Inventory of Bacterial Impairments in Central Appalachia

N.A. Cook
Department of Biological Sciences, Virginia Tech, Blacksburg, Virginia

L.A. Krometis
Department of Biological Sciences, Virginia Tech, Blacksburg, Virginia

E.A. Sarver
Department of Mining and Minerals Engineering, Virginia Tech, Blacksburg, Virginia

ABSTRACT

Although it has been over four decades since water-related regulations such as the CWA, SDWA, and NEPA were passed, significant water quality issues in the United States remain unresolved. In the eastern U.S. in particular, unacceptably high concentrations of pathogen indicator organisms (e.g., *Escherichia coli*, fecal coliforms) are the primary contaminant responsible for state-identified surface water impairments requiring Total Maximum Daily Load (TMDL) development. Anecdotal reports suggest that inadequate or non-existent wastewater treatment may represent a significant contributor to surface water contamination in remote or underserved regions of Appalachia. In some areas where residences are relatively close to creeks or streams, it is not uncommon for household sewage to be discharged directly to receiving waters, a practice known as "straight-piping."

Despite the widespread incidence of fecal indicator bacteria (FIB) impairments, a broad assessment of the extent of identified impairments and their relationship with land use, co-contaminants, and proximity to high-density populations has not been completed for Appalachia. As a preliminary review of these potential relationships, publicly available GIS data were compiled and analyzed for an area of interest that includes six geographically central states in the region, which also share coal production as a current and historical common economic driver. These data were analyzed for the purpose of extracting potential correlations between water quality designations and topographic or demographic factors, and for initiating dialogue on potential solutions that involve a variety of regional stakeholders. Given the relative significance of coal production in the area of interest, specific discussion is offered on the possible requirements and benefits that might be associated with strategies that involve coal industry members as key stakeholders.

INTRODUCTION

Although water-related regulations such as the Clean Water Act (CWA), the Safe Drinking Water Act (SDWA) and the National Environmental Policy Act (NEPA) have been in place for over four decades, significant water quality issues in the United States remain unresolved. In accordance with the federal Clean Water Act (CWA) of 1972, states are required to monitor all surface waters within their borders and report any failures to adhere to water quality standards appropriate to their given uses (e.g., fishing and swimming). Section 305(b) of the law requires that waters be classified by their state-designated use(s). This classification includes a set of accompanying numerical limits for various pollutants (e.g., bacteria) of potential concern published by the US Environmental Protection Agency (USEPA). States must monitor their waters and report those that fail to meet standards associated with specified designated uses pursuant to Section 303(d) of

the CWA; hence the list of these impaired waters nationally is frequently referred to as the "303(d) list." States are required to address waters on this list through the development of Total Maximum Daily Load (TMDL) plans, which identify minimum source-specific pollutant loading reductions required to achieve the designated use for each 303(d)-listed water body. States maintain the right to determine their own schedules of monitoring, methods of data collection, decisions on water body classification, and alternative standards (which may or may not be more stringent than federal standards) based on local land uses, stream designations, or regional hydrology characteristics (e.g., use attainability analyses). If any of these efforts are deemed unsatisfactory, states can be subject to penalty under federal law. This non-centralized decision-making paradigm means that a river that might be listed as impaired in one state may not be so listed in another. It can also lead to discrepancies when comparing data from multiple states. In an effort to eradicate data inconsistencies, the USEPA often issues guidance on best practices for TMDL development for specific pollutants; however, evolving priorities and technology can render goals a shifting target (NRC 2001, Keller and Cavallaro 2008).

In the eastern United States, unacceptably high concentrations of pathogen indicator organisms (e.g., *Escherichia coli*, fecal coliforms) are the primary contaminant responsible for state-identified surface water impairments requiring TMDL development (NRC, 2001; Gaffield et al., 2003; USEPA, 2011). Although generally non-pathogenic themselves, the presence of indicator organisms is associated with contamination by mammalian fecal material and public health risk (Paruch and Mæhlum, 2012). Exposure to waters containing high concentrations of coliform or enterococci bacteria have been linked with an elevated risk of gastroenteritis, respiratory infections, and skin infections in exposed human populations (Prüss, 1998). Common sources of pathogen loadings to receiving waters include inadequately treated wastewater discharges, septic leakage, wildlife, domestic animals, and runoff from manure-amended agricultural soils (Gerba and Smith, 2005; Ishii and Sadowsky, 2008). The degree of contamination by any given source is often related to overall watershed land use and topography (Mallin et al., 2000; Field and Samadpour, 2007).

Development of TMDLs generally follows a four step process: impairment identification; determination of the maximum pollutant load the water body can assimilate while maintaining minimum standards for its designated uses; establishment of links between pollutant sources and receiving water concentrations; and source load allocation to inform implementation plan development. A 2008 survey of TMDLs across the United States determined the leading challenges of TMDL development to be a lack of funding and lack of monitoring data to inform watershed characterization and predictive modeling. Successful implementation of existing TMDLs on private lands generally hinged on the engagement of local stakeholders and the availability of funds (Benham, 2008).

The Appalachian region comprises a wide variety of land uses associated with various potential sources of fecal loadings to surface waters, including: agricultural (livestock sources), forest (wildlife sources), and human communities (wastewater sources).As loadings of human waste are generally considered most likely to contain human-infectious pathogens and therefore of greatest health risk (Ishii and Sadowsky, 2008; Soller et al., 2010), reports of inadequate sanitation and discharges of untreated sewage in this region are of particular concern (Gasteyer and Vaswani, 2004; Wescoat et al., 2007). Many communities in the geographically central part of this region have evolved from coal camps in narrow mountain hollows along streams. Soils along these hollows are notoriously thin, and often inappropriate for septic systems, and housing density often makes appropriate siting of drain fields difficult. Even properly installed septic systems can contribute human waste due to the karst (cracked rock) geology of the region. Groundwater flows quickly through this geological strata, preventing the intended treatment by the system's drain field (Katz et al., 2010; Johnson et al., 2011). Some areas in the region simply discharge the grey water from their septic systems into trenches that run to the streams. In many cases, no septic system exists at all, and waste from household toilets, showers, and other plumbed fixtures is piped directly to the creek or into similar trenches ("straight-piping").

While historical precedent (i.e., the justification that "it's always been this way") or a failure to recognize potential consequences (i.e., lack of education) may contribute to the prevalence of straight-piping, inadequate water and sanitation issues in the United States are often strongly related to economic and/or political challenges (Gasteyer and Vaswani, 2004; Wescoat et al., 2007). According to the latest economic report published by the Appalachian Regional Commission (ARC; www.arc.gov), this region significantly lags the national average in employment, personal income per capita, investment income, and proprietor average income; and much of the central, coal-producing region lags even further behind (ARC, 2011). (The ARC is a federally-established partnership between state and local governments created by Congress in 1956 for the purpose of stimulating economic development in the Appalachian region.

Moreover, many of the rural counties in this area are comprised of isolated communities without a sufficiently large central municipality to organize widespread infrastructure efforts. Under such conditions, it is not surprising that centralized or advanced wastewater treatment systems are often absent or implausible. Collaboration between public and private regional stakeholders is likely necessary to improve sanitation and prevent related health risks.

The concept of a collaborative effort requires that parties affected by such decisions be identified. In Appalachia these might include municipal and county governments, taxpayers and citizens, private industries, and groups within the general citizenry that advocate for abstract entities, such as the environment or a specific political party. There are also a large number of NGOs (non-government organizations) that seek to influence the region through advocacy for their own specific interests as well. The relationships within and between these groups are often complex, making solutions to any problem in the region non-trivial. Often, ideological conflicts between opposing groups can overshadow concrete problems that can be more easily addressed with existing technology, such as sewerage issues in rural communities.

Much of the current environmental focus with respect to water quality in the central Appalachian region is on the abundance and diversity of stream macro-invertebrates, which are often used as a proxy for the general degradation of stream ecology (Pond et al., 2008; Echols et al., 2009). Relatively little attention, however, has been paid to pathogen indicator concentrations in surface waters and related human health risks. The present study describes an initial review of publically available GIS data related to surface water impairments, population density, and common land uses, including coal mining. The goal of this analysis is to examine the relationships between FIB impairments and other factors at the inventory scale in order to prioritize future more finely targeted analyses. To complete this initial inventory-level analysis, data were collected from the various state and federal agencies and projected onto a common GIS coordinate system for comparative analysis using the varied geoprocessing abilities of ArcGIS software. (ArcGIS software is distributed by ESRI Products, Redlands, California; www.esri.com.)

METHODS

Appalachia broadly refers to a cultural region in the eastern U.S., which the ARC has geographically defined to include a total of 420 counties in 13 states spanning from New York in the north to Alabama and Mississippi in the south. For the purposes of this study, the area of interest (AOI) was limited to the ARC counties within six geographically central states: Kentucky, Maryland, Ohio, Pennsylvania, Virginia, and West Virginia (Figure 1). This AOI is termed

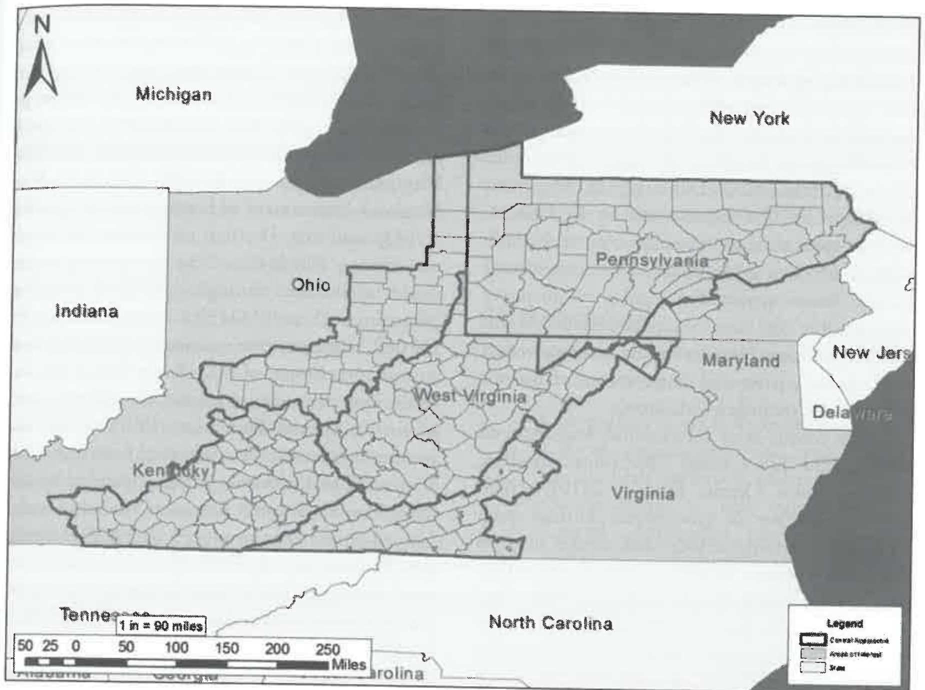

Figure 1. Central Appalachian region area of interest

"Central Appalachia" here. (The ARC has defined five sub-regions in Appalachia; the AOI in the current study includes all of Central Appalachia, as well as parts of Southern, Northern, and North Central Appalachia as defined by the ARC.)

This region accounts for the majority of the energy resource production (i.e., coal and natural gas) in Appalachia; Alabama and Mississippi do produce significant coal and gas, respectively, however, they are non-contiguous with the AOI and do not share many of the same regional geographic and cultural characteristics.

The following datasets were sought for the six states in the Central Appalachian study region as defined above:

- Census tract information
- Government unit boundaries (state and county boundaries)
- Hydrology data (stream and watershed shapefiles)
- Land use characteristics
- Surface coal mining activity (AMLs, active mining, permitted areas)
- Stream impairment information (303(b) and/or 303(d) shapefiles)

The two main goals governing data selection were to examine any potential relationships between stream impairments and other activities at the watershed level, as well as to examine the proximity of coal mining operations to such impairments as a methodology for quantifying the potential significance of targeted mitigation efforts by mine operators. Stream impairments in the form of 303(d) shapefiles represent the best publicly available dataset that describe the conditions of waters within the AOI, the states that comprise Central Appalachia, as well as the country as a whole. The information within the shapefiles are collected by state agencies as a part of their 305(b) and 303(d) responsibilities mandated by the CWA and reviewed by the USEPA. Because these data are formally accepted by both state and federal governments as a descriptor of surface water quality for regulatory purposes, they provide the most practical avenue towards making comparative assessments between watershed characteristics and impairments of interest (in this case, pathogen indicators).

The census tract information was acquired through the US Census TIGERlines database (United States Census Bureau, 2010), which provides borders of government entities such as counties, municipalities, and census districts (including census results). General hydrology data were secured via the National Hydrology Dataset (NHD); however, 303(d) data that were used for most analyses were collected directly from the relevant state agencies. This data often includes more updated hydrography than general NHD data (USGS, 2011). Land use characteristics were acquired as a raster (set of 30m × 30m pixels) from the NLCD (National Land Cover Database), which was initially completed in 2006 and is based on imagery collected in the early 2000s (Frye, 2011). Much of the remaining data collection required personal contact with relevant state agencies (e.g., Departments of Environmental Quality) to secure the most up-to-date information. While impairment information is submitted to the USEPA database regularly in keeping with the requirements of the CWA, states often have more recent assessments available locally.

For many states, boundaries of current or permitted coal mining areas were not readily available via generic internet searches. Mining information was alternatively obtained from either the state environmental agency or the state land management agency. For Pennsylvania, all data could be obtained via the Pennsylvania Spatial Data Access (PASDA), which is maintained by Penn State University, the Pennsylvania Office for Information Technology, the Geospatial Technologies Office, and collaborators. This website contains an FTP link through which any state-released GIS data can be downloaded. In states like Virginia, data were split between agencies such as Virginia's Department of Environmental Quality (DEQ) and the Division of Mines, Minerals and Energy (DMME). Data for mining layers could be obtained through interactive mapping programs such as DMME's Geoexplorer map or DEQ's Virginia Environmental Geographical Information Systems (VEGIS). In West Virginia, some data were acquired via the Department of Environmental Protection (DEP), while the mining information was acquired from the West Virginia GIS Technical Center (uploaded by the West Virginia Natural Resource Analysis Center from digitized data produced by DEP's Mining and Reclamation division). Data for other states were more difficult to find; in Kentucky, several searches were required to narrow down a web location for GIS data. Eventually the search led to the Kentucky Geological Survey (KGS) at the University of Kentucky, where links to mining GIS data and hydrology data (303d layers) could be found. Some states, such as Maryland and Ohio, presented greater challenges. Access to Ohio's data required direct electronic communication with specific state agencies, and it was necessary to interpret the data further upon receipt, which meant further person-to-person communication. Ohio data were separated into A, B, C, and D-Law categories based on their status as AMLs or as active mining sites. The data were found through the Ohio's Geographic Information Management Systems (GIMS), which did not allow data download, but provided electronic mail contacts for data requests. Maryland mining data were never recovered, despite multiple attempts to communicate with the relevant state agency. These missing data likely have a minimal impact on the GIS analysis as only three counties in the state of Maryland fall within the Central Appalachian region, and the state is responsible for little coal production.

With respect to surface water impairment data, most states had data readily available via online access at their respective environmental agencies. As mentioned previously, Kentucky, Virginia, Pennsylvania and West Virginia had readily available 303(d) GIS datasets for download. Two states (Maryland and Ohio) required direct contact to receive information, and the impairment information was only available at watershed resolution (as opposed to stream-segment level resolution). Maryland has scheduled the release of stream-segment level data for late 2012 (after the time of writing), but Ohio has no currently set timetable for improved data. In Pennsylvania, data were downloaded via PASDA, but the actual data were missing fields that were described in the metadata. This omission required contact with the appropriate contacts to resolve, whereupon the corrected data were downloaded via an FTP link.

Once all of the datasets were secured, the challenges associated with combining data from individual states with their own impairment terminology and categorization schemes became increasingly apparent. In the case of Kentucky, numerical rather than textual codes are reported for specific impairment classifications, so further communication with state employees was required to decipher the codes. Ohio and Kentucky have over seventy categories of impairments, while both Maryland and West Virginia have less than fifteen. Many states listed multiple impairments for a single stream (e.g., pathogen indicators and turbidity, etc.) while some states only listed one. Even the category of "FIB impairments" varied greatly between the six states, and the application of different indicator standards (fecal coliform standard versus *E. coli* standard) may result in differences in classification. Table 1 shows the different terms by state. The difference in resolution of the data as well as the difference in attribute naming required some intensive parsing to compare accurately. Data for which impairment entries were left blank or labeled "Insufficient Data" were regarded as non-assessed for the purposes of this study.

Table 1. Terms for FIB impaired waters by state

State	Terms Indicating FIB Impairment
Kentucky	Fecal Coliform, *Escherichia Coli*
Maryland	Bacteria
Ohio	*E. coli*
Pennsylvania	Pathogens
Virginia	*Escherichia Coli*, Fecal Coliform
West Virginia	Fecal/Bacteria

GIS Methodology

Following data collection and inventory, the following analyses were completed:

- Comparison of total impairments for the Central Appalachian and non-Central Appalachian sections of each state;
- Quantification of FIB impairments in Central Appalachia vs. non-Central Appalachia (in terms of number of watersheds or stream miles, as appropriate);
- Categorization of FIB-impaired watersheds by dominant land use;
- Comparison of population density in FIB-impaired watersheds; and
- Identification of mining operation proximity to FIB-impaired stream segments or watersheds.

Before performing any analysis on this collection of GIS information, a common projection was required; most of the AOI (Central Appalachia) falls within the NAD 1983 UTM Zone 17, therefore all data was projected to match this zone (most data was initially projected in local state plane formats). Additionally, for all processes requiring clipping, selecting or intersecting commands, geometry was re-calculated before summaries were completed. For most of these analyses, a simple command in ArcGIS software extracts the necessary information. To find the total impairments, the "select by location" command allowed the program to select stream impairments by their geographical location. While this process is not sufficient for high-accuracy raster processes required at the stream level, it sufficed for a large-scale approach where regions of interest were 12-digit watersheds or where a Central Appalachian versus non-Central Appalachian classification was desired. These impairments were tallied by stream mileage (where possible) for comparison. Applied to a subset of the impairment dataset (only FIB impairments), this same command gave a summary of the streams impaired for fecal coliform or *E. coli*. This step allowed the comparison of total FIB impairments in Central Appalachia versus those in non-Central Appalachia.

To complete the land use comparison, the 12-digit NHD watershed boundaries were used as zones for tabulating the pixels in the NLCD dataset. This information was joined with impairment information to connect both the impairments and the land use data to one attribute table. These data were exported to Microsoft Excel, where formulas were used to determine what the major land use per watershed was for all watersheds that contained FIB impairments. The original NLCD classifications present in the Central Appalachian region include a list of twenty different categories, which were condensed to eight for the purposes of this project. The categories of land use within the GIS analysis were barren, agricultural, developed, forest, herbaceous, shrub, open water and wetland.

It should be noted that some limitations are inherent in studying NLCD for such a large area, such as the inability to account for the effects of land usage in upstream watersheds on downstream basins. For this initial inventory of bacterial impairments over a relatively large study region, such effects were assumed to be negligible; but a more in-depth statistical study would be necessary to draw definitive conclusions about land usage at a finer scale. Another point of potential concern for this summary method is the scale resolution itself. For small stream branches, pixels at a 30 meter resolution may not be appropriate for fine-scale analysis. However, here comparisons were made using 303(d)-listed stream data, which generally only involve the main stem of 12-digit watersheds—thus 30 meter scale NLCD data are adequate for the purposes of this preliminary study.

In order to complete the population density comparison, census districts were intersected with watershed boundaries to determine the fractional population density of each watershed. A weighted sum was then calculated for each watershed using the census district fragments to find the average population density for each watershed. From this calculation, watersheds could be selected based on the presence of a FIB impairment using the "select by location" command once again. The population density factor was then binned by 2,590 people/km^2 (1,000 people/mi^2). While this method is limited by its assumptions of even population distribution within districts, an efficient inventory-level study necessitated a rather general approach for reviewing the more than 6,500 12-digit watersheds that comprise the six-state region of interest. In order to more accurately tie population densities to specific impaired streams (i.e., rather than uniformly spread population over an entire census district), a much more in-depth method for geo-locating population would be necessary. This necessity is based on the fact that census districts span several 12-digit watersheds in some cases, while several census districts may fall within a single 12-digit watershed in more developed areas. For a more accurate analysis, individual pixels could be assigned weighted population values according to the level of development within that pixel—and thus population density could be estimated at higher-resolution along impaired streams specifically, as opposed to generalizing about the 12-digit watershed.

A two-step method was used to quantify mining operation proximity to FIB impairments. First, a comparison was made based on the presence of both within the same watershed. Next, FIB impairments within a 25 km (~15 mile) search radius of mining permit boundaries were used to select watersheds that could be mitigation targets. The purpose of this section of the analysis was to quantify the potential effect targeted mitigation efforts by mining operations could potentially have on FIB impairments.

RESULTS AND DISCUSSION

For review of the following relationships, it should be noted that these examinations are for inventory purposes and preliminary analysis. To more closely examine any of these issues, formalized hypothesis testing and geostatistical analysis must be performed—which is the aim of ongoing work by the authors. Data collection and organization across six states in and of itself presented several challenges worthy of discussion. Regardless of specific project objectives, locating accurate and readily comparable environmental data are often a nontrivial challenge prior to the actual analyses, particularly when working across state boundaries. Between the six states reviewed in this study, data comparison required the translation of over 160 different impairment terms into a common terminology. States like Maryland simplified their categories into ten main terms, while states like Kentucky and Ohio listed over 50. Extensive person-to-person discussion with contacts from the individual state agencies was required to ensure the meaning of terms and the compatibility of terms from different states. A central database from which regional GIS data can be acquired would be of great benefit in facilitating geospatial studies on a regional scale. In addition, standardization of reporting formats would facilitate more efficient and accurate analyses.

Beyond basic impairment classification, analysis of available state 303(d) lists reveal that the six states in this region vary widely in their relative levels of completion of surface water assessment (Table 2) and in the level of detail associated with those assessments. Some coverage statistics are difficult to compare across states; Ohio and Maryland assess at the watershed level rather than stream segment level, resulting in an overestimation of completed stream assessment. In contrast, Pennsylvania's assessment coverage extends beyond the borders of their state, perhaps in an effort track specific pollution issues originating within their state borders. It should be noted that the impairments included in datasets summarized in Table 2 likely represent only a small fraction of the water quality impairments that actually exist in some states, like Kentucky and Virginia, where the assessment of only a small portion (<20%) of surface waters has been officially completed.

An examination of impairment causes indicates that elevated concentrations of *E. coli* or fecal coliforms account for a large proportion of identified impairments in assessed Central Appalachian surface waters (Table 3) but reveals no immediate contiguous trend throughout the region as a whole. Some states have more identified FIB impairments in their Central Appalachian regions versus their non-Central Appalachian regions, while in others the inverse is true. It is important to note that region-specific factors can have a large effect on these results. Assessment coverage (Table 2) shows that many streams have not been assessed, so making direct conclusions from this information is difficult. In West Virginia, only one impairment is listed per GIS shapefile feature, but a single stream may have spatially duplicate features that contain additional impairments for the same stream segment. While sweeping statements about FIB impairments cannot be made, it is clear that elevated concentrations of fecal indicator bacteria

Table 2. Impaired stream miles in states comprising central appalachia

State	Assessment Coverage	Central Appalachia Impaired Streams, Any Pollutant (km)	Non-Central Appalachia Impaired Streams, Any Pollutant (km)
Kentucky	11%	1,832.10	2,070.85
Maryland	61%	25 Watersheds*	113 Watersheds*
Ohio	80%	407 Watersheds*	697 Watersheds*
Pennsylvania	110%	8,176.74	3,480.32
Virginia	16%	1,905.27	5,621.00
West Virginia	41%	18,856.07	N/A

*Data only available at the watershed level.

Table 3. Fib impairments in states comprising Central Appalachia

State	Pathogen Impaired Streams (km)	% Regional Impairments Attributed to Fecal Indicator Bacteria	
		Central Appalachia	Non-Central Appalachia
Kentucky	1,813	47	46
Maryland	5,058*	39	31
Ohio	4,123*	22	21
Pennsylvania	3,266	5	12
Virginia	3,364	77	64
West Virginia	787	26	N/A
Total	18,413	32	25

*Numbers calculated by summing NHD stream layers within impaired watersheds.

Table 4. Statewide FIB impairments (and overall land area) vs. primary land use

State	% of Watersheds Containing FIB Impairments Where Land Use Category Represents Majority of Pixels in Raster (Overall State %)							
	Barren	Agricultural	Developed	Forest	Herb.	Shrub	Water	Wetland
Kentucky	0	37.99	4.17	57.60	0	0	0.25	0
	(.37)	(32.89)	(7.25)	(52.14)	(4.15)	(0.32)	(1.83)	(1.05)
Maryland	0	0	33.62	59.48	0	0	0	6.90
	(.40)	(32.01)	(17.84)	(33.63)	(1.76)	(1.76)	(1.18)	(12.89)
Ohio	0	68.66	10.45	20.90	0	0	0	0
	(.19)	(50.15)	(14.51)	(31.18)	(1.62)	(0.38)	(1.03)	(0.94)
Pennsylvania	0	0	23.14	48.76	0	0	0	28.10
	(1.30)	(2.22)	(11.37)	(51.87)	(6.56)	(3.42)	(0.00)	(23.26)
Virginia	0	11.73	4.86	81.64	0	0	0	1.78
	(.27)	(21.40)	(9.42)	(58.23)	(1.93)	(2.57)	(1.03)	(5.14)
West Virginia	0	3.17	1.46	95.37	0	0	0	0
	(.12)	(9.41)	(7.66)	(79.86)	(0.09)	(1.73)	(0.00)	(1.12)
Total	0	15.92	7.02	74.11	0	0	0.05	2.90
	(.44)	(24.68)	(11.34)	(51.15)	(2.44)	(1.70)	(0.85)	(7.40)

are not uncommon, and in some states, a major surface water quality issue.

Table 4 suggests that, within the six states that comprise the Central Appalachian region as defined in the AOI, FIB impairments typically are related to a few specific land uses. Watersheds with forest areas listed as the primary land use contain the overwhelming majority of listed FIB impairments—with forested areas accounting for nearly three quarters of all such impairments. It is important to note that while a watershed may be primarily forested, a small rural community with inadequate sewage could still be the primary cause for FIB impairment. It may be that the relationship between a largely forested watershed and FIB impairments parallels the increased incidence of non-centralized sewage disposal practices (septic tanks, straight-piping) in less developed watersheds, though substantial further study would be required to confirm this hypothesis. In Table 4, values are given for the percentage of watersheds in each state that contain FIB impairments, classified by land use category. For a watershed to be assigned to a specific land use category, the majority of the area (based on zonal tabulation of NLCD pixels) in that watershed was classified within the given land use category (a condensed version of NLCD classification). In parenthesis, the total percentage of land area in each state is given for comparison.

Table 5. Statewide FIB impairments vs. population density in states comprising Central Appalachia

State	% of FIB impairments in Watersheds vs. Population Density ppl/mi² [ppl/km²]						
	>1000 [>2560]	1000–2000 [2560–5120]	2000–3000 [5120–7680]	3000–4000 [7680–10420]	4000–5000 [10420–12800]	5000–6000 [12800–15360]	6000–7000 [15360–17920]
Kentucky	93.60	3.20	2.20	.99	0.00	0.00	0.00
Maryland	80.49	4.88	4.88	3.66	1.22	2.44	2.44
Ohio	91.04	5.97	0.00	2.99	0.00	0.00	0.00
Pennsylvania	57.27	36.00	4.69	2.31	0.00	0.00	0.00
Virginia	93.47	3.98	1.74	.50	.31	.50	.31
West Virginia	97.76	2.23	0.00	0.00	0.00	0.00	0.00
Total	85.61	9.38	2.25	1.74	.26	.49	.46

Based on this data, it does not appear that the trends in FIB-land use category can be simply explained by the overall percentages of watersheds in each category. For example, while approximately 58% of land area in Virginia is classified as forested, nearly 82% of total FIB impairments occur within watersheds that are classified as mostly forested. Indeed, the data gathered thus far make a strong case for examining this relationship further as part of any real efforts to reduce bacterial impairments within this region. Both Maryland and Pennsylvania showed a higher proportion of FIB-impaired waters related to development than the other states. This relationship mirrors the results of studies that point to urban stormwater as another source of pathogens in surface waters (Gaffield et al., 2003). On the other hand, Ohio has a far greater instance of FIB impairments near agricultural land uses, which may point to a variation in agricultural practices or methods of stream assessment between Ohio and other states.

Because the primary land use of a given watershed may not be directly responsible for observed concentrations of pathogen indicators, it is also critical to determine relationships between water quality and population density, as anthropogenic influence is often associated with surface water impairments. By mapping census tracts to 12-digit watersheds, a relationship between the population density of a watershed and the prevalence of FIB impairments could be investigated. The results presented in Table 5 along with Table 4 suggest that FIB impairments are common in rural areas. Over 85% of FIB impairments in the six states that comprise Central Appalachia were located within watersheds that had fewer than 2,560 people/km² (1,000 people/mi²). It is important to note that despite this classification, a watershed with a large proportion of forestland could be impaired by pathogen loading from a small, high-density developed area. However, these data again support the idea that a concerted effort to solve rural issues in water quality would most likely target a large proportion of these impairments.

The widespread nature of FIB impairments in rural Appalachia, in conjunction with anecdotal reports of inadequate or nonexistent wastewater treatment in rural communities suggests that an intervention is necessary to improve surface water quality. Given the stakeholders in this region and their associated resources, it is clear that expedient and realistic solutions will require novel strategies. Considering the significant presence of coal mining activities in Central Appalachia, and the increasing emphasis on environmental protection and corporate social responsibility by the mining industry, it appears that one viable alternative may include engaging mine operators as stakeholders with a key role to play (Craynon et al., 2012). Such an approach would, however, necessitate identification of and agreement on incentives for all stakeholders involved.

Given the spatial and temporal scales required for surface mining, and the complex topography and hydrology of Central Appalachia, interactions between mining activities and water

Table 6. FIB Impairment incidence with mining permits in AOI (Central Appalachia)

	Comparison of Mining Presence and FIB Impairments				
State	Total Watersheds	Impaired Watersheds	Watersheds w/ Mining	Watersheds w/FIB Impairment	Watersheds w/Mining and FIB Impairments
Kentucky	641	406	145	81	26
Maryland*	N/A	N/A	N/A	N/A	N/A
Ohio	663	407	142	143	15
Pennsylvania	1,177	708	163	69	14
Virginia	377	293	50	259	39
West Virginia	742	633	352	413	206
Total	3,600	2,447	852	965	300

*Comparison not made due to lack of mining GIS data.

resources are inevitable. At present, the coal industry faces serious challenges in gaining permits under the CWA—particularly since a new focus has been placed on heretofore unconsidered dissolved solids loadings from mine spoil discharges, and their potential effects on aquatic macro-invertebrates (Cox and Sarver, 2012). The CWA allows for a variety of compensatory mitigation schemes under some circumstances, including water quality impacts of discharged fill material into wetlands or streams (USEPA, 2008), although "in-kind" mitigation has been preferred.

Under an alternative strategy for improving overall regional environmental and human health, the underlying question becomes one of allowing and encouraging stakeholder participation in addressing FIB impairments. Should flexibility be integrated into the CWA permitting process to allow mitigation trade-offs in order to promote holistic water quality management? Such a strategy would require careful prioritization of water quality goals, and careful implementation in terms of trade-off credit valuation and meaningful stakeholder participation, but may well provide net positive impacts for ecological and public health. In relevant cases where scientific data and stakeholder input support holistic water quality management, an opportunity may exist for mine operators and NPDES and other CWA permittees to contribute to efforts to reduce FIB impairments as part of their overall commitment to environmental and social responsibility.

GIS analysis of the relationship between mining activity and FIB impairments is a cursory method of supporting the argument for flexible, targeted mitigation to support overall water quality improvement for the region. Generally, mitigation allowances are limited to the permitted area of mining operation or the stream reach on which the mining operation is located (i.e., only the drainage area potentially impacted by the mine). This narrow focus does not provide flexibility to mine operators(or other CWA permitees) to contribute to sustainable development in the larger region by addressing community issues. A "watershed approach," as increasingly emphasized in contemporary environmental management practices, would certainly broaden potential impacts.

Although FIB impairments are not directly associated with mining, Table 6 reveals a significant number of watersheds with mining activities do coincide with FIB impairments. Under an even more holistic "community approach" significant improvements might be realized with long-term benefits to human (and ecological) health and well-being. This type of approach would be aimed at social responsibility, wherein corporate citizens act to benefit the *communities* in which they operate; and it must be recognized that communities have economic, cultural, social and environmental ties to local industries, whether or not those industries operate within the specific drainage area or watershed occupied by community members. As the "community approach" is far outside the current regulatory framework

Table 7. Potential FIB impairment targets for mining operations in AOI (Central Appalachia)

State	Kentucky	Maryland	Ohio	Pennsylvania	Virginia	West Virginia	Total
% FIB Addressed (In-Watershed)	41.0%	N/A	10.5%	19.0%	14.5%	49.2%	38.6%
% FIB Addressed (25 km radius)	63.5%	N/A	37.8%	69.4%	32.9%	94.4%	76.8%

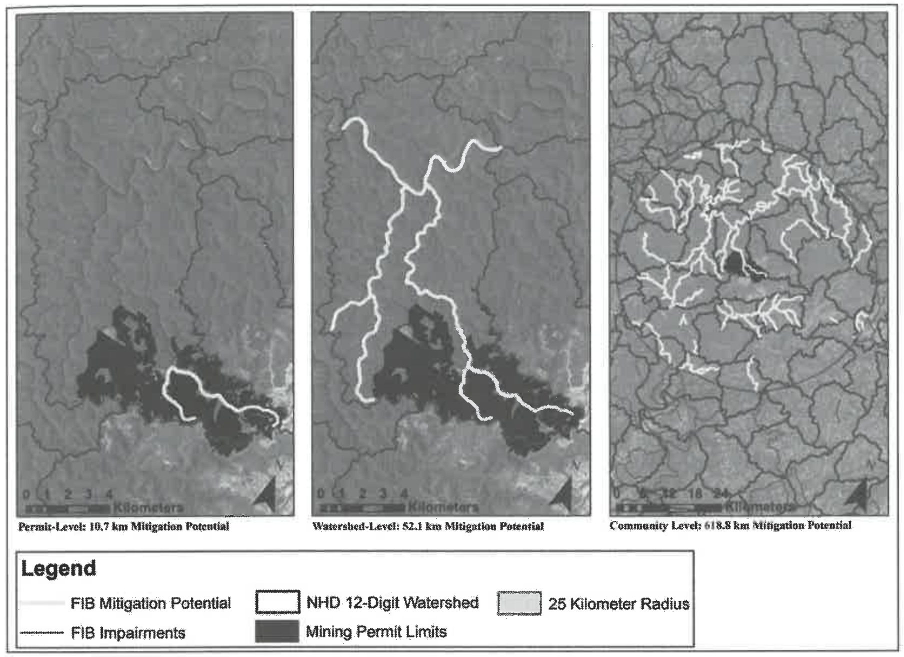

Figure 2. Drainage level, watershed level, and community level mitigation strategies at a West Virginia example location

and typical operating procedures, it is duly noted that adoption would require substantial changes in environmental policy and corporate culture—both of which should be underpinned by significant further scientific analysis.

Table 7 and Figure 2 illustrate the above arguments for FIB mitigation approaches based on corporate responsibility over those based on narrower criteria in the study region. While a "watershed approach" could potentially impact about one third of the total FIB impairments in the AOI, a "community approach" could significantly increase this impact. For example, by applying a generic 25 km (15 mile) radius to define the "community" around a given mine, it is expected that overt three quarters of the total FIB-impairments could be potentially addressed in the AOI. Although this definition of community may be too narrow or too wide on an individual-mine basis (i.e., community-mine associations are in reality very site- and factor-specific), the point is to demonstrate that a more flexible and holistic approach offers greater possibilities for results. In many cases, the economic, social and environmental impacts of mining operations (both positive and negative) cross watershed boundaries; therefore, it seems plausible that serving a community with mitigation efforts for FIB impairments should also extend beyond the watershed of physical operation. Indeed, the case for any flexibility is especially compelling in West Virginia, where even a watershed approach could potentially address half of that states' FIB impairments.

Although sewerage issues may be a primary environmental health concern in some rural watersheds in the Appalachian region, it is worth noting that EPA currently states that the majority of FIB impairments nationwide are associated with agricultural practices (e.g., livestock, manure amendment of soils). Therefore in a broader context, compensatory mitigation, in either a "watershed" or "community" approach, need not be limited to human sewage, but might be utilized to address a wide variety of water pollution sources that are detrimental to ecological stream health. Stream ecology could equally benefit from treatment structures removing pathogens, organic material and nutrients contributed by agricultural or livestock land uses. Overall, both human health and stream ecology might be improved through the permit-related mitigation process required of mine operators or other permittees. Resources available for mitigation could support the engineering work required to solve relevant water quality issues by implementing solutions (such as installing localized package plants), which could address problems such as *E. coli* presence in streams and poor health scores in benthic macroinvertebrate communities. While the current emphasis on "in-kind" mitigation may be appropriate in terms of hydrology, it overlooks some opportunities for improvement in both human and stream ecology health that a more diverse array of environmental remediation efforts would likely provide.

CONCLUSIONS

This initial inventory-level review of bacterial surface water impairments in the Central Appalachian region demonstrated significant challenges associated with the compilation of freely available GIS data at the multi-state level. In both the mining resources and the water quality arenas, differences in data availability (e.g., accessibility, resolution or non-existence) and formatting proved to be nontrivial pre-analysis hurdles. A collaborative database for natural resource and environmental data would greatly benefit all those who need to analyze data across state lines. Current collection of data in a patchwork fashion ultimately renders geoprocessing difficult and forces significant assumptions during the comparison of heterogeneous datasets. Data manipulation to facilitate comparisons across state lines inevitably introduces some error and uncertainty, as subjective evaluations are required. National formatting and labeling standards would greatly benefit regional studies.

Even if uniform and complete data were available for the targeted study region, the methods and relatively coarse data resolution (i.e., 12-digit watersheds) used here result in certain limitations. To more carefully study many of the relationships of interest would require a statistics-driven approach that includes hypothesis testing and completely raster-based geoprocessing techniques to increase analysis resolution from a general watershed inventory to a localized cause-and-effect study at the stream level. Despite these limitations, some useful initial conclusions can still be drawn from this inventory-level review of the data.

It is suggested by the literature that many FIB impairments are the result of a wide variety of sources, both urban and rural. In the Central Appalachian region, it appears that agricultural practices, wildlife populations, and the use of sub-standard sewage practices (failing septics and straight-piping) are all potential contributors to elevated in-stream pathogen concentrations. By analyzing the data contained in state-available GIS datasets, this variety of stressors seems to be supported by the relationship between land use types (mainly forest and agricultural, some developed) and FIB impairment presence. The GIS data also suggest a link between low population density and the presence of FIB stream impairments. It only takes a single small community lacking sewerage to impair a significant portion of a watershed for pathogens. This phenomenon is both a result of physical geography and economics in the region, and is reflected by the GIS data.

As discussed previously, these potential relationships between water quality and land use suggest possible strategies to address these impairments. Without a municipal tax base, solutions to sewerage issues in these rural areas will have to come from a collaborative effort supported by funding from a joint effort between public and private stakeholders in the region. The proximity analysis highlighted in Tables 6 and 7 (as well as Figure 2) suggests that coal mine operators in Central Appalachia could make a significant positive impact on environments and communities if encouraged to do so by the relevant regulatory agencies. Moreover, engaging local corporate citizens (i.e., mine operators in the case of Central Appalachia) to participate in local problem solving is critical to sustainable development: near-term economic and societal benefits of industry must be balanced with long-term health and well-being of environments and communities.

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REFERENCES

ARC, 2011. Economic Overview of Appalachia–2011.

Benham, B., 2008. Lessons Learned from TMDL Implementation Case Studies. Water Practice 2.

Cox, A., Sarver, E.S., 2012. Salt: an Emerging Concern for the Global Mining and Minerals Industries. Annual Meeting of the Society of Mining Professors, Wroclaw, Poland.

Craynon, J.R., Sarver, E.A., Robertson, D.P., 2012. Could a public ecology approach help resolve the mountaintop mining controversy? Resources Policy.

Echols, B.S., Currie, R.J., Cherry, D.S., 2009. Preliminary results of laboratory toxicity tests with the mayfly, *Isonychia bicolor* (Ephemeroptera: Isonychiidae) for development as a standard test organism for evaluating streams in the Appalachian coalfields of Virginia and West Virginia. Environmental Monitoring and Assessment 169, 487–500.

Field, K.G., Samadpour, M., 2007. Fecal source tracking, the indicator paradigm, and managing water quality. Water Research 41, 3517–3538.

Frye, J.e.a., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States. PE&RS.

Gaffield, S.J., Goo, R.L., Richards, L.A., Jackson, R.J., 2003. Public Health Effects of Inadequately Managed Stormwater Runoff. American Journal of Public Health 93, 1527–1533.

Gasteyer, S., Vaswani, R., 2004. Still Living Withouthe Basics in the 21st Century: Analyzing the Availability of Water and Sanitation Services in the United States. Rural Community Assistance Partnership, Washington, DC.

Gerba, C.P., Smith, J.E., 2005. Sources of Pathogenic Microorganisms and Their Fate during Land Application of Wastes. J. Environ. Qual. 34, 42–48.

Ishii, S., Sadowsky, M.J., 2008. *Escherichia coli* in the Environment: Implications for Water Quality and Human Health. Microbes and Environments 23, 101–108.

Johnson, T.B., McKay, L.D., Layton, A.C., Jones, S.W., Johnson, G.C., Cashdollar, J.L., Dahling, D.R., Villegas, L.F., Fout, G.S., Williams, D.E., Sayler, G., 2011. Viruses and Bacteria in Karst and Fractured Rock Aquifers in East Tennessee, USA. Ground Water 49, 98–110.

Katz, B.G., Griffin, D.W., McMahon, P.B., Harden, H.S., Wade, E., Hicks, R.W., Chanton, J.P., 2010. Fate of Effluent-Borne Contaminants beneath Septic Tank Drainfields Overlying a Karst Aquifer. Journal of Environment Quality 39, 1181.

Keller, A.A., Cavallaro, L., 2008. Assessing the US Clean Water Act 303(d) listing process for determining impairment of a waterbody. Journal of Environmental Management 86, 699–711.

Mallin, M.A., Williams, K.E., Esham, E.C., Lowe, R.P., 2000. Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds. Ecological Applications 10, 1047–1056.

NRC, 2001. Assessing the TMDL approach to water quality management. Committee to Assess the Scientific Basis of the TMDL Approach to Water Pollution Reduction, The National Academies Press, Washington, DC.

Paruch, A.M., Mæhlum, T., 2012. Specific features of *Escherichia coli* that distinguish it from coliform and thermotolerant coliform bacteria and define it as the most accurate indicator of faecal contamination in the environment. Ecological Indicators 23, 140–142.

Pond, G.J., Passmore, M.E., Borsuk, F.A., Reynolds, L., Rose, C.J., 2008. Downstream effects of mountaintop coal mining: comparing biological conditions using family- and genus-level macroinvertebrate bioassessment tools. Journal of the North American Benthological Society 27, 717–737.

Prüss, A., 1998. Review of epidemiological studies on health effects from exposure to recreational water. International Journal of Epidemiology 27, 1–9.

Soller, J.A., Schoen, M.E., Bartrand, T., Ravenscroft, J.E., Ashbolt, N.J., 2010. Estimated human health risks from exposure to recreational waters impacted by human and non-human sources of faecal contamination. Water Research 44, 4674–4691.

United States Census Bureau, 2010. 2010 Census TIGER/Line® Shapefiles (http://www.census.gov/geo/www/tiger/tgrshp2010/tgrshp2010.html).

USEPA, 2008. Wetlands Compensatory Mitigation.

USEPA, 2011. National Section 303(d) List Fact Sheet (http://oaspub.epa.gov/waters/national_rept.control).

USGS, 2011. Nationaly Hydrography Dataset (NHD): http://nhd.usgs.gov/.

Wescoat, J.L., Headington, L., Theobald, R., 2007. Water and poverty in the United States. Geoforum 38, 801–814.