Impacts of Acid Mine Drainage: Building Streams Database and Analyzing Toby Creek Sub-Basin

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Abstract

The Clarion River basin in northwestern Pennsylvania has locally been strip-mined for coal since the 1800's, leaving scars on the natural landscape and severely polluting many of the streams in the basin with, acid mine drainage (AMD). This paper concentrates on the Toby Creek sub-basin in Clarion County, one of the six polluted watersheds in the 200 square mile of Clarion River basin. We have constructed a database for all stream segments, which includes a detailed stream network and attribute tables, to define the levels of pollution in each stream using chemical data collected from the field. Future remediation sites can be identified by setting different criteria such as accessibility and the level of deterioration of the streams.

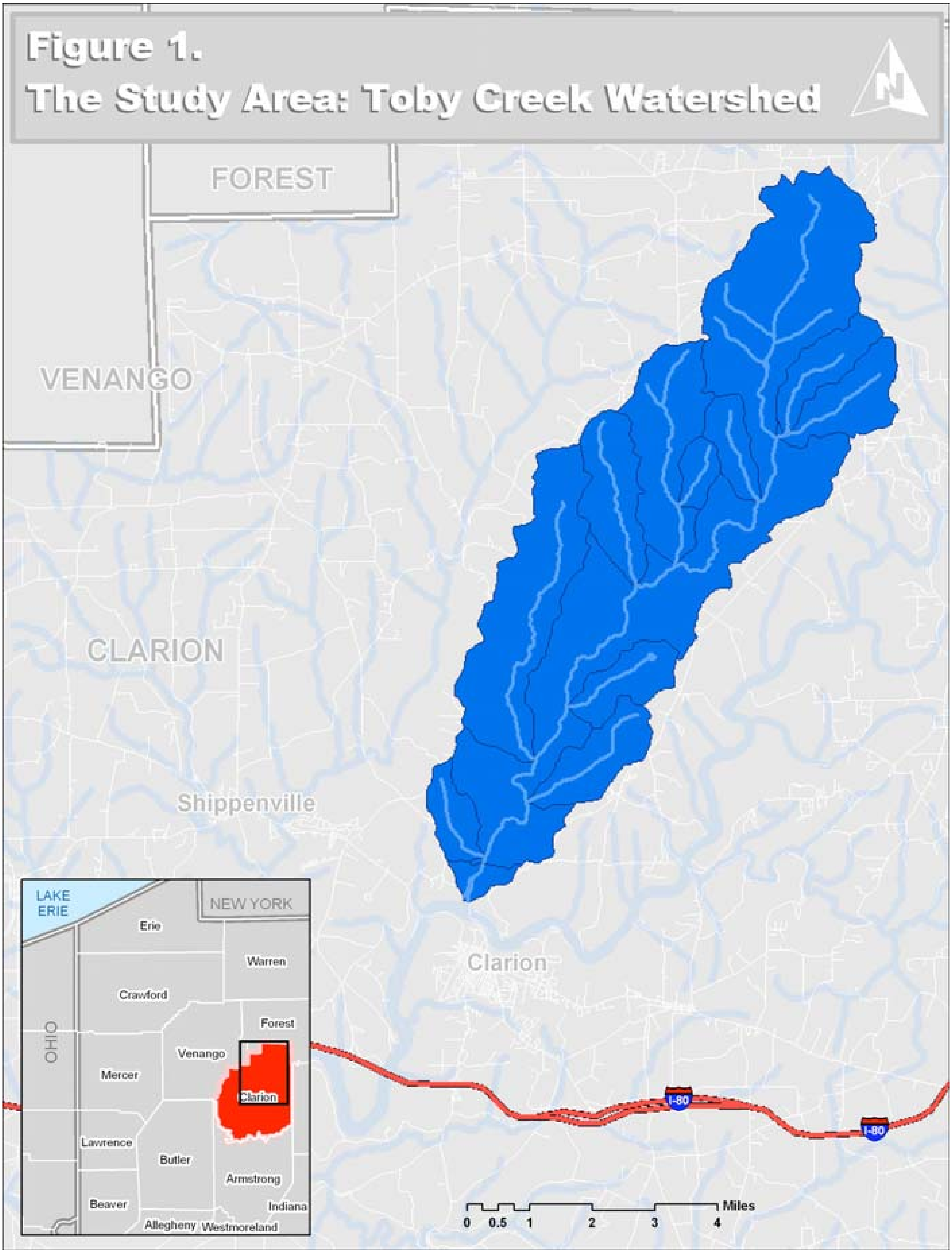
Introduction

The Clarion River Basin, located in Northwestern Pennsylvania (**Figure 1**), has been mined for coal since the early 1800's. Much of this has left scars on the natural landscape and severely polluted many of the streams in the basin. The most common environmental problem associated with coal mining in Western Pennsylvania is Acid Mine Drainage (AMD). Seven of the tributary watersheds contribute approximately 72 tons of acid each day to the Clarion River. Acid mine drainage is the result of chemical reactions involving sulfide minerals (mostly pyrite), a mineral that contains both sulfur and iron which occur naturally in and around coal seams. When pyrite comes in contact with air (oxygen) and water, the resulting product are sulfuric acid, iron oxides and hydroxides. These pollutants are continuously released at the surface mining sites, which are exposed to rain and other surface waters.

This paper concentrates on the Toby Creek Sub-Basin, one of the six polluted watersheds in the 200 square mile Clarion River Basin. Toby Creek rises in Farmington Township in Northeastern Clarion County and extends to the Southwest approximately 13 miles, entering the Clarion River just North of Clarion (**Figure 1**).

Toby Creek is fed by many smaller tributaries including Engle Run, Little Toby, Step Creek and Rapp Run. The 37-square mile basin is long and narrow, having an average width of 2.5 miles. It is characterized by steep hillsides and valleys in the south that give way to broad hilltop plateaus along the western perimeter and moderately sloped rolling hills to the north. Drainage patterns for the basin are typically dendritic. The central portion of the basin is heavily vegetated with brush and forest, while strip mines and farms characterize the perimeter.

Figure 1.
The Study Area: Toby Creek Watershed



The watershed under investigation has been the subject of intensive mineral resource recovery operations from the early 1800. Primarily, these activities have included the surface and underground extraction of bituminous coal and the drilling for petroleum and natural gas (PA-DEP, 1976). Parts of the watershed are affected by severe AMD from several surface coal strip mines and a few abandoned deep shaft mines. Mining activity ceased in the late 1930's, but water quality problems persist to this day at several locations. Headwater stream reaches unaffected by mining activity have near-neutral pH and normal water quality characteristics, which sustain small populations of small native brook trout. Fish and other aquatic life are totally absent in lower reaches of the stream because of low pH values and very high iron and Total Dissolved Solids (TDS) content (**See photos 1-4**).

In an effort to study the watershed, numerous research projects and class field projects in hydrogeology, environmental geoscience, environmental biology and ecology at Clarion University of PA have been conducted in the last ten years. Long-term data collection of stream discharge, temperature, pH, Eh, conductivity, iron, sulfate and nitrate show interesting relationships to drought conditions, excess precipitation, and normal seasonal fluctuations in the water budget. This abundance of research work has brought a wealth of information and data. However, the data is scattered in a multitude sources and formats. Regular activities that precede any research involve downloading data from many locations, import/export operations, data integrity manipulations and long times spent in compiling datasets for the study area, which involves the use of relatively complex operations in both GIS and Remote Sensing software. This situation is calling for an organized (not necessarily centralized) source of information that would be convenient not only for regular researchers but for casual users as well.

Therefore, the objective of this paper is twofold: managing the database, and dealing the AMD problem itself. The first facet will deal with the compilation of an organized database and the design of a user friendly interface for data accessibility using internet mapping capabilities. On the other hand, the second facet will present an attempt that was carried out in characterizing the level of pollution in the stream network and will propose a method to prioritize the streams for future remediation activities. In brief, the objectives of this paper can be summarized in the following three points:

1. To compile a database for the Toby Creek sub-basin and ensure its usability;
2. to make the data available to interested individuals and agencies through the use of internet mapping; and,
3. to analyze the basin for levels of pollution and prioritize stream segments for remediation.

Photo 1.

Photo 2.

Photo 3.

Photo 4.

Database Design

Data Assembly

Data was gathered from multiple sources. General state and county-level data were obtained from the Pennsylvania Spatial Data Access (PASDA) website or from the Census 2000 TIGER/Line provided by the U.S. Bureau of the Census through the Environmental Systems Research Institute's (ESRI) Geography Network (http://www.geographynetwork.com). The Pennsylvania Spatial Data Access web site (http://www.pasda.psu.edu) was a major source and/or link to information about Pennsylvania as a whole and about Clarion County in specific. Although the county-level information was limited but it served as a basis for laying out information. Local data, on the other hand, were either produced by researchers and/or students at Clarion University of Pennsylvania by means of field surveys, or extracted from the Pennsylvania Department of Environmental Protection (PA-DEP) reports on Toby Creek Watershed (e.g. Project SL 191, 1976). **Table 1** summarizes the available data, their sources and formats.

Data Preparation

Because the datasets came from different sources, almost each had different coordinate system and projection. In order to ensure the database integrity, all datasets were projected into Transverse Mercator projection with UTM grid coordinate zone 17 North and a North American Datum of 1927 (NAD27). Consequently, the Toby Creek Watershed boundaries were extracted from a larger dataset (PA small watersheds). The resulting polygons were used in clipping the study area from all datasets in the database.

On the other hand, coal seams lines and the strip mine polygons were digitized from a geo-referenced scanned paper maps that were part of a report done on the drainage basin (Project SL 191, 1976) (**Figure 2**). However, once overlaid on a topographic map, it became obvious that both layers did not reasonably align. Therefore they had to be spatially adjusted using multiple control points. The structure contours[1] were also digitized from the same scanned maps. The attribute tables were also edited to add the available fields (**Table 1**).

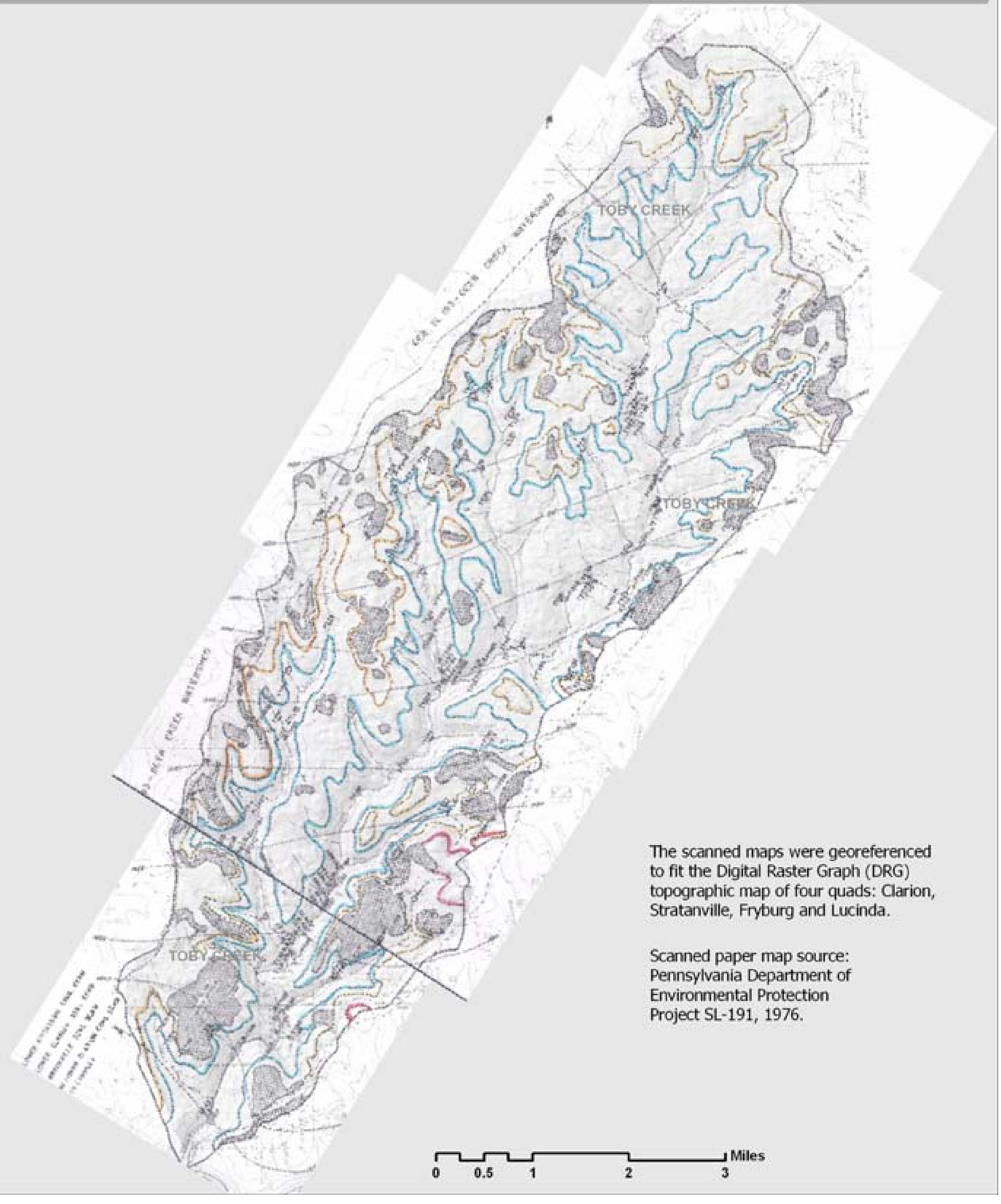
In the Project SL191, the PA-DEP conducted an investigation to look at the amounts of stream pollution due to acid mine drainage. For this study, they set up over 180 source sampling stations, or weirs, that were monitored over a twelve month period from the mid 1973 to mid 1974 to determine the degree and extent of mine drainage generated within the basin. Also thirteen stream sampling stations were established to monitor the effect pollution was having on Toby Creek watershed and its tributaries. The positioning of both the source and stream monitoring points was based on intense analysis of the geology of abandoned mine sites to determine the conditions responsible for the formation of acid mine drainage. To better organize the data, the PA-DEP identified 20 "problem sites" in the Toby Creek Watershed. Within these sites is the system of weirs and stream sampling points. Each site had a corresponding point on a large-scale topographic map. Therefore, the weirs and the source sampling points were on-screen

[1] A structure contour for a rock layer is simply the elevation above sea level for that particular formation.

Table 1
Toby Creek Watershed: Available data sources, formats and existing/possible attributes

Source	Dataset	Format	Attribute	Notes
Census 2000	▪ Streams ▪ County boundary ▪ Roads	Shapefile Shapefile Shapefile		▪ Census datasets were used as base maps for the current work. It was altered so that it conforms with the current goals
PA-DEP	▪ Lower-Clarion structure contours ▪ Coal seams	Paper map Paper map	**Possible Attributes:** ▪ Seam Code ▪ Seam Name	▪ Paper maps and tables were available from the PA-DEP Project SL191 report for Toby Creek watershed.
	▪ Strip mines ▪ Stream monitoring points ▪ Weirs ▪ Weirs Data	Paper map Paper map Paper map tables	**Possible Attributes:** ▪ Weir Number ▪ Average Flow ▪ Average Acidity ▪ Maximum Acidity ▪ Average Iron ▪ Maximum Iron	▪ Water quality recorded at each station
PA-DCNR	▪ Geology	Arc/INFO Interchange Format	▪ UNITNO ▪ NAME ▪ AGE ▪ LITH1 ▪ LITH2 ▪ LITH3	▪ UNITNO: A unique number assigned to each map unit in the data set. ▪ NAME: The name of the geologic unit in the explanation of the 1980 state geologic map. ▪ AGE: The age of the geologic unit as shown on the 1980 state geologic. ▪ LITH1: The dominant lithology, volumetrically, in the rock unit. ▪ LITH2: The second most dominant lithology, ▪ LITH3: Other major lithologies.
PASDA*	▪ Small watershed boundaries	Arc/INFO Interchange Format	▪ WRDS# ▪ HEIRLEVEL ▪ HEIRCODE ▪ HUC	▪ WRDS#: Stream code number of the Water Resources Data System database for PA. ▪ HEIRLEVEL: DEP identification of location stream in watershed waterway. ▪ HEIRCODE: DEP coding of relative location of the stream in the overall stream network of the watershed. ▪ HUC: USGS hydrologic unit code number
	▪ Soils	Coverage		▪ PA-wide dataset
USGS	▪ Topographic maps ▪ Elevation Data	DRG DEM		▪ Digital Raster Graph ▪ Digital Elevation Model
Field Surveys	▪ Water samples	Tables	**Possible Attributes:** ▪ Stream ID ▪ Location ▪ Date ▪ Temperature ▪ Conductivity ▪ pH ▪ Eh ▪ Fe ▪ SO4	▪ Data were collected at different locations and time intervals.

Figure 2.
Scanned Paper Map



The scanned maps were georeferenced to fit the Digital Raster Graph (DRG) topographic map of four quads: Clarion, Stratanville, Fryburg and Lucinda.

Scanned paper map source:
Pennsylvania Department of Environmental Protection
Project SL-191, 1976.

digitized. **Figure 3a and 3b** show the digitized data from the PA-DEP report. The attribute table was then edited and every point was assigned an identification number (ID). Tables containing the entire weir data, (e.g. Weir Number, flow rates, pH, Average/Maximum acidity and iron) (**Table 1**) were created and then joined with the weirs attribute table and stream sampling points based on their identifying number. In addition, detailed tables showing dates and more detailed chemical analysis were entered into a spreadsheet (**Table 2**).

Table 2.
Sample spreadsheet of detailed weir data

TY_22										
DATE	GPM	pH	ACID (PPM)	ALK (PPM)	T. Fe (PPM)	SO4 (PPM)	ALK (PPD)	ACID (PPD)	T. Fe (PPD)	SO4 (PPD)
10/01/1973	12.00	4.70	60.00	0.00	0.20	380.00	0.00	8.60	0.03	55.00
10/25/1973	2.00	4.50	58.00	0.00	0.01	370.00	0.00	1.40	0.00	8.90
11/29/1973	156.00	5.00	4.00	2.00	0.15	50.00	3.70	7.50	0.30	94.00
12/19/1973	34.00	4.60	8.00	2.00	0.29	70.00	0.80	3.30	0.10	29.00
01/17/1974	123.00	5.10	8.00	6.00	0.15	71.00	8.90	12.00	0.20	105.00
02/19/1974	42.00	4.20	18.00	0.00	0.89	125.00	0.00	9.10	0.40	63.00
03/26/1974	82.00	5.00	2.00	2.00	0.00	35.00	2.00	2.00	0.00	34.00
05/06/1974	22.00	5.00	8.00	10.00	0.20	46.00	2.60	2.10	0.10	12.00
05/24/1974	22.00	5.50	8.00	8.00	0.10	150.00	2.10	2.10	0.03	40.00
06/25/1974	9.00	4.50	40.00	0.00	0.20	260.00	0.00	4.30	0.02	28.00
07/23/1974	6.00	4.40	36.00	0.00	0.70	275.00	0.00	2.60	0.10	20.00
08/26/1974	6.00	5.80	40.00	4.00	0.00	225.00	13.20	2.90	0.00	16.00
10/03/1974	28.00	5.00	10.00	2.00	0.10	250.00	0.70	3.40	0.03	84.00
MINIMUM	2.00	4.20	2.00	0.00	0.00	35.00	0.00	1.40	0.00	8.90
MAXIMUM	156.00	5.80	60.00	10.00	0.89	380.00	13.20	12.00	0.40	105.00
AVERAGE	41.85	4.87	23.08	2.77	0.23	177.46	2.62	4.72	0.10	45.30

Streams Data Preparation

A special consideration was given to the construction of the streams dataset. This dataset was intended to be used for further identification of pollution levels and to be integrated in the analysis procedures. The analysis would take into account acidity level and iron concentration to locate the sites that are calling for special attention and/or remediation.

The base dataset was downloaded from the Geography Network as a shapefile. The Census 2000 TIGER/Line format includes attribute about addresses which was not logically required for the stream database. The unnecessary fields were deleted and others were added to best fit the aims of the current work. Spatial editing was necessary to refine the streams network. A Digital Raster Graph (DRG) of the study area was used as a reference to edit the stream lines. Lines had to be merged or split depending on the available sampling points from field surveys. The streams were interpolated to represent sampling segments instead of points. Sampling values (i.e. attributes) were assigned to each segment accordingly. Annual field data were collected from 1995 to 2003 in early summer (May) for specific locations (**Table 3**). Furthermore, some of those locations were sampled in early Fall (September/October). **Table 3** lists sample data collected in May 2001.

Figure 3a.
Weirs and Source Sampling Points

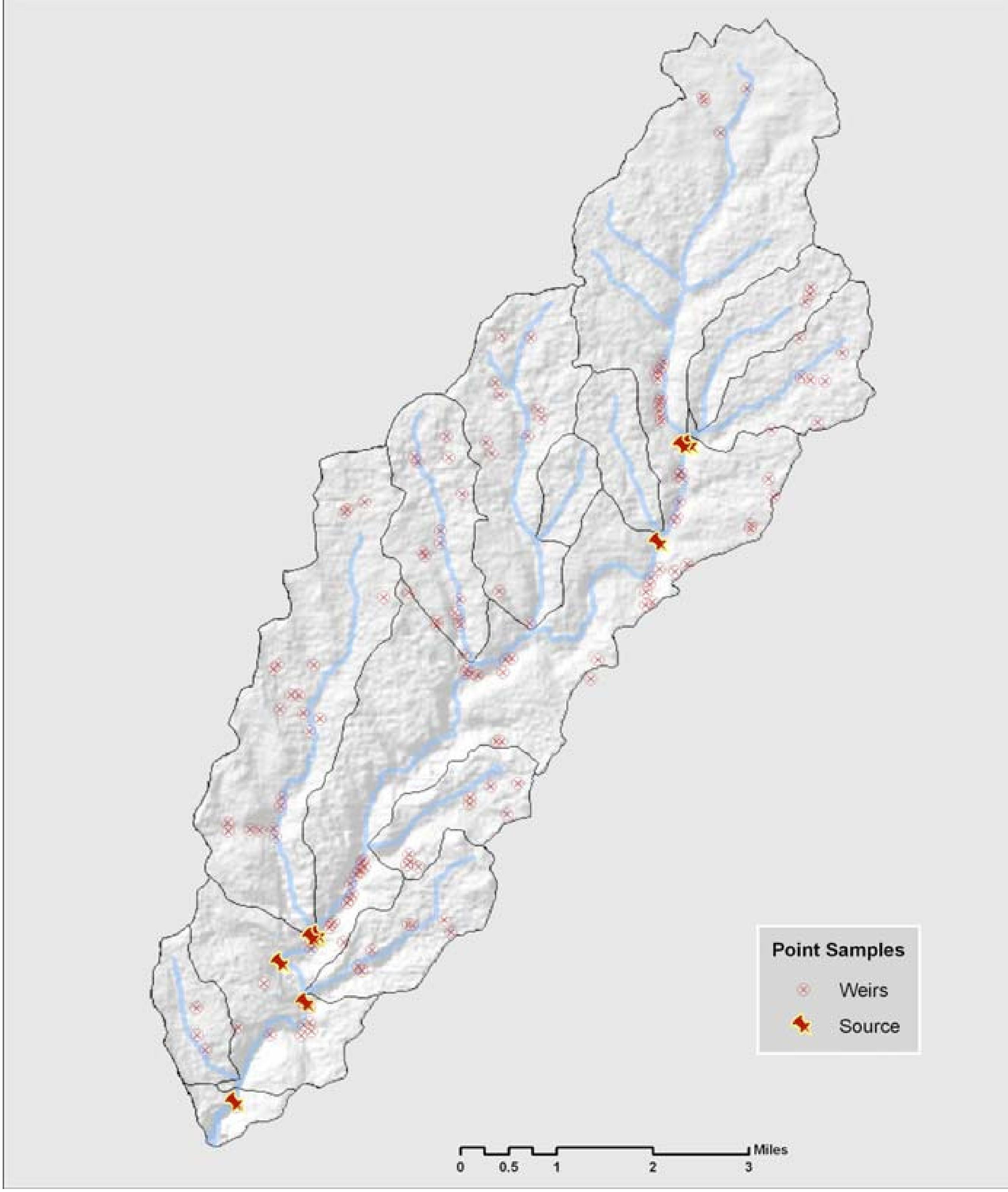


Figure 3b.
Coal Mining-Related Datasets

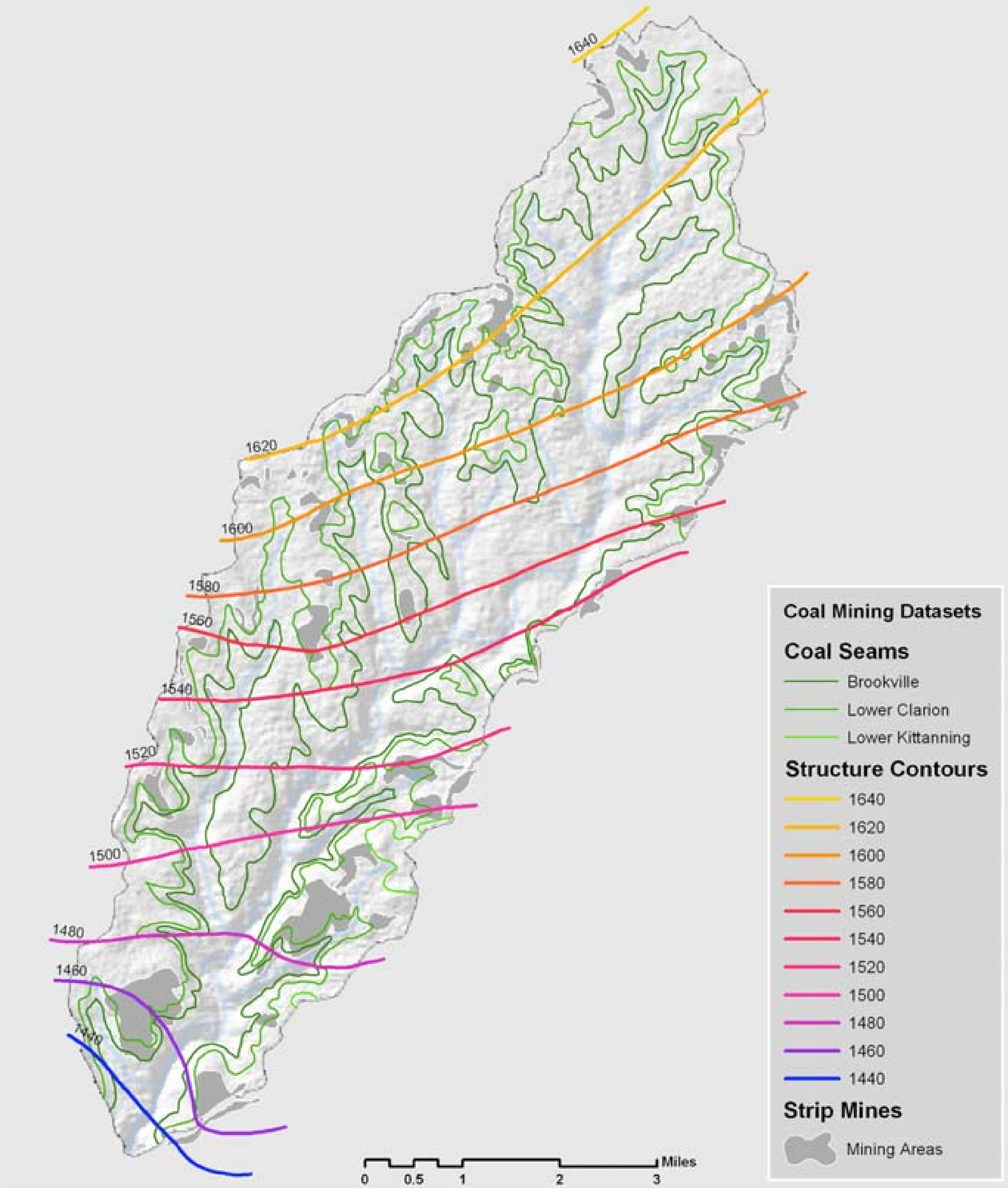


Table 3.
Sample field data for collected on 05/15/2001

STREAM_ID	LOCATION	DATE	TEMP	COND	pH	Eh	Fe	SO4
1	Helen Furnace Well Seep	05/15/01	14.70	918	5.70	165	57.10	40.00
2	Helen Furnace Pond	05/15/01	15.00	41	6.30	121	5.10	8.00
3	Toby Creek T562	05/15/01	12.00	52	3.00	280	2.00	17.00
4	Toby Creek Headwaters	05/15/01	15.00	10	5.60	120	0.20	4.00
5	Toby Creek Headwaters(road)	05/15/01	14.80	3	5.20	138	0.30	4.00
6	Toby Creek Headwaters (downstream)	05/15/01	14.20	7	5.10	131	0.10	4.00
7	Toby Creek Rt. 36	05/15/01	13.70	6	5.00	132	0.30	4.00
8	Henry Run T618	05/15/01	13.90	227	3.20	175	1.00	17.00
9	Toby Creek T619	05/15/01	16.10	55	4.20	170	2.00	4.00
10	Toby Creek T113	05/17/01	14.10	182	4.50	128	2.00	8.00
11	Rapp Run T576	05/17/01	12.70	881	2.00	405	13.30	5.60
12	Toby Creek (above Rapp Run)	05/17/01	12.70	265	2.80	368	4.20	41.00
13	Toby Creek (below Rapp Run)	05/17/01	13.00	453	2.50	314	5.50	54.00
14	Step Creek	05/17/01	13.00	338	2.30	313	2.10	57.00
15	Toby Creek (below Step Creek)	05/17/01	12.60	346	2.60	247	2.80	28.00
16	Toby Creek (above Step Creek)	05/17/01	12.20	107	2.80	321	3.90	51.00
17	Toby Creek T577	05/17/01	11.00	706	5.00	144	64.00	40.00
18	Step Creek (upstream)	05/17/01	14.00	469	2.20	217	10.00	38.00
19	Step Creek T578	05/17/01	15.40	254	1.60	352	37.40	40.00
20	Step Creek T578 (downstream)	05/17/01	13.80	338	2.00	336	12.20	49.00
21	Step Creek T578&T613 (above bridge)	05/17/01	13.50	296	2.50	205	3.40	20.00
22	Step Creek T578&T613 (drainage ditch)	05/17/01	12.60	547	5.20	28	38.10	81.00
23	Step Creek T578&T613 (below bridge)	05/17/01	13.00	124	2.20	248	26.30	45.00
24	Step Creek T850	05/17/01	14.30	81	2.00	333	5.50	43.00
25	Little Toby Creek T851	05/17/01	12.80	180	2.10	184	9.90	43.00
26	Engle Run	05/17/01	14.80	159	2.70	231	1.10	12.00

TEMP *= TEMPERATURE in degrees Celsius,* ***COND*** *= CONDUCTIVITY*

Analyzing Streams Pollution Level

Levels of acidity and iron concentrations were reclassified into a high, medium and low scale. **Table 4** summarized the results of this categorization.

Table 4.
The reclassification scheme of the acidity and the iron concentration for the streams dataset

Category	pH	Fe
High	<3	>25
Medium	3 to 5	9 to 25
Low	>5	<9

Subsequently, the pH ranking of High, Medium and Low was given the numerical value of 3, 2 and 1 respectively. Then a sub-class was made to combine the iron concentration with the pH ranks. The iron subclasses were given the value of A, B and C for High, Medium and Low concentrations respectively. Another field for remediation class identification (CLASS_ID) was added to the streams attribute table. **Table 5** summarizes the classification and the priority ranks associated with each sampled stream segment. The priority ranks for the sampled streams are presented in **Figure 4**.

Table 5.
Remediation priority and ranking of stream segments according to their level of acidity and iron concentration

Class ID	pH	Fe	Priority	# of Streams	Notes
3A	3	A	Extremely High	4	▪ **Extremely High**: High in both pH and Fe ▪ **Very High**: High in one and moderate in the other ▪ **High**: High in one and Low in the other ▪ **Moderately High**: Moderate in both pH and Fe ▪ **Moderate**: Moderate in one and low in the other ▪ **Low**: Low in both pH and Fe
3B	3	B	Very High	5	
3C	3	C	High	8	
2A	2	A	Very High	1	
2B	2	B	Moderately High	0	
2C	2	C	Moderate	11	
1A	1	A	High	1	
1B	1	B	Moderate	0	
1C	1	C	Low	4	

Data Accessibility

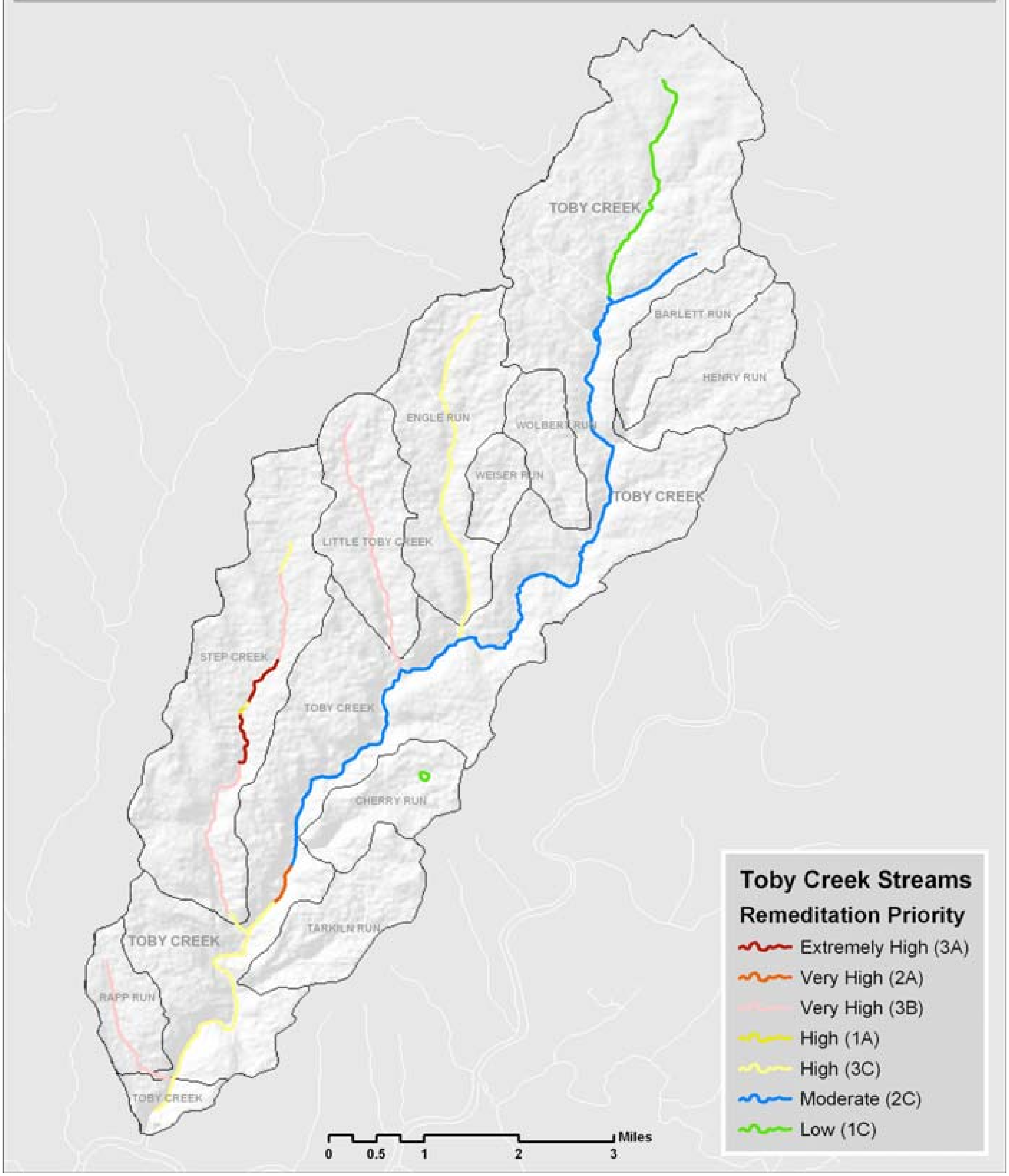
One of the major aims of this study was to construct a website that hosts the collection of the datasets and the results of the analysis for the Toby Creek watershed. The reason for this is to provide future studies with an easy to use/access comprehensive database. One of the easiest, most economic and user friendly ways is to provide an access to a pre-designed map composition through the internet. Web browsing is becoming more and more familiar tool to a wide variety of people. It does not require any specific high level of knowledge or expertise, therefore it constituted a top choice to provide professional besides inexperienced people with information about the environmental conditions of Toby Creek watershed.

Internet mapping was created using ArcIMS version 3.0. The generated website is still in its initial stages; therefore the accessibility is limited to a small range of on-campus computers. Future plans involve making the website available to the public.

Special consideration was given to extend the identification results of the weir sampling data to include a hyperlink to the extension tables in a separate window in order to display detailed data for the selected weir. Furthermore, HTML viewer was used instead of Java viewer since it could be customized and did not require users to download any supporting files for Java (Java run-time environment and Java applet).

The website was built with future considerations in mind. It not only allow the customization of its look and functionality but it open the possibilities of adding and modifying the datasets in order to serve more interested researcher and casual visitors. **Figure 5** shows a snapshot of the website and the identification result.

Figure 4.
Intervention Priority Ranks



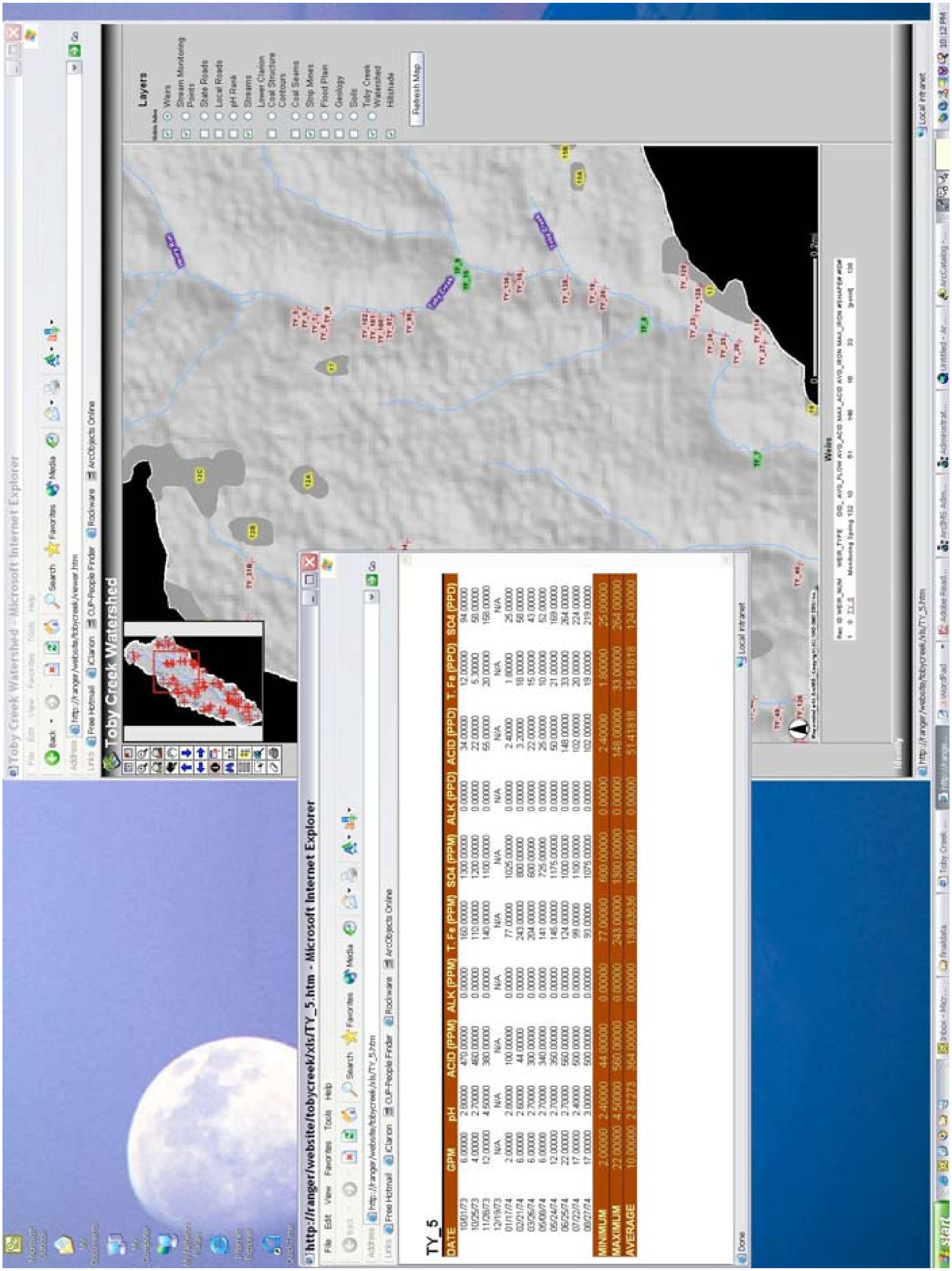


Figure 5.
A snapshot of the Toby Creek Watershed website and a sample data extension of a selected weir.

Conclusions and Future Expectations

The current paper tackled the issue of Acid Mine Drainage for Toby Creek watershed in three different ways. First it represented an effort in gathering, assembling, refining and documenting data from different sources and with multitude of formats and accuracies. Second it traced an example of how to determine the streams with the highest impact risk. A method of prioritizing future intervention was carried out using acidity level and iron concentration. The results showed the location and the type of pollution of the different stream segments, each was ranked for priority for future remediation/intervention. Third, in order to make the work on the watershed useful for a wide variety of users, a website was initiated using internet mapping capabilities.

Although the current paper objective started by compiling data from different sources of information concerning the AMD problems of Toby Creek Watershed, it was extended to establish the foundation for a comprehensive database that surpassed its initial aims. Even if the main focus is still on the AMD problems, there is a significant desire from different colleagues at Clarion University to proceed in a steady, harmonious and serious collaboration to contribute to the current efforts.

This study only considered limited field data; it can be expanded to include all existing field data as well as having the option to plug in any future collected data. For future consideration, more data can be added to the database and monitoring of the sub-basin in different time interval and diverse locations.

Cited Reference: PA Department of Environmental Protection, 1976. Project SL-191. *Toby Creek Watershed*.

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