Geospatial Tools to Support Watershed Environmental Monitoring and Reclamation: Assessing Mining Impacts on the Upper Susquehanna-Lackawanna American Heritage River[1]

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Abstract: As a community participant in the American Heritage River (AHR) Program for the Upper Susquehanna-Lackawanna (US-L) Watershed, the Pennsylvania GIS Consortium (PAGIS) has developed and tested a suite of integrated geospatial tools and technologies to facilitate efforts to preserve and restore the integrity and function of river ecosystems and their watershed condition. The US-L watershed (2000 sq. mi. area) is impacted by abandoned mine lands (AML), acid mine drainage (AMD), and combined sewer overflows --- which total over $2.5 billion in cleanup and reclamation costs. Our GIS watershed analysis has allowed us to rank and prioritize 12 impacted watersheds from which we selected a subset of key sites for "near-real-time" environmental monitors to measure water quality trends and patterns. In a paired watershed comparison (AML-AMD vs. reference), conductivity and total dissolved solids were statistically higher and redox potential, pH, and dissolved oxygen were significantly lower in the impacted watershed; data on water quality and associated watersheds are made available to the public via a community RiverNet Web portal and Web-based GIS (ESRI's ArcIMS software). Ongoing geospatial analyses of watersheds include use of CITYgreen software (American Forests) to demonstrate the benefits of reforestation as a reclamation strategy and 3-D CommunityVIZ software (Orton Foundation) to visualize land use and impact patterns relative to mining. Working in partnership with Digital Globe (now with a new downlink facility in Wilkes-Barre, PA), PAGIS has recently showcased the integration of 2 ft pixel panchromatic satellite data with multispectral satellite data; this new data fusion process (in ERDAS) has numerous new potential GIS applications in reclamation design, floodplain management, water quality monitoring, and watershed management.

Additional Keywords: GIS, GPS, remote sensing, real-time monitoring, water quality, watershed pollution & river ecology, 3-D GIS, acid mine drainage, and Web based GIS.

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Introduction

Scientific consensus indicates that changing land use is the single most important component of global environmental change affecting ecological systems (Vitousek, 1994, National Research Council, 1993). Land use changes are also the dominant stressor on freshwater ecosystems and watersheds on a world-wide basis (Carpenter et al., 1992). Assessment of change in land use and land cover at landscape and watershed scales of resolution has been challenging but technologies like geographic information systems (GIS) and remote sensing (RS) have emerged as critical tools to this broad-scale approach in environmental monitoring, assessment, and management (Wessman, 1992, Vitousek, 1994, Wiersma and Bruns, 1996, O'Neill et al., 1997, Jones et al., 1997, Bruns and Wiersma, 2004). For example, O'Neill et al. (1997) recommended the use of GIS and remote sensing data, along with recent developments in landscape ecology, to assess biotic diversity, watershed integrity, and landscape stability.

In this context, geospatial technologies are currently being evaluated by the PA GIS Consortium (PAGIS, a consortium for partnering with industry, regional universities, and local, state, and federal government for community GIS projects) for application to integrated environmental monitoring and assessment of landscapes, watersheds, and stream ecosystems impacted by past and ongoing mining operations (Bruns et al., 2001, Bruns and Wiersma, 2004). A major goal of our studies has been the improvement in efficiency and cost-effectiveness for monitoring, managing, and reclamation of damaged environments in the Anthracite Fields of eastern Pennsylvania (Bruns et al., 1997a,b). In addition, as reviewed by Bruns and Wiersma (2004), GIS and remote sensing imagery have strongly facilitated a hierarchical (i.e., stream reaches to watersheds to landscapes – based on O'Neill et al., [1988]) approach to spatial scale and watershed analysis. This has been due, in part, to the better availability of geospatial data and technology, but this also is based on the relevancy of these regional environmental assessments for broad geographic extents (O'Neill et al., 1997, Hunsaker and Levine, 1995).

Our GIS and geospatial watershed applications have been evolving since our initial pilot study started in 1994 (Bruns et al., 1997a,b) when we first applied GIS and related technologies to assessment of 18 subcatchments and water quality sampling sites. This study area of 300 square miles, surrounding the city of Wilkes-Barre, encompassed 16,000 acres of abandoned mining lands. At that time, a newly found land conservancy group (Earth Conservancy) had just purchased these abandoned lands after being in the bankruptcy court for 19 years, a national record.

In 1998, we expanded our work to cover 2000 square miles in the watershed of a newly designated American Heritage River. GIS related technologies and a watershed approach had been incorporated as a key component in this successful community proposal (60 of 196 local governments endorsed the proposal). Later in 1998, President Clinton designated the Upper Susquehanna-Lackawanna (US-L) River as one of 14 American Heritage Rivers (AHR) from a field of over 120 applicants nationwide (AHR, see www.epa.gov/rivers/98rivers/). In 2001, we completed a Phase I GIS Watershed Plan (Bruns et al., 2001) for this study area. This GIS Plan focused on community GIS database gaps as part of a regional "digital divide," environmental assessment of 42 tributary watersheds, and a community data distribution strategy in the context of a "locally independent and regionally coordinated GIS." An implementation program was also recommended that included community-leveraging and cost sharing for data acquisition, environmental monitoring and assessment, and a Web based GIS strategy to regional sharing of local ortho-imagery data. Our AHR watershed has also been designated a National Spatial Data Infrastructure Community Demonstration Project (www.fgdc.gov/nsdi). In 2000, PAGIS received a National Hammer Award (with five other national sites) from Vice President Gore's Program in Re-Inventing Government for our work with GIS technologies applied to environmental problems in the AHR watershed (www.pagis.org/CurrentWatershedHammer.htm).

The objectives of this paper are intended to highlight aspects of our ongoing research to apply and evaluate the use of geospatial technologies to assess, prioritize, and facilitate reclamation activities in the US-L American Heritage River Watershed. These include: reviewing aspects of watershed analysis to rank tributaries for mining impacts (Bruns et al., 2001) to facilitate selection of sites for real-time water quality monitoring based on environmental design concepts (Bruns et al., 1997a, Bruns and Wiersma, 2004); profiling water quality data on a paired-watershed basis for a reference vs. mining impacted catchment (Bruns and Sweet, 2004); highlighting aspects of our Web-based GIS for public access to monitoring data and watershed conditions; and showcasing software applications (CITYgreen and CommunityVIZ) of selected GIS watershed tools (Bruns and Wiersma, 2004, Bruns and Sweet, 2004).

Study Area

Portions of the following description of our study area are taken from Bruns and Yang (2002) and Bruns and Sweet (2004). The Susquehanna River drains the largest basin on the Atlantic coast of the U.S. and is the sixteenth largest river in the U.S.; over half of the freshwater inflow to the Chesapeake Bay is from the Susquehanna River (Edwards, 1994). There are almost 4 million people living in the drainage basin (U.S. Bureau of the Census) yet only about 9% of the basin is in urban land use while over 63% is forested, 20% is agriculture, about 1.5% is water, and almost 7% is pasture (Ott et al., 1991). In addition, coal mining on the West and North Branches of the Susquehanna has resulted in extended areas impacted by acid mine drainage with clean-up cost estimates from the late 1980's in the range of $1.5 to 2.5 billion (Stranahan, 1993). More recently, the Office of Surface Mining (U.S. Department of Interior) provided testimony at Congressional hearings in 2000 and indicated that the costs of mining reclamation in the Eastern Anthracite Field alone have approached $2 billion and would take 200-300 years at current rates of state and federal funding (Bruns et al., 2001).

Estimates by Dr. Roger Hooke (cited in Monastersky, 1994) indicate that people move roughly 40 billion tons of soil and rock each year as part of landscape impacts worldwide that exceed any single geomorphic agent like water, wind, or ice. The environmental impact of such large-scale disturbance of the landscape is strongly evident in northeastern Pennsylvania where over 5 billion tons of anthracite coal had been removed from four coal fields between 1807 and 1967 (Ladwig et al., 1982). In the Scranton/Wilkes-Barre area (see Fig. 1) of the Northern Anthracite Field, numerous coal seams were mined to depths of several hundred meters below sea-level and massive de-watering was required to keep deep mines operational (Ladwig et al., 1982). In addition, significant amounts of strip mining activity (e.g., Goddard, undated [ca. 1975] PA Department of Environmental Resources Report on Newport Creek) also occurred in this region at locations where coal seams (Llewellyn Formation) were situated near the surface.

The AHR watershed for the US-L River ecosystem covers a 2000 square mile area in the lower portion of the North Branch of the Susquehanna River near Wilkes-Barre, PA (see map, Fig. 1 with the AHR watershed outlined in red) and represents the most heavily impacted portion of the watershed due to over 150 years of coal mining as noted above and from more than 225 combined sewer overflows (CSOs) that unload human sewage mixed with stormwater into the

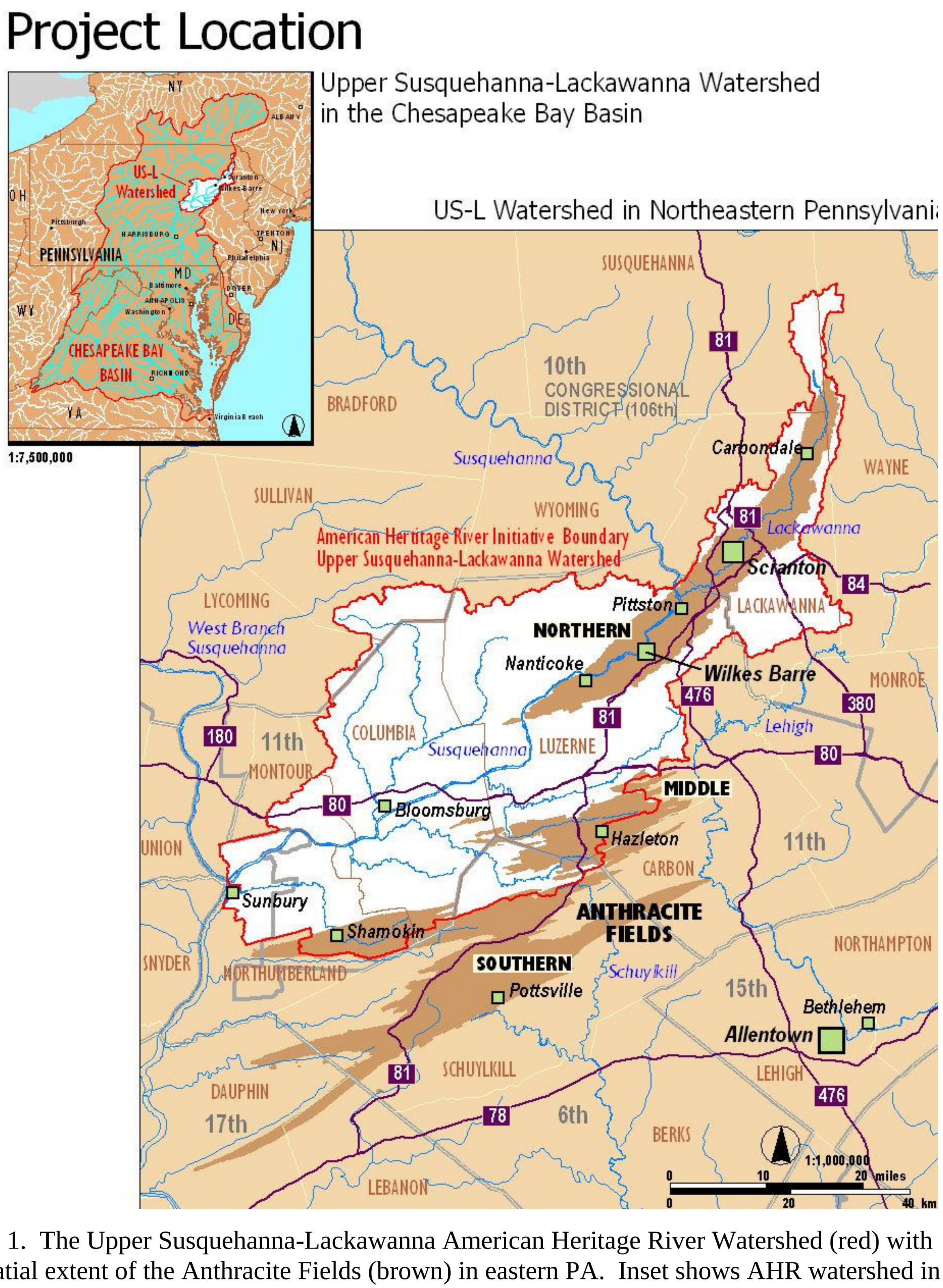

Figure 1. The Upper Susquehanna-Lackawanna American Heritage River Watershed (red) with geospatial extent of the Anthracite Fields (brown) in eastern PA. Inset shows AHR watershed in the context of the larger Chesapeake Bay Watershed.

river during storm events from a population of almost 500,000 people. Extensive land damage from mining and degradation of a large river ecosystem has resulted in significant economic stagnation in this 10 county area of the AHR with over 190 townships, cities, and boroughs.

It is important to note that most of the environmental destruction from past coal mining predated state and federal environmental regulatory agencies, statutes, and regulations. Also, the historical ecological devastation from mining in the Wilkes-Barre portion of this river subbasin is perhaps unprecedented even by 19th century "industrial barons" standards. The following quote from Stranahan (1993) illustrates a key riverine and watershed impact as recently as 1958 when mining underneath the Susquehanna River (up to 1000 feet deep beneath the river for over a 60 mile stretch of valley) resulted in a large "hole" in the river channel with a "runaway whirlpool" of 100,000 gallons/minute draining into the underground mine tunnels:

"In an effort to plug the giant cataract...... a rail line was diverted, and more than 200 rail cars were dumped into the hole. Truckloads of rocks, railroad ties, utility poles, and hay were thrown in as well, disappearing without a trace. By then, however, the Susquehanna had flooded almost all mines in the Wyoming Valley [Anthracite Field], and the anthracite era came to a ...... halt."

Unfortunately, since the demise of the mining industry in the area, significant reclamation efforts have been needed to deal with the mine-water discharges from these underground mine tunnels to the Susquehanna River. In 1991, 100 sites had discharges over 1cfs (cubic feet per second) each and collectively they accounted for 823 cfs of acid mine discharge to the river that was high in acidity, sulfate, and metals like iron (over 5 tons per day to the river) and manganese (Wood, 1994). Clearly, the watershed of the Upper Susquehanna/Lackawanna American Heritage River is one of extreme contrast in land use, landscape, and the quality of the river ecosystem, all requiring a national mandate for environmental reclamation from past mining activities on a landscape scale of disturbance – with Congressional Hearings validating these problems and costs from a variety of agencies.

There are approximately 500,000 people in this region with over 350 separate boroughs, townships, and municipal areas each with their individual sewer system. Typically, such systems may have combined sewer overflows (CSOs) whereby human sewage mixed with stormwater is dumped directly into tributaries and the mainstem river whenever there is a moderate to heavy rainfall in the area. In addition, other related waste problems and issues in the watershed include individual septic systems and on-lot treatment facilities. Sanitary authorities have jurisdiction over the CSO points but the separate entities of local government control their combined sewer systems on an individual "ad hoc" basis. For example, the Wyoming Valley Sanitary Authority is responsible for over 50 CSOs but monitoring of water quality with grab sampling only started in the past several years and their control system only indicates whether flow is qualitatively (no quantitative measures of flow or water quality) present or not through a particular CSO. The Wyoming Valley Sanitary Authority maintains a service area that includes 36 different communities (townships, municipalities, etc.,) with a collective population of 211,000 people (1990 census).

Finally, it should be noted that this region is in close proximity to the very high human populations of the eastern Atlantic Urban Corridor; this area is only 3 hours drive from New York City (7.3 million people) and is within less than one day's drive for over 20 million people from Boston to Washington, DC. Over 10 million people per year visit the Pocono Mountains region alone (forming the eastern edge of the AHR watershed). Thus, the general area encompasses a broad range of land uses and is currently undergoing rapid transformation and development pressure due to recreation, tourism, commercial development (especially as a transportation and distribution corridor to New England), and suburbanization.

Methods

The materials below summarize the approach, methods, and data relative to our research components being highlighted in this paper. Fuller details are provided in Bruns et al., (2001).

Tributary watershed analysis for environmental monitoring design

We designated 42 different tributary watersheds in the overall US-L watershed including the river corridor itself along the mainstem of the Susquehanna River. The tributaries were selected to represent the next level in the ecosystem hierarchy (O'Neill et al., 1986, 1988, Interagency Team, 1998, and Bruns and Wiersma, 2004) relative to the US-L watershed. This GIS data layer was composed from the "small-sheds" GIS data layer from the PA State GIS Web site at PASDA (http://www.pasda.psu.edu/flash.shtml). The small-sheds data are available with FGDC metadata and were used to document metadata in the creation of the "tributary watersheds" GIS data layer used in this analysis. We used the Mid-Resolution Land Characteristics (MRLC) data set derived from the Thematic Mapper (30m spatial resolution) for land cover analysis relative to forests, grasslands (pastures and agricultural land cover classes), urban, barren (predominantly mining in the US-L watershed), and water. Our approach to land cover, tributary watershed analysis is provided below in Fig. 2.

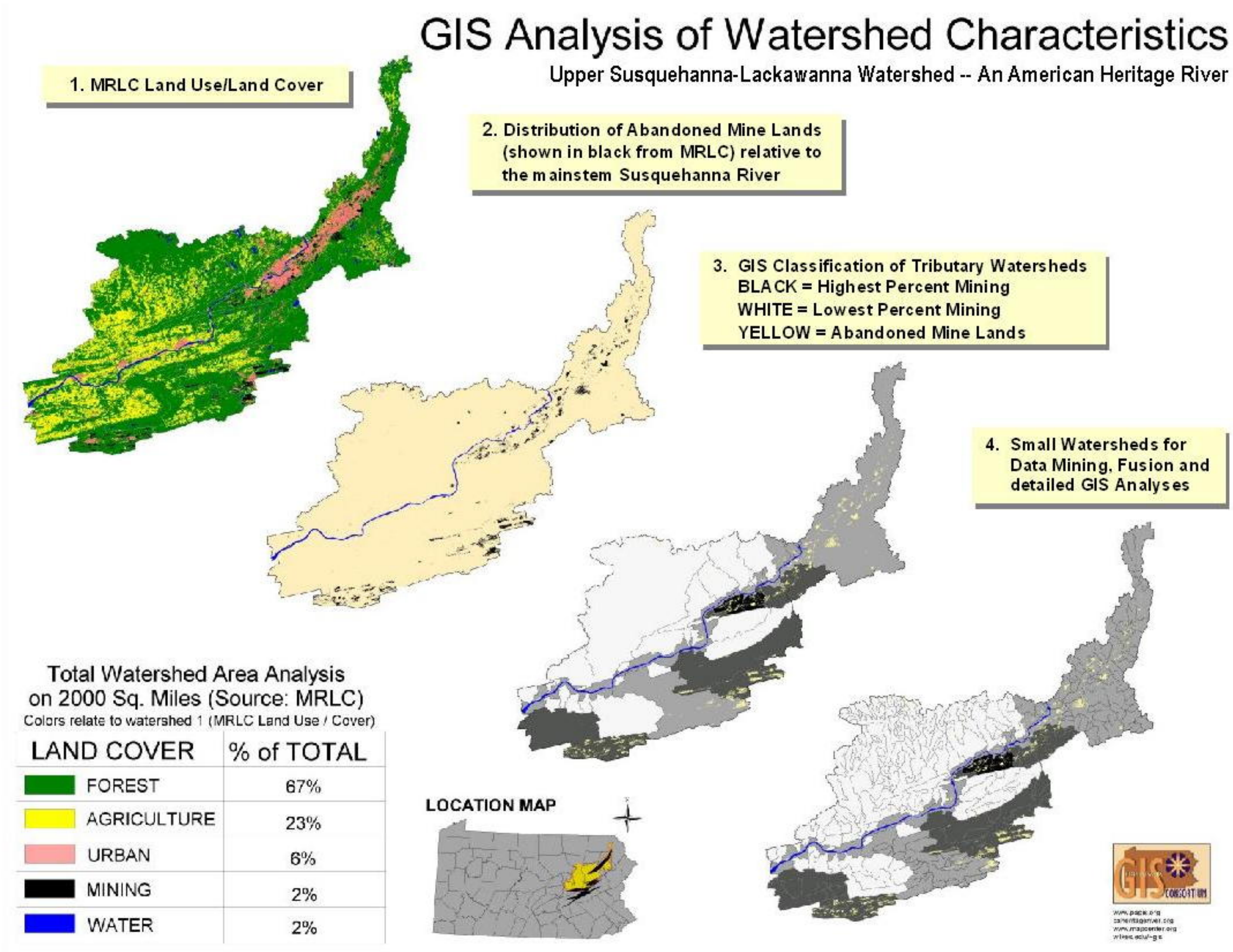

Figure 2. GIS tributary watershed analysis to prioritize mining lands in design of a real-time water quality monitoring program.

The other GIS data used for these tributary watershed analyses included:

- wetlands (GIS coverage, from Department of Interior, National Wetland Inventory)
- largest AMD outfalls, loading and number (Wood, 1996, see Bruns et al., 2001), and
- CSO data (GIS locations from EPA EnviroMapper, also EPA Web page).

A summary of FGDC compliant metadata documentation had been provided in Bruns et al., (2001). Metadata are available on request for GIS data layers created for this watershed assessment, including tributary watersheds, the 100 largest AMD outfalls, and CSO data. We used ArcView (ESRI, Redlands, CA) to classify all 42 tributary watersheds based on their ranking in five percentage categories (20% groupings or quintiles) for six watershed parameters: mining land cover, forest cover, wetlands cover, hydrogen loading (calculated from AMD outfalls), iron loading (calculated from AMD outfalls), number of AMD outfalls, number of CSOs, and an "average" index calculated over the six best indicators (Bruns et al., 2001).

Real-time water quality monitoring

YSI (Yellow Springs Instruments) real-time monitoring units have been employed in our study. This system is capable of providing data on the following parameters: temperature, conductivity, pH, dissolved oxygen, water depth, salinity, turbidity, oxidation-reduction (redox), ammonia, and nitrate. The YSI real-time monitoring instruments come fully operational "off the shelf" and this includes a data logging unit, and a telemetry system. The data logging and telemetry system facilitate data processing and management, data transmittal (from field to GIS laboratory), quality control, calibration, and documentation. We have employed the telemetry units based on the use of cellular telephones. Essentially, monitoring units and their data loggers can be programmed at selected intervals to automatically call up (daily) the receiving PC in the GIS laboratory for automatic downloading of data. This approach and technology appeared to give us the easiest and most cost-effective method for data acquisition and transfer.

To the extent possible, we have used software developed as part of the data logging system as it exists off the shelf for purposes of data management, processing, and delivery via cellular phone. For example, the YSI multiprobe sonde software is based on an intuitive, menu-driven guide that directs one through calibration, data display, logging setups, and data download. Instruments were calibrated with known standards, based on EPA methods for a QA/QC plan for this project; details and procedures are available on request as part of our Information Management Plan.

For this paper, we emphasize a paired watershed approach by statistically comparing a tributary watershed highly impacted by mining activities on the landscape in addition to significant sources of AMD from outfalls vs. a reference tributary with limited mining activity (no outfalls and mining land cover less than 1 % of the watershed). At this time, our QA/QC checks indicates good confidence in data from the real time monitors on conductivity, total dissolved solids (TDS), redox (reduction-oxidation potential), pH, and dissolved oxygen (DO), and these data are reported in this paper; these parameters also best reflect potential impacts or "signatures" associated with mining affects. Data on ammonia and nitrates are not analyzed at this time since they require more detailed evaluation from a QA/QC perspective (including potential instrument drift) and reflect impacts more likely associated with urban runoff and CSO affects, rather than mining.

CITYgreen and CommunityVIZ software applications

CITYgreen is a GIS software tool for regional, local, and watershed-landscape analysis on the environmental function and economic value of trees and forests, especially in urban areas (American Forests, 2002, and reviewed in Bruns and Wiersma, 2004). We used only selected model output parameters in this study since our objective here is to evaluate the potential for carbon sequestration (and storage) if extensive re-forestation and ecosystem restoration efforts were to be implemented on a selected tributary watershed with extensive areas of barren, abandoned mining lands. Therefore, we used this environmental planning tool with regional satellite imagery (MRLC as described above) classified for land cover. For our application, we employed CITYgreen analysis on a reference tributary (Toby Creek) to derive regression relationships between forest cover and estimated carbon sequestration rates and storage. Comparisons are then made to our mining impacted watershed, Nanticoke Creek, where we also conducted real time water quality monitoring as reported in this paper. We followed the CITYgreen reference manual (American Forests, 2002) for procedures and used 0.5 to 60 acre "sampling quadrants" (delineated as GIS shapefiles in ArcView) for analysis of carbon sequestration and storage (due to forests) vs. forest land cover derived from MRLC.

CommunityVIZ was used as a visualization tool based on 3-D GIS for the AHR watershed. We followed the standard reference manual and employed USGS 30m digital elevation models (DEM) to create a triangulated irregular network (TIN) for purposes of 3-D graphics of CommunityVIZ. MRLC land cover data and tributary watershed boundaries were "draped" over this digital topography to illustrate the value of 3-D GIS in visualization of "reforested" areas.

Results and Discussion

GIS tributary watershed analysis for monitoring design and site selection

It was our intention to use geospatial analysis to select tributaries for monitoring of water quality conditions affected by abandoned mining land (AML) disturbances, acid mine drainage (AMD), and combined sewer overflows (CSOs). A detailed statistical analysis (Bruns et al., 2001) was conducted on the five land cover classes noted in our methods section and additional indicators based on the number of CSOs and AMD outfalls (including iron and hydrogen loading) in a watershed. Fig. 3 shows an example of the ranking and classification of watersheds for mining and forest land covers in quintiles; red shows the most impacted watersheds in the worst 20% category vs. green in the less impacted conditions.

We also ran t-tests for 12 tributary watersheds with greater than 1% of land cover in mining vs. four rural, non-impacted reference watersheds with less than 1% land cover in mining and with previous EPA water quality survey data (based on Bruns et al., 2001). These tests were conducted for all land cover categories, and their rankings within quintiles (see Fig. 3 as an example), along with the other watershed indicators noted in the methods (AML, AMD, and CSOs). The following watershed indicators were found to be statistically significant in their detection of impacts between the 12 mining tributaries vs. the reference streams (rated for effectiveness, based on level of statistical significance, with "medium" being $P < 0.05$ and "extremely high" at $P<0.0001$):

- Mining (extremely high): calculated based on percent land cover (MRLC)
- CSOs (very high): calculated as the number of permitted CSOs per watershed
- Averaged index (high): average of these five parameters plus iron loading, percent wetland cover, and percent forested cover (MRLC)
- Hydrogen ion loading (medium): based on fall USGS (1991) water quality survey of 100 largest AMD outfalls in the Anthracite Region of eastern PA
- AMD outfall number (medium): number of outfalls per watershed based on USGS (1991) water quality survey.

Because of the extremely high performance of the mining land cover index, we decided to prioritize this criterion in the design of our water quality monitoring network. On this basis, three tributaries were ranked in the "worst" quintile: Newport , Nanticoke, and Warrior creeks, all occurring in the Wyoming Valley, in the "heart" or center of the AHR watershed (Fig. 3). We selected Nanticoke Creek as our AML impacted watershed for water quality monitoring, over the other two, on the basis of better site logistics, safety, access to power, and security.

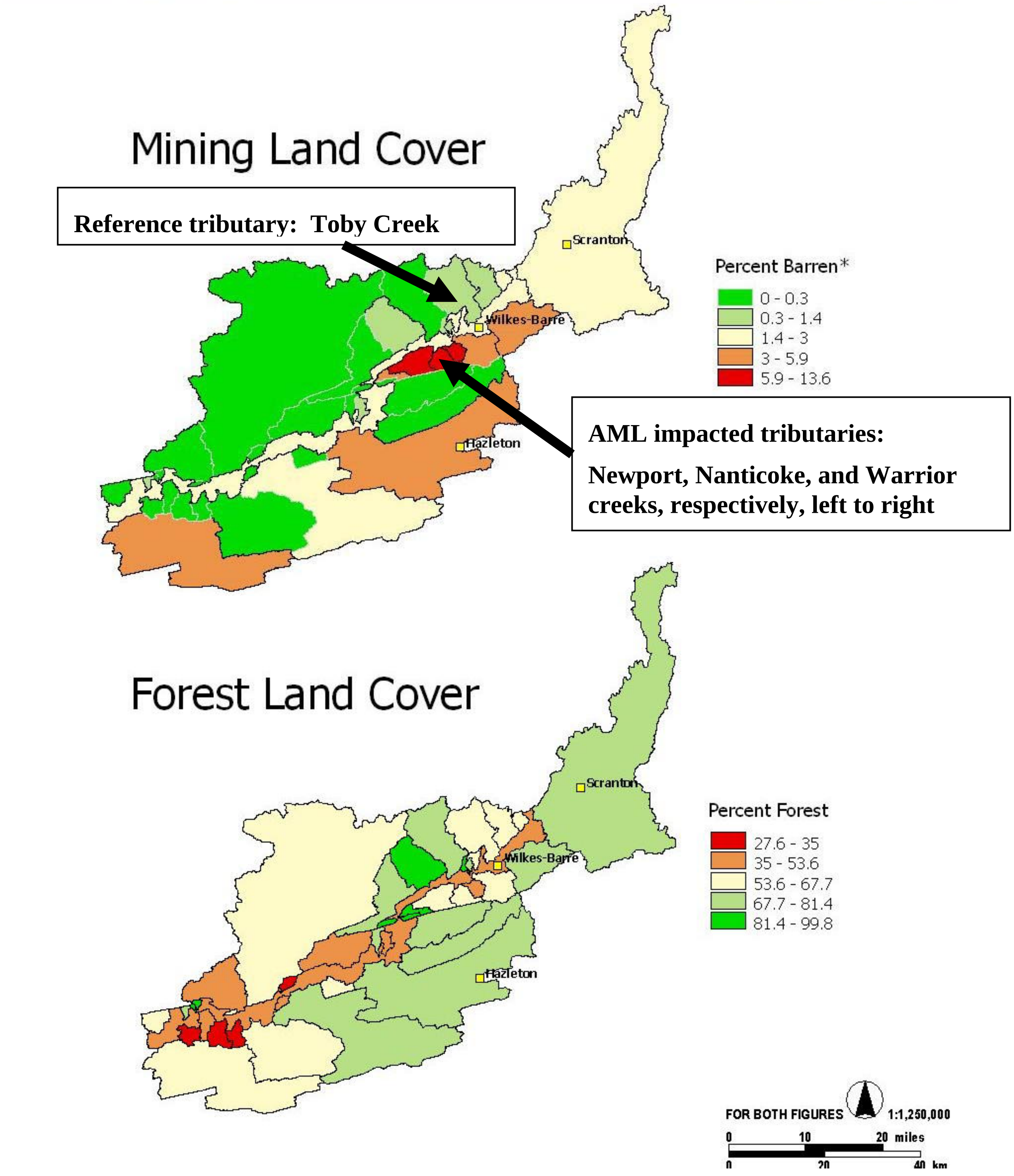

Figure 3. GIS classification of 42 tributary watersheds into 20% categories or quintiles (red is most impacted while green is the least impacted category). See Bruns et al., (2001) for details.

As noted above, the CSO index was highly significant as a means of statistically separating impacted watersheds from reference watersheds. This GIS classification tended to sort out on the basis of the urban corridor along the mainstem Susquehanna and Lackawanna rivers (Bruns et al., 2001). This also provided the basis for selecting water quality sites on both rivers, but these sites are more focused on urban runoff parameters and CSO impacts rather than mining impacts exclusively, since acid buffering capacity (alkalinity) is relatively high based on other survey data (Bruns et al., 1997b). Therefore, we do not report GIS watershed analysis and water quality data for those river sites in this paper.

In our original proposal for real-time water quality monitoring to EPA's EMPACT program, we proposed monitoring at Solomon and Newport creeks, rather than Nanticoke Creek. Mining land cover was slightly higher for both streams and AMD outfall loading rates were somewhat higher. However, before permanent sites were selected, extensive surveys were collected on a limited time basis with the real-time monitors. This work included site-specific, field evaluations of logistics along with a concurrent review on the availability of related data, studies, and reclamation activities. On this basis, Nanticoke Creek was the preferred site. Thus, a final site selection for an AML impacted stream was based on an iterative process between geospatial analysis and practical considerations.

Our approach to evaluating and selecting water quality monitoring sites is consistent with environmental monitoring design principles developed by Bruns et al., (1997a) and Bruns and Wiersma (2004). For example, our geospatial data, GIS methodology, and associated maps (as shown in Fig. 2) reflect source-receptor pathways of mining wastes and land disturbance linked along hydrologic flow paths to ecosystem endpoints like river and stream water chemistry. In addition, we employed data integration with GIS and image processing software (Avery and Berlin, 1992, Lunetta et al., 1991, Wiersma et al., 1995) and accounted for the need for several "iterative" loops in the site selection process consistent with recommendations of the National Academy of Sciences report on environmental monitoring (Boesch et al., 1990).

Fig. 4 shows a more detailed overview of the Wyoming Valley from the confluence of the Lackawanna River with the Susquehanna River down to the southwest terminus of the Northern Anthracite Field. Consistent with Bruns and Wiersma (2004), this GIS map summarizes sources of pollution (AMD boreholes and AML [shown as stripped mined areas], CSOs, the urban corridor, and the subsurface "mine pool"), ecological receptors (adjacent streams and the river corridors), and the proposed YSI site selection locations (green "+" symbol on Fig. 4) based on the GIS watershed indicators highlighted above.

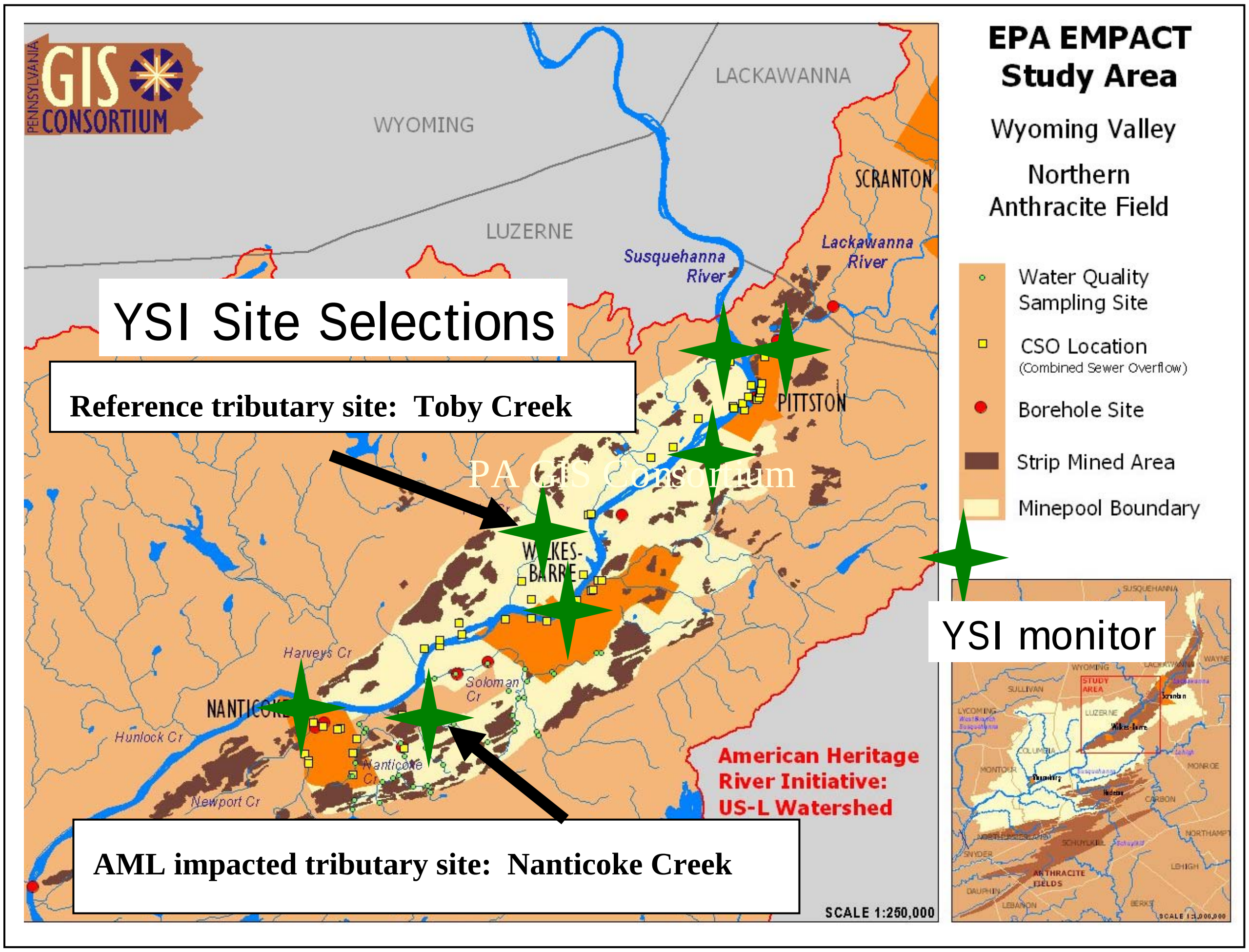

Figure 4. Sources of environmental impacts from AMD boreholes, AML (stripped mining lands), and CSOs in reference to adjacent streams and river corridors; proposed YSI site selections based on GIS watershed analysis. See text and Bruns et al., (2001).

Paired watershed analysis of water quality data

Table 1 provides an overview of watershed characteristics of Toby Creek vs. Nanticoke Creek. It should be noted that mining lands (< 1% land cover) of the Toby Creek watershed are clustered in one small area near the mouth of the creek and the single CSO is located also at the mouth. Our water monitor was located upstream of both mining areas and the CSO. Examination of our watershed analyses (Bruns et al., 2001) indicated that Toby Creek was better assigned to the reference watershed subset of tributaries rather than to the impacted subset. For example, Toby Creek scored in the highest, most ecologically preferable category in 4 of 7 of the watershed indicators and in the second most preferable category for two other indicators. Overall with more than 80% of its watershed in forests and agricultural lands (Table 1), Toby Creek is largely rural in character and is well-suited as a reference stream (Bruns et al., 2001). Nanticoke Creek had 10.3% in AML (the third highest for a tributary in the AHR watershed) and a lower percentage in agricultural land cover relative to Toby Creek; other categories of land cover (forest, wetlands, and urban) were more comparable between streams while Nanticoke had 4 CSOs (Table 1).

Table 1. Watershed characteristics for paired-watershed analysis

Watershed Characteristic	Toby Creek	Nanticoke Creek
Watershed area	36 square miles	8 square miles
% Forest land cover	61.3	67.3
% Grassland land cover	19.6	8.6
% Urban land cover	16.4	12.2
% Mining land cover	0.6	10.3
% Wetlands land cover	2.1	1.6
Number of AMD outfalls	0	0
Iron loading from outfalls	0	0
Hydrogen loading from outfalls	0	0
Number of CSOs	1	4

Overall, 2% percent of the US-L River watershed is in mining land cover (Fig. 2). This figure can be used as a relative point of comparison since individual tributary watersheds vary considerably, from less than 0.3% to nearly 14%. As noted in the EPA regional landscape assessment (Jones et al., 1997), 67% is in forests, the predominant land cover category for the whole watershed of concern. The agricultural land cover class can also be seen in Fig. 2 and, at 23 % of the watershed, it is apparent why a major EPA watershed-landscape analysis (Jones et al., 1997) included a number of indices dealing with this land use issue. Finally, urban areas make up about 6% of the AHR watershed based on the MRLC land cover data (Fig. 2 and Bruns et al., 2001).

Table 2 provides water quality data for the two comparison streams relative to parameters to assess AML and AMD cumulative impacts on a paired watershed basis. Conductivity and total dissolved solids were statistically higher (t-tests, all significantly different at $P < 0.001$) and redox

Table 2. Water quality data from real-time monitors (Jan. 2003 - July 2004; readings at 15 min. intervals for Toby Creek; readings at 30 min. interval for Nanticoke Creek).

Conductivity (uS/cm)	**Toby Cr**	**Nanticoke Cr**	**Reference (EPA BASINS)**			
Mean	155	740	**Toby Cr:**	**Mean**	**Std Dev.**	**Obs.**
Standard Deviation	43.9	167.5	1970-1974	163	69.7	7
Observations	38371	7717	1975-1979	164	51.2	40
df	7931		1980-1984	216	45.8	56
t Stat	-304.7		1985-1989	204	41.7	37
Significance (one-tail)	P < 0.001		**Nanticoke Cr: no data**			
t Critical one-tail	1.65		**Criterion:** none listed			
TDS (mg/L)	**Toby Cr**	**Nanticoke Cr**	**Reference (EPA BASINS)**			
Mean	117	622	**Toby Cr:**	**Mean**	**Std Dev.**	**Obs.**
Standard Deviation	30.6	137.2	1970-1974	no data collected		
Observations	38372	7717	1975-1979	126	46.5	29
df	7871		1980-1984	140	65.1	56
t Stat	-321.57		1985-1989	207	264.7	37
Significance (one-tail)	P < 0.001		**Nant. Cr (80-84):**	1772	none	0
t Critical one-tail	1.65		**Criterion:** 500 mg/L as monthly average			
Redox Potential (mV)	**Toby Cr**	**Nanticoke Cr**	**Reference (EPA BASINS)**			
Mean	440	120	**Toby Cr:**	**Mean**	**Std Dev.**	**Obs.**
Standard deviation	92.9	136.4	1970-1974	no data collected		
Observations	36688	7717	1975-1979	no data collected		
df	9275		1980-1984	no data collected		
t Stat	196.4		1985-1989	no data collected		
Significance (one-tail)	P < 0.001		**Nanticoke Cr: no data**			
t Critical one-tail	1.65		**Criterion:** none listed			
Diss. Oxygen (mg/L)	**Toby Cr**	**Nanticoke Cr**	**Reference (EPA BASINS)**			
Mean	11	7	**Toby Cr:**	**Mean**	**Std Dev.**	**Obs.**
Standard deviation	2.5	2.8	1970-1974	10	1.4	14
Observations	39373	7717	1975-1979	11	2.9	28
df	10141		1980-1984	9	3.4	25
t Stat	116.60		1985-1989	8	1.8	36
Significance (one-tail)	P < 0.001		**Nanticoke Cr:**	8	0.6	2
t Critical one-tail	1.64		**Criterion:** 6 mg/L minimum daily ave.			

Table 2. Water quality data from real-time monitors (continued).

pH	Toby Cr	Nanticoke Cr	Reference (EPA)			
Mean	7.35	6.72	**Toby Cr:**	**Mean**	**Std Dev.**	**Obs.**
Standard deviation	0.15	0.18	1970-1974	7.12	0.59	12
Observations	39373	7717	1975-1979	7.58	0.46	23
df	9895		1980-1984	6.99	0.82	30
t Stat	289.43		1985-1989	7.06	0.36	24
Significance (one-tail)	P < 0.001		**Nant. Cr (80-84):**	6.98	0.04	2
t Critical one-tail	1.65		**Criterion:** 6.0 to 9.0			

potential, pH, and dissolved oxygen were significantly lower in the impacted watershed. Where they are available, EPA water quality criteria are provided in Table 2. Only total dissolved solids (TDS) were higher on average at Nanticoke Creek relative to the EPA (and PA Department of Environmental Protection) water quality criterion to protect aquatic life. Thus, in general, impacts due to AML and AMD were apparent but not at severe levels; these characteristics indicate that water quality might best be characterized as “mine drainage” (with lowered pH, DO, and redox and higher conductivity and total dissolved solids) but not as “acid mine drainage” given that pH has always been above 6.0, a condition of slightly acidic waters.

Table 2 also summarizes available data for Toby and Nanticoke creeks from EPA’s BASINS. BASINS refers to Better Assessment Science Integrating Point and Nonpoint Sources and is a multipurpose environmental analysis system for use by natural resource agencies to perform watershed- and water-quality-based studies. BASINS (EPA 2001) is intended to support a watershed-based approach to environmental and ecological studies in a watershed context. As such, the system has been designed to be flexible with a capability to support analysis at a variety of scales using tools that range from simple to sophisticated. Comprehensive multimedia data sets (from both state and federal agency monitoring programs) compiled by EPA are provided in BASINS and we have accessed and queried these datasets through a GIS “data mining” tool (Table 2). Several observations can be made about these data. First, given the severity of environmental impacts in the region, very limited monitoring has been conducted for Nanticoke Creek since only some data were available for the 1980-1984 interval only. Second, monitoring at Toby Creek was eventually curtailed given that there were no data in BASINS on this stream for the time intervals 1990-1994 and 1995-1997, both of which are represented in BASINS for other streams in PA. And third, except for the single TDS value at Nanticoke Creek in the 1980-1984 sampling interval, most average parameters from BASINS were in the general range for our 2003-2004 data sets from the real-time monitors. Historically, conductivity and TDS were slightly higher at Toby Creek relative to our study but these seem within the range of natural and anthropogenic variability, especially since salts are thrown on roads during winter storms in the higher "mountain" elevations of this watershed. Our findings are consistent with those in Bruns et al., (1997b) and Herlihy et al., (1990).

Web-based GIS and the Community RiverNet Web Portal

Our AHR environmental master plan has a focus on data that have been locally acquired, stored, and maintained yet available in a regionally coordinated fashion (Bruns et al., 2001). The local storage of this information, including water quality data from this study, creates a need for a distributed data model that functions differently than the usual locally independent yet isolated model and State or Federal "Stove Pipe" models typical of such programs in the 1990s. Generally, each participating local entity can plan to serve up their data through both secure and unsecured channels or portals to internal as well as external customers that range in experience from sophisticated, using complex GIS/analytic software, to the less demanding, using simple generic web browsers (Bruns and Sweet, 2004). Fig. 5 represents the GIS architecture and data structure of a single, participating local entity in the distributed data distribution model and is the one we have demonstrated in our RiverNet community program. Several software products by the Environment Systems Research Institute (ESRI) are employed including the spatial database engine (SDE) and an internet map server (ArcIMS).

The diagram below in Fig. 5 describes the flow of data among a community of such local data providers and/or state and federal data portals. Fig. 5 represent the prototype that PaGIS has been demonstrating as a viable concept (http://www.pagis.org/CurrentWatershedEPAdemo.htm) to allow participating users to have the ability to catalog available geodatabases that describe the region (Bruns and Sweet, 2004). For example, in regard to digital aerial photography and locally (county-level) derived ownership parcels, we have accomplished this for demonstration purposes only for several counties in our region and have had these linked to the federal portal of Geospatial One Stop (http://www.geodata.gov/gos).

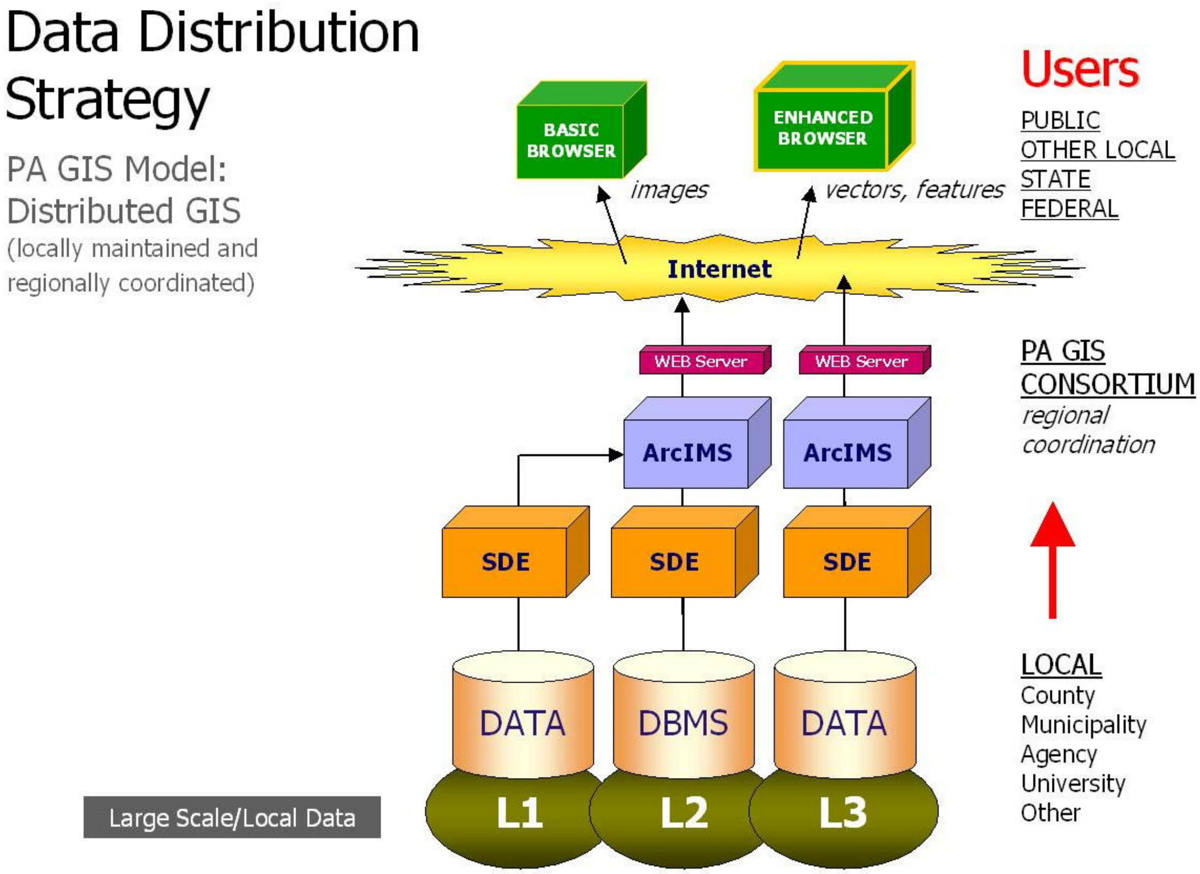

Figure 5. Regionally coordinated and locally maintained and distributed Web-based GIS for multiple entities and the basis for our RiverNet Community Data Portal. See also Bruns and Sweet (2004).

The public and environmental groups can access water quality in various ways as described by Bruns and Sweet (2004). One of these is built upon our Web-based GIS architecture and is shown in Fig. 6 as an on-line query of both Toby and Nanticoke creeks. This is an interactive GIS web server or ArcIMS map service that ties together GIS data on CSOs (small red dots), abandoned mine lands (gray areas), mining outfalls (visible when zoomed to a local scale), tributary watersheds (i.e., shaded mosaic), local towns and cities, and monitoring sites. Selected data from the water monitors can be queried a (http://66.197.254.10/website/epa_empact_rivernet/viewer.htm). It should be noted that users only need to have one of several popular Web browsers to access and query this database with geospatial (GIS) tools being provided by the server.

The public can also access water quality datasets from more conventional Web pages designed for the RiverNet project. One of these is shown below in Fig. 7 below. Related aspects of Web-based GIS and the RiverNet data portal has been discussed by Bruns and Sweet (2004).

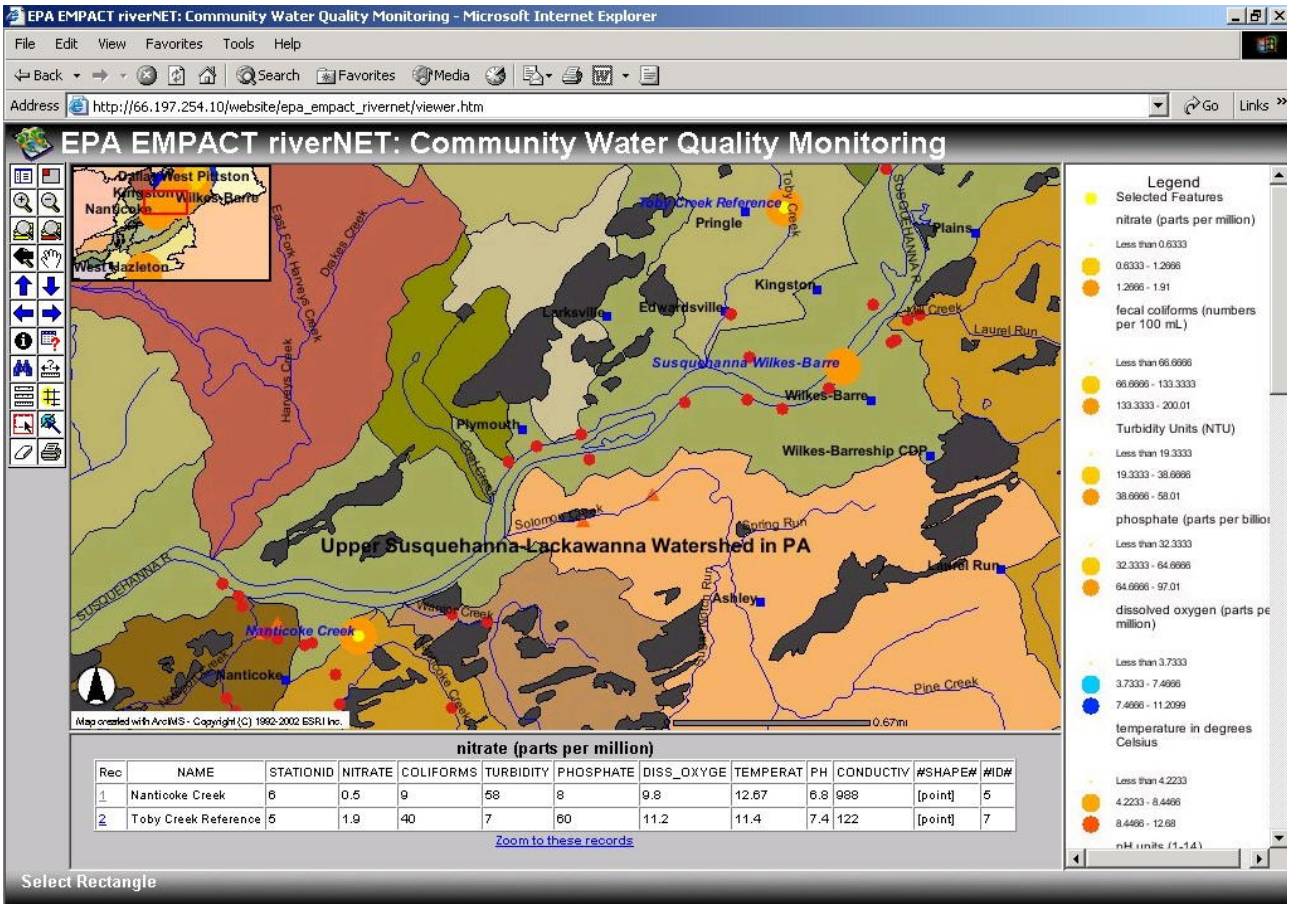

Figure 6. EPA EMPACT RiverNet: Web-based GIS Map Service showing watershed information and water quality data from real-time monitors. GIS query of Toby and Nanticoke creeks. See text.

CITYgreen GIS predictions on benefits of reforestation

We are currently conducting analyses with CITYgreen to evaluate the potential for carbon sequestration if extensive re-forestation and ecosystem restoration efforts were to be implemented on regional areas of barren mining lands within the AHR watershed. Figs. 8 and 9 show the relationship of carbon stored and carbon sequestered, respectively, as a function of forest cover (calculated in CITYgreen based on MRLC satellite derived data – see methods) estimated from land use and land cover conditions in the Toby Creek watershed. We created GIS shapefile "study plots" in CITYgreen and located them randomly in contiguous forest stands in the upper (undeveloped) portions of the Toby Creek watershed; we used eight study plots ranging in size from slightly over one half-acre and up to about 60 acres in order to plot data and calculate predictive regression equations (Figs. 8 and 9). On this basis, it is predicted that if the abandoned mining lands (527 acres) in Nanticoke Creek watershed were reforested as part of an overall ecological reclamation

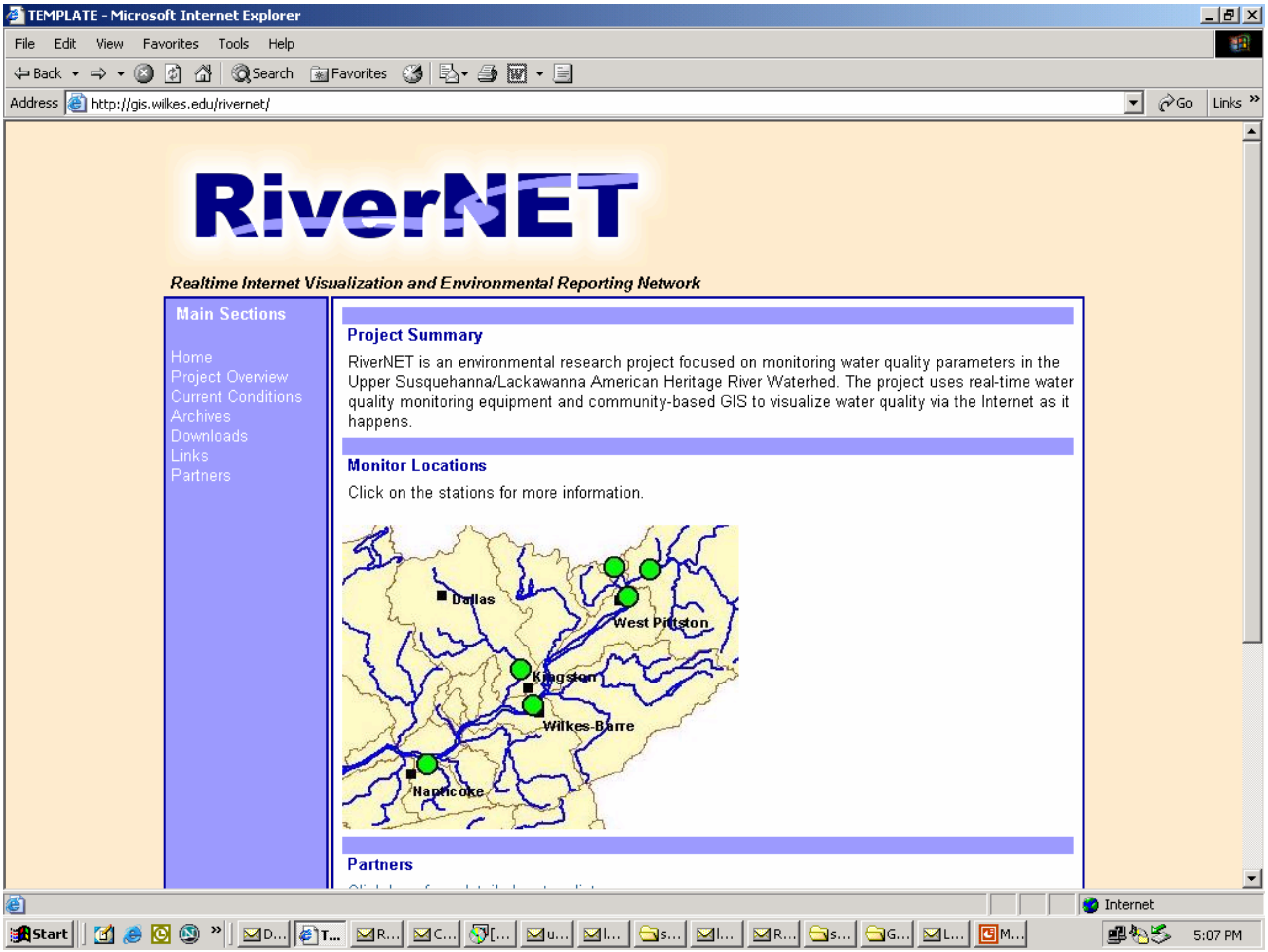

Figure 7. RiverNet Data Portal for “conventional” Web page access to water quality data.

strategy, an estimated 22,676 tons of carbon could be stored when trees reach maturity (Fig. 8). In addition, on average, the annual carbon sequestration rate for the reforested lands on the Nanticoke Creek watershed is estimated at 179 tons per year (Fig. 9).

From 1975 to 1985, reforestation of AML received support from several federal agencies (see Vogel, 1977, 1980, and review in Bruns et al., 2001). Also, OSM has been re-examining methods that would enhance post mining land use plans that promote the planting of trees on active and abandoned surface coal mines. Benefits of reforestation are many and would include improving wildlife habitat and recreation opportunities, restoration of clean water resources, erosion prevention, and the creation of new economies based on forest products. Coupled with the President's recent Executive Order outlined below in regard to an Interagency program on bioenergy and bioproducts, OSM's program could be utilized as part of the U.S strategy on Global Climate Change and promote ecosystem restoration efforts on AML.

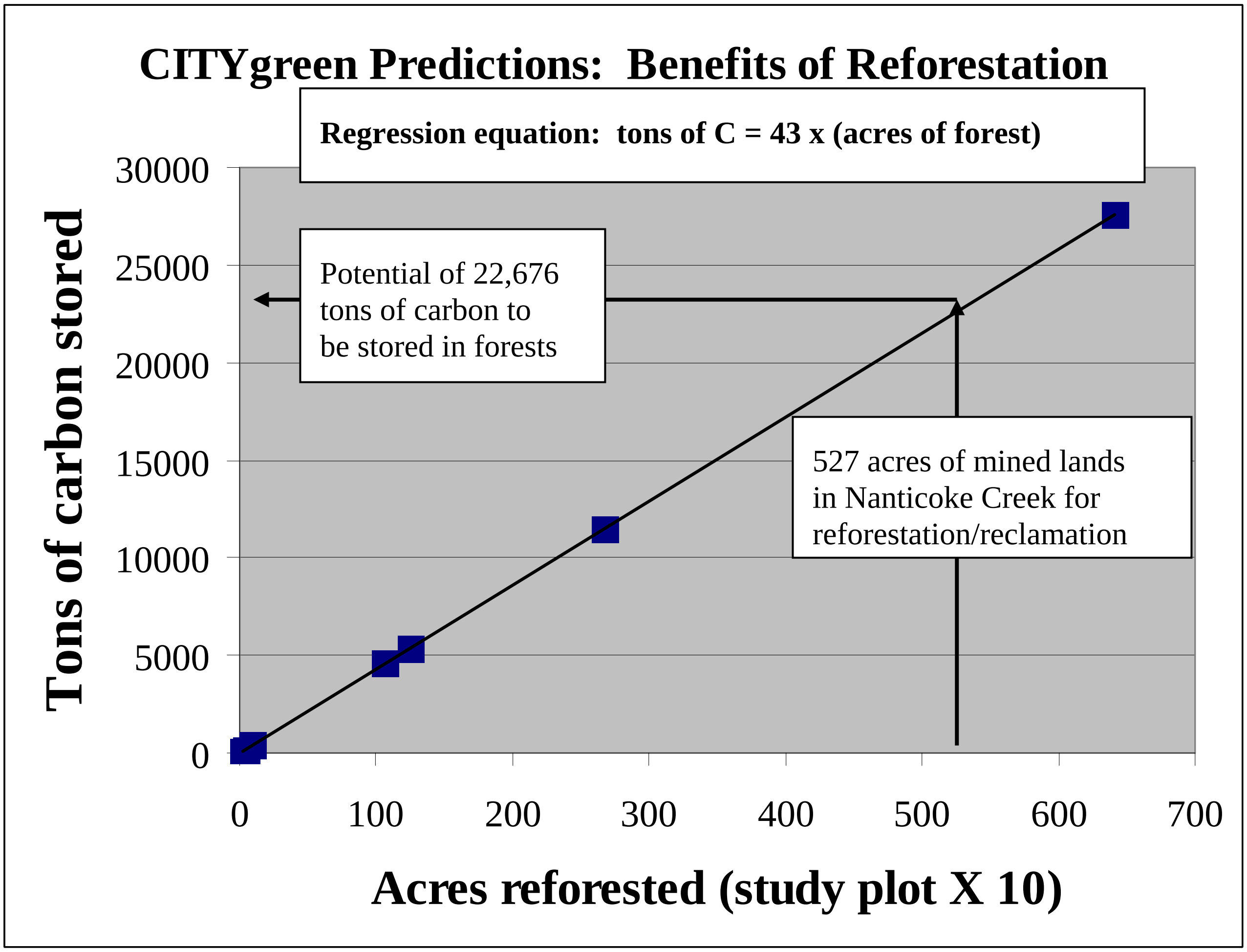

Figure 8. CITYgreen GIS regression of carbon stored in forest stands over 8 study plots within the Toby Creek watershed. Interpolation of CITYgreen predictions based on acres of abandoned mining lands in the Nanticoke Creek watershed.

On August 12, 1999, President Clinton announced new steps to spur bio-based technologies, enhance U.S. energy security, and meet environmental challenges like global warming. The President issued an Executive Order coordinating Federal efforts to accelerate these 21st century technologies - which can convert crops, trees, and other "biomass" into a vast array of fuels and materials - and set a goal of tripling U.S. use of bioenergy and bioproducts by 2010 (cited in Bruns et al., 2001). It is expected that this program would enhance interagency cooperation for new applications in forest development and products. It could have positive incentives to use reforestation as an effective mining reclamation practice with benefits to carbon sequestration and offsets in carbon emissions from the fossil fuel utilities.

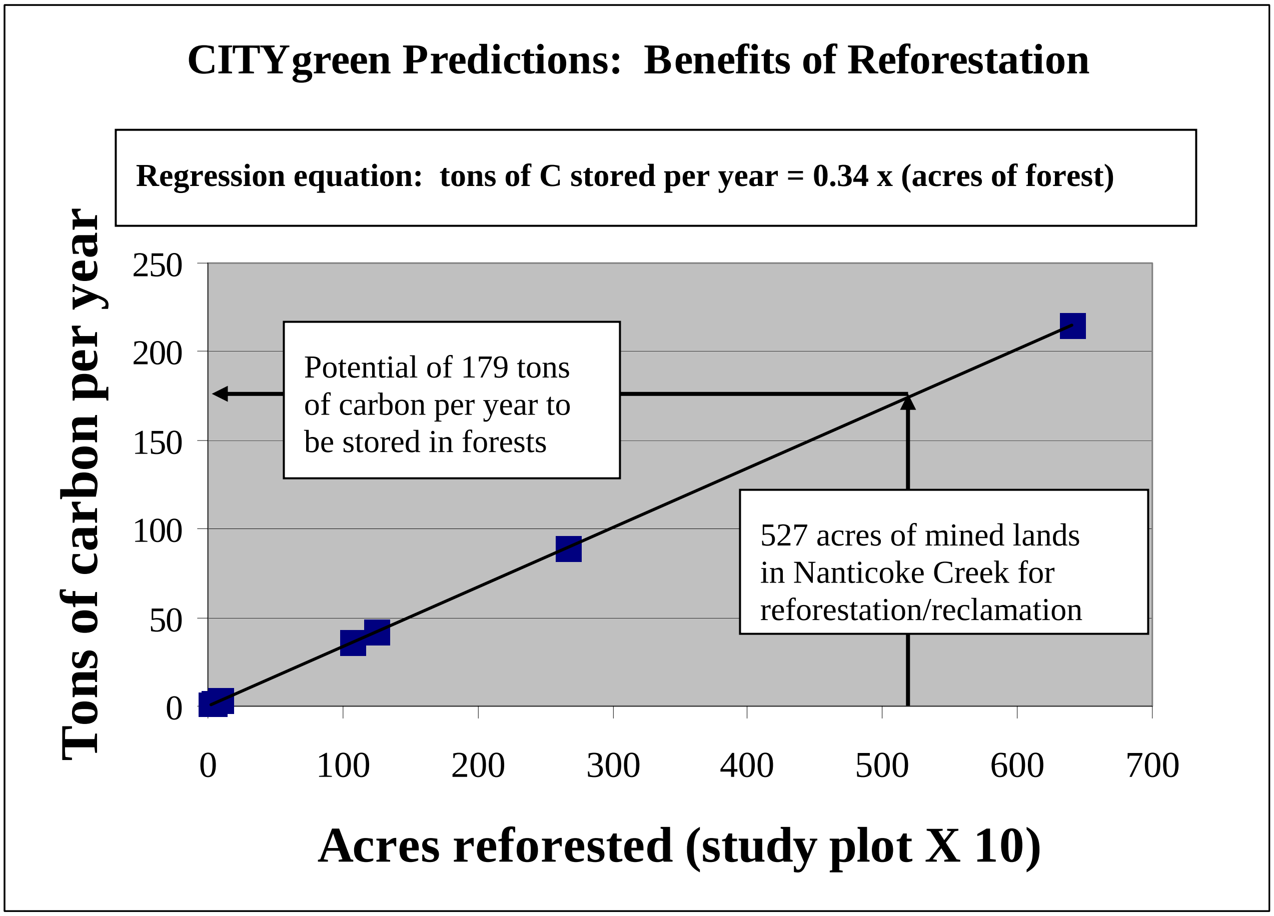

Figure 9. CITYgreen GIS regression of carbon stored in forest stands over 8 study plots within the Toby Creek watershed. Interpolation of CITYgreen predictions based on acres of abandoned mining lands in the Nanticoke Creek watershed.

CommunityVIZ and 3-D GIS Visualization

CommunityVIZ is a useful interactive planning tool based on GIS. Previously, we have made applications to the Toby Creek watershed (Bruns and Sweet, 2004). The Toby Creek watershed was originally selected in our initial AHR GIS master plan (Bruns et al. 2001) as a reference stream relative to AMD and AML streams more directly in the Anthracite Coal. However, Toby Creek itself is under intense development pressure as more people leave the urban corridor to more scenic, adjacent areas of “Back Mountain” and the “Endless Mountains” – both associated with the Toby

Creek watershed. For these reasons (Bruns and Sweet, 2004), we have included Toby Creek as a critical site within our RiverNet community monitoring project. Fortunately, a number of positive initiatives are underway through the leadership of the Manager for Dallas Borough, near the headwaters of Toby Creek. These community initiatives include: development of a watershed association, start of a council of governments (to deal with regional planning and the watershed, a successful regional planning grant, and a visioning group looking at sustainable development.

In the context of AML and reforestation as a proposed approach to ecological reclamation efforts, CommunityVIZ has the potential to provide 3-D visualizations of forest cover, including individual trees and other aspects of natural ecosystems like wetlands. Fig. 10 shows selected aspects of these natural features that can be used to illustrate such an approach to reclamation. These features were designed based on real land cover GIS data and conservation zoning categories being utilized by the Borough of Dallas in Toby Creek watershed. As such, they may serve as a model on how recovered, restored, and reclaimed mining lands might appear on the landscape.

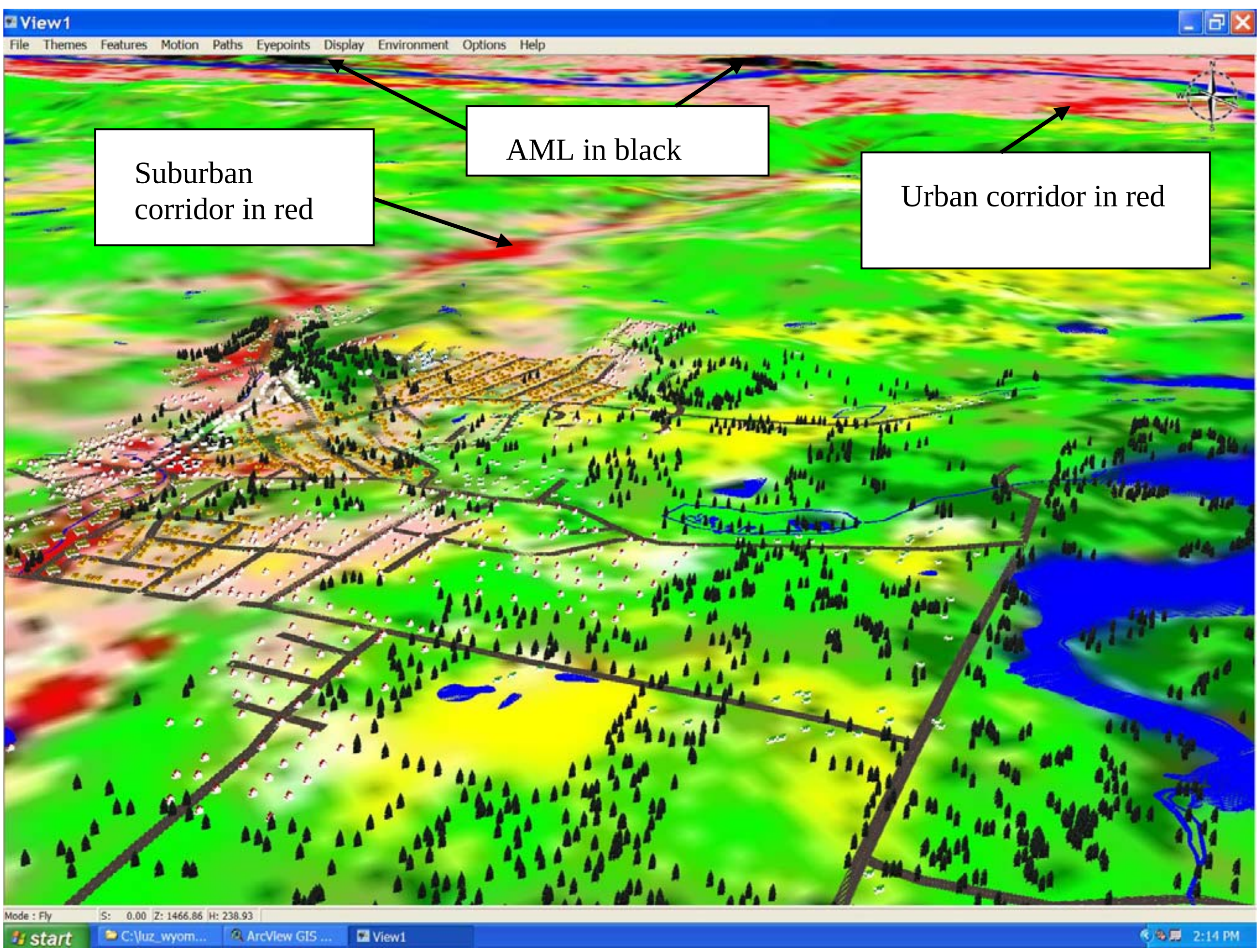

Figure 10. CommunityVIZ 3-D GIS “fly-through” of Toby Creek watershed and the Borough of

Dallas. Satellite image classified for land cover (note red for urban/suburban corridors and black "AML" areas at the top of the figure). Individual trees shown along with aquatic ecosystems.

Conclusion and Future Directions

Bruns et al., (1997a) and Bruns and Wiersma (2004) have outlined the integration of GIS, the global positioning system (GPS), and remote sensing technologies for ecological applications in watershed monitoring and assessment with a focus on coal mining impacts. The following represents the key components of this approach to environmental monitoring system design:

- a conceptual framework of terrestrial-aquatic linkages within a river drainage basin (Minshall et al., 1985, Cummins, 1992),
- a heuristic ecosystem diagram (e.g., see Fig. 2) of source-receptor pathways of mining wastes and land disturbance (Nihlgard and Vylvanainen, 1992),
- multimedia characterization of water, soils, and biota (including remote sensing of vegetation) (Bruns et al., 1991, Lillesand and Kiefer, 1987),
- ecosystem endpoints like stream and river macroinvertebrate communities and water chemistry (Bruns et al., 1992),
- data integration with GIS and image processing software (Avery and Berlin, 1992, Lunetta et al., 1991, Wiersma et al., 1995), and
- landscape spatial scaling based on remote sensing imagery (SPOT, Landsat) and a landscape sampling design (Lillesand and Kiefer, 1987, Wessman, 1992, Heal et al., 1993).

In the present study, these components have been highlighted in various ways. Our monitoring design has included a drainage basin approach to delineate 42 tributaries for ranking environmental problems on a holistic basis through the use of indicators specific to land use problems of the AHR. In addition, we have delineated source-receptor relationships, especially AML determined by remote sensing and AMD outfalls "logged in" along the mainstem corridor by GPS, both in respect to ecological receptors within drainage network patterns throughout the AHR watershed and individual tributaries (e.g., see Fig. 2). Landscape (watershed) scaling and the use of remote sensing data and GIS models like ArcIMS, CITYgreen, and CommunityVIZ also encompass several of the geospatial environmental design principles identified above.

In particular, one of our objectives was to profile the multiple benefits of natural colonization, especially forests. In this context, we have proposed using 3-D "fly-through" GIS programs like CommunityVIZ (integrated with CITYgreen) that allow us to visualize naturally recolonized ecosystems like forests on recovered mining lands. In addition to visualizing benefits, we can use this GIS software (i.e., CITYgreen) to calculate the economic benefits of new forests and trees in removing air pollutants, diminishing stormwater runoff and providing important "ameliorating" benefits on global climate by carbon sequestration (with potential voluntary support from utilities).

At the Urban and Regional Information Systems Association (URISA) annual conference on public participation GIS, Bruns and Sweet (2004) reviewed several developments that has immediate and future application to the AHR watershed for addressing problems of AML in the region. These include the following:

- New data products – Working in partnership with Digital Globe (now with a new downlink facility in Wilkes-Barre, PA), PAGIS has recently showcased the integration of 2 ft pixel panchromatic satellite data with multispectral satellite data (Figure 11, top); this data fusion process has numerous new potential GIS applications in reclamation design, floodplain management, water quality monitoring, and watershed management. Fig. 11 (bottom) below also highlights how this new data product might be used to track mining operations, permit conditions, or to update state and federal GIS data bases on AMLs.

- 3-D GIS environmental design and "precision reclamation" – PAGIS is proposing to test the use GIS software modules like ESRI's 3-D Analyst and Spatial Analyst for "cut and fill" GIS calculations to efficiently estimate reclamation design parameters for direct use with GPS units mounted on heavy earth-moving equipment for mining clean-up activities. This is analogous to similar applications in "precision agriculture" and "precision mining" (e.g., Trimble GPS and Caterpillar applications).

- Ecological landscape reclamation, restoration, and recovery – PAGIS has examined numerous field sites and GIS databases on land cover from satellite images and digital aerial photography for the US-L AHR watershed. Based on landscape concepts and patterns derived from GIS analyses, there are many areas of the landscape impacted by mining where natural recovery has occurred and this might be replicated and/or accelerated through geospatial design concepts in "ecological engineering."

Geospatial data, tools, and GIS models have allowed us to evaluate and rank 42 tributaries in the AHR watershed for prioritization in monitoring and reclamation. This geospatial approach has also facilitated our site selection process for ongoing, real-time, automated water quality monitoring on a

Figure 11. Top: overview of Digital Globe, Quick Bird Imagery with panchromatic (2' pixel) "fused" with multispectral (6' pixel) = natural color at 2' pixel. Bottom: Abandoned refuse pile – areas of good agreement vs. poor match with features and potential to identify areas of reforestation or colonization.

paired-watershed basis. In addition, two GIS environmental modeling tools, CITYgreen and CommunityVIZ, have allowed us to start examining a more ecological, ecosystem viewpoint on environmental reclamation efforts in AML impacted watersheds, where the benefits of re-forestation can be estimated and viewed for planning purposes. And finally, newer data products like Quick Bird imagery appear to be very useful for a range of environmental planning, analysis, and reclamation efforts, especially in regard to exploiting the advantages of the better spatial scale resolution of panchromatic data, "fused" with multispectral signatures for better land cover classification. This is particularly apparent when compared with our previous applications with SPOT or Thematic Mapper data (Bruns and Yang, 2002). Overall, it is our hope and goal that this geospatial approach and related studies, investigations, and applications will help to improve the efficiency and cost-effectiveness for monitoring, managing, and reclamation of damaged environments in the Anthracite Fields of eastern Pennsylvania and the AHR watershed.

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