU (Figure 14). These differences are likely attributed to the differences in SO_4 , Mg, Mn, and Ca. Average concentrations of SO_4 , Mg, Mn, and Ca for BU were 2.6, 2.8, 5.0, and 2.0 times greater than AU, respectively. Concentrations of dissolved Fe were less than the detectable limit (0.02 mg/L) for 78% of AU samples and 61% of the BU samples. Concentrations of dissolved Al were less than the detectable limit (0.2 mg/L) for 81% and 92% of the samples for AU and BU, respectively (Tables 3-6).

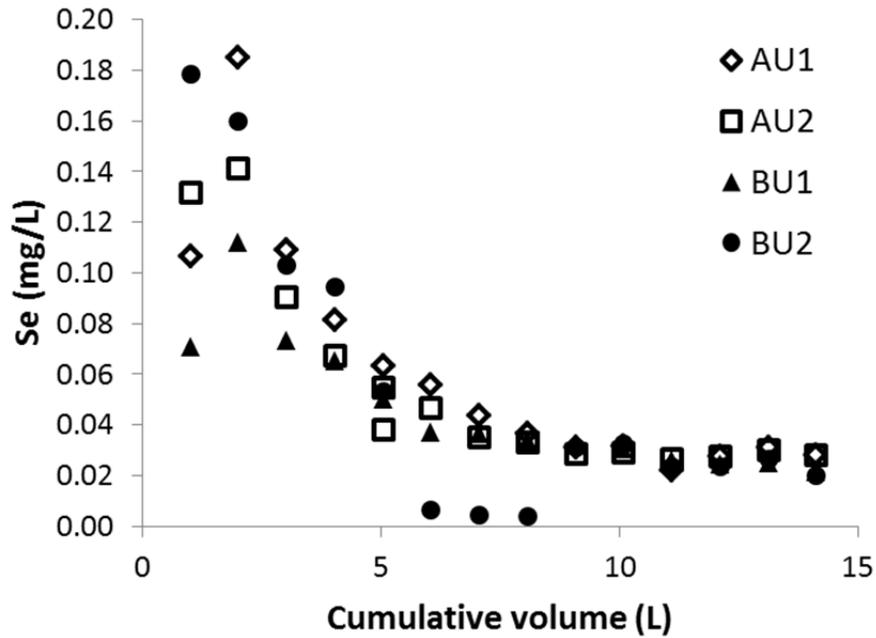


Figure 11. Selenium concentrations (unsaturated tests)

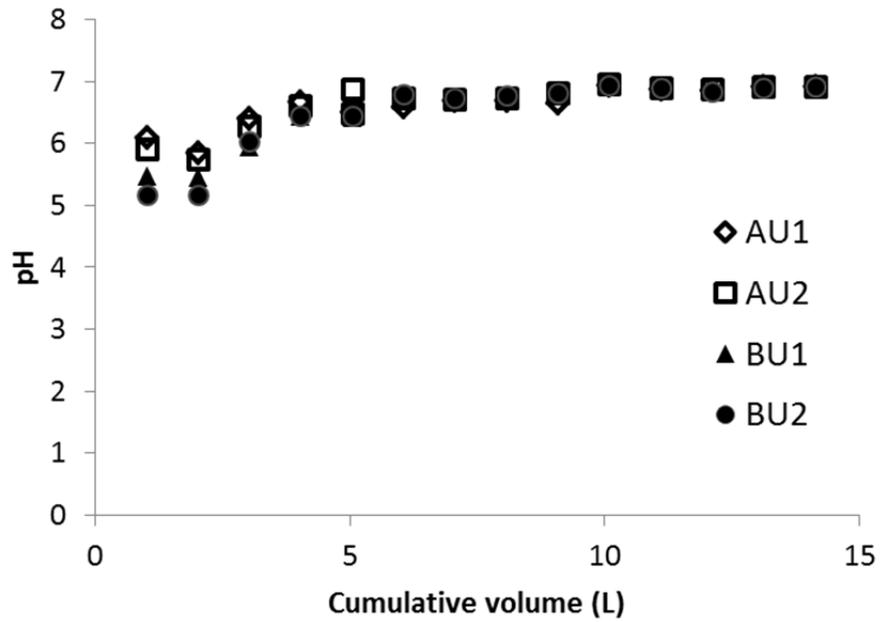


Figure 12. Distribution of pH values (unsaturated tests)

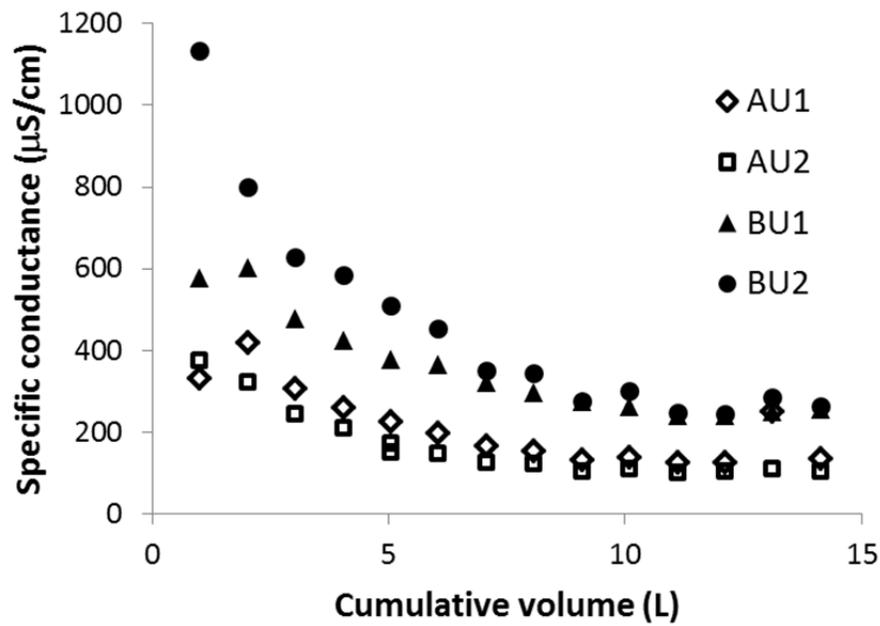


Figure 13. Distribution of conductivity (unsaturated tests)

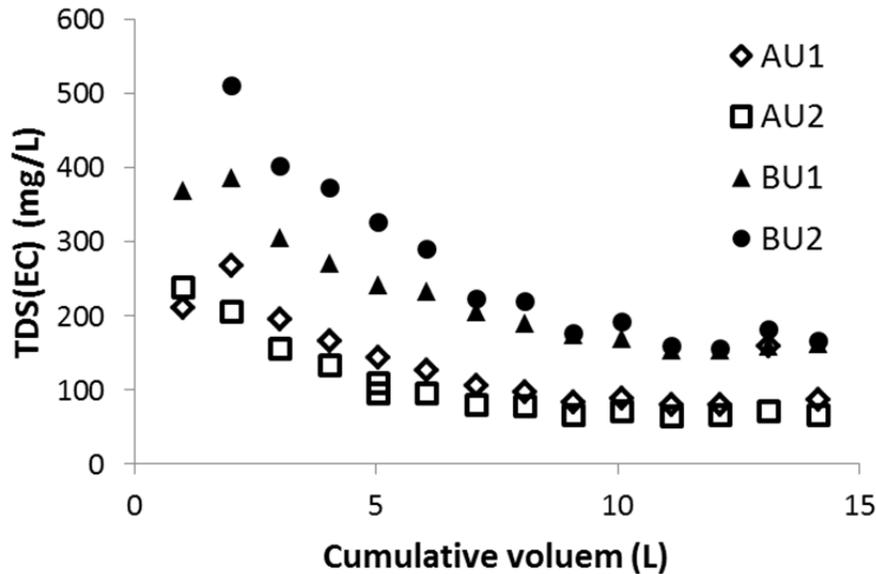


Figure 14. Distribution of total dissolved solids (unsaturated tests)

Saturated tests

Selenium concentrations increased substantially within the first day after saturation for all samples, reaching a value of 0.76 mg/L, 0.88 mg/L, 0.57 mg/L, and 0.50 mg/L for AS1, AS2, BS1, and BS2, respectively. While Se concentrations had a decreasing or stabilizing trend after the first 5-7 days, there was much variability (standard deviation (σ): $\sigma_{AS1} = 0.21$ mg/L, $\sigma_{AS2} = 0.23$ mg/L, $\sigma_{BU1} = 0.16$ mg/L, $\sigma_{BU2} = 0.23$ mg/L). Like the unsaturated tests, all selenium concentrations were greater than the chronic aquatic life standard (Figure 15). Desorption coefficients will be calculated with these data. Preliminary results indicated that the desorption coefficient for AS is on the order of 10^1 mL/g while the desorption coefficient for BS is on the order of 10^2 mL/g.

pH values (5.4-7.2) reached equilibrium 12-14 days after saturation for all samples. The equilibrium value was 7.2, 7.2, 6.9 and 6.8, for AS1, AS2, BS1, and BS2, respectively (Figure 16). These values are close to the 6.9 value reached in the unsaturated experiments.

Like the unsaturated tests, conductivity values for BS samples (1190-2940 μ S/cm) were, on average, two times the values for AS (503-1335 μ S/cm) (Figure 17). TDS values were also greater for BS than AS (Figure 18). These differences are also attributed to the differences in SO_4 , Mg, Mn, and Ca. Average concentrations of SO_4 , Mg, Mn, and Ca for BS were 2.5, 2.5, 5.0, and 1.9 times greater than AS, respectively; these differences are similar to the unsaturated results. Sixty percent of the Fe concentrations for AS were at or above detectable limits (average concentration = 0.13 mg/L). More than 90% of the Fe concentrations for BS were above detectable limits (average concentration = 1.0 mg/L). The majority of Al samples met detectable limits. The average Al concentrations for AS and BS were 0.54 and 0.50 mg/L, respectively (Tables 7-10).

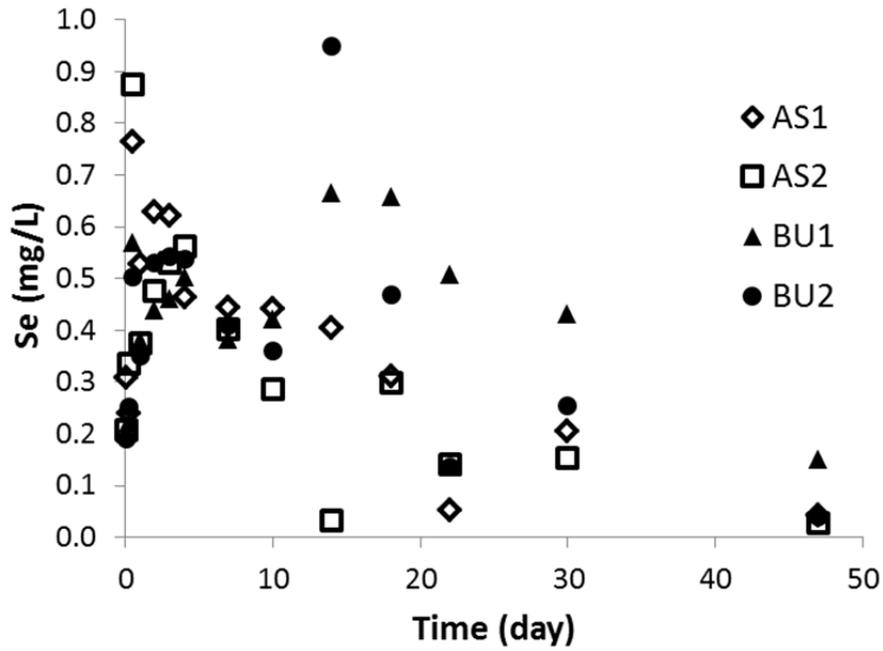


Figure 15. Selenium concentrations (saturated tests)

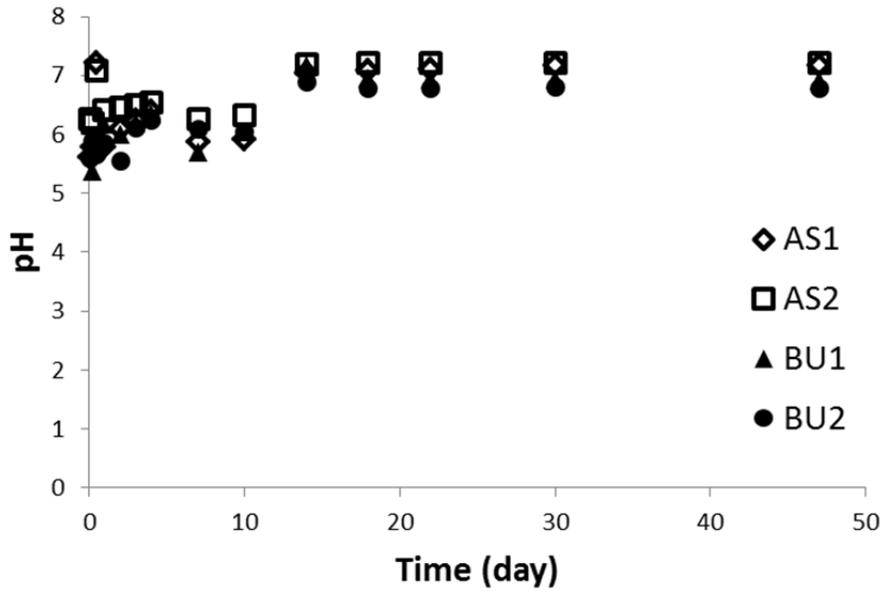


Figure 16. Distribution of pH values (saturated tests)

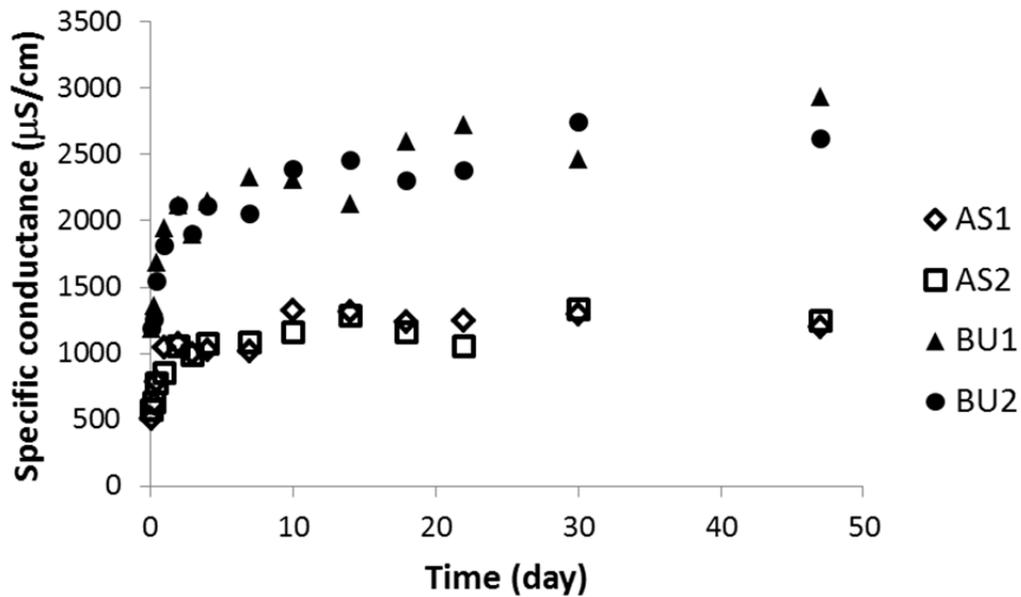


Figure 17. Distribution of conductivity (saturated tests)

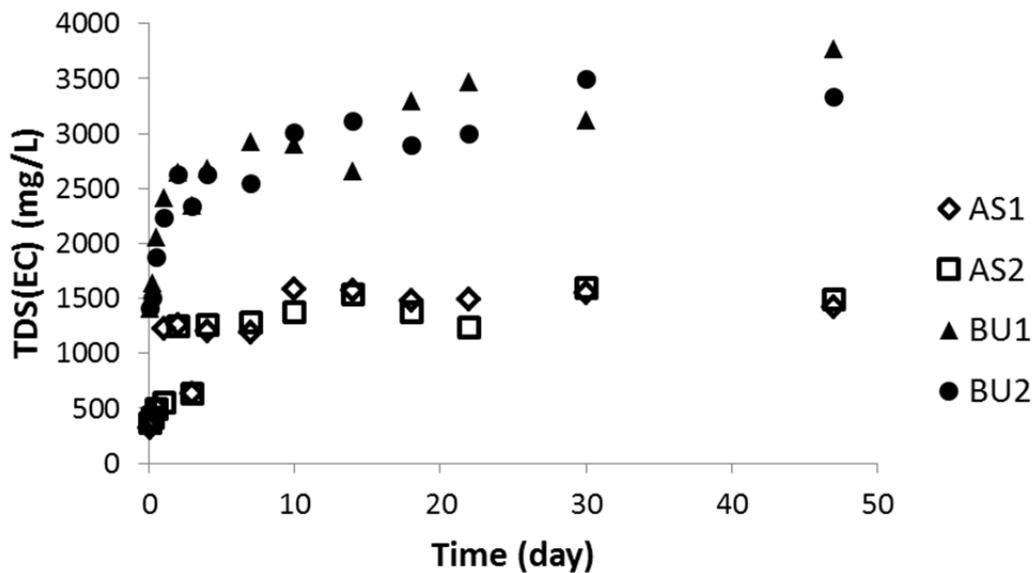


Figure 18. Distribution of total dissolved solids (saturated tests)

Conclusions

Experimental leaching studies were completed for two mine soils under both unsaturated and saturated conditions. Selenium, the main parameter of concern, reduced significantly within the first five leaching pours for the unsaturated condition; however, concentrations remained above the chronic aquatic life standard. There was a large amount of variability in the saturated

selenium results, but preliminary analysis indicates different desorption coefficients for the two different rock types. These results will be used in groundwater modeling to inform reclamation design.

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Appendix: Concentration Data

Table 3. Unsaturated data for Mine A, sample 1; detection limit in italics

Sample	Se (mg/L)	pH	Alk (mg/L)	Acd (mg/L)	SO ₄ (mg/L)	Cond. (μS/cm)	D.Fe (mg/L)	D.Al (mg/L)	D.Ca (mg/L)	D.Mg (mg/L)	D.Mn (mg/L)
<i>Detection</i>	<i>0.001</i>		<i>1.00</i>	<i>1.00</i>	<i>0.12</i>	<i>2.20</i>	<i>0.02</i>	<i>0.02</i>	<i>0.06</i>	<i>0.03</i>	<i>0.02</i>
AU1-1	0.1063	6.09	15.46	8.92	125	330					
AU1-2	0.1848	5.84	15.66	7.03	161	418	0.01	0.01	39.31	16.76	0.42
AU1-3	0.1091	6.4	12.96	8.63	128	305	0.02	0.05	30.35	12.1	0.36
AU1-4	0.0815	6.66	14.61	13.92	100	260	0.01	0.02	25.63	9.94	0.26
AU1-5	0.0632	6.51	16.36	5.36	77.3	226	0.01	0.01	21.6	8.36	0.23
AU1-6	0.0555	6.58	13.46	11.58	79	197.4	0.03	0.01	16.47	6.98	0.15
AU1-7	0.0438	6.69	12.95	8.13	61.3	164.7	0.04	0.02	13.03	5.69	0.15
AU1-8	0.0367	6.68	15.17	8.88	53.4	152.4	0.03	0.01	12.05	5.28	0.09
AU1-9	0.0309	6.64	15.2	10.04	46.2	131.8	0.03	0.01	9.92	4.51	0.08
AU1-10	0.0318	6.93	16.21	10.55	40.2	138.5	0.09	0.02	11.79	5.16	0.12
AU1-11	0.0218	6.87	16.45	5.24	35	125.4	0.03	0.01	10.14	4.59	0.09
AU1-12	0.0275	6.86	16.71	8.56	33.7	126.2	0.03	0.01	10.3	4.72	0.09
AU1-13	0.0308	6.91	5.71	19.5	102	249	0.03	0.01	19.36	11.72	0.63
AU1-14	0.0278	6.92	16.86	8.45	36.9	135.6	0.03	0.01	11.27	5.2	0.09

* Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

Table 4. Unsaturated data for Mine A, sample 2; detection limit in italics

Sample	Se (mg/L)	pH	Alk (mg/L)	Acd (mg/L)	SO ₄ (mg/L)	Cond. (μS/cm)	D.Fe (mg/L)	D.Al (mg/L)	D.Ca (mg/L)	D.Mg (mg/L)	D.Mn (mg/L)
<i>Detection</i>	<i>0.001</i>		<i>1.00</i>	<i>1.00</i>	<i>0.12</i>	<i>2.20</i>	<i>0.02</i>	<i>0.02</i>	<i>0.06</i>	<i>0.03</i>	<i>0.02</i>
AU2-1	0.1316	5.9	17.71	9.49	144	374					
AU2-2	0.1414	5.74	14.49	11.24	116	321	0.01	0.04	30.07	12.011	0.39
AU2-3	0.0903	6.28	9.81	11.03	96.8	244	0.01	0.01	22.88	8.81	0.17
AU2-4	0.0674	6.6	8.76	10.29	81.4	209	0.01	0.01	18.46	7.55	0.16
AU2-5a	0.0382	6.49	6.31	10.61	54.7	150.5	0.01	0.01	12.14	5.13	0.1
AU2-5b*	0.0545	6.88	17.06	10.84	56.4	171.1	0.06	0.01	16.13	5.64	0.11
AU2-6	0.0464	6.72	7.86	13.42	54.9	148.6	0.05	0.01	11.31	4.81	0.11
AU2-7	0.0349	6.71	8.81	11.69	48.6	125.3	0.03	0.01	9.29	4.01	0.08
AU2-8	0.033	6.72	10.61	13.39	42.6	121.3	0.03	0.01	8.74	3.82	0.08
AU2-9	0.0284	6.8	8.26	10.83	36.1	104.3	0.03	0.01	7.55	3.31	0.08
AU2-10	0.0289	6.95	12	15.81	30.8	110.9	0.02	0.01	8.89	3.78	0.09
AU2-11	0.0264	6.9	11.66	14.13	26.1	100	0.03	0.01	7.67	3.27	0.09
AU2-12	0.0275	6.87	10.06	11.71	27.1	102.4	0.03	0.01	7.92	3.4	0.09
AU2-13	0.0302	6.91	10.31	27.95	31	111.3	0.03	0.01	8.71	3.76	0.11
AU2-14	0.0278	6.92	12.33	11.03	27.8	104.6	0.03	0.01	8.06	3.48	0.09

*Two samples analyzed due to increased pour volume

** Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

Table 5. Unsaturated data for Mine B, sample 1; detection limit in italics; detection limit in italics

Sample	Se (mg/L)	pH	Alk (mg/L)	Acid (mg/L)	SO ₄ (mg/L)	Cond. (μS/cm)	D.Fe (mg/L)	D.Al (mg/L)	D.Ca (mg/L)	D.Mg (mg/L)	D.Mn (mg/L)
	<i>0.001</i>		<i>1.00</i>	<i>1.00</i>	<i>0.12</i>	<i>2.20</i>	<i>0.02</i>	<i>0.02</i>	<i>0.06</i>	<i>0.03</i>	<i>0.02</i>
BU1-1	0.071	5.47	2.51	26.31	262	576					
BU1-2	0.112	5.46	3.75	20.63	274	603	0.23	0.01	51.46	28.85	1.03
BU1-3	0.0734	5.95	3.5	17.93	204	478	0.02	0.01	43.89	23.86	0.89
BU1-4	0.0652	6.44	3.01	16.09	187	423	0.01	0.01	37.59	21	0.85
BU1-5	0.0504	6.42	3.21	14.79	164	378	0.01	0.01	31.22	18.1	0.73
BU1-6	0.0372	6.73	4.41	17.43	163	364	0.03	0.01	28.24	16.65	0.72
BU1-7	0.0365	6.75	4.52	19.02	133	322	0.03	0.01	24.35	14.4	0.63
BU1-8	0.0341	6.77	4.56	19.24	121	298	0.09	0.03	21.37	13.11	0.61
BU1-9	0.0328	6.85	3.95	20.02	112	274	0.03	0.01	20.39	12.48	0.57
BU1-10	0.0305	6.93	4.97	24.84	110	264	0.03	0.01	19.98	12.02	0.61
BU1-11	0.0261	6.92	5.76	17.29	99.7	242	0.03	0.01	18.46	11.04	0.57
BU1-12	0.0245	6.89	5.56	21.88	97.6	240	0.07	0.06	18.54	11.17	0.64
BU1-13	0.0248	6.91	5.71	19.5	102	249	0.03	0.01	19.36	11.72	0.63
BU1-14	0.0216	6.95	5.76	24.8	103	255	0.03	0.01	19.33	11.46	0.64

* Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

Table 6. Unsaturated data for Mine B, sample 2; detection limit in italics

Sample ID	Se (mg/L)	pH	Alk (mg/L)	Acid (mg/L)	SO ₄ (mg/L)	Cond. (μS/cm)	D.Fe (mg/L)	D.Al (mg/L)	D.Ca (mg/L)	D.Mg (mg/L)	D.Mn (mg/L)
	<i>0.001</i>		<i>1.00</i>	<i>1.00</i>	<i>0.12</i>	<i>2.20</i>	<i>0.02</i>	<i>0.02</i>	<i>0.06</i>	<i>0.03</i>	<i>0.02</i>
BU2-1	0.1783	5.17	4.4	13.21	597	1132					
BU2-2	0.1600	5.16	4.44	19.01	380	798	0.11	0.01	76.29	44.32	1.63
BU2-3	0.1028	6.03	4.65	16.33	274	628	0.02	0.01	67	35.74	1.41
BU2-4	0.0943	6.44	4.46	17.6	250	584	0.01	0.01	54.93	30.18	1.27
BU2-5	0.0532	6.44	5.71	13.72	214	510	0.01	0.01	43.97	24.6	1.15
BU2-6	0.0063	6.78	6.06	18.16	256	454	0.03	0.01	37.03	21.21	1.01
BU2-7	0.0043	6.73	6.06	16.46	143	349	0.03	0.01	27.19	15.72	0.77
BU2-8	0.0038	6.76	8.31	18.13	137	342	0.03	0.01	25.89	15.27	0.84
BU2-9	0.0313	6.81	7.51	20.65	108	276	0.03	0.01	19.98	11.86	0.68
BU2-10	0.0324	6.93	7.96	16.34	125	300	0.02	0.01	23.88	13.6	0.79
BU2-11	0.0235	6.90	8.41	16.54	98.1	248	0.03	0.01	19.14	10.99	0.67
BU2-12	0.0237	6.84	9	15.85	93.5	244	0.03	0.01	18.72	10.92	0.72
BU2-13	0.0263	6.9	9.91	23.56	116	284	0.03	0.01	22.84	13.15	0.86
BU2-14	0.02	6.92	8.76	17.72	104	261	0.02	0.01	20.33	11.83	0.79

* Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

Table 7. Saturated data for Mine A, sample 1; detection limit in italics

Sample	Se (mg/L)	pH pH	Alk (mg/L)	Acd (mg/L)	SO₄ (mg/L)	Cond. (μ S/cm)	D.Al (mg/L)	D.Ca (mg/L)	D.Fe (mg/L)	D.Mg (mg/L)	D.Mn (mg/L)
	<i>0.001</i>		<i>1.00</i>	<i>1.00</i>	<i>0.12</i>	<i>2.20</i>	<i>0.02</i>	<i>0.06</i>	<i>0.02</i>	<i>0.03</i>	<i>0.02</i>
AS1-1	0.3076	5.61	12.82	22.48	214	503	0.11	40.87	0.01	19.5	0.34
AS1-2	0.2394	5.79	16.26	19.18	280	625	0.46	53.7	0.01	25.6	0.35
AS1-3	0.764	7.22	23.26	38.91	356.5	782	0.06	84	0.06	35.13	0.53
AS1-4	0.5285	5.78	14.56	30.83	595	1043	0.05	147.68	0.18	61.9	1.08
AS1-5	0.6293	6.08	21.56	25.04	555	1075	0.04	149.9	0.08	62.84	1
AS1-6	0.6214	6.23	22.51	19.75	437	995	0.03	131.55	0.09	55.94	0.84
AS1-7	0.4645	6.38	21.76	19.38	525	1024	0.03	142.04	0.1	61.87	0.98
AS1-8	0.4436	5.87	28.1	9.26	472.5	1013	0.01	102.03	0.01	46.67	0.83
AS1-9	0.4414	5.91	23.95	16.04	665	1320	0.01	145.86	0.01	69.36	1.58
AS1-10	0.4042	7.03	39.45	19.2	660	1314	4.43	166.13	0.68	70.15	1.4
AS1-11	0.3107	7.09	41.26	4.12	626	1238	0.36	154.88	0.03	66.37	1.23
AS1-12	0.0509	7.11	44.71	1.12	632	1251	0.3	167.66	0.02	72.44	1.54
AS1-13	0.2055	7.16	56.21	0.5	655	1298	0.74	162.05	0.08	70	1.51
AS1-14	0.042	7.18	54.96	0.5	577	1198	0.76	143.75	0.09	63.39	1.54

* Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

Table 8. Saturated data for Mine A, sample 2; detection limit in italics

Sample	Se (mg/L)	pH pH	Alk (mg/L)	Acd (mg/L)	SO₄ (mg/L)	Cond. (μ S/cm)	D.Al (mg/L)	D.Ca (mg/L)	D.Fe (mg/L)	D.Mg (mg/L)	D.Mn (mg/L)
	<i>0.001</i>		<i>1.00</i>	<i>1.00</i>	<i>0.12</i>	<i>2.20</i>	<i>0.02</i>	<i>0.06</i>	<i>0.02</i>	<i>0.03</i>	<i>0.02</i>
AS2-1	0.2075	6.26	9.71	24.02	232.5	574	0.01	51.77	0.01	23.94	0.42
AS2-2	0.3359	6.2	11.06	33.52	252	635	0.01	58.35	0.01	27.72	0.4
AS2-3	0.8752	7.08	17.36	23.5	396	775	0.01	85.49	0.01	36.04	0.6
AS2-4	0.3748	6.41	15.96	18.77	398.5	852	0.03	113.09	0.08	46.79	0.68
AS2-5	0.4769	6.46	19.46	26.48	525	1057	0.03	147.08	0.1	61.48	0.92
AS2-6	0.5299	6.49	23.46	14.56	492.5	987	0.06	137.52	0.11	59.13	0.86
AS2-7	0.5624	6.54	23.25	17.23	545	1073	0.04	150.38	0.08	64.13	1.03
AS2-8	0.403	6.26	27.89	13.66	535	1087	0.74	117.52	0.07	54.07	0.79
AS2-9	0.2851	6.33	48.86	0.5	550	1162	0.01	128.08	0.01	60.01	0.93
AS2-10	0.0325	7.2	37.16	9.79	659	1288	2.86	158.96	0.42	66.77	1.25
AS2-11	0.2985	7.21	37.36	4.04	583	1164	0.28	138.67	0.01	58.95	1.28
AS2-12	0.1407	7.21	38.75	3.45	502	1056	0.07	127.57	0.01	54.26	1.21
AS2-13	0.1526	7.21	48.81	0.5	670	1335	0.37	168.59	0.02	71.88	1.58
AS2-14	0.0278	7.21	42.36	4.67	610	1249	0.17	156.14	0.01	66.7	2.02

* Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

Table 9. Saturated data for Mine B, sample 1; detection limit in italics

Sample ID	Se (mg/L)	pH pH	Alk (mg/L)	Acid (mg/L)	SO₄ (mg/L)	Cond. (μS/cm)	D.Al (mg/L)	D.Ca (mg/L)	D.Fe (mg/L)	D.Mg (mg/L)	D.Mn (mg/L)
<i>Detection</i>	<i>0.001</i>		<i>1.00</i>	<i>1.00</i>	<i>0.12</i>	<i>2.20</i>	<i>0.02</i>	<i>0.06</i>	<i>0.02</i>	<i>0.03</i>	<i>0.02</i>
BS1-1	0.2	5.74	6.9	43.75	650	1192	0.19	107.9	0.42	59.38	1.72
BS1-2	0.2225	5.38	6.56	51.72	715	1363	0.01	113.72	0.93	73.76	2.24
BS1-3	0.5693	5.96	7.75	65.52	991	1686	0.01	195.62	0.05	105.67	3.13
BS1-4	0.3787	6.18	6.72	53.45	1190	1949	0.05	283.13	0.45	155.14	4.64
BS1-5	0.439	6.01	7.06	53.18	1340	2120	0.05	315.92	1.03	171.71	5.36
BS1-6	0.4602	6.2	8.31	45.25	1160	1902	0.06	276.52	0.21	153.25	4.47
BS1-7	0.5034	6.34	6.77	73.32	1360	2150	0.07	335.39	0.7	188.05	5.98
BS1-8	0.3819	5.7	6.91	55.24	1400	2330	0.01	244.84	0.31	156.38	5.49
BS1-9	0.4217	6.05	8.17	53.96	1350	2310	0.01	246.11	0.01	158.78	5.97
BS1-10	0.6661	7.18	12.91	63.39	1320	2130	3.26	216.43	1	115.97	4.35
BS1-11	0.6579	6.95	12.95	62.66	1700	2600	1.31	266.28	0.66	145.17	6.51
BS1-12	0.5072	6.94	16.29	55.29	1608	2720	1.52	281.26	0.46	156.3	7.09
BS1-13	0.4319	6.93	18.26	48.71	1590	2470	0.34	267.51	0.64	152.54	7.05
BS1-14	0.1502	6.9	29.96	54.1	1910	2940	0.55	329.41	0.3	193.08	10.49

* Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

Table 10. Saturated data for Mine B, sample 2; detection limit in italics

Sample	Se (mg/L)	pH pH	Alk (mg/L)	Acid (mg/L)	SO₄ (mg/L)	Cond. (μS/cm)	D.Al (mg/L)	D.Ca (mg/L)	D.Fe (mg/L)	D.Mg (mg/L)	D.Mn (mg/L)
<i>Detection</i>	<i>0.001</i>		<i>1.00</i>	<i>1.00</i>	<i>0.12</i>	<i>2.20</i>	<i>0.02</i>	<i>0.06</i>	<i>0.02</i>	<i>0.03</i>	<i>0.02</i>
BS2-1	0.1907	5.58	6.78	45.25	610	1190	0.29	105.2	0.28	57.72	1.67
BS2-2	0.2511	5.89	8.4	39.1	665	1260	0.23	109.73	0.2	63.05	1.7
BS2-3	0.5035	5.66	8.18	56.56	854	1542	0.01	174.17	0.14	93.34	2.72
BS2-4	0.3494	5.84	6.38	56.48	1230	1812	0.05	262.07	2.06	143.63	4.1
BS2-5	0.5311	5.54	6.86	80.63	1430	2110	0.05	301.15	12.17	166.67	5.09
BS2-6	0.5432	6.11	7.16	46.85	1170	1895	0.06	291.92	1.18	162.26	4.55
BS2-7	0.5383	6.24	8.61	50.93	1330	2110	0.07	331.91	0.38	185.01	5.86
BS2-8	0.4087	6.08	10.65	46.7	1220	2050	0.01	200.08	0.43	117.48	3.65
BS2-9	0.3605	6.04	10.46	57.21	1440	2390	0.01	261.58	0.01	166.07	6.12
BS2-10	0.9477	6.88	13.16	53.96	1540	2460	1.42	260.79	0.38	144.01	5.51
BS2-11	0.4685	6.77	11.05	50.82	1440	2300	0.45	233.64	0.79	128.58	5.21
BS2-12	0.135	6.77	20.11	44.55	1490	2380	0.14	250.07	0.64	138.56	5.85
BS2-13	0.2537	6.8	24.62	53.08	1800	2740	0.16	304.69	0.21	172.41	8.49
BS2-14	0.0397	6.77	17.01	58.21	1670	2620	0.23	262.32	2.07	148.42	8.47

* Values less than the detection limit were recorded as half of the detection limit (USEPA, 1998).

1. Publications:

NA

2. Information Transfer Program:

- Abstract accepted to present at the West Virginia Academy of Science meeting in April 2014 (abstract to be published).
- Abstract accepted to present at the Annual AEES meeting in June 2014 (abstract to be published)

3. Student Support:

Category	Number of students supported with 104b base grant	\$ Value of students supported with 104b base grant	Number of students supported with matching funds	\$ Value of student support with matching funds	Total number of students supported	Total \$ value of student support
Undergraduate						
Masters	1				1	
Ph.D.						
Post-Doc						
Total	1				1	

4. Notable Achievements and Awards:

Monongahela River Basin TDS Calculation PA and WV

Basic Information

Title:	Monongahela River Basin TDS Calculation PA and WV
Project Number:	2013WV215S
Start Date:	3/8/2013
End Date:	2/28/2014
Funding Source:	Supplemental
Congressional District:	
Research Category:	Water Quality
Focus Category:	Water Quality, Non Point Pollution, Surface Water
Descriptors:	
Principal Investigators:	Paul Ziemkiewicz, Paul Ziemkiewicz

Publications

There are no publications.

**USACE Project WRI-163a:
Monongahela River Basin TDS Calculation Study
Pennsylvania and West Virginia**

Draft Final Report

Grant/Contract No.: G13AP00015

**Reporting Period
From: March 1, 2013
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1. Abstract

This study developed and calibrated a mass balance Microsoft Excel 2007 spreadsheet tool that can forecast the mean TDS concentration at specified points on the Monongahela River. Included in the spreadsheet's TDS calculations are estimation calculations of the uncertainty of the calculated TDS concentrations based upon Taylor (1997).

This study also developed a process for managing industrial discharges from known sources to maintain TDS below the USEPA secondary drinking water standards. The spreadsheet can be used to calculate TDS concentrations with various levels of AMD treatment plant pumping rates to determine the maximum pumping rate consistent with the maintenance of USEPA secondary drinking water standards in the Monongahela River.

2. Table of Contents

Contents

1. Abstract.....	2
2. Table of Contents.....	3
3. Executive Summary.....	4
4. Introduction	4
5. Workplan Goals and/or Objectives.....	4
a. Task 1: Develop Spreadsheet.....	4
b. Task 2: Calibrate Spreadsheet.....	4
6. Experimental Methods.....	5
a. Task 1: Develop Spreadsheet.....	5
b. Task 2: Calibrate Spreadsheet.....	10
7. Results and Discussion	10
8. Conclusions	11
9. References	11
10. Tables.....	12
11. Figures.....	16
12. Publications.....	20
13. Information Transfer Program	20
14. Student Support.....	20
15. Notable Achievements and Awards.....	20

3. Executive Summary

This study developed and calibrated a mass balance Microsoft Excel 2007 spreadsheet tool that can forecast the mean TDS concentration at specified points on the Monongahela River and developed a process for managing industrial discharges from known sources to maintain TDS below the USEPA secondary drinking water standards. Included in the spreadsheet's TDS calculations are estimation calculations of the uncertainty of the calculated TDS concentrations based upon Taylor (1997). The developed spreadsheet will allow Corps, industry and other agency managers to easily calculate allowable discharge loadings and resulting concentrations at the nearest, downstream gauged point along the Monongahela River. Future work in this area should be devoted towards expanding the scope of the spreadsheet to the entire Pittsburgh USACE district and the installation of USGS stream gages to some or all of the ungauged Monongahela River tributaries.

4. Introduction

The purpose of this study is to develop a spreadsheet tool that can forecast the mean TDS concentration at specified points on the Monongahela River and develop a process for managing industrial discharges from known sources to maintain TDS below the USEPA secondary drinking water standards. The project will produce a spreadsheet that will allow Corps, industry and other agency managers to easily calculate allowable discharge loadings and resulting concentrations at the nearest, downstream gauged point along the Monongahela River.

5. Workplan Goals and/or Objectives

a. Task 1: Develop Spreadsheet

The goal of this task was to develop a Microsoft Excel spreadsheet tool to perform a mass balance of TDS concentration for the Monongahela River at RM 102, 89, 82, 61, 23, and 11. The tool was written in Visual Basic for Applications and used Microsoft Excel for the tool's input and output.

b. Task 2: Calibrate Spreadsheet

The goals of this task were to ensure that all of the major sources of TDS have been accounted for in the Monongahela River mass balance that is calculated by the spreadsheet tool designed in Task 1 and that the spreadsheet replicates observed TDS concentrations at RM 82 and 23.

6. Experimental Methods

a. Task 1: Develop Spreadsheet

The tributary streams contributing to the Monongahela River mass balances are listed in Table 1, the AMD treatment plants included in the mass balances are listed in Table 2, and the AML sources are listed in Table 3.

The discharge flow rate for the Monongahela River at RM 102 was calculated by summing the discharge flow rates of the West Fork River, Tygart Valley River, Indian Creek, Whiteday Creek, and Flaggy Meadow Run. The TDS load for the Monongahela River at RM 102 was calculated by summing the loads for the aforementioned streams plus the loads from the AMD treatment plants listed in Table 2 and the AML sources listed in Table 3 for RM 102.

The discharge flow rate calculated by the tool for the Monongahela River at RM 89 was calculated by summing the discharge flow rates for the Monongahela River at RM 102 and for Decker's Creek and Robinson Run. The TDS load for the Monongahela River at RM 89 was calculated by summing the loads for the Monongahela River at RM 102, the loads for the aforementioned streams, the loads from the AMD treatment plants listed in Table 2 for RM 89, and the loads from the AML sources listed in Table 3 for RM 89.

The discharge flow rate calculated by the tool for the Monongahela River at RM 82 was calculated by summing the discharge flow rates for the Monongahela River at RM 89 and Cheat River, Dunkard Creek, and Whitley Creek. The TDS load for the Monongahela River at RM 82 was calculated by summing the loads for the Monongahela River at RM 89, the loads for the aforementioned streams, the loads from the AMD treatment plants listed in Table 2 for RM 82, and the loads from the AML sources listed in Table 3 for RM 82.

The discharge flow rate calculated by the tool for the Monongahela River at RM 61 was calculated by summing the discharge flow rates for the Monongahela River at RM 82 and Tenmile Creek. The TDS load for the Monongahela River at RM 61 was calculated by summing the loads for the Monongahela River at RM 82, the loads for the aforementioned streams, the loads from the AMD treatment plants listed in Table 2 for RM 61, and the loads from the AML sources listed in Table 3 for RM 61.

Because there are no major tributaries to the river between RM 61 and RM23, the discharge flow rate at RM 23 was calculated by multiplying the discharge flow rate at RM 61 by the drainage area at RM 23 and dividing by the drainage area at RM 61. Because there are no treatment plant loads below RM 61, the TDS load for the Monongahela River at RM 23 was calculated by summing the loads for the Monongahela River at RM 61 and the loads from the AML sources listed in Table 3 for RM 23.

The discharge flow rate calculated by the tool for the Monongahela River at RM 11 was calculated by summing the discharge flow rates for the Monongahela River at RM 23 and Youghiogheny River. The TDS load for the Monongahela River at RM 11 was calculated by

summing the loads for the Monongahela River at RM 82, the loads for the Youghiogheny River, and the loads from the AML sources listed in Table 3 for RM 11.

The tributary streams contributing to the Monongahela River mass balances are listed in Table 1. Some of those streams have USGS gages near the mouth, and those streams are noted in Table 1. The mean daily discharge flow rate of those streams without gages has to be estimated from the mean daily discharge flow rate data from those streams with gages.

Discharge flow rate data from the Buffalo Creek and Dunkard Creek gages were compared using the following general formula. This formula is also used when data is not available for a particular gage or the gage is not working properly.

$$\frac{Q_1}{Q_2} = \left(\frac{A_1}{A_2} \right)^m \quad (1)$$

Where:

Q_1	=	Discharge flow rate at Dunkard Creek gage, ft ³ /s.
Q_2	=	Discharge flow rate at Buffalo Creek gage, ft ³ /s.
A_1	=	Drainage area of the Dunkard Creek gage, 229 mi ² .
A_2	=	Drainage area of the Buffalo Creek gage, 116 mi ² .
m	=	Empirical dimensionless constant, 0.7409.

The empirical dimensionless constant was calculated with the sum of the mean daily discharge flow rate data from each gage from January 1, 1941 to December 31, 2006 and equation (1). This period was selected because it was within the period of record for both gages and before the hydrograph for Dunkard Creek gage was modified by local mining activities. The mean daily discharge flow rate data and the line defined by this calculation are shown in Figure 1.

$$m = \ln(\sum Q_1 / \sum Q_2) / \ln(A_1 / A_2) \quad (2)$$

Because storms tend to pass from west to east across the Monongahela River, the discharge flow rate from ungaged tributary streams on the west side of the Monongahela River will be estimated from the data for the Buffalo Creek and Dunkard Creek gages, and the discharge flow rate from ungaged tributary streams on the east side of the river will be estimated from the Deckers Creek gage. Indian Creek (20 mi²) and Flaggy Meadow Run (1.6 mi²) are on the west side of the river. Whiteday Creek (33 mi²) is on the east side of the river. Applying equation (1) to Whiteday Creek:

$$\frac{Q_{WC}}{Q_{DC}} = \left(\frac{A_{WC}}{A_{DC}} \right)^m = \left(\frac{33}{63.2} \right)^{0.7409} = 0.6179 \quad (3)$$

Applying equation (1) to Indian Creek and Flaggy Meadow Run:

$$\frac{Q_{IC}}{Q_{BC}} = \left(\frac{A_{IC}}{A_{BC}} \right)^m = \left(\frac{20}{116} \right)^{0.7409} = 0.2719 \quad (4)$$

$$\frac{Q_{FMR}}{Q_{BC}} = \left(\frac{A_{FMR}}{A_{BC}} \right)^m = \left(\frac{1.6}{116} \right)^{0.7409} = 0.04185 \quad (5)$$

The remaining ungaged tributaries in the Upper Monongahela River watershed are Robinson Run (7.6 mi²), Whiteley Creek (0.784 mi²), and Tenmile Creek (67.4 mi²). Robinson Run, Whiteley Creek, and Tenmile Creek are on the west side of the river. Applying equation (1) to Robinson Run using the closer Dunkard Creek (229 mi²) gage:

$$\frac{Q_{RR}}{Q_D} = \left(\frac{A_{RR}}{A_D} \right)^m = \left(\frac{7.6}{229} \right)^{0.7409} = 0.08020 \quad (6)$$

Whiteley Creek (54.4 mi²) and Tenmile Creek (67.4 mi²) are near the USGS gage South Fork of Tenmile Creek (22.3 mi²). Applying equation (1) to these tributaries:

$$\frac{Q_{TC}}{Q_{SFTC}} = \left(\frac{A_{TC}}{A_{SFTC}} \right)^m = \left(\frac{67.4}{22.3} \right)^{0.7409} = 2.269 \quad (7)$$

$$\frac{Q_W}{Q_{SFTC}} = \left(\frac{A_W}{A_{SFTC}} \right)^m = \left(\frac{54.4}{22.3} \right)^{0.7409} = 1.936 \quad (8)$$

While the upstream portions of the Cheat River are gaged, the mouth of the Cheat River is not gaged because the mouth is downstream of Cheat Lake, which is a run of the river hydroelectric power station. Because hydroelectric power stations of this type do not store significant amounts of water from one day to the next, this study estimated the discharge flow rate at the mouth of the Cheat River by estimating the inflow rate of Cheat Lake and adjusting for the increased drainage area.

During the study period, when the Albright gage was operational, the following formula was employed. A fudge factor was introduced to prevent Cheat Lake from releasing more water than was present in the Monongahela River. Left superscripts indicate the date for each mean daily discharge datum.

$$\begin{aligned} {}^t Q_{CR} &\approx \min(A_{CR} ({}^t Q_{Rock} + {}^t Q_{Alb}) / (A_{Rock} + A_{Alb}), f {}^t Q_{RM82}) \\ &= \min(1.1431 ({}^t Q_{Rock} + {}^t Q_{Alb}), f {}^t Q_{RM82}) \end{aligned} \quad (9)$$

Where: Q_{CR} = Daily mean discharge flow rate at mouth of the Cheat River, ft³/s.
 Q_{Rock} = Daily mean discharge flow rate of Big Sandy at Rockville, ft³/s.

Q_{Alb}	=	Daily mean discharge flow rate of Cheat at Albright, ft ³ /s.
A_{CR}	=	Drainage area at the mouth of the Cheat River, 1422 mi ² .
A_{Rock}	=	Drainage area of the Big Sandy River at Rockville, 200 mi ² .
A_{Alb}	=	Drainage area of the Cheat River at Albright, 1044 mi ² .
Q_{RM82}	=	Daily mean discharge flow rate of Mon. River at RM 82, ft ³ /s.
f	=	Fudge factor, 40%.

When the Albright gage was not operational during certain periods, the following formula using the Parsons gage was employed. Because the distance between the Parsons gage and Cheat Lake, mean daily discharge data from the Parsons gage was lagged by one day.

$${}^tQ_{CR} \approx \min(A_{CR} ({}^tQ_{Rock} + {}^{t-1}Q_{Par}) / (A_{Rock} + A_{Par}), f {}^tQ_{RM82})$$

$$= \min(1.5423({}^tQ_{Rock} + {}^{t-1}Q_{Par}), f {}^tQ_{RM82}) \quad (10)$$

Where:	Q_{Rock}	=	Daily mean discharge flow rate of Big Sandy at Rockville, ft ³ /s.
	Q_{Par}	=	Daily mean discharge flow rate of Cheat at Parsons, ft ³ /s.
	A_{Rock}	=	Drainage area of the Big Sandy River at Rockville, 200 mi ² .
	A_{Par}	=	Drainage area of the Cheat River at Parsons, 722 mi ² .

The uncertainty of the calculated TDS load at the various locations on the Monongahela River was calculated with the following formula. The uncertainty level is approximately one standard deviation.

$${}^n\sigma_L = \sqrt{{}^{n-1}\sigma_L^2 + L_{TP}^2 \left(\frac{\sigma_{TP}}{L_{TP}} \right)^2 + \sum_{i=1}^{m_n} \left(Q_i^2 C_i^2 \left(\frac{\sigma_Q^2}{Q_i^2} + \frac{\sigma_C^2}{C_i^2} \right) \right)} \quad (11)$$

Where:	n	=	River location, RM102, RM89, RM82, RM61, RM23, or RM11.
	${}^n\sigma_L$	=	Absolute uncertainty in TDS load in the river at location, n .
	L_{TP}	=	Load from Treatment Plants or AML sources, mg/L-ft ³ /s.
	σ_{TP}/L_{TP}	=	Relative uncertainty in TDS load from Treatment Plants or AML sources, assumed to be equal to 20%.
	m_n	=	Number of tributary streams for the river location, n .
	Q_i	=	Discharge flow rate from tributary stream, i , ft ³ /s.
	σ_Q/Q_i	=	Relative uncertainty in discharge flow rate from tributary stream, assumed to be equal to 20%, when the tributary has a USGS gage at the mouth, otherwise it is assumed to be 50%.
	C_i	=	TDS concentration of water from tributary stream, i , mg/L.
	σ_C/C_i	=	Relative uncertainty in measured TDS concentration of water from tributary stream, assumed to be equal to 5%.

The uncertainty in the discharge flow rate of the Monongahela River at the various locations was calculated with the following formula.

$${}^n\sigma_M = \sqrt{{}^{n-1}\sigma_M^2 + \sum_{i=1}^{m_n} \left(Q_i^2 \left(\frac{\sigma_Q^2}{Q_i^2} \right) \right)} \quad (12)$$

Where: M = Discharge flow rate calculated for the Monongahela River at the various locations, ft³/s.
 ${}^n\sigma_M$ = Absolute uncertainty in calculated discharge flow rate in the river at location, n .

The TDS and the uncertainty in the TDS were calculated for the Monongahela River at the various locations was calculated with the following formulas.

$${}^nT = \frac{{}^nL}{{}^nM} \quad (13)$$

$${}^n\sigma_T = {}^nT \sqrt{\left(\frac{{}^n\sigma_L}{{}^nL} \right)^2 + \left(\frac{{}^n\sigma_M}{{}^nM} \right)^2} \quad (14)$$

Where: nM = Discharge flow rate calculated for the Monongahela River at the various locations, n , ft³/s.
 nL = TDS load calculated for the river at the various locations, n , mg/L-ft³/s.
 nT = TDS concentration calculated for the river at the various locations, n , mg/L.
 ${}^n\sigma_T$ = Absolute uncertainty in the calculated TDS for the river at the various locations, n , mg/L.

The aforementioned uncertainty calculations were based upon the fundamental concepts of the propagation of uncertainty as outlined by Taylor (1997).

Missing TDS values are replaced by the spreadsheet with values calculated with a regression formula with the following form. The numerical constants are for unit conversion.

$$C = 408.734569a \frac{(0.028316846Q)^b}{Q} \quad (15)$$

Where: Q = Tributary stream discharge flow rate, ft³/s.
 C = Tributary stream TDS concentration, mg/L.
 a, b = Empirical regression constants.

The empirical constants in equation (15) for each of the tributaries are listed in Table 4. Cells in the tab FORECAST with a TDS value calculated by a regression formula are colored yellow.

Figure 2 is a screenshot of the tab FORECAST in the TDS calculation spreadsheet. To operate the spreadsheet tool, one should follow these steps:

1. Set the starting date of the ten-day forecast period by changing the date in the cell D5 that is marked blue in the FORECAST tab.
2. Adjust the TDS loads from the AMD treatment plants and the AML sources by changing the data in the blue cells in the tabs: TP-102, TP-89, TP-82, TP-61, TP23, and TP11, if needed.
3. Delete the TDS values calculated by the TDS regression formulas during the previous run by clicking the button marked “Delete Regression TDS” on the FORECAST tab.
4. Update the discharge flow rate and TDS data available to the spreadsheet by clicking the button marked “Refresh Data” on the FORECAST tab and waiting for the refresh process to complete. Normally, this action only needs to be performed once a day.
5. Start the calculation process by clicking the button marked “Calculate” on the FORECAST tab.
6. When the calculation process has been completed, examine the calculated values in cells A24 through G47 and the charts: 102, 89, 82, 61, 23, and 11.

b. Task 2: Calibrate Spreadsheet

The spreadsheet was calibrated by adjusting the pumping rates for the AMD treatment plants listed in Table 2 and comparing the calculated TDS values for RM82 and RM23 against observed TDS values for those locations. In order to get the calculated and observed TDS values at RM82 and RM23 to match, the pumping rates from the AMD treatment plants had to be greatly reduced from the initially estimated pumping rates.

7. Results and Discussion

Figure 3 and 4 show the calculated and observed TDS values for the river at RM82 and RM23, respectively. The observed TDS values were calculated by multiplying the daily mean specific conductance in $\mu\text{S}/\text{cm}$ of the river at those locations by 0.69.

Figure 3 shows a good match for the observed and calculated TDS values except for the period between 22 February 2014 and 23 February 2014 when the TDS concentrations were less than the lower uncertainty limit. Figure 4 shows a good match for the observed and calculated TDS values except for 21 February 2014 when the TDS concentration was greater than the upper uncertainty limit.

Adjusting the pumping rates from the AMD treatment plants to calibrate the spreadsheet at RM82 (RM23) would worsen the problems at RM23 (RM82), so the current pumping rate level was chosen as a compromise.

8. Conclusions

The spreadsheet has been calibrated such that it generates reasonable forecasts of the TDS for the Monongahela River at RM102, RM89, RM82, RM61, RM23, and RM11. Operational forecasts will require some knowledge of the current pumping rates and TDS concentrations for the AMD treatments plants in the watershed. Industrial discharges from AMD treatment plants can be managed by using the spreadsheet to run calculations with adjusted AMD treatment plant pumping rates until USEPA secondary drinking water standards in the river are maintained and requesting that the AMD treatment plants adjust their pumping rates appropriately.

Future work in this area should be devoted towards expanding the scope of the spreadsheet to the entire Pittsburgh USACE district and the installation of USGS stream gages to some or all of the ungaged Monongahela River tributaries.

9. References

Taylor, J. R., 1997: An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements. 2nd ed. University Science Books, 327 pp.

10. Tables

Table 1. Streams contributing to the Monongahela River mass balance.

Stream	USGS gage at Mouth	River Mile of Mon. River
West Fork River	Yes	102
Tygart Valley River	Yes	
Indian Creek	No	
Whiteday Creek	No	
Flaggy Meadow Run	No	
Decker's Creek	Yes	89
Robinson Run	No	82
Cheat River	No	
Dunkard Creek	Yes	
Whitley Creek	No	
Tenmile Creek	No	61
Youghiogheny River	Yes	11

Table 2. AMD treatment plants included in Monongahela River mass balance calculations.

Treatment Plant	Discharge Flow Rate, GPM	TDS, mg/L	Location
Dogwood Lake	200	3,933	RM102
Flaggy Meadows	500	6,264	RM102
Llewlyn	100	6,561	RM102
Sears	200	2,355	RM102
Thorn	50	8,284	RM102
Lowe	100	4,800	RM89
Bowlby Mills	200	5,000	RM89
Cumberland No. 1 Refuse	50	5,000	RM82
Cumberland No. 2 Refuse	50	4,250	RM82
Emerald	100	7,500	RM82
Steele Shaft	50	10,200	RM82
Beaver Pond	50	17,714	RM82
Colvin	100	3,481	RM82
Rices Landing	100	2,714	RM82
St. Leo	100	7,433	RM82
Sugar Run	50	9,701	RM82
Federal 003	100	3,550	RM82
Federal 026	50	12,500	RM82
Federal 402	20	3,200	RM82
Nemacolin	0	0	RM82
Emerald No. 1 Refuse	200	3,500	RM61
Emerald No. 2 Refuse	100	3,500	RM61
Emerald No. 4 Bleeder	50	4,500	RM61
Clyde	200	5,000	RM61

Table 3. AML sources included in the Monongahela River mass balance calculations.

AML Discharges	Q, gpm	TDS, mg/L	Location
Adah	213	533	RM61
Backyard	171	751	RM102
Borland 1	624	498	RM11
Brownsville	1,137	723	RM23
Douglas Run	1,718	822	RM11
Erie South	261	733	RM102
Export	1,410	433	RM11
Gates	255	592	RM61
Grays Landing	150	2,539	RM61
Guffey	213	828	RM11
Guffey Lower	317	853	RM11
Iron Falls	329	897	RM11
Maiden 3B	300	1,313	RM82
Norway	805	728	RM102
Owens 34b	726	446	RM102
Palmer2	346	654	RM61
Palmer	6	535	RM61
Ruby 2c	101	661	RM102
Ruby 2d	77	482	RM102
Taylorstown 2B SW (DS)	695	1,650	RM82
Taylorstown 2A (4)	500	1,374	RM82
West Fork 2	544	1,163	RM102
West Fork 5	230	664	RM102
Phillips	157	968	RM23
Borland 2	511	503	RM11

Table 4. TDS regression constants for the estimation of missing TDS values.

Tributary Name	<i>a</i>	<i>b</i>
West Fork River	55.209	0.7961
Tygart River	10.627	0.8577
Indian Creek	104.72	0.6658
Whiteday Creek	5.1061	0.7156
Flaggy Meadow Run	413.25	0.9060
Decker's Creek	19.191	0.6552
Robinson Run	113.86	0.8063
Cheat River	6.9809	0.9018
Dunkard Creek	195.43	0.4398
Whiteley Creek	148.76	0.6011
Tenmile Creek	45.332	0.7816
Youghiogeny River	80.495	0.7108

11. Figures

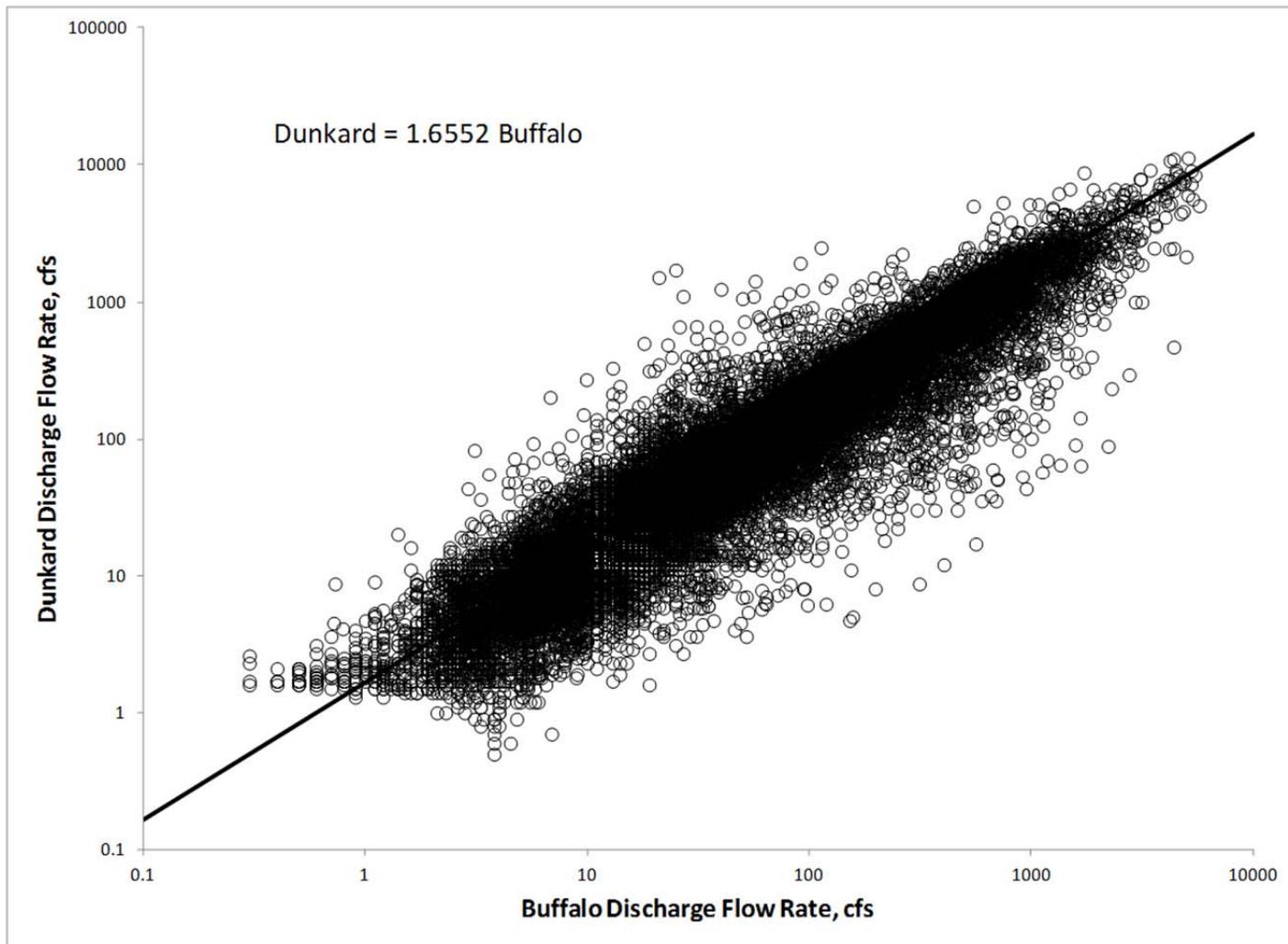


Figure 1. Mean daily discharge flow rate data for the Dunkard Creek versus Buffalo Creek.

MONONGAHELA RIVER TDS FORECAST SPREADSHEET												
Input Data												
Stream	Q, CFS	TDS, mg/L	Date	West Fork River		Tygart + 3 Forks Rivers		Youghiogheny River		Stream	Q, CFS	
				Q, CFS	TDS, mg/L	Q, CFS	TDS, mg/L	Q, CFS	TDS, mg/L			
Indian Creek	241.18	638	02/18/2014	882	595	1,826	70	2,103	321	Buffalo Creek	837	
Whiteday Creek	256.47	34	02/19/2014	2,943	577	2,015	69	2,992	414	Decker's Creek	406	
Flaggy Meadow Run	40.39	4,723	02/20/2014	7,005	333	3,089	65	5,920	377	Big Sandy at Rockville	1,137	
Decker's Creek	406.13	96	02/21/2014	8,343	295	4,685	61	11,496	336	Cheat River at Parsons	3,766	
Robinson Run	131.74	1,021	02/22/2014	6,832	284	4,600	62	14,133	274	Cheat River at Albright	5,768	
Cheat Lake discharge	7,893	48	02/23/2014	2,986	325	7,119	58	10,303	247	Dunkard Creek	1,466	
Dunkard Creek	1,466	396	02/24/2014	2,595	369	9,569	55	8,944	227	South Fork of Tenmile Creek	1,056	
Whiteley Creek	1,984	345	02/25/2014	2,235	387	9,166	56	7,503	217			
Tenmile Creek	2,309	239	02/26/2014	1,931	399	8,736	56	6,302	206			
Mon. River Location	Treatment Plant TDS Load, tons/day		02/27/2014	1,717	407	8,309	57	5,528	200			
RM102	45.54											
RM89	8.89											
RM82	46.43											
RM61	18.93											
RM23	5.85											
RM11	20.02											
Results												
Monongahela River, TDS Concentration, mg/L												
Date	River Mile 102	River Mile 89	River Mile 82	River Mile 61	River Mile 23	River Mile 11						
02/18/2014	315	317	189	196	182	196						
02/19/2014	358	356	211	215	200	219						
02/20/2014	330	329	211	214	199	223						
02/21/2014	302	302	213	215	200	233						
02/22/2014	240	244	197	201	187	223						
02/23/2014	204	209	180	185	172	206						
02/24/2014	176	183	165	172	160	186						
02/25/2014	152	160	153	161	150	170						
02/26/2014	146	154	150	158	147	162						
02/27/2014	146	154	150	159	147	159						
Uncertainty in Monongahela River, TDS Concentration, mg/L												
Date	River Mile 102	River Mile 89	River Mile 82	River Mile 61	River Mile 23	River Mile 11						
02/18/2014	67	63	62	59	61	58						

Delete Regression TDS

Refresh Data

Calculate

Figure 2. Screenshot of the tab FORECAST in the TDS calculation spreadsheet.

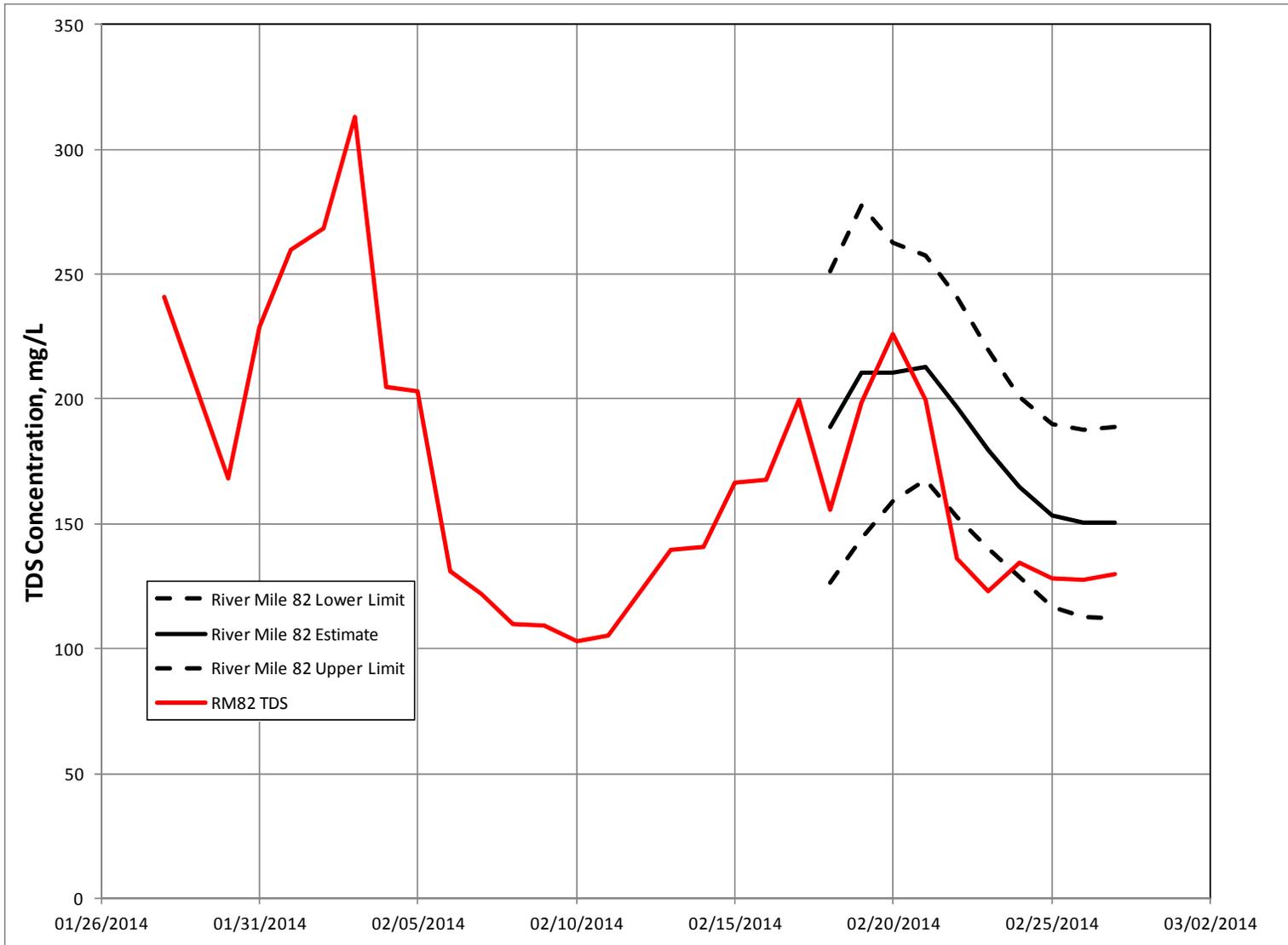


Figure 3. Calculated and observed TDS concentrations for the river at RM82.

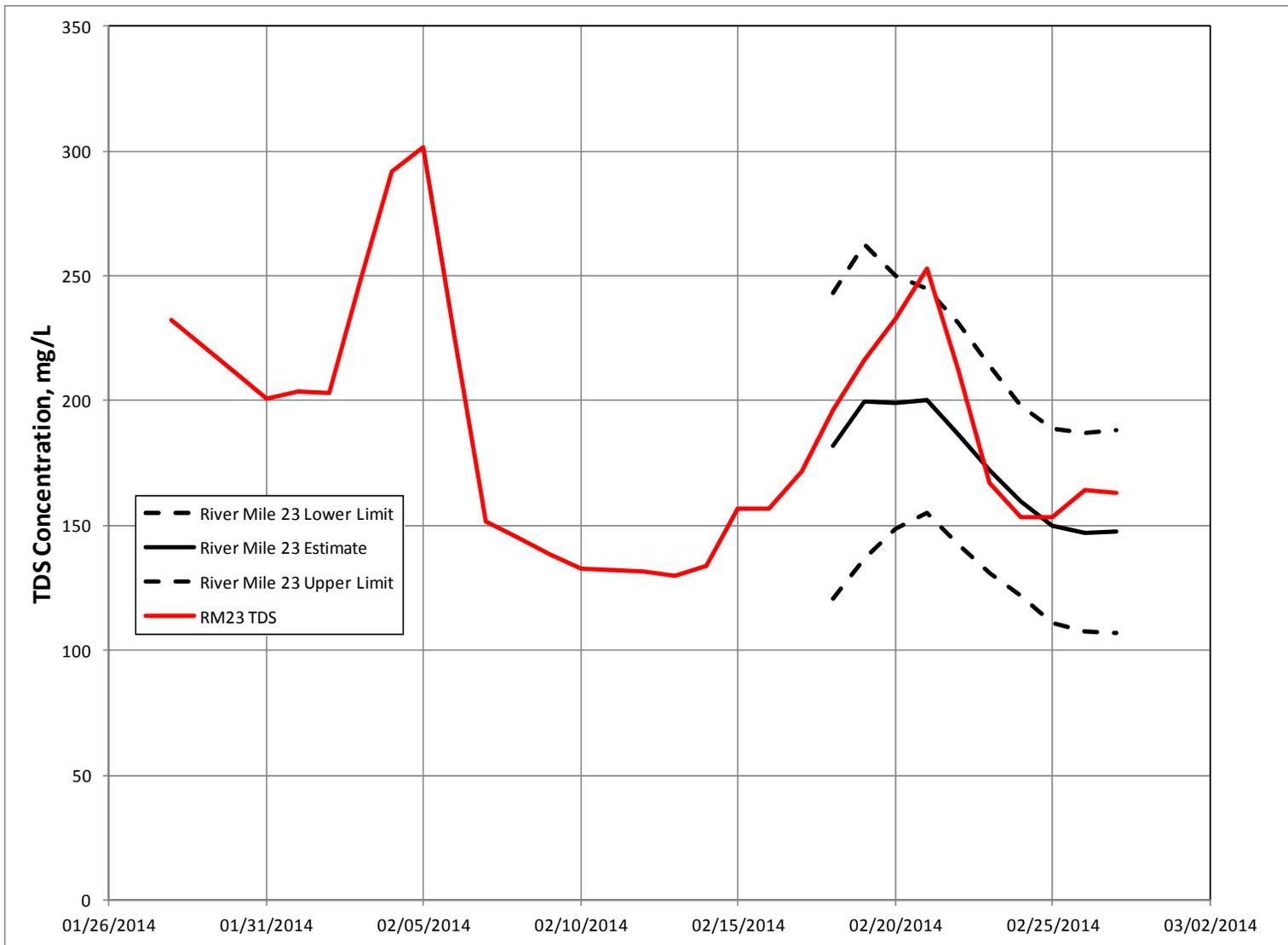


Figure 4. Calculated and observed TDS concentrations for the river at RM23.

12.Publications

There were no publications of this work during the study period.

13.Information Transfer Program

Associated with this study were two meetings with the USACE and other project stakeholders:

- February 28, 2013
- January 23, 2014

14.Student Support

Category	Number of students supported with Federal funds	\$ Value of students supported with Federal funds	Number of students supported with matching funds	\$ Value of student support with matching funds	Total number of students supported	Total \$ value of student support
Undergraduate	0	\$0.00	0	\$0.00	0	\$0.00
Masters	0	\$0.00	0	\$0.00	0	\$0.00
Ph.D.	0	\$0.00	0	\$0.00	0	\$0.00
Post-Doc	0	\$0.00	0	\$0.00	0	\$0.00
Total	0	\$0.00	0	\$0.00	0	\$0.00

15.Notable Achievements and Awards

There were no notable achievements or awards for this research during the study period.

Information Transfer Program Introduction

None.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	2	2	0	0	4
Masters	9	2	0	0	11
Ph.D.	0	1	0	0	1
Post-Doc.	0	0	0	0	0
Total	11	5	0	0	16

Notable Awards and Achievements

A peer-reviewed journal paper and a peer-reviewed book chapter were published, both including student authors.

Two publications in peer-review international journals and one in process.

\$2M collaborative research follow-on funding award received from the National Science Foundation to understand microbial methanogenesis in geological formations.

\$250,000 follow-on funding award received from US Department of Energy - National Energy Technology Laboratory to better understand natural gas migration pathways.

A MS student in Civil and Environmental Engineering was selected as a student moderator for an international conference: international Erosion Control Association (IECA) 2014 Environmental Connection Conference, February 25-28, 2014, Nashville, TN. The student was awarded travel and registration costs.

A PhD student won a 2013-2014 Student Research Enhancement Award, WVU Women in Science and Engineering (WiSE) for \$1,250 to present "Improvement of Water Supply on Reclaimed Appalachian Surface Mine Sites" at an international meeting.

One graduate student graduated with a MS in December 2013.

Two abstracts were accepted and two graduate students presented results at professional meetings.