West Virginia Water Resources Research Institute
Annual Technical Report
FY 2006

Introduction

West Virginia Water Research Institute

Introduction

The West Virginia Water Research Institute (WVWRI) addresses the key water resource issues facing policy makers, agency staff and the public. Our research program is guided by the West Virginia Advisory Committee for Water Research. It includes representatives from the following:

$ West Virginia Department of Natural Resources $ West Virginia Department of Health & Human Resources $ West Virginia Chamber of Commerce $ West Virginia Coal Association $ West Virginia Department of Environmental Protection $ West Virginia Farm Bureau $ U.S. Federal Bureau of Investigation $ U.S. Geological Survey $ U.S. Environmental Protection Agency $ U.S. Department of Energy - National Energy Technology Laboratory $ U.S. Army Corps of Engineers - Huntington, WV District $ West Virginia University

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

Funding Strategy

The Institute receives a grant of roughly $92,000 annually through the U.S. Geological Survey CWA section 104b program. We use this funding to develop research capabilities in priority areas and to provide service to State agencies, its industry and citizen groups. As a result of successful leveraging, we supported a program with an average yearly value of over $2M. Our strategy relies on using the USGS section 104b funding to develop competitive capabilities that, in turn, translate into successful proposals funded by a broad spectrum of Federal and State agencies.

Our strategy also relies on maintaining a broad cadre of researchers within WVU and other institutions within the state. We also work with faculty from institutions across the country to form competitive research partnerships. As West Virginia University is the State's flagship research institution, its researchers have played the dominant role. Over the past 15 years over 50 WVU faculty members have been supported by WVWRI projects while over 25 faculty from other State institutions have participated in the program. Our funding strategy relies on successful competition for Federal dollars while teaming with State agency and industry partners. The later provide test sites, in-kind support and invaluable background data.

Research Capability

The bulk of our research is undertaken by academic faculty. Since West Virginia University is the flagship research institution in the State, its faculty have received the bulk of Institute funding. Over 50 WVU researchers have been supported by the WVWRI representing 20 departments. In addition, the Institute has a staff of 12, with three research contractors. Roughly half of the Institute is directly engaged in research projects.

Successes

West Virginia's Nonpoint Source Program received a $50,000 performance bonus. WVDEP expressed thanks to the WVWRI for all the hard work of watershed associations, WVDEP and partner agencies.

The reason was summed up by Fred Suffian, Region 3 NPS Coordinator, Our decision was based upon significant improvements in your program over the past several years relating to development and implementation of Watershed Based Plans, accomplishing and reporting environmental results, and significant improvements in grants management, i.e. GRTS reporting and draw downs.

It's rare in government programs to get a bonus' for doing a good job so this is pretty significant. This reward is the result of everybody's efforts and we all should be proud. Every one of you have put forth much effort to restore streams, prevent further degradation and adapt to the ever shifting world of the Nonpoint Source Program. Your focus on sending in your grants and reports on time and in a professional format has for the last 2 years made WV the first state in Region 3 to gets its grants approved. We really appreciate your efforts.

Thank you,

Alvan Gale and Teresa Coon, WVDEP

Future Direction

The following programs of the WVWRI are expected to continue to remain stable and grow modestly into the future:

$ National Mine Land Reclamation Center $ Combustion Byproducts Recycling Consortium $ Hydrology Research Center $ Geo-Engineering Center $ Northern WV Brownfields Assistance Center

Outreach

The WVWRI performs outreach through meetings, workshops, conferences, site visits, web site, newsletters, and publications.

West Virginia Water Conference 2006

A conference was held October 11-13, 2006 in which the WVWRI served as lead. The West Virginia Bureau for Public Health and the National Environmental Education Training Center co-sponsored this event. This 2-1/2 day event was held at the Stonewall Conference Center in Roanoke, WV. There were over 30 presenters and approximately 100 attendees.

WVWRI Web Site

A web site (http://wvwri.nrcce.wvu.edu) contains information on all the WVWRI programs and projects. This site is updated on an on-going basis as new information becomes available.

WVWRI Brochure

A new brochure on the WVWRI was developed and distributed at the October 2006 water conference. It is periodically distributed at other meetings and events as well.

Newsletter

The WVWRI puts out a free quarterly newsletter on one of its programs: the Combustion Byproducts Recycling Consortium. This newsletter, Ashlines, is available on the CBRC page of the WVWRI web site at http:wvwri.nrcce.wvu.edu/programs/cbrc.

Publications

Some WVWRI publications are listed on the WVWRI web site. A searchable publications database is to be developed Fall 2007.

Research Program

Evaluation of the Environmental Hazard of Selenium in Coal-Associated Rocks of the Southern WV Coal Basin (WRI-83)

Basic Information

Title:	Evaluation of the Environmental Hazard of Selenium in Coal-Associated Rocks of the Southern WV Coal Basin (WRI-83)
Project Number:	2006WV69B
Start Date:	3/1/2006
End Date:	2/28/2008
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Congressional District:	District 1
Research Category:	Water Quality
Focus Category:	Toxic Substances, Hydrogeochemistry, Water Quality
Descriptors:	None
Principal Investigators:	Ronald B Smart, Jack Renton

Publication

1. PUBLICATIONS 1. I. Pumure, J.J. Renton, and R.B. Smart, Accelerated aqueous leaching and speciation of selenium and arsenic from coal-associated rock samples using ultrasound extraction, Environmental Geology, submitted for publication, June, 2007. STUDENT SUPPORT Mr. Innocent Pumure, Ph.D. Candidate, West Virginia University, Department of Chemistry, $4000, Summer, 2006.

Title:	Evaluation of the Environmental Hazard of Selenium in Coal-Associated Rocks of the Southern WV Coal Basin
Annual Report:	March 1, 2006 - February 28, 2007
Principal Authors:	Dr. Ronald B. Smart and Dr. John J. Renton
Report Issued:	May 31, 2007
USGS Award No.	WRI-83
Submitting Departments:	Department of Chemistry, West Virginia University, PO Box 6045 Department of Geology and Geography, West Virginia University, PO Box 6300

ABSTRACT

Mountaintop removal-valley fill coal mining involves the removal of the mountain top and the filling of nearby valleys with overburden to result in a level surface that can be used for a variety of purposes. According to a USEPA report, (Bryant et al. 2002) selenium concentrations in several streams and rivers associated with mountaintop removal-valley fill mining areas in southern West Virginia were found to contain up to 50 ng /L , a concentration that is ten times the West Virginia stream standard (5 ng /L). Pre-mining data indicated that the valley fills were responsible for the elevated selenium levels.

Our study focused on comparative ultrasound-assisted kinetics of the leaching of selenium and arsenic from pulverized samples of rock that are associated with coal mining activities. Most traditional batch extraction methods utilize lengthy mechanical shaking or soxhlet extractions that may take hours or days for a single extraction to be performed. For the ultrasound method, a five-minute application of ultrasound energy to a pulverized rock sample mixture in a 1:10 solid to solution ratio was found to produce useful results for a single extraction. The rock samples were collected from a core supplied by the West Virginia Geological and Economic Survey (WVGES). The samples were collected from Kayford Mountain in Kanawha County, West Virginia (USA).

The amount of arsenic extracted with ultrasound was three orders of magnitude greater than the selenium. No arsenic was previously detected in the stream waters (Bryant et al. 2002), even though the accelerated rate constants appeared to be ten times greater than those for selenium (Table 4), which suggests that arsenic is sequestered from the aqueous phase by a different mechanism compared to selenium. The rate of release of total arsenic and total selenium did not depend on their respective concentrations in rocks but rather on the type of rocks analyzed.

The reactivity and toxicity of arsenic and selenium depend on their oxidation states. The primary arsenic species found in the environment are inorganic As (III), arsenite, and As (V), arsenate, as well as several organoarsenic compounds. Selenium species include Se (IV), selenite, and Se (VI), selanate, Se (0) and Se (-II), as well as several organic forms. The most toxic species are Se (IV) and As(III), and Se (VI) and As (III) are more bioavailable compared to the other oxidation states. Sequential extractions of BT700 indicated that most of the extractable is Se (IV) whereas in BT571 the predominant extractable form is Se (VI).

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Introduction

Temperature controlled ultrasound extractions provide important kinetic data that can be useful in describing the chemistry at the solid-solution interface. The solid – solution chemistry can then be used to infer the bioavailabilities of metals released into associated aquatic systems. Most traditional batch extraction methods utilize lengthy mechanical shaking or soxhlet extractions that may take hours or days for a single extraction to be performed. For the ultrasound method, a five-minute application of ultrasound energy to a pulverized rock sample mixture in a 1:10 solid to solution ratio was found to produce useful results for a single extraction. Ultrasonic extraction enhances dissolution process by causing acoustic cavitations that result in bubble formation and subsequent collapse generating high-pressure gradients, thereby increasing reactivities (Brunori et al. 2004; Suslick 1989).

The use of ultrasonic energy has been proven to be an easy, convenient, and fast way of desorbing inorganic (Luque-Garcia and de Castro 2003; Perez-Cid and Bola 2001; Perez-Cid et al. 1999) and organic pollutants (Tse and Lo 2002) from sediments, soil and biological samples (Arruda et al. 2003; Mierzwa et al. 1997). Focused ultrasonic probes enable efficient adjustment and monitoring of temperature in a water-jacketed extraction vessel and this methodology was used in this study to study the kinetic releases of arsenic and selenium from pulverized samples of rocks associated with coal mining activities. Since natural rock dissolution is a lengthy process (Sparks 1989), ultrasound extraction was used to mimic the natural weathering of coal associated rocks on a much shorter time scale.

Mountaintop removal-valley fill coal mining involves the removal of the mountain top and the filling of nearby valleys with overburden to result in a level surface that can be used for a variety of purposes. According to a USEPA report, (Bryant et al. 2002) selenium concentrations in several streams and rivers associated with mountaintop removal-valley fill mining areas in southern West Virginia were found to contain up to 50 ng /L , a concentration that is ten times the West Virginia stream standard (5 ng /L). Pre-mining data indicated that the valley fills were responsible for the elevated selenium levels.

Although low concentrations of selenium and arsenic are dietary essentials, higher concentrations pose a serious heath risk to terrestrial and aquatic organisms (Jukes 1983; Yih et al. 2005). Elevated concentrations of these metalloids have also been shown to stunt the growth of some plants (Lejeune et al. 1996; Terry et al. 2000) which could inhibit a critical process required in the remediation of filled sites.

Our study focused on comparative ultrasound-assisted kinetics of the leaching of selenium and arsenic from pulverized samples of rock that are associated with coal mining activities. The most common models used to describe the kinetics for the release of inorganic and organic substances from solids into solution are parabolic diffusion, Elovich, power function and first and second order kinetic models. (Aharoni et al. 1991; Goh and Lim 2004; Kithome et al. 1998; Shimizu et al. 2004). These models are often used to approximate the overall chemical kinetics of intricate reactions occurring in complex matrices that are often unknown. Although the first order and parabolic diffusion models are both very important in describing the surface film diffusion or intraparticle diffusion of materials from rocks into solution (Sparks 1989), the first order kinetic model was found to be most useful in comparing the rates of accelerated rock disintegration and the concomitant release of arsenic and selenium from coal-associated rocks. Thus, the ultrasound assisted extraction rate is proportional to the following parameters: 1) the mobility of the selenium and arsenic compounds from the solid to liquid phase, 2) the chemical potential of these species, 3) lithology of rocks extracted, 4) the surface area of particles, and 5) the level of ultrasonication power.

Methods and materials

An Ultrasonic Sonicator (Misonix, Model XL 2020) with a 0.3 mm diameter titanium probe was used to deliver sound energy (200 W/cm^2) to a mixture of 1g of pulverized sample and 10 mL water. A 38-ml capacity water-jacketed extraction vessel (22mm ID x 10 cm quartz tube) was designed. The ultrasonic power was measured by calorimetry (Contamine et al. 1995; Mason et al. 1992). A thermocouple was immersed into the extraction solution to monitor the temperatures during extraction and ultrasound energy measurement processes. The water/pulverized rock mixture was ultrasonicated for a period of five minutes followed by centrifugation for 20 minutes at 3400g. The supernatant solution was decanted and placed in a 25-mL polyethylene vial. The solid residue was returned back to the sonication vessel followed by the addition of a fresh 10-mL aliquot of water for the second ultrasonication step. The process was repeated seventeen times for a total 90 minutes of sequential extraction. Each extract was analyzed for total selenium and arsenic by graphite furnace atomic absorption spectrophotometry and Se (IV) and As (III) were measured by hydride generation atomic spectrophotometry. A Varian atomic absorption spectrometer (Model 55B) was used to analyze all the samples.

The total arsenic and selenium concentrations in the unextracted rocks were determined after microwave digestion. Each of the three samples (0.5g) were digested in triplicate using 5 ml concentrated HNO_3 , 5 ml concentrated HF and 3 mL concentrated HCl in a microwave oven (CEM Corporation MARS-5- Explorer version 194A04) followed by analysis of digests using graphite furnace atomic absorption spectrophotometry.

Sampling

The rock samples were collected from a core supplied by the West Virginia Geological and Economic Survey (WVGES). The samples were collected from Kayford Mountain in Kanawha County, West Virginia (USA). The core was obtained by drilling from the mountaintop down to 270 m below the surface. Three samples (BT60, BT571 and BT700) were analysed. These samples were collected at depths of 18 meters (BT60), 174 meters (BT571) and 214 meters (BT700), respectively. Each sample was subdivided lengthwise, pulverized and passed through a 60 mesh sieve. The sieved rock powders were then subjected to ultrasonic extraction.

Mineralogical examination of pulverized rocks

Lithologic analyses of the rocks were performed by analysts at WVGES. The results obtained indicated that BT60 was sandstone, while BT571 and BT700 were claystones. Sample BT60 was comprised of 81% SiO_2 , most of which was present as quartz as shown in Tables 1 and 2. Samples BT571 and BT700 had 62.25 % and 63.83 % SiO_2 of which about half of BT571 and about a third of BT700 was quartz. The two claystone samples had about six times the percentage of illite as that in BT60. There were no significant differences in kaolin composition in the three samples as indicated in Table 1. The Fe_2O_3 and % chlorite compositions in BT60 were below 0.01% as shown in Tables 1 and 2.

Results and discussion

Comparison of extraction methods

Most kinetic batch extraction experiments reported in the literature are carried out at aqueous concentrations that are higher than those found in natural environments. In these studies pure solids (e.g. kaolin, silica, illite, iron oxides) are equilibrated with organic or inorganic substances of interest to allow them to adsorb onto the solid surfaces prior to performing desorption experiments. Because ionic concentrations used in such adsorption and desorption experiments are too high, kinetic studies are limited due to equilibrium conditions that are quickly established during the onset of extractions (Skopp 1986). The reason most workers in this area prefer to use continuous flow methods is that there is no flow back or re-adsorption of the materials that had been released earlier into the solution (Barry et al. 1993; Huertas et al. 1999; 2002). The initial extractions in kinetic batch experiments are known to release most of the metals being extracted, therefore during the first extraction, there is a greater chance of establishing equilibrium between the adsorbed and free metals in solution. Thus, concentrations so obtained cannot be used to describe the kinetics of extraction but rather only provide equilibrium conditions (Sabbah et al. 2005). Such conditions prompted the use of temperature-jump experiments (Zhang and Sparks 1990) to study the adsorption and desorption kinetics of selenate and selenite at the goethite surface.

In order to establish that equilibrium was not reached during the first 5 minutes of ultrasonic extraction, results for 120 minutes of continuous sonication were compared with those obtained from the initial 5 minutes of sonication of a 90-minute sequential extraction experiment consisting of 5 minute ultrasonications. The concentrations of total arsenic and selenium obtained by different extraction methods and microwave digestions are summarized in Table 3.

Although there was a large initial increase for both the arsenic and selenium concentration obtained during the first five minutes of the 90-minute sequential extraction, there is a statistically significant difference in the values obtained after first 5 minutes of the 90 minute sequential extraction to the Se concentration that was extracted after 120 minutes of continuous sonication ($P \leq 0.11$, $n = 9^*$). Based on this, it can be concluded that the concentration of both metals in solution obtained after five minutes would not have reached equilibrium with arsenic and selenium still encapsulated, sorbed or remaining within the pulverized rock particles.

There is an apparent three orders of magnitude (ng/g vs.µg/g) difference between the Se and As concentrations extracted from the rock samples. The values obtained after 2 hours of continuous sonication were smaller than the values obtained by the 90-minute sequential sonication. These data indicate equilibration and/or reabsorption could have been established during the course of the 2-hour extraction. In order to promote the non-equiliribrium conditions needed for kinetic studies it was found necessary to use the sequential extraction method. Thus the observed non-equilibrium conditions at 5 minutes of ultrasonication time could be described in terms of a slow readsorption process of the released metals compared to a faster desorption rate at $200 W/cm^2$ of ultrasonication power. These extraction conditions were used to simulate the accelerated kinetic release of selenium and arsenic from valley fills into streams.

The amount of arsenic extracted with ultrasound was three orders of magnitude greater than the selenium as shown in Figures 2 and 3. No arsenic was previously detected in the stream waters (Bryant et al. 2002), even though the accelerated rate constants appeared to be ten times greater than those for selenium (Table 4), which suggests that arsenic is sequestered from the aqueous phase by a different mechanism compared to selenium.

Sample BT60 was found to have the lowest concentrations of arsenic and selenium compared to BT571 and BT700 as shown in Table 1. Although BT700 had the highest total and extractable arsenic and selenium species, the rates of their releases from the solid into the solution were smaller than those of BT571 and BT60 as shown in Table 4.

The rate of release of total arsenic and total selenium did not depend on their respective concentrations in rocks but rather on the type of rocks analysed. Sample BT60, a sandstone had the lowest amounts of selenium yet it was all extracted during the first three extractions. Jenkins and Schaer (2005) found that darker overburden with large amounts of humic and fulvic substances had the highest selenium concentrations. These observations were consistent with our findings in that the claystones (BT700 and BT571) were dark in appearance and had the highest amounts of selenium and arsenic (Table 3).

Organic acids which originate from dead plants are often incorporated into rock lattices during rock formation. Any selenium that is bound to organic acids will become part of the rock and some of this sorbed selenium can become bioavailable as the rocks weather (Liu et al. 2006). In the rocks analysed, it appears there are two forms of organic bound selenium, with one weakly sorbed and the other strongly sorbed. The weakly sorbed forms are readily available and the strongly sorbed take more time and energy to become bioavailable. This information could explain the fact that samples BT571 and BT700 had more selenium which was not readily leachable compared to BT60.

Peak and Sparks (2002) found that selenate and selenites both bind strongly to iron oxides and this could be the reason the selenium in BT60 was easily extracted compared to BT571 and BT700 (Table 2). Such kinetic information is useful in determining procedures that are necessary to be undertaken when disposing different types of mining waste. Another complication is that the toxicity and bioavailability of the released metalloids depend on chemical speciation which suggests the need to differentiate the selenium and arsenic compounds released.

The reactivity and toxicity of arsenic and selenium depend on their oxidation states. The primary arsenic species found in the environment are inorganic As (III), arsenite, and As (V), arsenate, as well as several organoarsenic compounds. Selenium species include Se (IV), selenite, and Se (VI), selanate, Se (0) and Se (-II), as well as several organic forms. The most toxic species are Se (IV) and As(III), and Se (VI) and As (III) are more bioavailable compared to the other oxidation states.

Effects of ultrasonic power on the speciation studies for Se (IV)/ Se (VI) and As (III)/As (V)

In order to determine the effects of ultrasonic power on the stability of arsenic and selenium, 10 ml of 5 ng/mL solutions of As (III)/As (V) and Se (IV)/Se (VI) in a 1:1 ratio were separately monitored as a function of ultrasonication time using 200W/cm^2 power intensity. A fresh 10-ml solution of 5 ng/L arsenic /selenium was sonicated for each of the following sonication times (5 min, 10 min, 15 min … up to 2 hours). All experiments were done in triplicates. As illustrated in Figure 4, As (III) concentration decreased by 70% after only five minutes of sonication followed by a slow decrease to reach values that are 96 % lower than the initial concentration within a period of two hours. Solutions containing 1:1 mixtures of 5, 10 and 15 ng/mL of As (III) and As (V) also showed similar trends. Hence, ultrasonication extraction cannot be applied for the speciation studies of As in rocks. Analysis of the total arsenic in the ultrasonicated solutions revealed no arsenic losses due to evaporation.

On the other hand Se (IV) concentration remained constant over the entire 120 minutes of continuous sonication. No significant changes in total selenium concentrations were observed after a two-hour continuous sonication of 5, 10 and 15 ng/mL of 1:1 Se (IV)-Se (VI) mixtures. Hence, Se (IV) solutions are not easily oxidized under the experimental conditions used.

Comparison of the extraction of Se (IV) and total Se in samples

Sequential extractions of BT700 indicated that most of the extractable is Se (IV) whereas in BT571 the predominant form is Se (VI), as shown in Figures 5 and 6. The Se (IV) concentration increased in the order BT60< BT571 < BT700.

Conclusions

Ultrasound dissolution is a useful tool for the kinetic extraction of arsenic and selenium and the speciation of selenium from coal-associated rocks. The release of arsenic and selenium from coal-associated rocks depend both the type of rock and the concentrations found in rocks. These metalloids are released at different rates indicating that they bound at different sites and by different mechanisms.

The extracted arsenic concentrations are 3 orders of magnitude higher than selenium concentrations, and the speciation of the extracted selenium is also dependent on the rock material. Additional work is currently in progress to determine the type of binding and the locations of arsenic and selenium in these coal-associated rocks as well as the fate of arsenic and selenium that has been leached from valley fills.

Acknowledgements

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Table 1: X-ray diffraction results

Sample	Lithology	% Quartz	% Orthoclase Feldspars	% Plagioclase (Na/K Feldspar)	% Illite	% Kaolinite	%Chlorite
BT60	Sandstone	81.0	3.2	< 0.1	6.8	9.1	< 0.01
BT571	Claystone	32.1	0.4	0.5	40.1	12.2	14.7
BT700	Claystone	22.6	0.5	0.9	46.6	7.5	21.9

Courtesy, West Virginia Geological and Economic Survey

Table 2: X-ray fluorescence results

	% MnO	% K_2O	% SiO_2	% Al_2O_3	% Fe_2O_3	% Na_2O	% MgO	% TiO	% CaO
BT60	0.01	2.48	81.05	15.28	< 0.01	0.07	0.48	0.86	0.22
BT571	0.04	4.91	62.25	23.95	5.17	0.05	2.15	1.34	0.04
BT700	0.03	5.52	63.83	23.28	4.16	0.19	1.97	1.27	<0.01

Courtesy, West Virginia Geological and Economic Survey.

Table 3: Comparison of extraction techniques

	Total available Selenium	Total Selenium Extracted			Total available Arsenic	Total Arsenic extracted		
Sample	Microwave digestion ng/g	120 min continuous sonication* ng/g	Partial 5 minute of the 90 minute sequential sonication* ng/g	Total 90 minute sequential sonication ng/g	Microwave digestion µg/g	120 min continuous sonication* µg/g	Partial 5 minute of the 90 minute sequential sonication* µg/g	Total 90 minute sequential sonication µg/g
BT60	93.3 ± 3.7	78.4 ± 3.1	69.7 ± 2.5	93.2 ± 3.4	5.05 ± 0.15	2.19 ± 0.55	0.78 ± 0.11	4.15 ± 0.4
BT571	1088 ± 18	261.1 ± 15	208.3 ± 35	387.0 ± 14.5	48.2 ± 5.9	8.71 ± 1.07	9.07 ± 0.67	11.6 ± 1.4
BT700	1126 ± 122	153.8 ± 9.6	101.7 ± 10.1	428.8 ± 20.2	61.8 ± 5.4	15.7 ± 1.4	4.55 ± 1.76	27.7 ± 2.21

Table 4: Accelerated first order kinetic modeling for the extraction of total Se and total As

Sample	Se		As	
	[b]Rate constant min^{-1}	R^2 value	[b]Rate constant min^{-1}	R^2 value
BT60[a]	-	-	0.050 $\pm$ 0.003	0.9404
BT571	0.0089 $\pm$ 0.0002	0.9474	0.013 $\pm$ 0.003	0.9847
BT700	0.0052 $\pm$ 0.0001	0.9949	0.034 $\pm$ 0.001	0.9950

[a]Not enough data points were available for total Se kinetic modeling. All Se was leached out in the first three extractions.

[b]Accelerated extraction rate constant $\pm$ standard error of the slope obtained from First order model $\mathbf{\ln(1 - C_t / C_\infty) = -kt}$, where $\mathbf{C_t}$ is the concentration of extracted species at sonication time **t** and $\mathbf{C_\infty}$ is the extracted species concentration at infinite sonication, **k** is the accelerated extraction rate constant

Table 5: First order kinetic modeling for the release of Se (IV)

Sample	Rate constant (min^{-1})	R^2 value
BT571	0 .034 ± 0.002	0.9837
BT700	0.026 ± 0.001	0.9905

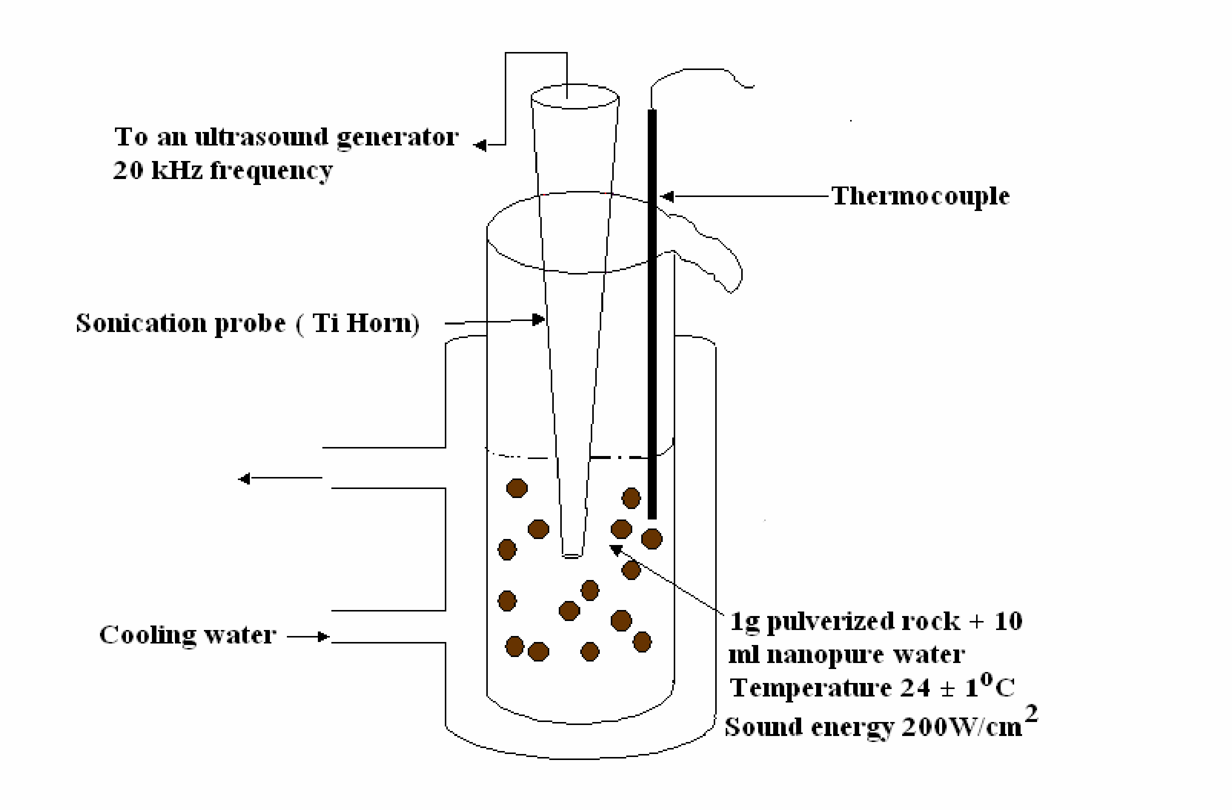

Figure 1: Ultrasound extraction experimental set up

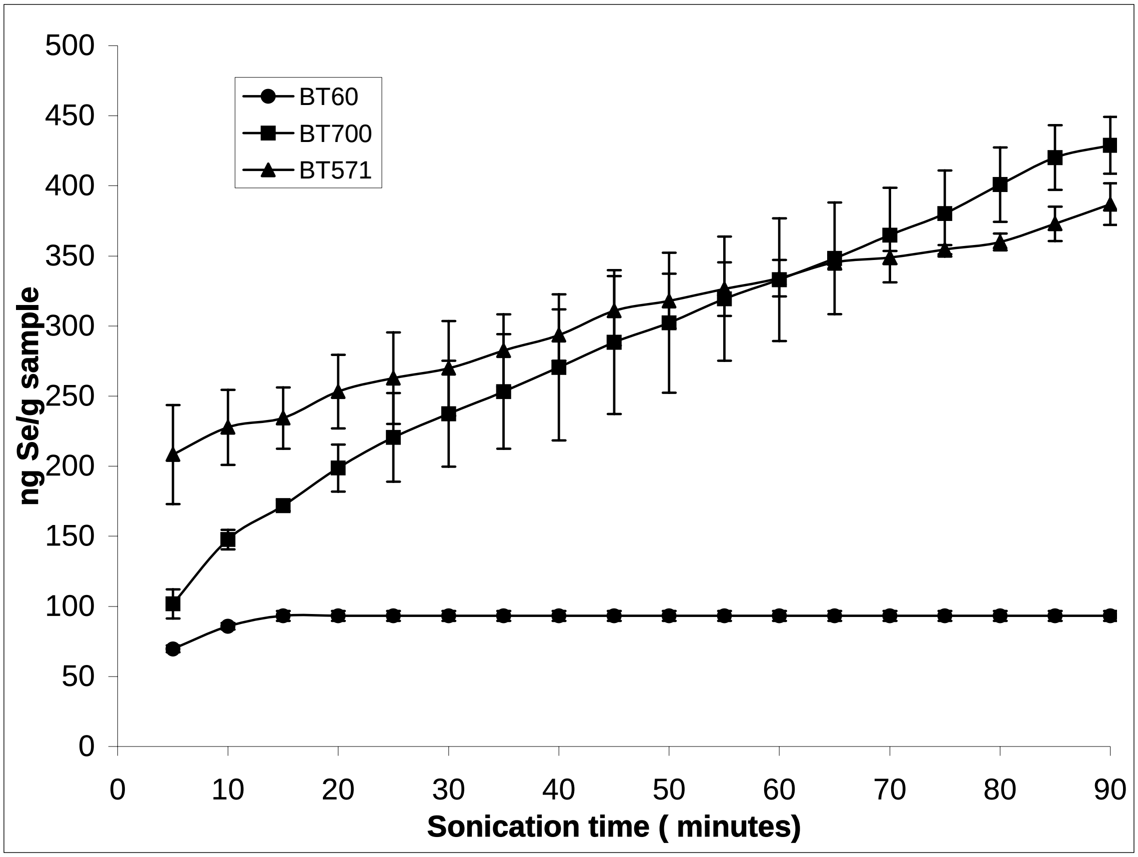

Figure 2: Release of total Se (ppb) as a function of sonication time

Conditions: Sequential five minute ultrasonic extractions, ultrasound pulse 40 %, probe diameter 0.3 cm, sonication power 200 watts/cm^2, temperature 24 $\pm$ 1^{o}C. 1 g sample in 10 mL nanopure water.

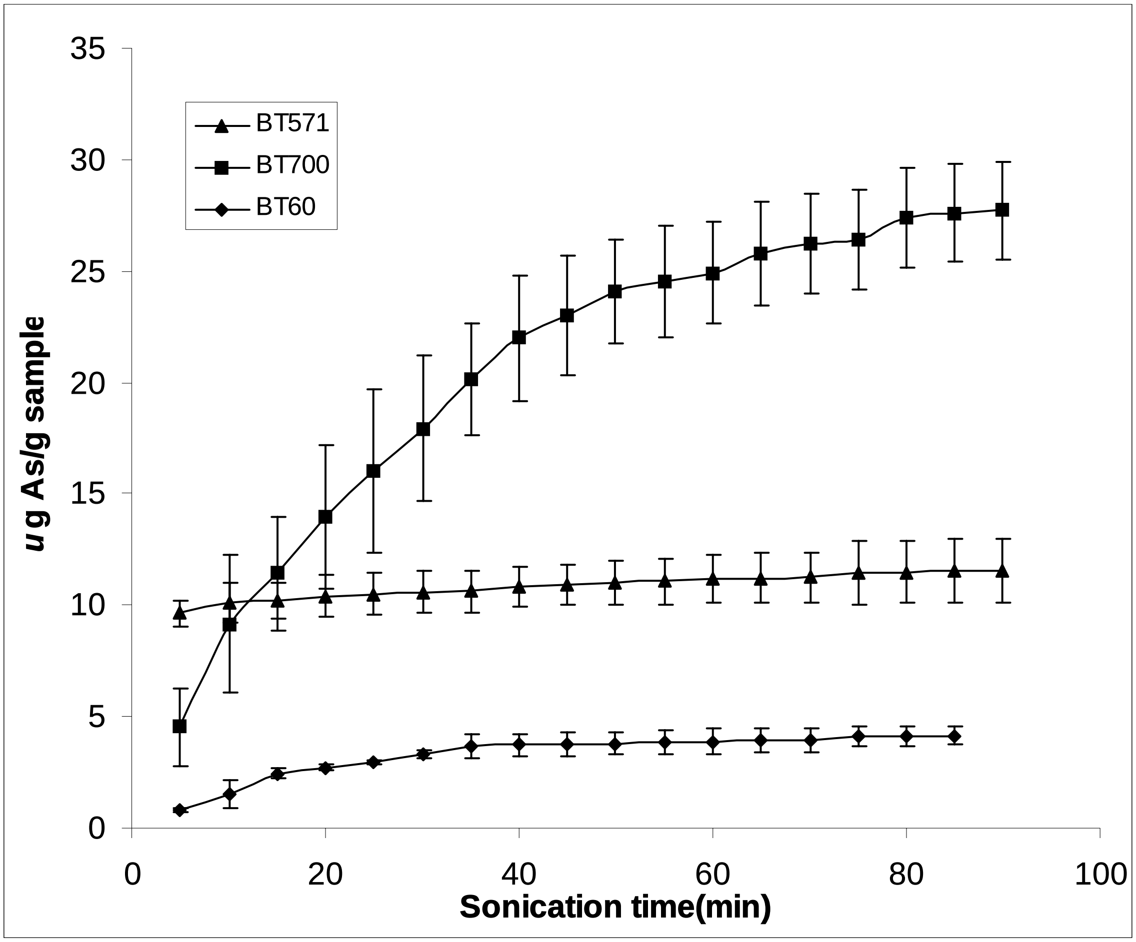

Figure 3: The release of total Arsenic (ppm) as a function of sonication time

Conditions: Sequential five minute ultrasonic extractions, ultrasound pulse 40 %, probe diameter 0.3 cm, sonication power 200 watts/cm^2, temperature 24 $\pm$ 1^{o}C. 1 g sample in 10 mL nanopure water.

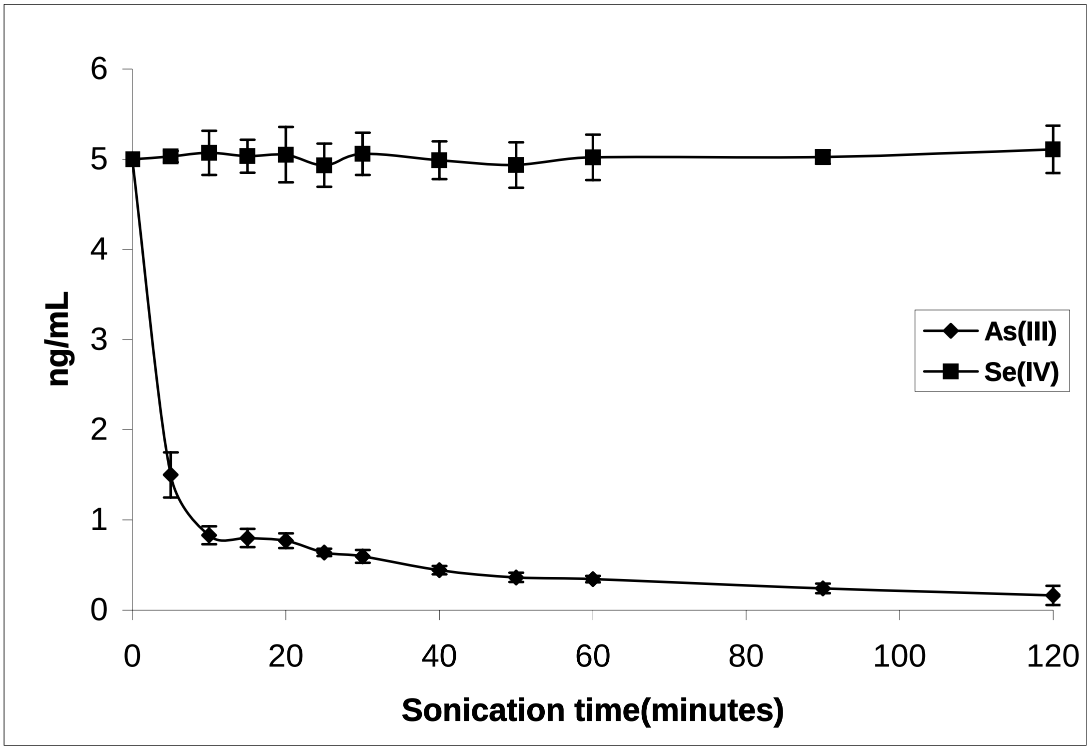

Figure 4: Variation of Se (IV) and the disappearance of As (III) as a function of sonication time

Conditions: 10 ml solutions of 5 ng/ml of 1:1 Se (IV)/Se (VI) and As (III)/As (V) sonicated at 200W/cm^2 , continuous sonication, ultrasound pulse 40 %, probe diameter 0.3 cm, 24 $\pm$ 1^{o}C.

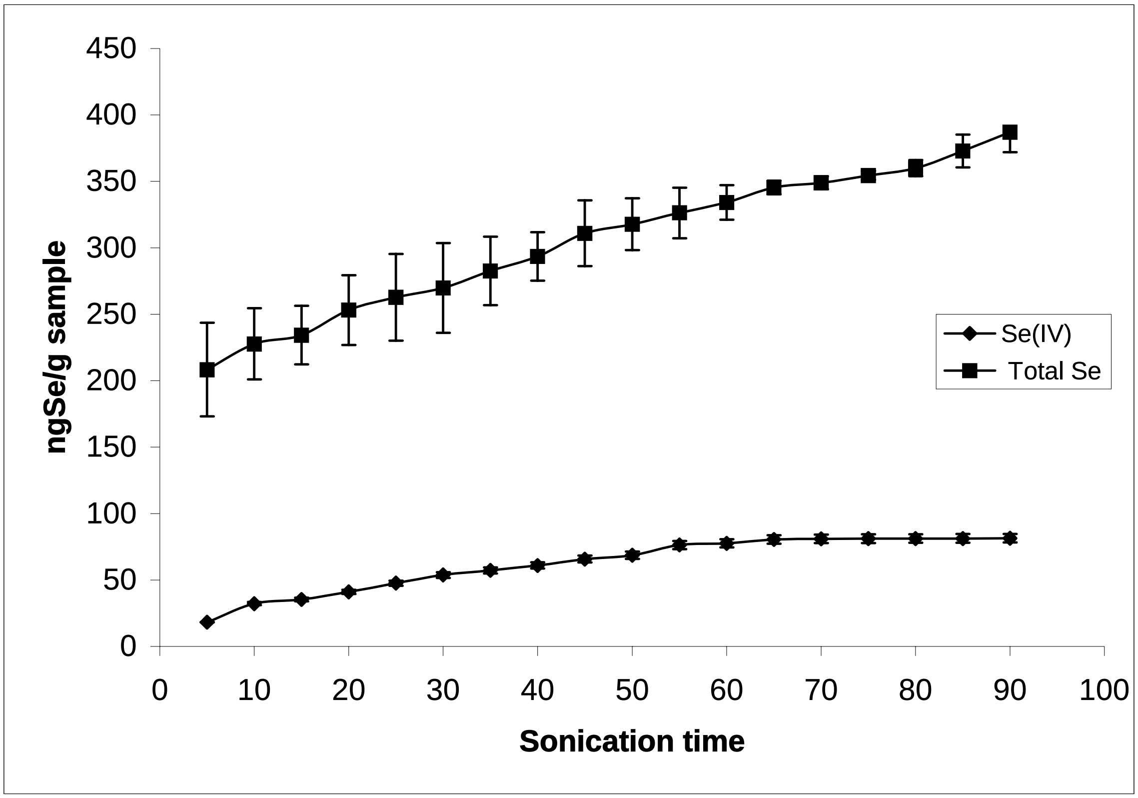

Figure 5: The release (ppb) of total Se and Se (IV) from BT571 as function of sonication time

Conditions: Sequential five minute sonications, sonication pulse 40 %, probe diameter 0.3 cm, Sonication power 200 watts/cm^2, temperature 24 $\pm$ 1^{o}C. 1 g sample in 10 mL nanopure water.

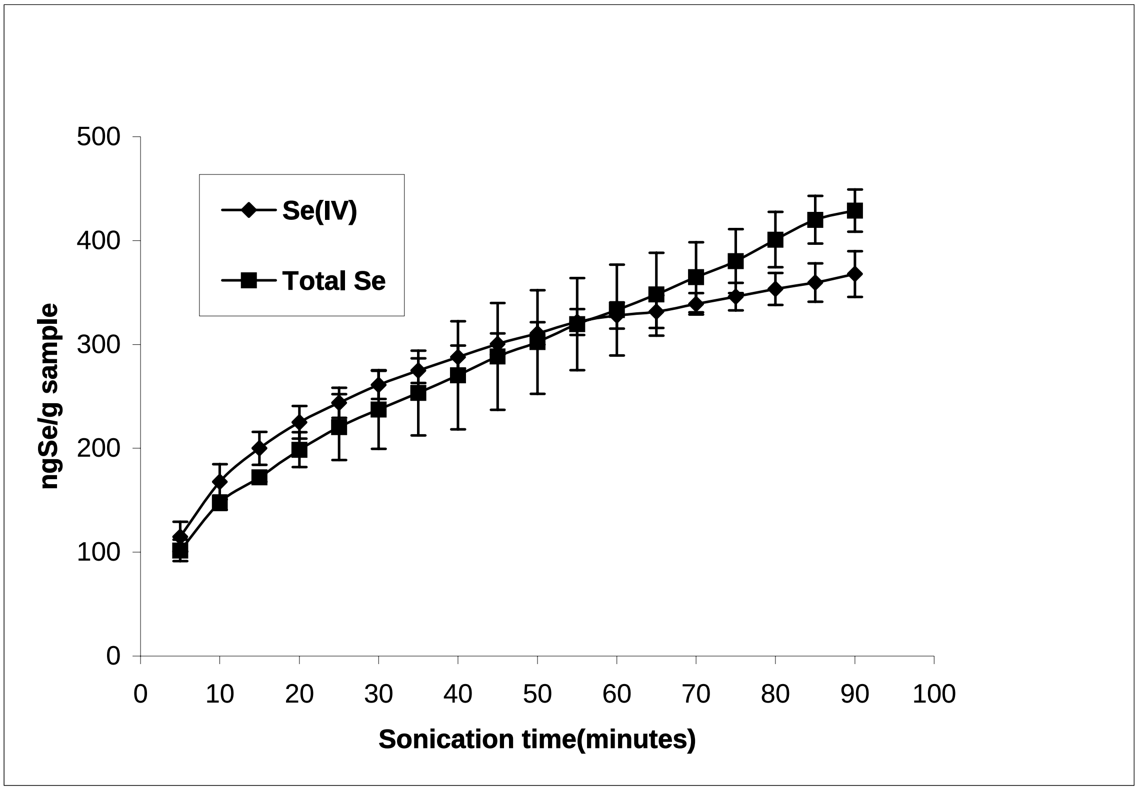

Figure 6: The release of total and Se (IV) from BT700 as a function of sonication time. **Conditions**: Sequential five minute ultrasonications, sonication pulse 40 %, probe diameter 0.3 cm, Sonication power 200 watts/cm^2, temperature 24 $\pm$ 1^{o}C. 1 g sample in 10 mL nanopure water.

In-Stream Turbidity and Suspended Sediment Changes Following Improvements to a Forest Road and Harvesting (WRI-82)

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1. Research

Abstract

In 1999, a study was initiated in two forested headwater channels to compare and contrast changes to in-stream suspended sediment and turbidity following the construction of a forest haul road. Turbidity (NTU), suspended sediment concentrations (SSC) (mg L^{-1}) and streamflow (L s^{-1}), were measured throughout May 2005. Both catchments are ephemeral/intermittent tributaries of the Left Fork of Clover Run in the Cheat River watershed. To exclude inputs of hillside sediment both catchments were continuously lined with silt fence from constructed gauging/sampling stations to the upper most portions of their drainage network. In July 2002, construction of a 0.93 km (0.58 mi) road (FS 973), encompassing 1.3 ha (3.3 ac) of the 32.7 ha (80.8 ac) treatment watershed, was initiated. FS 973 was completed in September 2003. Data were separated for comparison by road construction initiation (i.e. pretreatment and post-treatment), although, some analysis focused solely on the construction period independently. During the construction period, several tons of sediment were deposited in the stream channel. Following construction, the treatment watershed's stream turbidity, in relation to both watersheds pretreatment period and in respect to the reference watersheds post treatment period, increased significantly. While the highest turbidity value recorded in the treatment watershed (2352 Nephelometric turbidity units (NTU)) was 6.4 times larger than the highest turbidity sampled in the reference watershed, it was sampled during low streamflow (<1.4 L s^{-1} or <0.05 ft^3s^{-1}(CFS)). Fourteen post-treatment samples exceeded 100 NTU at discharges greater than 56.5 L s^{-1} (2.0 CFS) when the treatment watersheds average streamflow was 5.5 L s^{-1} (0.20 CFS). The reference watershed's samples stayed within expected ranges throughout the duration of this study. Turbidity increased significantly due to the construction of FS 973, specifically due to the prolonged period in a pioneered condition, construction of three culverted stream crossings, an inadequate cross-drain, and a constructed stream channel.

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Executive Summary

A forest road was constructed through a watershed in summer 2002 and was left in poor condition from fall 2002 through mid-summer 2003. During mid-summer of 2003 the condition of the road was improved through installation of water control features, sediment traps, seeding of the fill slopes and cut banks, and graveling of the driving surface.

Turbidity and suspended sediment levels in both the control and treatment watersheds fell within expected ranges during the 3 pretreatment years prior to road construction. Both parameters increased to very high levels on the treatment watershed prior to its finalization. After road improvements were made, reductions in turbidity and suspended sediment were observed on the treatment watershed.

The objectives of this study were to:

1) describe turbidity before and after haul road construction,

2) determine if or when in-stream turbidity levels decreased after construction of a haul road in the treatment watershed, and

3) if possible, given the short pre and post treatment periods, evaluate if recovery was linear, exponential, or if turbidity levels off at a level higher than pretreatment at some point in time.

Introduction

Turbidity, the refractive index of a solution, is an indirect measure of in-stream suspended sediment concentrations (Anderson and Potts 1987). Although, turbidity can be affected by dissolved air, solution color, particle size and shape, and solution concentration, it often is a better predictor of in-stream suspended sediment concentrations than discharge (Anderson and Potts 1987).

Road construction and use are recognized as the primary sources of sediment production during forest operations (Hornbeck and Reinhart 1964). Roads accelerate erosion, affects run-off, and increases effective channel lengths in headwater watersheds (Reinhart 1964, Binkly and Brown 1993, Jones and Grant 1996, Wemple et al. 1996). One year after road construction in north central West Virginia, treatment watershed maximum turbidity exceeded maximum reference watershed turbidity by 3,700 JTU (Jackson turbidity units) (Hornbeck and Reinhart 1964). Turbidity increases were primarily attributed to the poorly located skid roads and skidding in streams (Kochenderfer and Hornbeck 1999).

Turbidity is the primarily water quality parameter used to asses water quality in the East. “West Virginia water quality regulations permit no more than a 10 NTU increase from baseline conditions, specifically, “No point or non-point source to West Virginia's waters shall contribute a net load of suspended matter such that the turbidity exceeds 10 NTU's over background turbidity when the background is 50 NTU or less, or have more than a 10% increase in turbidity (plus 10 NTU minimum) when the background turbidity is more than 50 NTUs. This limitation shall apply to all earth disturbance activities and shall be determined by measuring stream quality directly above and below the area where drainage from such activity enters the affected stream. Any earth disturbing activity continuously or intermittently carried on by the same or associated persons on the same stream or tributary segment shall be allowed a single net loading increase.” (USEPA 2006).

Experimental Methods

In-stream suspended sediment, turbidity, and streamflow (i.e. stage and velocity) in two headwater streams were measured since 1999. Both streams are located within the Clover Run Watershed, Monongahela National Forest, north central West Virginia (Fig. 1). This design adopts the typical paired watershed design (e.g. reference and treatment watersheds) to evaluate the effects of road construction on water quality (i.e. turbidity and suspended sediment).

Monitoring stations (Fig. 2) were constructed in both watersheds to facilitate this study. The monitoring stations were constructed at the watersheds outlet to house automated samplers, which collected suspended sediment samples and stream stage and velocity measurements. Silt fences (Fig. 3) around the active stream channels were installed in both watersheds, from the monitoring stations to the upper most portions of their drainage networks. In the beginning, the primary goal of this study was to measure to-stream sediment delivery, hence, the silt fence lining the stream channels, although, due to a number of events that led to a substantial amount of sediment being deposited in the stream channel, which is thoroughly described in a later section, the primary focus of this study shifted towards measuring changes to in-stream suspended sediment.

Data from a weather station (1973-2004) located approximately 3.4 air kilometers away (operated by the US Forest Service's Northern Research Station), indicate the average precipitation for the area is approximately 161 cm yr^{-1}. The months of April through July generally receive the most precipitation, while September through November generally receives the least precipitation. The largest rainfall events are typically the result of tropical storms and hurricanes moving inland from the Atlantic Ocean. In addition, convective thunderstorms commonly produce intense periods of rainfall during the summer. Snowfall is common between November and March although can occur earlier or later. During the dormant season, a snow pack can remain on the ground for the majority of the winter or periodic rain-on-snow or fluctuating temperatures can produce intermittent ground coverings (Edwards, P.J. Submitted).

Water samples have been collected and streamflow (i.e., stage and velocity) has been measured in the treatment and reference streams since 1999. Housing for stream gauging and sampling equipment (Fig. 2) was constructed in both watersheds near their mouths. Five-minute streamflow velocity and stage readings were recorded at both stations using an American Sigma 950 flow meter. Stream water samples were collected for turbidity analyses. Daily samples were collected with an American Sigma model 900s automatic sampler in each watershed. Stormflow samples were collected with an Isco model 2700 automatic sampler in each watershed. The Isco model 2700s were actuated using precipitation rather than stage and then sampled on pre-set time intervals following the first sample to obtain a better representation of sediment responses during storms (Edwards and Owens 1995). Funnels

Stormflow sampling started November 2, 1999 and lasted until June 4, 2002 in both watersheds. One-hundred and fifty-three storms were sampled during pretreatment. Of these 70 were paired storms – that is, they were sampled on both the treatment and reference watershed. Stormflow sampling in the reference watershed started again on November 1, 2002 and lasted until April 30, 2005. Treatment watershed storm sampling started again on October 15, 2002 and lasted until April 30, 2005. One-hundred and thirty-four storms were sampled during post-treatment. Of these forty-two were paired storms. Samples were not collected from June 4, 2002 to October 15, 2002 for safety purposes during construction.

Stream velocity and stage measurements were made on 5-minute intervals since October 1, 1999. The velocity measurements from the American Sigma equipment were unstable and inaccurate, but the stage readings remained quite stable following calibration. Consequently, discharge was estimated from the stage measurements using Manning's equation in HEC-RAS software (www.hec.usace.army.mil/software/hec-ras/). These calculations were made by the Forest Service. Stage < 2.0 cm (0.8 in) could not be measured accurately because of equipment limitations. Samples collected during these streamflows represented anywhere from 8 to 45 percent of the routine and storm samples during pre and post-treatment periods. These samples are referred to as samples collected when streamflow was below detection limits. Streamflow also could not be calculated when the streams were frozen or when samplers malfunctioned (Edwards, P.J. Submitted). Turbidity analysis relative to streamflow was nonexistent due to some large variations in streamflow regressions and peak streamflow comparisons. Streamflow is presented in liters per second ($L\ s^{-1}$).

Road (FS 973) construction in the treatment watershed began July 8, 2002 and lasted throughout September 2003. FS 973 extended for 0.93 km (0.58 mi), encompassing 1.3 ha (3.3 ac) of the 32.7 ha (80.8 ac) treatment watershed. FS 973 extended for another 2.6 km (1.6 mi) after exiting the treatment watersheds drainage divide. Road construction is defined as the day heavy machinery began working within the treatment watershed to the day the haul road met BMP standards within the treatment watershed. Except for seeding, mulching, fertilizing, blowing hay, and installing a check dam on October 22, 2002 and May 7, 2003, road construction was ceased between October 15, 2002 and May 7, 2003 to avoid the winter months and the wet spring months.

During FS 973 construction, three permanent culverts and two temporary culverts were used to form three stream crossings. The fills over these crossings reached 9 m (30 ft). The first temporary culvert, later removed and replaced with the first permanent culvert, was used to proceed further into the watershed. The second temporary culvert was inadequately draining a steep tributary, therefore, it had to be removed. FS 973 construction was a slow process because the fills over the culverts were large (i.e. up to 15 m (50 ft)), thus the fillslopes had to be meticulously constructed and compacted, some road cuts lead into large portions of bedrock that needed to be cut through and properly sloped, a culvert failed and had to be removed while the stream had to be diverted to another culverted stream crossing via a constructed rip-rap channel, and the treatment watershed was relatively remote and the number of trucks was limited, therefore, graveling the road became a very slow process.

Water samples were processed for turbidity at the US Forest Service's Timber and Watershed Libratory in Parsons, West Virginia. Turbidity, in nephelometric turbidity units (NTU), was determined using a Hach Ratio Turbidimeter, which was calibrated using formazin standards (Edwards, P.J. Submitted). The samples were first shaken to distribute the sediment throughout the bottle. A sub sample was then poured into a small glass tube. The sides were wiped free of fingerprints and other dirt, and the glass tube was placed in the turbidimeter. After approximately 5 seconds, the turbidity value was recorded.

After measuring turbidity, the sub-sample was poured back into the original bottle so suspended sediment concentrations could be calculated. Before measuring suspended sediment concentrations, the entire sample was weighted. The bottle, lid, and sample were weighed then subtracted from the known bottle and lid weight to obtain the weight and of the water/sediment sample. Each sample was filtered through one or more pre-dried and pre-weighted ashless GF/C glass microfiber filters using vacuum filtration. The bottles were rinsed several times, and each time the rinse water was filtered. The number of filters needed depended on the amount of sediment in the bottle. Although, most samples required only 1-3 filters, a few required 30 or more. All samples were then dried at 100 ºC (212°F) for 2 hours then re-weighed. This weight minus the initial dry filter weight is the combination of the organic and inorganic material (g/L). The filters were then combusted in a muffle furnace for 1 hour at 550 °C (1022°F) and then re-weighed. This weight plus a 0.001 filter correction for filter loss during combustion, minus the initial dry filter weight, is the amount of inorganic material (g). The dry weight minus the combusted weight plus a 0.001 filter correction is the amount of organic material. These samples were determined using U.S. EPA method 160.2. All analysis involving suspended sediment concentrations used both organic and inorganic material.

Statistical Analysis Systems (SAS 1988) was used to analyze these data. Nonparametric methods primarily were used because the data were not normally distributed. Wilcoxon signed-rank tests and median scores (Proc NONPAR1WAY) were used to transform the data to an ordinal scale to make statistical conclusions about the location differences (higher lower or no difference (random)) between both watersheds' turbidity. Median scores were used to test for differences between watersheds turbidity.

The relationship between turbidity and SSC (TS ratio) was created to compare the turbidity of a sample to the suspended sediment concentration. This ratio compares two different types of water clarity measurements and samples between watersheds were of different volumes, therefore, any conclusions formed should be viewed with skepticism. However, sample volumes averaged by month and by storm were not significantly different between watersheds pretreatment and post-treatment periods. Parametric analyses were used on non-normal untransformed data in the form of regression analysis only. Log base 10 transformations were used to increase data normality and express changes to variability. Statistical significance was tested at 0.05 level.

Results and Discussion

The reference watershed's storm and routine samples prior to construction were statistically more turbid than the treatment watershed's. The reference watershed's routine samples contained more sediment by weight relative to its turbidity index. Storm samples and TS ratios were similar between watersheds. The reference watershed produced less turbidity per sediment than the treatment watershed. This is probably the result of past disturbance in the reference watersheds (i.e. roads, farming, and timbering) as the reference watershed generally had larger median substrate than the treatment watershed (Bills 2005).

Substantial variation to streamflow occurred from pretreatment to post-treatment. Several studies have measured changes to streamflow following timber removal (Hornbeck et al. 1993, Jones and Grant 1996). Few studies have intensively measured streamflow changes due to road construction, therefore, streamflow responses due to road construction are uncertain. Roads theoretically increase the efficiency of water transfer from hillsides to stream channels by intercepting subsurface streamflow and precipitation then directing the intercepted water directly to stream channels and/or in more concentrated levels onto the hillside below (Reinhart 1964, Wemple et al. 1996). Streamflow measurements and classes were not used rigorously to analyze turbidity because streamflow was modeled and deviated substantially from predicted values. For example, one predicted peak stormflow level differed between watersheds by 280 L s^{-1} (10 cfs) when the average streamflows were less than 28 L s^{-1} (1 cfs). The Forest Service employees who created the model would be better suited to evaluate any changes to streamflow due to road construction, therefore any analysis that uses streamflow such as turbidity and streamflow relationships and/or SSC and streamflow relationships should be viewed with skepticism.

The results of this study demonstrated the effects of road construction on water quality. Several studies have identified roads as the primary source of to-stream sediment during forest operations and have identified road to stream interactions as the most problematic within the road network (Irvin and Sullivan unpublished data, in Bilby et al. 1989, Wemple et al.1996). This study isolated most of the road network from the stream channel (e.g. silt fence), therefore, the majority of sediment that entered the treatment watershed's stream channel was the result of stream crossing construction. FS 973 occupies 4.1 percent of the treatment watershed and stream crossings occupy less than one percent of the treatment watershed.

Average and median turbidities for these watersheds were below 5 NTU during pretreatment. Turbidity is noticeable around 5 NTU (Strausberg 1983, in Edwards Submitted) therefore, these streams normally have clear water. Prior to treatment, the treatment watershed's stream samples (2680) exceeded 25 NTU 29 times or 1 percent of the time and the reference watersheds samples (3059) exceeded 25 NTU 55 times or 2 percent of the time.

Maximum pretreatment turbidities were less than 400 NTU in both watersheds. They occurred during the largest storm events or during summer thunderstorms. Turbidities were elevated throughout the summer months during pretreatment. Stormflows that produced larger turbidities were relatively short-lived and storms samples overall produced clockwise hysteresis. Clockwise hysteresis is an indicator of a sediment supply limitation.

In July 2002 road construction was initiated within the treatment watershed. Very few samples were collected between July 2002 and July 2003, therefore, changes to in-stream turbidity during the 1st year post-treatment are unknown. Several studies site that the largest deviations to background levels occur within the first few months following disturbance (Hornbeck and Reinhart 1964, Fredriksen 1970), however, this may not be the case here as mitigation structures could have trapped and stored and disturbed sediment. However, sediment that does reach the stream channel during disturbances typically flushes quickly during the first couple of storms. In Oregon, sediment concentrations were measured 250 times expected levels during the first storm post-treatment, 9 times larger 2 months later, and remained elevated 2 to 3 times expected levels 2 years later (Fredriksen 1970). In West Virginia, average turbidity was 12.9 and 149.5 times larger during forest operations than first year after treatment from a clearcut and diameter limit harvest, respectively. Average turbidity was 38.0 and 6.0 times larger after the first year post-treatment than the second year post-treatment (Hornbeck and Reinhart 1964).

These samples were too few or occurred during insignificant times to provide an adequate account of turbidity during the first few storms post-treatment. However, if pretreatment values were increased to the same magnitude as in Hornbeck and Reinhart 1964 during treatment, then average turbidity values could have been as high as 255 and 525 NTU for routine and storm samples respectively. These values would be deemed excessively high by all the past literature however, it does show the potential changes to both stormflow and routine during the first few storms during treatment.

The reference watershed stayed within normal background levels after treatment even though the treatment watershed's average and median turbidities were above 5 NTU. Fourteen percent of the turbidities exceeded 25 NTU in the treatment watershed. Elevated turbidities were the result of stream crossing construction. Areas in stream crossings were less than 1 percent of the treatment watershed using 10 m aerial photographs.

Maximum turbidity in the treatment watershed following treatment reached 2,352 NTU and occurred during the initiation of a storm event. The treatment watershed's turbidities were less seasonally dependent, that is, the largest average monthly turbidity, occurred more so in late fall and during the winter months. The treatment watershed's stormflow turbidities were substantially elevated during the initiation of all storm events and are believed to be the result of precipitation impact remobilizing easily suspended channel sediment. Stormflows produced larger peak, average, and median turbidity values. Stormflow turbidities were relatively longer-lived and even maintained and increased after peak stormflow. Several storms produced counter-clockwise hysteresis towards the end of the 1st year post-treatment. Counter-clockwise hysteresis is an indicator of an energy limited situation and an abundance of sediment in the stream channel.

Conclusions

This study illustrates that significant increases to average turbidity during forest operations are not exclusively the result of similar increases to average SSC. For example, the treatment watershed routine and storm samples average SSC was 1.4 and 1.0 times the pretreatment levels post-treatment while average turbidity was 4.5 and 9.9 times the pretreatment levels post-treatment, respectively. By comparison, the reference watershed routine and storm samples average SSC were 0.7 and 0.5 times the pretreatment levels post-treatment while average turbidity were 1.0 and 1.2 times the pretreatment levels post-treatment, respectively. SSC measurements are an inadequate indicator of water quality as decreases to water clarity were probably the result of smaller inorganic and organic sediment that weighed less than average pretreatment sediments.

The TS ratio indicated that the treatment watersheds turbidities were significantly lower during pretreatment although less sediment per weight produced them. The reference watershed was transporting relatively more sediment with less turbidity. After treatment, the TS Ratio increased to 1.4 as the majority of turbidity values were larger than the SSC values. Towards the end of the post-treatment sampling period the TS ratio drops to around 0.5 as the majority of the turbidity values were half the SSC values. This indicates a considerable shift to sediment properties that influenced turbidity and SSC concentrations. The TS ratio went from the highest levels to the lowest levels relative to pretreatment levels in 2 years or by the 3rd year post-treatment. Although, turbidity is a better predictor of SSC than streamflow, the relationship between SSC and turbidity changed substantially between sample types, pretreatment and post-treatment periods, and levels of turbidity to warrant the use of several different regressional relationships.

Prior to treatment, average daily rainfall was a statistically significant predictor of average stormflow turbidity. Average daily precipitation explained 11 and 38 percent of the variation to average stormflow turbidity during pretreatment. Average daily precipitations were not a statistically significant predictor of average stormflow turbidity during post-treatment. The relationship did not return to pretreatment values for the duration of this study. There was no statistical significance between the two parameters in the reference watershed.

Stream crossing have to be constructed with better soil conservation practices. This road extended throughout the treatment watershed before the crossings were finalized. Time study analysis may be useful to help contractors increase road production and efficiency while decreasing costs associated with road construction while increasing soil conservation. Although, these crossings are legally defined as non-point sources of pollution, this study illustrates that very specific points along the road network were mainly responsible for water quality degradation. Bridges should be used instead.

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2. Publications

“In –stream turbidity changes resulting from forest haul road construction” Planned for submission to Journal of the American Water Resource Association. Currently out for external review prior to journal submission, as per Forest Service requirements.

A masters thesis and at least 2 resulting journal articles from that thesis are anticipated within the next ~6 months. Thesis completed in May 2007.

3. Information Transfer Program

Wang, J. 2006. “Sustainable forest operations in West Virginia’s watersheds.” West Virginia Water Conference 2006 – Ensuring water resources for West Virginia’s Future. October 11-13, 2006. Stonewall Resort, Roanoke, WV.

4. Student Support

William Sharp, M.S. Student (Graduates May 2007)

Category	Number of Students supported With 104b Base grant	$ Value of students supported With 104b base grant	Number of students supported With matching funds	$ Value of student support with matching funds	Total number of students supported	Total $ value of student support
Masters	1		1		1	

5. Noticeable Achievements and Awards

Wang, J.	2006	Determining Factors Contributing and Controlling Sediment Delivery to Stream Channels.	Monongahela National Forest	$33,355

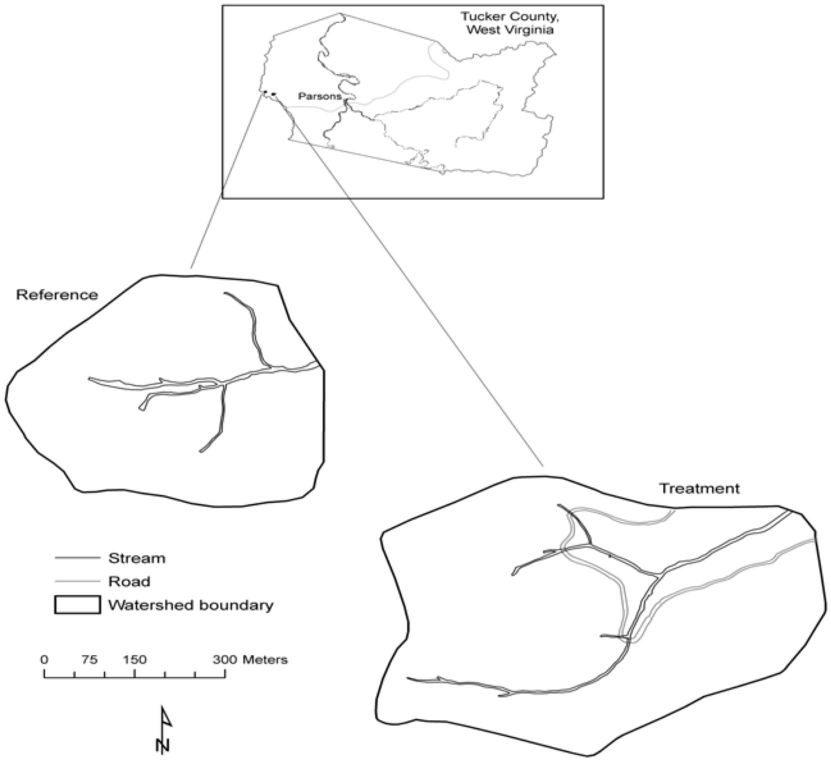

Figure 1. The study area and delineated watersheds illustrating the general aspect of both watersheds.

Figure 2. A constructed monitoring station used to collect water samples and record streamflow velocity.

Figure 3. Example of the sediment fence that was lined around all stream channels in both watersheds. Picture was taken while standing on a stream crossing.

Systematic determination of water resource data & information management needs in West Virginia (WRI-81)

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WRI-81

Abstract

The nation and world are rapidly recognizing the value of water resources and becoming aware of the changing use, climate, and precipitation trends that affect supply, quality, and frequencies of peaks and dips in resource stocks and flows. Unfortunately, state and federal government agencies are simultaneously disinvesting in the streamgaging and groundwater monitoring well networks that provide the data foundation upon which nearly all US water resource research and management rests. West Virginia's history of flooding and drought, as well as its water resource abundance and location relative to eastern seaboard population centers, lends it to being a state with a particular stake in collecting quality information about water resource trends. This report is an institutional review of how water resource data is collected and managed with an emphasis on security of long term water resource trend data. The report also provides a tool for and results from an interagency participatory streamgage prioritization exercise designed and conducted in cooperation with the WV Gaging Council.

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Executive Summary

The streamgage and groundwater monitoring well network in West Virginia has been threatened by consistent funding shortages for almost 15 years. Moreover, our gages with long-term histories of data collection – those upon which we most rely for evaluating patterns today against historical trends – are often among those that suffer during cutbacks. Ten years of peakflow values from a stream gage is the generally accepted minimum requirement for development of a flood probability estimate (Cleaves & Doheny, 2000). Our lost ability to relate more complex current weather and water events to past patterns severely weakens our ability to understand and manage our most important state resource – freshwater. Heightened public awareness just after severe flooding can often result in periodic windfalls of network funding, but the lost years of data or changed new locations of the re-funded gages significantly undermines the value of the historical trend data. Also, these gages may be replaced with funding to monitor real-time stages for floodwarning and recreational use, but without sufficient funding to collect, store and present that data to the public in a way that preserves it as trends in flow data.

Insecure gage and well funding results in lost water resource data. This, in turn, results in lost analysis and therefore lost or mismanaged opportunities over time. Ending data collection at gages with years of historical record removes the possibility of conducting reliable research and analysis now and in the future; the data will not exist to support important research or decisions about climate change, bridge sizes, road design, building codes, factory locations, and flood management infrastructure (USGS, 1998). Economic development opportunities are lost, and a lack of information results in mismanaged resources.

Moreover, when WV agencies' budget cuts reduce gage and well network state funding, the USGS Federal-State Cooperative Water Program (CWP) is forced to cut back its matching funds accordingly, doubling the loss to the network. Annual funding cuts that started in the late 80s and continue today, cost WV tens of thousands of dollars in lost wages as personnel from multiple state agencies, organizations, and research institutes invest time and effort into scrambling, year after year, to negotiate complex coverage of funding gaps or to decide where data collection effort must end.[1] An interagency council that exists to manage this annual crisis, unfunded, has even turned to seek private charitable donations to cover basic state operations of gaging operations – an expensive and unreliable endeavor. Members of the WV Gaging Council travel to meet four to five times a year in addition to fulfilling inter-meeting efforts. Time taken for these activities is time taken away from agencies' other duties and goals.

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[1] This estimate is based on wage estimates for those attending quarterly WV Gaging Council meetings and conducting related work in between meetings. The estimate quickly surpassed $20,000 without including time used to conduct legislative and interagency negotiations.

The 2004 Statewide Flood Report and the 2006 Water Resources Protection Act Report both underscored the importance of reinvesting in reliable water resource information collection and management. Requests from the state legislature to identify flood and drought prone areas and to estimate water supply and demand balances remained largely inconclusive in the final reports, in great part due to the lack of available historical streamgage and groundwater monitoring well data needed to conduct these analyses. Much of the analysis that was provided in the report had to be based on 30 year trend data from 1964-1994 because of the severe drop in the number of gages with significant data history after the gaging network budget cuts that ran from 1994-1997.

For this report, an interagency participatory survey was developed to assess and prioritize streamgaging needs and priorities in the state. The survey, or prioritization tool, which targeted members of the WV Gaging Council, reflected the challenge of coordinating diverse stakeholders to identify their agencies' priorities in the gage network. Asked to rank WV's river Basins in order from 1-8 based on how well each watershed was covered by the gaging network, respondents revealed many opposing perspectives on gage network resources and gaps; one basin alone was ranked 4^{th}, 7^{th}, 8^{th}, and 2^{nd} by four responding agencies.

From the survey, the existing gage stations received an average rating of 3.184, using a scale of 1-4 (not useful:1, critically important 4). Looking at ratings of just the United States Geological Survey's (USGS) National Streamflow Information Program (NSIP) gages (prioritized for receiving guaranteed federal funding), state agencies rated these gages at an average of 3.476, indicating better agreement among agencies for the importance of the core set of NSIP gages. Selecting the highest rated gages on the survey would help define a second set of WV-core gages identified to receive secure state funding annually if WV had a program similar to the federal NSIP program. As stated earlier, such a list would be preliminary and would then have to be discussed by primary stakeholders.

The prioritization tool was used for analysis of streamgage priorities only. Because of the small number of groundwater monitoring wells N=8, it was not useful to prioritize them – though funding for even those eight is threatened annually.[2] A separate analysis is necessary of where groundwater monitoring wells are necessary for sound water resource management in West Virginia. For the 2006 Water Resource Protection Act Report, WVDEP conducted a preliminary review of groundwater monitoring well needs and identified notably important gaps in the western regions of the state in particular (WVDEP, 2006).

[2] This absence of a groundwater monitoring network in WV should be cause for concern among public decision makers in WV. WV has monitoring wells despite the approximately 33 billions of gallons of groundwater extracted annually in the state for public and private uses. By comparison, Maryland has 141 wells, Delaware 96, Pennsylvania 65, Virginia 256, and Ohio 140. (WVDEP, 2006)

Acronyms

COE – US Army Corps of Engineers
CWP - USGS Federal-State Cooperative Water Program
NSIP – National Streamflow Information Program
OWRC - Ohio Water Resources Council
USGS – United States Geological Survey
WRPA – Water Resource Protection Act
WVCA – WV Conservation Agency
WVDNR – WV Department of Natural Resources
WVDEP – WV Department of Environmental Protection

1. Introduction

This report provides an institutional overview and analysis of the state gaging network limitations related to providing adequate and reliable streamflow data for the diverse group of public and private users that rely on that network to meet their organizations' objectives. The report also provides a participatory gage prioritization tool to support gage network resource allocation decisions, and it presents preliminary results from an initial application of that tool among state agencies and organizations actively involved in the WV Gaging Council, an organization with a mission to "*ensure that reliable water resources gaging data are available to meet the needs of the State's varied stakeholders*".

This report addresses the problem of insufficient, inconsistent, and unevenly distributed streamflow monitoring efforts that fail to provide adequate information for governments, academia, or private interests to assess, manage, and/or develop the state's valuable and extensive water resources.

A primary challenge to consistent and adequate provision of streamflow data is the institutional separation among the many and diverse users of gage data, the funders of that data collection, and the managers of the data (Cleaves, 1998). Table 2 describes primary types of gage data, the users, and the funders of a gaging network.

The United States Geological Survey (USGS) manages the vast majority of the state's real time and historical water resource data through its Federal-State Cooperative Water Program – a program which provides federal matching funds for states' investments in their water gaging networks and related water science research and analysis.

In West Virginia, USGS Federal-State Cooperative Water Program funds are matched by a quilt of different state agencies' contributions which vary year by year. Each year, the WV USGS office must invest weeks of staff time into accounting for promised contributions from each agency, comparing expected contributions with total anticipated costs of managing the gaging network, and then making additional solicitations, network cuts, and negotiations among agencies accordingly. Each agency has an incentive to default on their financial responsibility if other agency/agencies will cover the shortfall in order to protect the data (a traditional Prisoners' Dilemma game or Tragedy of the Commons[3]).

The lack of secure gage and groundwater monitoring well funding results in lost water resource data.[4] These annual data fluctuations result in weakened analytical capacity and

[3] The Prisoner's Dilemma is a more detailed analysis of another well known management problems called the Tragedy of the Commons. In both of these situations, individual agents have an incentive to "free ride" or shirk their responsibility and can reasonably expect other agents or stakeholders to continue contributing enough to maintain the common good, at least for the short or medium term. This Tragedy of the Commons is considered a tragedy because, without a change in institutional design, the commons are eventually abused/abandoned by all to a degree that makes the common pool resource unusable or beyond reasonable restoration costs.

[4] This absence of a groundwater monitoring network in WV should be cause for notable concern among public decision makers. WV has only 8 groundwater monitoring wells despite the approximately 33

therefore foregone or mismanaged economic and public safety opportunities over time. The trend of ending data collection at gages with years of historical record removes the possibility of conducting reliable research and analysis now and in the future (Figure 1); the data will not exist to support important research or decisions about climate change, bridge sizes, road design, building code design, factory locations, and flood management infrastructure (USGS, 1998). For example, ten years of peakflow values from a stream gage is the generally accepted minimum requirement for development of a flood probability estimate (Cleaves & Doheny, 2000).

Moreover, when WV state agencies' budget cuts result in reduced funds for gages and wells, the USGS Federal-State Cooperative Water Program is forced to cut back its matching funds accordingly, doubling the losses to the networks. Annual funding insecurity costs tens of thousands of dollars in lost wages as personnel from multiple state agencies, organizations, and research institutes invest time and effort into scrambling, year after year, to negotiate complex coverage of funding gaps or to decide where data collection effort must end.[5] An interagency council that exists to manage this annual crisis, unfunded, has even turned to seek private charitable donations to cover basic state operations of gaging infrastructure – an expensive and unreliable endeavor which is akin to asking private businesses to make charitable donations for state road maintenance. Members of the WV Gaging Council travel to meet four to five times a year in addition to fulfilling inter-meeting efforts. Time taken for these activities is time taken away from agencies' other duties and goals.

The 2004 Statewide Flood Report and 2006 Water Resources Protection Act Report underscored the importance of reinvesting in reliable water resource information collection and management. Requests from the state legislature to identify flood and drought prone areas and to estimate water supply and demand balances remain largely unmet, in great part due to the lack of available historical gage and well data with which to conduct these analyses. Moreover, both reports underscored the importance of preserving and supplementing the state streamgaging network and making specific recommendations for streamgages. The WRPA report also underscored the link between ground water monitoring data and analysis of streamflow data as critical for facilitating development of the state's energy and industrial sectors, planning around population growth, and protecting water supply (Table 1). State contributions to building and protecting reliable water monitoring networks must acknowledge the importance of this link.

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billions of gallons of groundwater extracted annually in the state for public and private uses. By comparison, Maryland has 141 wells, Delaware 96, Pennsylvania 65, Virginia 256, and Ohio 140. (WVDEP, 2006)

[5] This estimate is based on wage estimates for those attending quarterly WV Gaging Council meetings and conducting related work in between meetings. The estimate quickly surpassed $20,000 without addressing much of the time used to conduct legislative and interagency negotiations.

Table 1 Comparison of groundwater monitoring resources regionally in absolute and relative numbers. Figures in this table for wells are from the USGS website (June 2006).

State	Groundwater Monitoring Wells	Counties with Monitoring Wells / Total Counties	State Sq. Miles
Pennsylvania	68	66/67	45,888
Ohio	100+	83/89	44,828
Virginia	47	26/95	42,769
Maryland	10	6/24	12,407
West Virginia	7	3/55	24,231

Some stakeholders only need real-time gage data for immediate decisions (recreation companies, vacationers, flood emergency response agencies, etc.). For these users, moving gages for temporary convenience or taking them off line during budget crises does not a pose a significant problem. For many others, the value of a year or two of gage data is exponentially more valuable if it can be compared with historical trend data collected at that site over time. Therefore, losing state gages that have been providing historical data for decades is the loss of much more than a year or two of data. Evaluating data over time allows us to recognize and respond to changing weather and hydrology trends – predicting and preventing where damage is likely to occur rather than just reacting event by event. Gaps in data cannot be recovered later when budgets are more robust. In fact, these gaps permanently weaken our ability to make informed, safe, and/or economically proactive decisions in all facets of the state's pubic, private, and research sectors. Mark Anderson, Director of the South Dakota Water Science Center states, "If you have a discontinuity of a couple of years even, you lose part of the substantial investment that's been made in the period of record (of that gage). It's like you're squandering the investment of your predecessors."

Historical streamgage data gaps present an obstacle for two important state goals – sustainable economic development and protection of the citizens of West Virginia. To sustainably attract and locate industries that require use of WV's significant water resources requires an understanding of the extent of water supplies in the state as well as historical patterns of drought and flooding, dynamic relationships among landuse, groundwater, and surface water supplies in various regions of the state. This information is also critical for the recreation economy, and environmental standards are established based analysis of streamflow trends over time. For private and public service engineers to safely design roads, bridges, factories, and developments requires historical water trend data that can be analyzed to safely anticipate future trends in water resource behavior. As well, premier research at our state's universities in disciplines such as engineering, forestry and agriculture, chemistry and geology, and even in economics and political science frequently requires an accurate analysis of water resource supply dynamics that can only be provided if historical and contemporary streamflow data are collected and archived responsibly and consistently from the same stream locations.

1.1. *Streamgaging in the United States & West Virginia*

The national network of streamgages expends some $120 million annually to run about 7,400 gauges, down from a peak of 8,221 in 1968. Each gauge costs, on average, $13,500 to run per year. These costs include capital investments, operation and maintenance of the gage itself, monitoring and cleaning incoming data from gages and providing that data to the public through various web interfaces, among other costs (Schwartz, 2006). As budget cuts have affected the national network of gages, so too has WV's network suffered significant losses in the early 80s and again in the mid-90s (Figure 1 & 2).

Losses of gages with valuable historical data collection periods are exceptionally alarming (Figure 3). In 2006, 216 gages were on the chopping block across 26 states' networks. On the list of cuts was a gage in Kentucky with 98 years of data, in Hawaii with 87 years, and in Illinois with 97 years.

Between 1994 and 1997, WV lost nearly 20 stream gages with significant histories of gage data. Losses like this in WV and in many other states through the country have prompted USGS to secure funding for a core set of gages through the National Streamflow Information Program, which collect data that cannot be compromised with budget and political fluctuations at federal, state, and local levels (Figure 3).

> "The National Streamflow Information Program (NSIP) has been formulated by the U.S. Geological Survey (USGS) to create a stable, federally funded *base network* of streamgages and to enhance the information derived from this network with intensive data collection during major floods and droughts, periodic regional and national assessments of streamflow characteristics, enhanced streamflow information delivery to customers, and methods development and research." (Water Science and Technology Board, 2004)

This base network of streamgages is designed to meet five minimum federal streamflow information goals, namely, (1) interstate and international agreements, (2) flow forecasts, (3) river basin outflows, (4) long-term monitoring using benchmark (sentinel) watersheds, and (5) water quality.

Robin G. Middlemis-Brown, director of the Geological Survey's Iowa Water Science Center, said he was especially sorry to see a gauge go offline that had been providing data on the Des Moines River in Iowa for 87 years. "If you don't know your past, you can't tell your future," Mr. Middlemis-Brown said. "It's like going blind, slowly" (Schwartz, 2006). While the NSIP serves to protect the core data needs of the nation, with over 800 different state and local funding partners, juggling donors' fluctuating commitments to "keep states from going blind" becomes almost a full time job for state network coordinators.

Over the past ten years in West Virginia, funding crises have arisen nearly every year (Evaldi, 2006). In 1996, the state defaulted on providing its share of matching funds to the USGS Cooperative Water Program. The next year, the Legislature filled the gap when flooding raised public concern. In 1998, funds are used to address flood warning problems – shifting resources to realtime stage data monitoring. Three years of stability were followed by a $200,000 cut by one single agency, which again caused USGS to cut back on its federal matching contribution.

In 2003, state agencies met informally to pool funding resources and cover the funding gap left by the $200,000 cut. This interagency scramble occurred again in 2004 and in 2005. Agencies willing to step up to fill gaps realize that each agency faces the prisoner's dilemma to not contribute or to contribute less than the gage network is worth. Other agencies value the gage data regardless and are willing to increase contributions if possible to prevent data losses.

This repeating scenario, in part, prompted agencies to develop the WV Gaging Council – Council members' existence rely significantly on maintaining a stable and adequate water monitoring network. Founding Council member organizations included the following agencies and organizations: U.S. Geological Survey, U.S. Army Corps of Engineers, National Oceanic and Atmospheric Administration, WV Department of Environmental Protection, WV Division of Natural Resources, WV Conservation Agency, WV Division of Homeland Security and Emergency Management, NOAA, WV Department of Transportation, WV Water Research Institute, West Virginia Rivers Coalition, Michael Baker Corporation, and the Canaan Valley Institute.

While the Council mission and objectives are somewhat broader, Council members collaborate primarily on closing funding gaps for supporting the streamgage and monitoring well networks. The Council indirectly serves to help each agency identify and involve itself with the network funding problem - ideally this would generate greater commitment and reduce the agencies' willingness to free ride[6]. Accordingly, most Council agencies seem to be successful at negotiating among themselves to fill funding gaps.

The separation between gage information users and gage information funders/managers is important at two levels. At the state agency level, contributors have an incentive to step back and let the other agencies manage alone. At the public level, the gage information is valuable to many other public users (academics, engineering firms, the recreation industry, etc.). The Council's interest in public fundraising is intended to address that gap by allowing more direct and indirect users of gage data to help support the network that produces that data.

[6] Free riding is a term from economic game theory that describes scenarios when an agent faces a perverse incentive to not contribute a "fair share" to maintain a jointly used resource (common pool resources) if other actors are likely to continue contributing and providing the good. The danger in this scenario is not that one agent will free ride, but rather that the example creates an unfair scenario, reducing others' interest in contributing.

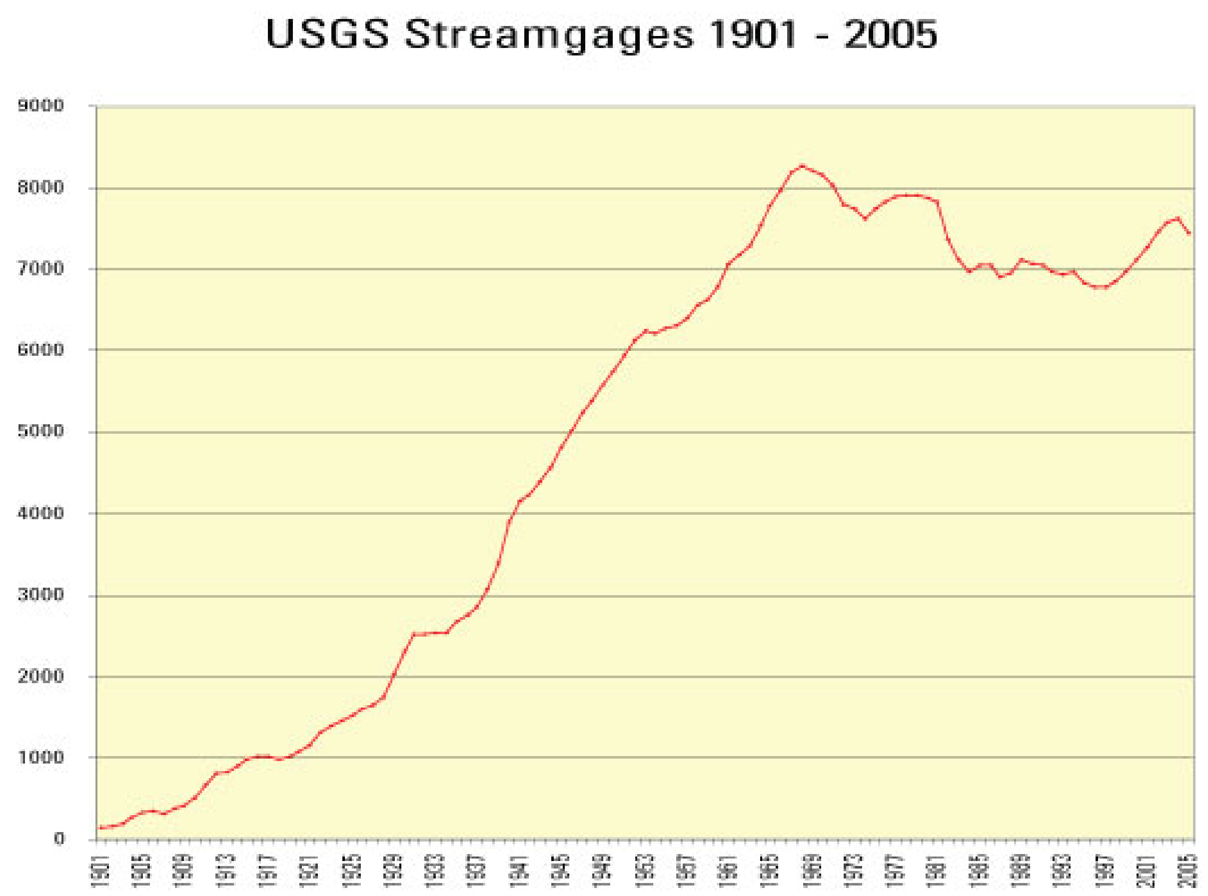

Figure 1 Total streamgages (stage and discharge) managed by USGS from 1901-2005, Source: USGS NSIP.

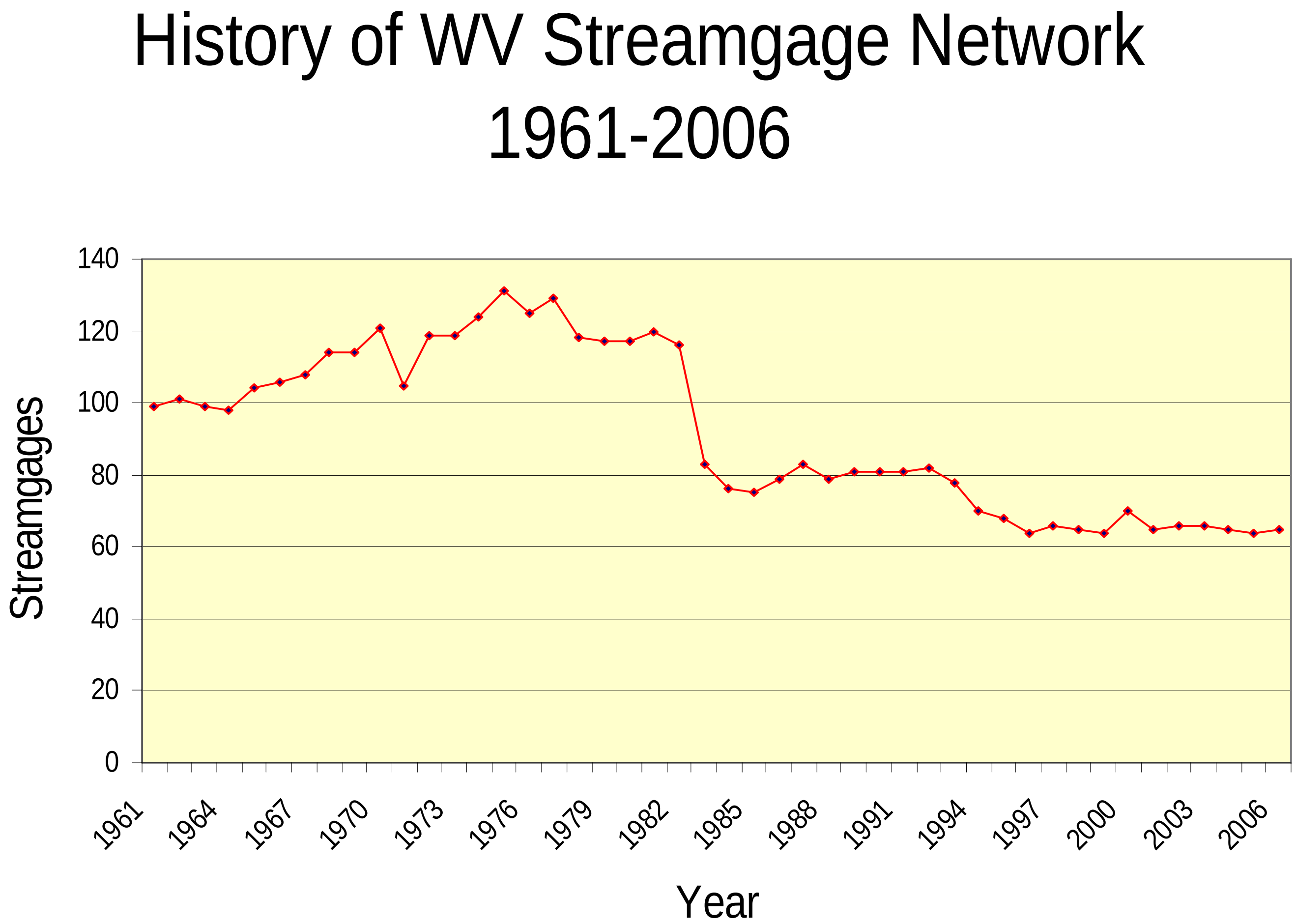

Figure 2 History of WV streamgage network reflects decline in effective data collection capacity. Source: USGS, WV Office.

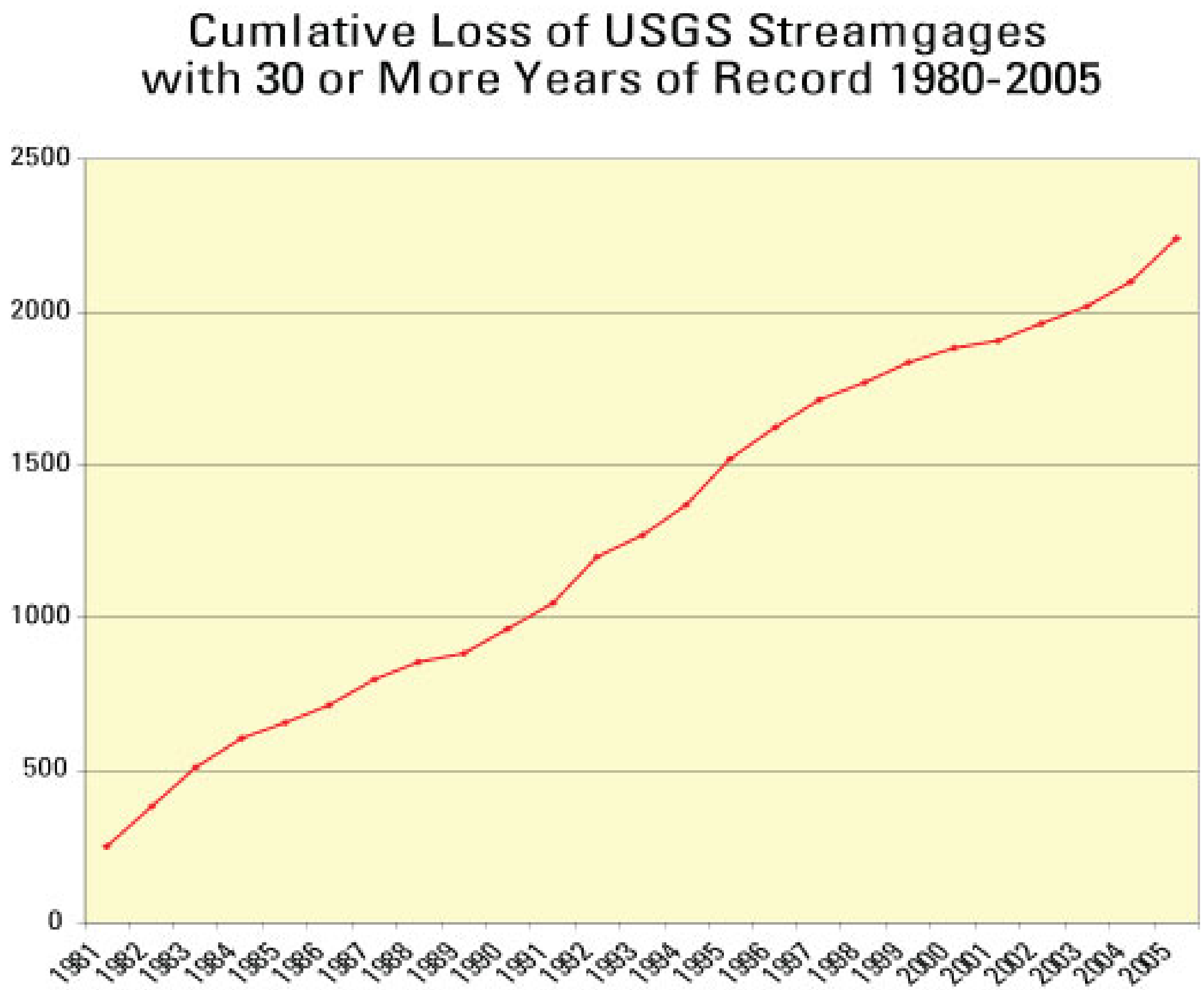

Figure 3 Number of "long record" streamgages (those with 30 years or more of historical data) that have been de-funded and no longer report data for historical trends. Source: USGS NSIP.

Table 2 Taxonomy of WV stream gage data, uses, users, and funding sources

Primary types of gage data	Uses of gage data	Primary users that rely on gage information	Offices that annually coordinate to provide funding, installation, operations, maintenance, and public information sharing services in WV
STREAM			
Real-time stage data (how high the water is currently relative to a fixed benchmark)	> Flood warning systems > Transportation advisories > Recreation	> Governmental and non-governmental emergency flood response agencies > Citizens/Businesses potentially affected by flooding > Citizens/Businesses frequently accessing streams > Recreational users of waters (fishermen, boaters, etc) > Recreation-based service providers	> US Geological Survey (operator/funding agency) > US Army Corps of Engineers (operator/funding agency) > National Weather Service (operator) > WV Office of Homeland Security / Emergency Services (operator/funding agency) > Department of Natural Resources (funding agency) > WV Conservation Agency (funding agency) > WV Department of Transportation (funding agency) > WV Department of Environmental Protection (funding agency) >American Whitewater (funding agency, limited) > Private companies (funding agency, limited)
Historical stage and flow data (realtime data from cleaned and archived over life of the gage which provides stage information as well as flow volume)	> Private, federal, state, and academic research of historical climate, landuse, and water supply trends. > Planning, designing, managing public or private water use systems. > Mapping & managing floodplains. > Designing bridges and roads. > Managing water rights. > Establishing safe pollutant discharge control limits. > Siting and design of mining/energy development projects	> Federal agencies and research institutes > State agencies (DEP, Division of Highways, Department of Natural Resources, etc.) >Engineering firms > WVU/MU and other research institutes	
Water quality data (quality data collected at a stage and flow gage which is usually associated with a specific water use goal and/or pollutant presence/threat)	> Monitoring env conditions and protecting aquatic habitat.	> WVU/MU and other research institutes > DEP/EPA/NPDES permittees > Public water supply providers	

Gaging Council time that has been invested into fundraising among private firms with interests in local water quality has been unsuccessful to date. Promotional fundraising materials have been in the development phase for approximately two years. This is possibly in part due to the absence of a paid staffer for the organization and possibly in part because of the undefined nature of how contributions would be managed. There seem to be a few primary approaches to how private donations might serve the gage network.

1. Donations could support specific gages located in a donor's watershed. This would make them marketable, but would also make data collection at that point subject to the private party's continued charitable contribution.
2. A list of "high priority" gages could be put up for "adoption." High priority could be used to refer to gages that are most critical to the state based on average interagency rating, years in service, gages that are threatened to lose funding, or gages that are most critical for flood warning, etc. "Adoption" could mean that the business funds the gage O&M costs, the average costs, or just the fixed costs of installation and/or a necessary upgrade. This again makes gages more marketable from year to year, but also creates a pattern of unreliable funding flows.
3. Funds could be solicited to provide general operating funds to the Council and/or to the USGS, COE, or other agencies that incur operating costs for gage and gage data management. This option may create a more sustainable flow of funds

Two formidable challenges related to each of these approaches remain. One is the time commitment needed to see them through effectively - identifying potential donors, soliciting funds, and providing the public relations assistance or other follow up needed to retain private donors year after year. Without staff funded to work on this issue specifically, the commitment can quickly become overwhelming. The second challenge is the remaining problem of not being able to secure continuity of the donations year after year and, again, the time commitment associated with trying to.

1.2. Surrounding states

West Virginia's neighboring states have not faced the same challenges in maintaining their long term network stability. This section is a brief description of some of the more interesting elements of neighboring programs that have helped bridge the institutional gaps that have lead to WV gaging losses and shortfalls.

OHIO: The Ohio Water Resources Council (OWRC - http://www.dnr.state.oh.us/owrc/goals.htm) was chartered by the state legislature in 2001 to facilitate interagency cooperation and public private partnerships to help stabilize the state gaging network. As a result, significant cuts made to the network in the 80's have all been recovered and the state tends toward gaining gages rather than cutting them (Mangus, 2007).

Ohio seems to have tackled the tragedy of the commons problem through formal institutional arrangements and informal investment in creating an atmosphere of interagency investment and cooperation. Codified in Ohio Revised Code Section 1521.19 the OWRC is recognized by the state as being a critical public organization that is necessary for the proper management of their water resources. Nine partner agencies and the governor's office make up the council. Each agency is represented by a deputy director with significant decision making authority and the "departments of agriculture, development, environmental protection, health, natural resources, and transportation shall transfer moneys to the fund *in equal amounts* via intrastate transfer voucher"; additional agencies or private organizations may contribute as well but are not mandated to do so. Twenty private and non-profit organizations make up the Council's advisory board including major industrial and environmental stakeholders in the state.

The OWRC convened an interagency gaging prioritization workgroup in 2007. The workgroup provided agencies with a list of gages by basin with their various attributes and the primary uses of the gage data. Agencies then worked together to select a process for allocating each gage points. This process differs from our approach because the participating agencies were asked to come up with common criteria that were important to the state network rather than those specific to their own agency. Their ranking categories included data quality/duration, public safety, environmental concerns, health and economic concerns, and project support. WV USGS has a copy of the OH workgroup tool, or it can be requested from James Mangus, jpmangus@usgs.gov.

MARYLAND: The Maryland Water Monitoring Council has been working to develop an approach to maintaining an efficient state stream-gaging network in Maryland since 1995 (http://mddnr.chesapeakebay.net/MWMC). The 24 Council members come from stakeholder agencies and organizations in the private, non-profit, academic/research, and public sectors. The Council tackles a broad set of water issues through its workgroups and committees including a Data Management Committee, Groundwater Monitoring Workgroup, Monitoring and Assessment Committee, and a Programmatic Coordination Committee. The Council has a paid staff and also funding resources to convene and fund interagency workgroups and studies.

The Council's Stream-Gage Committee convened a workshop in 1997, after losing several gages to funding cuts. The task of the workshop was to investigate the status of stream gaging in Maryland and the issues related to continued operation and needed growth of the current network. The focus was on two specific aspects of stream gaging: "the representativeness of the principal physical characteristics of Maryland watersheds, and an inventory of streamflow data users and their applications." This process included a survey of over 500 streamgage data and a series of workgroup discussion meetings to inform the survey design and final report content which was published three years later (Cleaves & Doheny, 2000). The Maryland process essentially allowed the workgroup staff to prioritize gages for each main gage data use separately first and then examine the overlaps and gaps respectively.

KENTUCKY: While Maryland and Ohio have exemplary scenarios to follow, the political reality of funding for water projects in states with a Great Lake or a Chesapeake Bay asset is not necessarily something that WV can follow. Kentucky is in more of a similar position as WV and is facing some of the same problems. Kentucky convened a Water Gaging Council about a year after the WV Council was established. They also worked with their Water Research Institute to set up a mechanism to accept private funds through the University of Kentucky.

In KY as well, efforts to raise funds from the private sector fizzled and the USGS continues to cobble together funding year to year based on state and local agencies' annual willingness and ability to contribute to the network. In the case of KY, the past couple of years have not posed significant problems, and so the Council is all but dissolved as of 2007 (Griffin, 2007). The new ability of USGS to accept private funds directly as of 2006 further undermined the Council's nascent *raison d'etre*.

1.3. Another alternative: Legislative funding in Georgia

An alternative to the patchwork quilts of state, local and private funding efforts that states have traditionally used is being attempted by Georgia's legislature, which funds the entire gaging network through a line item within the Environmental Protection Division's budget (A J-C, 2006).

The Georgia Water Science Center counts 44 cooperative partners in its WCP. But in Georgia these agencies provide programmatic support and planning input, they are not primarily responsible for funding monitoring gages. The cooperative relationship however, makes it easier for the organizations to organize amongst themselves and mobilize. The Georgia State Legislature tried to cut funding for the state's CWP matching contribution in 2006 – nearly $800,000 for the network and other water monitoring associated costs. This threat made for an easy and effective way for all water data managers and users to coordinate with one another and voice their concerns and express the importance of the network to the public and private sectors and to the environment – the funding was quickly and fully restored to the budget in its final draft (News&Views, 2006).

2. Experimental Methods

This work was conducted in the following four phases: 1) background research about the issues of gage network funding and stability and general Gaging Council survey; 2) development and beta test of gage prioritization tool in Monongahela River Basin; 3) survey of Gaging Council members with revised gage prioritization tool covering entire state; 4) data analysis. The methodology for each is described below.

There are various methodologies used to evaluate stream gage networks and the relative value of individual gaging stations. The two primary and interrelated approaches are 1) statistical analysis to determine the value of the network and individual gages for the purposes of running regional regressions to estimate flow patterns at ungaged sites (e.g.

entropy analysis, generalized least squares) and 2) qualitative evaluation of use, characteristics, and overall value of gages within the network (Markus et al., 2003).

Developing a single statistical analysis would require a narrow definition of the use of or objective for the gage network data. Statistical analyses could be a useful complementary approach used by each individual agency to help them identify the most important gages for their specific agency goals and objectives. A qualitative survey approach, at the interagency level however, helps to find the common ground among agencies for gage network evaluation, allowing each agency to provide input based on their own goals and objectives.

The principles of integrated natural resource management (INRM) contributed to the choice of survey design methodology and the choice to use a survey rather than a model to prioritize stream gages within the network. Integrating survey respondents into the design of the survey is critical to allowing a collective and collaborative design process that removes some of the survey designer-survey participant imbalance. This approach is based on a long history of literature about common-pool resource problem solving among parties with diverse interests, particularly as it applies to natural resource management decision making.

The streamgage network is largely managed by USGS, COE, and the Dept of Homeland Security. Each of these agencies has diverging objectives from the others, and other agencies that contribute to the gage network funding have additional priorities and objectives. This survey approach allowed each agency to determine what gages are priorities for that agency – using their own appropriate model, best guess, political weights, population weights, or combination of these strategies. The outcome of the survey is not meant to be a final answer for which gage should be funded/cut first, but rather the final prioritization worksheet should serve as a departing point on which future *discussions* can be based as funding ebbs and flows affect how many gages can be funded.

2.1. Background Research

Background literature research was conducted according to standard literature review methods. In addition to research of academic literature, a search of agency, non-profit and popular literature was conducted to help identify and understand the nature of the gage funding and prioritization problem. The first introduction of the project to the Gaging Council coincided with the Council's independent initiation of a discussion of developing a tool to prioritize gages among the member agencies; the foundation of this survey tool was based on the design elements provided by that discussion and further refined by survey participants themselves. Interviews were conducted with members of the Gaging Council in small focus groups and on an individual basis to acquire feedback on and refinement of the gaging prioritization tool design. A letter of intent and survey were sent to all Council members describing the intended approach and requesting feedback on the nature of their agencies' use of gage data (Appendix 1).

2.2. Draft Prioritization Tool and Beta Test

Descriptive gage characterization information was developed for each gage within the Monongahela River Basin. This river basin was selected for its diversity of land and water use trends and the variation in population density throughout the basin. A basin map was distributed with gage locations noted over a map layer of streams and major incorporated cities. Information was provided for each gage in two categories – information about the specific gage itself and information about the drainage area that the gage served. These two categories of characteristics are listed below.

Gage station characteristics:

- Gage name
- If stage or discharge data collected
- Water quality equipped
- Temperature equipped
- Telemetry type
- Upgrades recommended by Statewide Flood Plan
- Current O & M agency responsible
- Past years of archived data
- If funding is supplemented by private funds

Drainage area characteristics:

- 8-Digit HUC
- % Drainage that is forested
- % Drainage that is urban
- Drainage area upstream from gage (km^2)
- County served
- County population
- County population density

Three beta testers were selected to fill out and comment on the draft prioritization tool. Each respondent was given a fixed quantity of points to allocate among the listed watershed gages (more points indicating greater need for that gage). An option was provided for the respondent to allocate points to a new/proposed gage if the respondent feels a particular area is under-covered or to allocate points for an upgrade of an existing gage. For each gage, the respondent was asked to also rank gage use by importance.

Methodology for watershed landcover analysis for each gage coverage area can be found in Appendix 2.

2.3. Final Prioritization Tool and Survey

The final tool was revised based on the Beta testing comments. Comments returned indicated that distributing a fixed number of total points for all gages or even by basin was too difficult and we adopted the suggestion that each gage be ranked rather than allocated points; each gage was to be ranked on a scale of 1-4. Each gage was listed for each 8-HUC with gage and area served characteristics; Flood Plan-suggested gages were listed by HUC, but without the gage characterization information. In addition to the information in the Beta survey, gages were listed by Basin and by 8 digit HUC. Additional service area characteristics were figured as follow in red:

About the drainage area:

- 8 Digit HUC
- 10 Digit HUC
- 12 Digit HUC
- % Drainage that is forested, 12 Digit HUC and cumulative drainage
- % Drainage that is urban, 12 Digit HUC and cumulative drainage
- Drainage area upstream from gage (km^2)
- County served
- County population
- County population density
- County population growth rate 1986-2000

Additionally, respondents had the opportunity in the revised survey to rank the state's eight river basins by how well (or deficiently) they were covered by gage sites. Respondents were also asked to suggest areas/streams where new gages should be installed or former gages re-installed/brought back on-line. Finally, respondents were asked to categorize the primary and secondary nature of their agencies' use of gage data. These options were categorized into the following three categories: 1) historical discharge data; 2) historical discharge data and water quality data; 3) realtime stage data only. Within each main category of data type, respondents identified how they used each category of data, e.g. 7Q10 for water quality management, emergency flood management, recreation, etc.

Responses: Council member response rate was quite positive. Seven of the ten active member agencies responded to the survey.[7] Unfortunately, the member agency representing recreation and citizen action and the agency primarily focused on flood hazard mitigation and response are two of the agencies that did not respond. Because they were the only representatives from those categories, the analysis cannot be expected to reflect all interests on the Council without further follow up with missing agencies.

Surveys were sent out to the Gaging Council by the council administrator at the time from the Water Research Institute. A third presentation and question session was conducted at the following two Council meeting (in person and by conference call respectively), a reminder email was re-sent with the survey tool, and phone calls were made to each of the Council member representatives at least once to increase the initially low response rate.

Surveys were not all completed in their entirety or in the same manner possibly due to unclear instructions being and/or time constraints of respondents. This primarily affected

[7] A survey was not filled out on behalf of the WV Water Research Institute by decision, though in hindsight, it seems that WVWRI should have filed a response based on the critical importance of gages to the many WVWRI-affiliated professors and their academic departments.
Throughout the 14 month period of this project, Canaan Valley Institute and the Division of Highways did not attend any Gaging Council meetings and so lack of response on the survey was expected.
Division of Homeland Security and Emergency Management, unfortunately, was the one agency with a very salient stake in the gaging program that did not respond to the survey.

the results of the Basin Prioritization tool was intended to order basins in order from 1 to 8 based on how well they are gaged relative to one another. Some respondents used the 1-8 scale as a rating rather than an ordinal rank. Full results are in Appendix 3.

3. Analysis

Survey analysis was conducted by simply averaging each gage's rankings from all responding agencies. Averages are presented directly. Averages were also to be weighted by basin prioritization rank; however responses were submitted inconsistently in methodology and cannot be used in this manner. The basin prioritization exercise asked each respondent how well they thought each of eight WV river basins were covered by the streamgage network, ranking them in order from best to worst. The results of this simple analysis are compared with the National Streamflow Information Program's selection of critical WV gages which are currently guaranteed federal funding for a permanent set of core streamgages that will be uncompromised by fluctuating funding from state and local partners, allowing state partners to focus on the remaining gages in the network.

4. Results and Discussion

This gage prioritization tool was designed to be a starting point for further interagency streamgage prioritization discussions rather than a final conclusive answer to where investments and/or cuts should be made in the network.

The results of this survey reflect the diversity of perspectives on where investments/cuts should be made. While full results of this survey tool are in Appendix 3, the table below reveals some of the complexities in attempting to make interagency decisions on resource allocation for the gaging network. By the end of the survey it became clearer to the authors and the respondents that some important information was missing. One respondent suggested that the gage characteristics chart also have information regarding the relative 'flooding/drought' problems experienced in the area. Another respondent suggested including the physiographic regions as a layer on the map or a column in the spread sheet.

The average gage station rank was 3.184. Looking at ratings of just the NSIP gages that are prioritized by the federal USGS program, state agencies ranked these gages at an average of 3.476, indicating better agreement among agencies for the core set of NSIP gages. Using average station rank across agencies would be a first step in determining a secondary set of core gages to receive secure state funding annually. As stated earlier, such a list would be preliminary and would then have to be discussed by primary stakeholders.

Table 2 compares the average ratings for gage stations within each basin with the respondents' rank of gage network coverage adequacy (intended to determine which basins are perceived to require the most overall investment and attention relative to where their current network coverage status). It illustrates, perhaps first and foremost, the problems with the perhaps excessive complexity of the survey tool or lack of clarity of instructions. Two agencies did not respond to this portion of the survey and two other agencies of the seven did not order the basins, but rather scored them on a scale of 1-8, resulting in multiple basins receiving the same score. Because we were only looking for order, we averaged the five agencies' responses to this question despite the two approaches reflected.

We expected to find that basins identified as having poor coverage overall (low basin rank), would also have high average ratings for each gage station. This was based on the assumption that if coverage were considered poor in a basin, then every gage in that basin would matter a lot; if existing coverage were considered to be very good, then some gages may be less important than those in critical watersheds. The cells highlighted in this table indicate significant exception to this assumption.

Interestingly, there was significant disparity among agencies regarding how satisfied each was with network coverage of basins. For example, DNR ranked Kanawha Basin as having the worst network coverage (1) while USGS ranked it as 7th best out of 8. Both USGS and DNR ranked the Ohio as having poor network coverage (1 and 2 respectively). And while DNR and WVCA generally agreed on their ranking of the Kanawha's coverage (1 and 2 respectively), they were almost directly opposed on their rank of the Ohio's coverage (2 and 8 respectively).

We expected that in the basins that are judged to be most lacking in gage coverage would also be the basins with higher average gage rate scores. This assumed that if there is insufficient coverage at the start (too few gages), then the gages that were in place would be ranked more consistently as 4's (very important). Those basins judged to have adequate network coverage already would have had lower average gage rankings – more 2s and 3s. The tables below indicate that this expectation was not met.

The following tables show a simple prioritization of gage stations, by basin, based on survey responses. The average rating given to gages by responding agencies for each basin is highlighted and used as a breaking point to offer a definition for "high priority" gages – at least for the purposes of the following tables.

Table 3 Ordering of Basin's Gage Network Coverage Adequacy (1-Worst coverage, 8 - Best coverage) compared with average rate of importance for gages within each basin (1: least important, 4 most important). Basins ranked as having least adequate network coverage (Kanawha, Ohio) did not have gage stations that were, on average, ranked as most important to agencies (4).

	Ordering of Network Coverage Adequacy (1-8) Worst coverage=1; Best coverage=8						
Rank of network coverage adequacy from worst to best	**NWS**	**COE**	**USGS**	**DNR**	**WVCA**	**Basin coverage rank/rate average**	**Average rating of gage stations in each basin**
1. Kanawha	4	8	7	1	2	**4.4**	**3.1**
2. Ohio	8	4	1	2	8	**4.6**	**3.2**
3. Guyandotte	5	8	3	4	4	**4.8**	**3.5**
4. Potomac	7	8	8	3	1	**5.4**	**3.3**
5. Twelvepole	7	6	2	6	7	**5.6**	**3.5**
6. Monongahela	4	8	6	8	3	**5.8**	**3.5**
7. Big Sandy	8	8	4	7	5	**6.4**	**3.1**
8. Little Kanawha	8	8	5	5	6	**6.4**	**3.4**

Table 4 Ranking of basins by Agency and average gage rating by basin.

	NWS		COE		DNR		WVCA	
BASIN	Basin Rank	Ave Gage Rate	Basin Rank	Ave Gage Rate	Basin Rank	Ave Gage Rate	Basin Rank	Ave Gage Rate
1. Kanawha	4	3.2	8	2.6	7	2.7	2	2.9
2. Ohio	8	4.0	4	3.8	1	3.3	8	2.3
3. Guyandotte	5	3.3	8	3.6	3	2.9	4	3.1
4. Potomac	7	3.6	8	2.2	8	3.4	1	3.4
5. Twelvepole	7	3.5	6	3.8	2	3.3	7	3.3
6. Monongahela	4	3.2	8	3.4	6	3. 5	3	3.0
7. Big Sandy	8	3.7	8	2.4	4	1.7	5	2.9
8. Little Kanawha	8	3.6	8	3.0	5	3.7	6	3.4

Table 5 Ohio Basin priority gages

Basin	Gage Name	Ave Rate
Ohio Mainstem	Ohio River at Willow Island Lock & Dam, WV	**3.8**
Wheeling Creek	Wheeling Creek at Elm Grove, WV	**3.7**
Ohio Mainstem	Ohio River at Pike Island Lock & Dam, WV (Lower)	**3.3**
Ohio Mainstem	Ohio River at Point Pleasant, WV	**3.3**
AVE		3.2
Ohio Mainstem	Ohio River at Hannibal Lock & Dam, WV	**3.2**
Ohio Mainstem	Ohio River at Belleville Lock & Dam, WV	**3.2**
Ohio Mainstem	Ohio River at Huntington, WV	**3.2**
Ohio Mainstem	Ohio River at Robert C. Byrd Lock & Dam, WV	**3.2**
Ohio Mainstem	Ohio River at Racine Lock & Dam, WV	**3.0**
Ohio Mainstem	Ohio River at Parkersburg, WV	**3.0**
Wheeling Creek	Kings Creek at Weirton, WV	**2.8**
Ohio Mainstem	Ohio River at Wheeling, WV	**2.8**

Table 6 Potomac Basin priority gages

Basin	Gage Name	Ave Rate
Potomac	South Fork South Branch Potomac River at Brandywine, WV	**3.7**
Potomac	North Fork South Branch Potomac River at Cabins, WV	**3.7**
Potomac	Cacapon River near Great Cacapon, WV	**3.7**
Potomac	Opequon Creek near Martinsburg, WV	**3.7**
Potomac	South Branch Potomac River near Springfield, WV	**3.5**
Potomac	South Branch Potomac River near Moorefield, WV	**3.5**
Potomac	South Fork South Branch Potomac River near Moorefield, WV	**3.5**
Potomac	South Branch Potomac River near Petersburg, WV	**3.5**
Potomac	South Branch Potomac River at Franklin, WV	**3.5**
Potomac	Shenandoah River at Millville, WV	**3.5**
AVE RATE		3.3
Potomac	Patterson Creek near Headsville, WV	**3.2**
Potomac	Stony River near Mount Storm, WV	**3.0**
Potomac	North Branch Potomac River at Barnum, WV	**2.8**
Potomac	Potomac River at Paw Paw, WV	**2.8**
Potomac	Potomac River at Shepherdstown, WV	**2.8**
Potomac	Waites Run near Wardensville, WV	**2.7**
Potomac	Potomac River at Harpers Ferry, WV	**2.5**

Table 7 Guyandotte Basin priorities

Basin	Gage Name	Ave Rate
Guyandotte	Guyandotte River at Logan, WV	**3.8**
Guyandotte	Guyandotte River at Branchland, WV	**3.8**
Guyandotte	Guyandotte River at Man, WV	**3.7**
Guyandotte	Guyandotte River below R.D. Bailey Dam, WV	**3.7**
AVE		3.5
Guyandotte	Guyandotte River near Baileysville, WV	**3.2**
Guyandotte	Guyandotte River at Pineville, WV	**3.2**
Guyandotte	Clear Fork at Clear Fork, WV	**3.0**

Table 8 Big Sandy Basin priorities

Basin	Gage Name	Ave Rate
Big Sandy	Tug Fork at Matewan, WV	**3.7**
Big Sandy	Tug Fork at Williamson, WV	**3.3**
Big Sandy	Tug Fork at Kermit, WV	**3.2**
Big Sandy	Tug Fork at Welch, WV	**3.2**
AVE		3.1
Big Sandy	Tug Fork at Litwar, WV	**3.0**
Big Sandy	Dry Fork at Beartown, WV (Bradshaw)	**3.0**
Big Sandy	Panther Creek near Panther, WV	**2.3**

Table 9 Little Kanawha Basin priorities

Basin	Gage Name	Ave Rate
Little Kanawha	Little Kanawha River at Palestine, WV (Elizabeth)	**4.0**
Little Kanawha	Little Kanawha River at Glenville, WV	**3.7**
Little Kanawha	Little Kanawha River at Burnsville, WV	**3.7**
Little Kanawha	Little Kanawha River near Wildcat, WV	**3.5**
AVE		3.4
Little Kanawha	Little Kanawha River at Grantsville, WV	**3.3**
Little Kanawha	West Fork Little Kanawha River at Rocksdale, WV	**3.2**
Little Kanawha	West Fork Little Kanawha River at Creston, WV	**2.5**

Table 10 Twelvepole Basin priorities

Basin	Gage Name	Ave Rate
Twelvepole	Twelvepole Creek below Wayne, WV	**3.8**
Twelvepole	East Fork Twelvepole Creek below East Lynn Dam, WV	**3.7**
Twelvepole	East Fork Twelvepole Creek near Dunlow, WV	**3.5**
AVE		3.5
Twelvepole	Beech Fork below Beech Fork Dam, WV	**3.0**

Table 11 Monongahela Basin prioritization

Basin	Gage Name	Ave Rate
Monongahela	Cheat River at Highway 50 near Rowlesburg, WV	**4.0**
Monongahela	Dry Fork at Hendricks, WV	**4.0**
Monongahela	Tygart Valley River near Dailey, WV	**4.0**
Monongahela	Blackwater River at Davis, WV	**3.8**
Monongahela	Buckhannon River at Alton, WV	**3.8**
Monongahela	Cheat River near Parsons, WV	**3.8**
Monongahela	Middle Fork River at Audra, WV	**3.8**
Monongahela	Shavers Fork below Bowden, WV	**3.8**
Monongahela	Tygart Valley River at Belington, WV	**3.8**
Monongahela	Tygart Valley River at Philippi, WV	**3.8**
Monongahela	West Fork River at Weston, WV	**3.8**
Monongahela	Buckhannon River at Buckhannon, WV	**3.7**
Monongahela	Buckhannon River at Hall, WV	**3.7**
Monongahela	Blackwater River near Davis, WV	**3.5**
Monongahela	Cheat River at Albright, WV	**3.5**
Monongahela	Cheat River below Lake Lynn Dam, WV	**3.5**
Monongahela	Dry Fork at Gladwin, WV	**3.5**
Monongahela	Dry Fork at Job, WV	**3.5**
Monongahela	Middle Fork River at Ellamore, WV	**3.5**
Monongahela	Shavers Fork near Cheat Bridge, WV	**3.5**
Monongahela	Three Fork Creek near Grafton, WV	**3.5**
Monongahela	Tygart Lake Outflow near Grafton, WV	**3.5**
Monongahela	Tygart Valley River at Valley Head, WV	**3.5**
Monongahela	West Fork River at Butcherville, WV	**3.5**
Monongahela	West Fork River at Enterprise, WV	**3.5**
Monongahela	West Fork River below Stonewall Jackson Dam, WV	**3.5**
AVE		3.5
Monongahela	Big Sandy Creek at Rockville, WV	**3.3**
Monongahela	West Fork River at Walkersville, WV	**3.3**
Monongahela	West Fork River near Mount Clare, WV (Clarksburg)	**3.3**
Monongahela	Buffalo Creek at Barrackville, WV	**3.2**
Monongahela	Deckers Creek at Morgantown, WV	**3.2**
Monongahela	Monongahela River at Morgantown Lock & Dam, WV	**3.2**
Monongahela	Shavers Fork at Bemis, WV	**3.2**
Monongahela	Tygart Valley River at Colfax, WV	**3.2**
Monongahela	Middle Fork River at Adolph, WV	**3.0**
Monongahela	Tygart Valley River near Elkins, WV	**3.0**
Monongahela	Tygart Valley River at Millcreek	**2.8**
Monongahela	Sand Run near Buckhannon, WV	**2.7**
Monongahela	Glady Fork at Evenwood, WV	**2.5**

Table 12 Kanawha Basin prioritization

Basin	Gage Name	Ave Rate
Kanawha	Elk River at Queen Shoals, WV	**4.0**
Kanawha	Greenbrier River at Hilldale, WV	**3.8**
Kanawha	New River at Hinton, WV	**3.8**
Kanawha	Elk River below Sutton Dam, WV	**3.8**
Kanawha	Bluestone River near Pipestem, WV	**3.7**
Kanawha	Greenbrier River at Buckeye, WV	**3.7**
Kanawha	Gauley River above Belva, WV	**3.7**
Kanawha	Gauley River below Summersville Dam, WV	**3.7**
Kanawha	Gauley River nearr Craigsville, WV	**3.7**
Kanawha	Kanawha River at Kanawha Falls, WV	**3.7**
Kanawha	Elk River below Webster Springs	**3.7**
Kanawha	Kanawha River at Lock 6 at Charleston, WV	**3.7**
Kanawha	Elk River at Clay, WV	**3.5**
Kanawha	Coal River at Tornado, WV	**3.5**
Kanawha	Cranberry River near Richwood, WV	**3.3**
Kanawha	Kanawha River at London Lock & Dam, WV	**3.3**
Kanawha	Elk River near Frametown, WV	**3.3**
Kanawha	Greenbrier River at Alderson, WV	**3.2**
Kanawha	New River at Thurmond, WV	**3.2**
Kanawha	Meadow River near Mount Lookout, WV	**3.2**
Kanawha	Williams River at Dyer, WV	**3.2**
Kanawha	Kanawha River at Marmet Lock & Dam, WV	**3.2**
Kanawha	Big Coal River at Ashford, WV	**3.2**
AVE		3.1
Kanawha	Gauley River at Camden-on-Gauley, WV	**3.0**
Kanawha	Clear Fork at Whitesville, WV	**3.0**
Kanawha	Greenbrier River at Renick, WV	**2.8**
Kanawha	Greenbrier River at Durbin, WV	**2.8**
Kanawha	New River below Hawks Nest Dam, WV (The Drys)	**2.8**
Kanawha	Kanawha River at Southside Bridge at Charleston, WV	**2.8**
Kanawha	Greenbrier River at Caldwell, WV	**2.7**
Kanawha	Piney Creek at Raleigh, WV	**2.7**
Kanawha	Knapp Creek at Minnehaha Springs, WV	**2.5**
Kanawha	Right Fork Holly River at Gurdian	**2.5**
Kanawha	Left Fork Holly River near Replete, WV	**2.5**
Kanawha	Fourpole Creek near Huntington	**2.5**
Kanawha	Hurricane Creek at Hurricane, WV	**2.5**
Kanawha	Greenbrier River at Ronceverte, WV	**2.3**
Kanawha	Greenbrier River at Clover Lick, WV	**2.3**
Kanawha	Peters Creek at Lockwood, WV	**2.3**
Kanawha	Kanawha River at Railroad Bridge at Charleston, WV	**2.3**
Kanawha	Anthony Creek at Blue Bend, WV	**2.0**

5. Conclusions & recommendations

West Virginia does not border the great lakes or the Chesapeake Bay, so state funding is more challenging to secure in any scenario or under any institutional design, but its contribution to the Ohio River and Bay drainage are not insignificant. Furthermore, though the significance may not be as apparent to the public eye as other such large water bodies that affect multiple economic sectors of interstate regions, WV's water resources are equally critical to our state's short and long term economic stability and the vitality of its character as the Chesapeake Bay is to Maryland's economy. As WV's leadership angles the state to focus on energy production and to promote our state as one with abundant natural resources to serve its own citizens *and* the many major population centers that lie within a day's travel of the state, understanding our resources – monitoring and predicting resource patterns - is critical. These goals are impossible to achieve sustainably or responsibly for the benefit of future citizens of the state without building plans on a foundation of reliable water resource monitoring data.

West Virginia's stream gaging network has been in steady decline over the past twenty years. In 1975, WV had 131 streamgages. Funding cuts in 1983 and again in 1994 resulted in two compounding sharp drops in the number of gaging stations collecting continuous data on the state's water resource trends. Cuts continued through 2007 costing the state in lost analytical and management capacity, as well as time lost while agencies are forced to patchwork together stopgap agreements each year.

This report recommends that members of the West Virginia Gaging Council and other key stakeholders work with local, county, state, federal, academic, and non-governmental stakeholder agencies to identify a core set of streamflow gages that are *de minimus* necessary for accurately characterizing West Virginia's streamflow resources and for evaluating regional hydrologic conditions *over time* as well as hydrologic responses of streams to geological, physiographical, and land-use change, and to climate variability (gages that are priority to WV, above and beyond the NSIP gages in WV that are already guaranteed federal funding). This effort may want to use the results in this study as an initial foundation for discussion. Alternatively, the tool produced for this study may be used with the suggested revisions and additional feedback from other respondents.

It is recommended that the cost of upgrading and maintaining this core WV network be guaranteed adequate state budget funding annually in coordination with the USGS Cooperative Partnership program. Funding flexibility should be available for the additional gages which are needed temporarily. One option would be that the funds go directly to the WV Conservation Agency or to WVDEP or another state agency directly and then be transferred to the USGS or other monitoring programs.

It is recommended that the Gaging Council continue to convene to carry out the other purposes listed in its mission even past an immediate funding crisis. These meetings reduce some of the pressure on USGS to maintain multiple bilateral relationships by facilitating a network of communications among agencies with a shared interest in water resource management – despite the variation in specific uses.

Finally, while we were unable to acquire a draft of formal documents describing the partnership between Georgia's Environmental Protection Division and its USGS Water Science Center in time for this report, it is recommended that follow up steps be taken to learn more about how various states are guaranteeing funding through legislative budget allocations. This institutional funding arrangement realigns interests among tax paying stakeholders and public agencies that are otherwise funded by the public to provide services to the public so that they are benefited by cooperating with one another rather than annually facing costly divisions over budget cuts and allocations and shell games.

Documents that arrive to the WV Water Research Institute regarding additional state programs will be shared with the WV Gaging Council via email (namely information on funding programs in Georgia and Michigan). A copy of the Ohio and WV gaging network prioritization tools are available upon request.

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7. Student support, Notable achievements or awards.

One graduate student in WVU's Fisheries and Wildlife program contributed to the mapping and data collection efforts used to develop the gage prioritization tool.

Appendix 1 – Letter of Intent to Gaging Council and Preliminary Questionnaire

MEMORANDUM

To: West Virginia Water Gaging Council Members

From: Alyse Schrecongost, Program Coordinator

Date: May 15, 2006

Re: Preliminary survey about your agency's use of stream monitoring data in West Virginia.

In an attempt to fulfill requirements of the West Virginia Water Resource Protection Act 2004, a proposal, *Systematic Determination of Water Resource Data and Information Management Needs in West Virginia*, was developed by West Virginia Water Research Institute personnel and submitted to USGS to address the following problems:

1. Insufficient and unevenly distributed water resource monitoring data to support effective water resource assessment and management.
2. Inaccessibility of existing data stemming from the diversity of agencies and methods used to collect, store, and analyze water resource data and information.

The results of this project will include: 1) a statewide evaluation of existing water quantity and quality monitoring data sources; and 2) a participatory and credible, interagency spatial analysis of critical monitoring data gaps prioritized by importance to state agencies and other principal users. The final project report will supplement the West Virginia Department of Environmental Protection Water Resource Protection Act final report submitted to the West Virginia Legislature in December of 2006 as part of an on-going comprehensive effort to evaluate state water resource balances.

In order to fulfill not only the obligations to the USGS and the State, but to address needs raised by the West Virginia Water Gaging Council, we have developed a preliminary survey intended to learn more about your use of stream monitoring data in West Virginia. This enclosed survey is intended to be used to develop a system for monitoring gage and well prioritization. This survey will help us develop a tool for quantitatively identifying gaging investment priorities (approach outlined below). We are interested both in your survey feedback and your feedback on our planned approaches to developing a system for gage prioritization. A separate approach will be developed for well prioritization after the stream gage phase is underway.

Prioritization Approach Outline:

1. Survey Gaging Council members and select other relevant stakeholder organizations and agencies with open-ended survey tool developed by Liz Garland (Attachment 1; hypothetical responses Attachment 2) to determine general uses of gage and well data. ***Please complete this step by June 1. Comments on prioritization strategy welcome at this time as well.***

2. This qualitative survey information will be collected and used to inform a final report and to inform the field selection for a quantitative survey instrument that will allow agency representatives prioritize gage data needs.

3. Descriptive gage characterization sheets will be developed for each gage (on-line and off-line gages) within two adjacent demonstration 8-Digit HUC watersheds (see preliminary list characterization fields in Excel WS 1, Attachment 3). A watershed map will be distributed with gage locations noted over a map layer of streams and incorporated cities. ***Suggestions for trial watersheds welcome by June 1.***

4. A trial quantitative survey will be conducted among Council members to prioritize gage investments within the trial watershed. Each respondent will be given a fixed quantity of points to allocate among watershed gages. An option will be provided for the respondent to allocate points to a new/proposed gage if the respondent feels a particular area is under-covered or to allocate points for an upgrade of an existing gage. For each existing or proposed gage, the respondent will be asked to also rank gage use by importance (see model survey in Excel WS 2, Attachment 4). ***Suggestions on how to rank investment on upgrades as opposed to installing basic gages welcome.***

5. For trial survey, respondents will also be asked to critique survey instrument design and offer suggestions for revisions.

6. Survey results will be aggregated and gages will be mapped with a progressive color scale to indicate resulting priorities (with a specific legend value). Proposed gages will also be mapped and addressed in a discussion section of an interim report.

7. Critiques and suggestions will be addressed in Council meetings. Council members will comment on whether prioritizations should be conducted by watershed or at a state level. Additional stakeholders will be identified to participate in survey. Final survey will be conducted, analyzed, and will inform a final report.

Thank you in advance for taking the time to review the enclosed documents and to provide responses to the initial survey (Attachment 1). I will be at the June 1, 2006 meeting of the Gaging Council and can address any questions you may have at that time. However, if you wish to contact me before then, feel free to call me at 304-293-2867 x5418 or email me at amschrecongost@mail.wvu.edu. I look forward to discussing this further with you on June 1.

Please respond to the following questions. For reference, see hypothetical example of responses for the US Army Corps (Attachment 2).

What type of user do you represent/serve?

What is your interest in gage or gage data?

What is the geographic scope of your need (location characteristics)?

Do you need real time data, historical data, recent historical data, etc?

What is the most ideal format for gage data for your use?

What parameters are most important to you?

Please let us know if you would like an electronic copy of this information.
Please return responses to:

Alyse Schrecongost
West Virginia Water Research Institute
150 Evansdale Drive
PO Box 6064
Morgantown, WV 26501
304.293.2867 x5418
amschrecongost@mail.wvu.edu

Appendix 2 - Watershed land cover analysis methodology

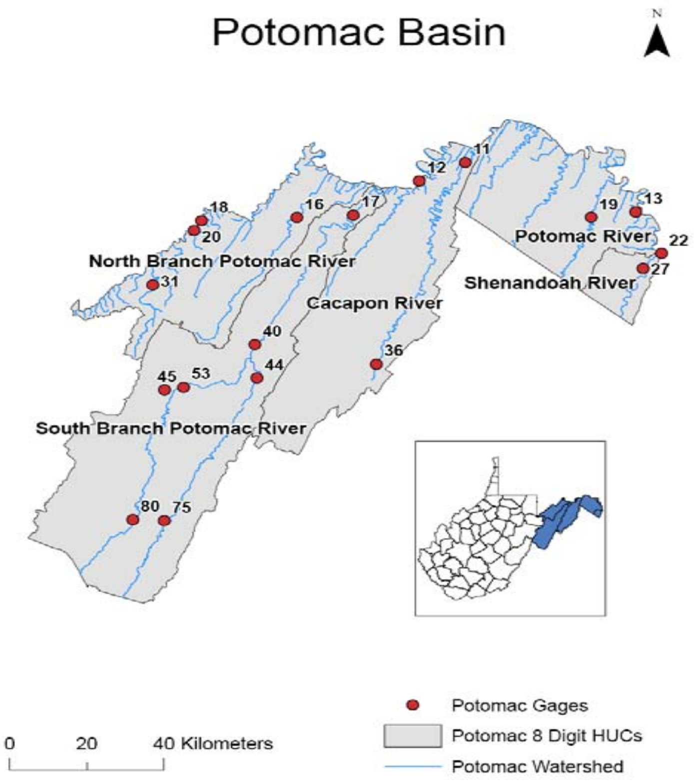
Watershed land cover attributes were calculated for each stream gage using West Virginia Gap Analysis (WV-GAP) land classification data (Yuill et al. 2000). The WV-GAP source data were acquired from multiple 30-meter Landsat imagery obtained from 1992-1994 and field checked with videography. The raster representation of this data includes cell counts for 25 land cover types across the state.

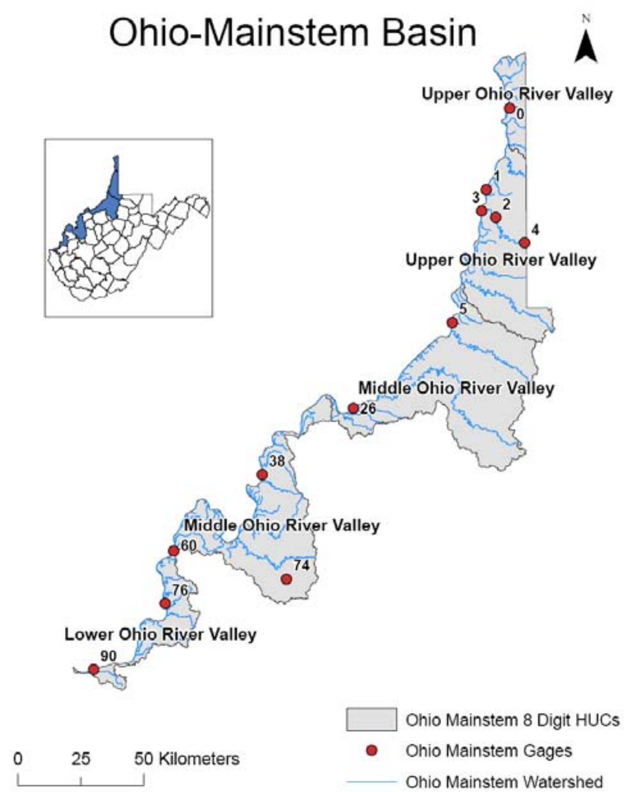
Using the Spatial Analyst function in ArcMap (ESRI 2005), a new raster dataset was created in which the 25 land cover types were reclassified into two types: forested and nonforested. The "forested" classification included the following land cover types: woodland, conifer plantation, floodplain forest, forested wetland, cove hardwood forest, diverse/mesophytic hardwood forest, hardwood/conifer forest, oak dominant forest, mountain hardwood forest, mountain hardwood/conifer forest, and mountain conifer forest. Forested cells in the raster were given a value of one, while the nonforested cells were assigned a value of zero. This reclassification process was then repeated for urban and nonurban land cover types. The "urban" classification included light intensity urban, moderate intensity urban, and intensive urban land cover types.

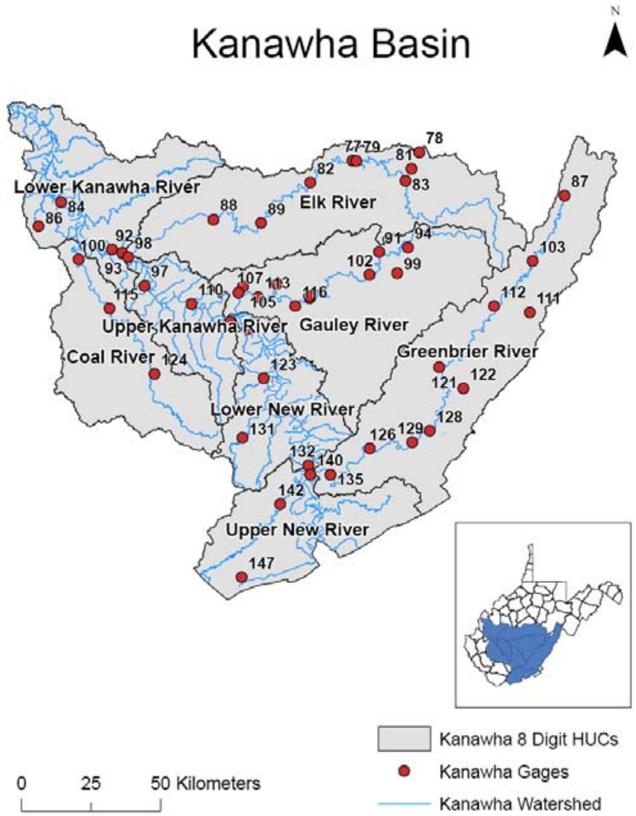
Using the zonal statistics feature of Spatial Analyst, the sum of the forested/urban cells as well as a total cell count was calculated for each 12-digit Hydrologic Unit Code (HUC) watershed. The result was a count of the total number of cells, the total number of forested cells, and the total number of urban cells for each 12-digit watershed in the state. Land cover values for each 12-digit watershed were then accumulated in a downstream direction using the Twelve Digit Hydrologic Unit Code Accumulator Program (Strager and Strager 2006) in ArcView 3.3 (ESRI 2002). In 12-digit watersheds that contained stream gages, the cumulative sum of the forested and urban cells were each divided by the total cumulative cell count for the watershed and multiplied by 100 to determine the cumulative percent of the gage watershed that was classified as forested or urban.

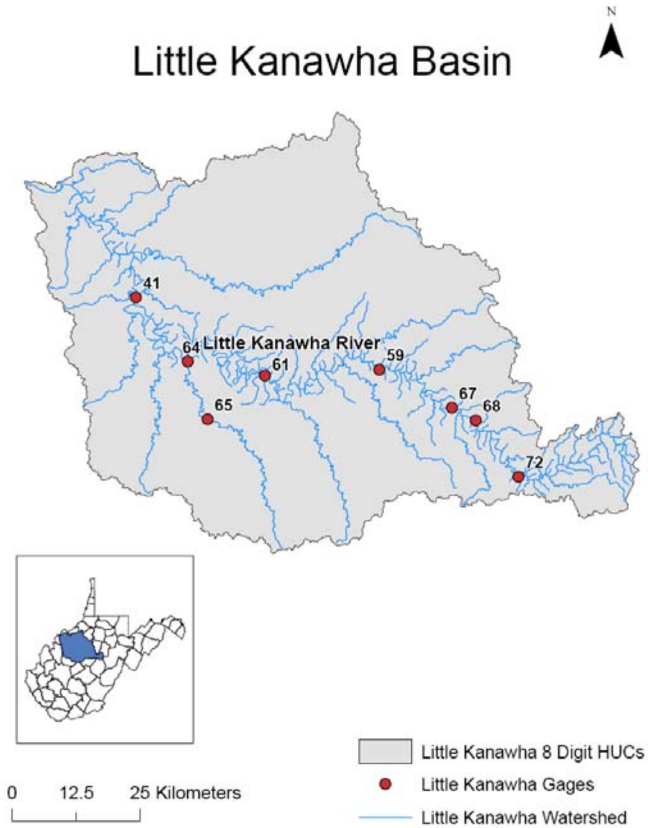
This watershed accumulation process allows for the examination of watershed processes at multiple scales (Strager et al. *In Review*). Streams can be impacted by local (within a 12-digit HUC) influences as well as watershed scale (cumulative 12-digit HUC) factors. As an alternative to static watershed delineations, the accumulation of small sub-watersheds provides information on both local and watershed scale influences.

Appendix 3 – River basin maps of streamgages rated






Kanawha Basin
N
Lower Kanawha River
Elk River
Upper Kanawha River
Gauley River
Coal River
Greenbrier River
Lower New River
Upper New River
Kanawha 8 Digit HUCs
Kanawha Gages
Kanawha Watershed
0 25 50 Kilometers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Little Kanawha River
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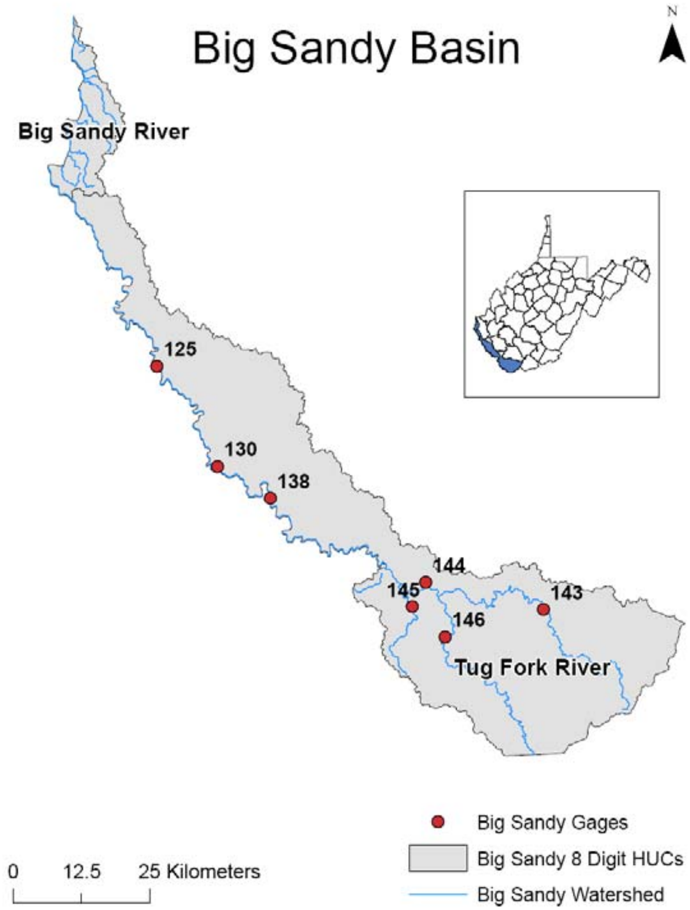
Little Kanawha Gages
Little Kanawha Watershed
0 12.5 25 Kilometers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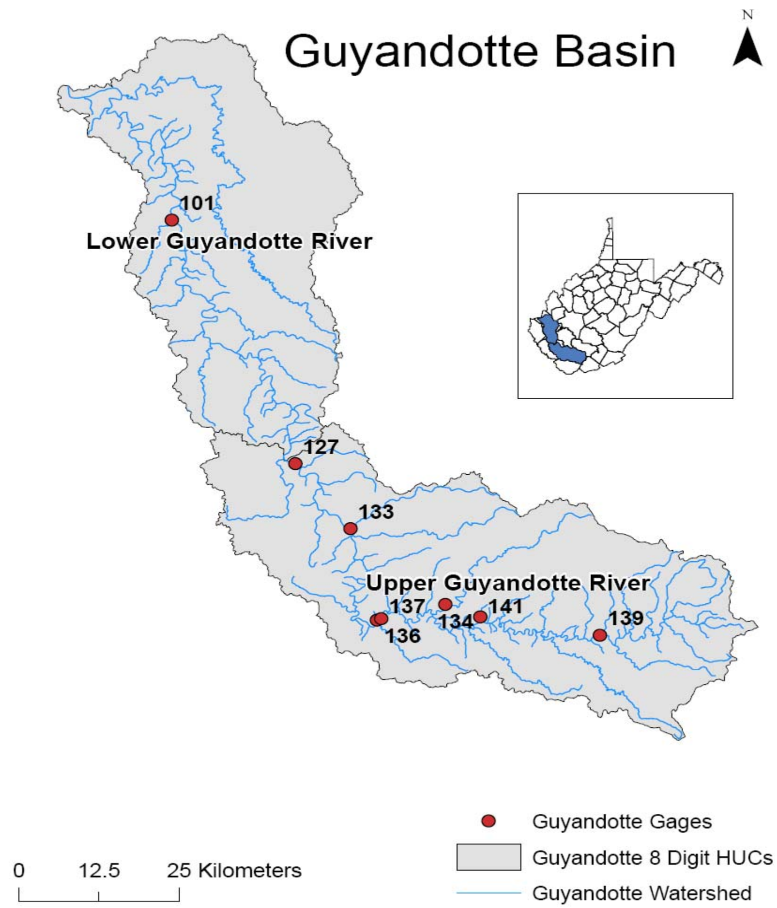
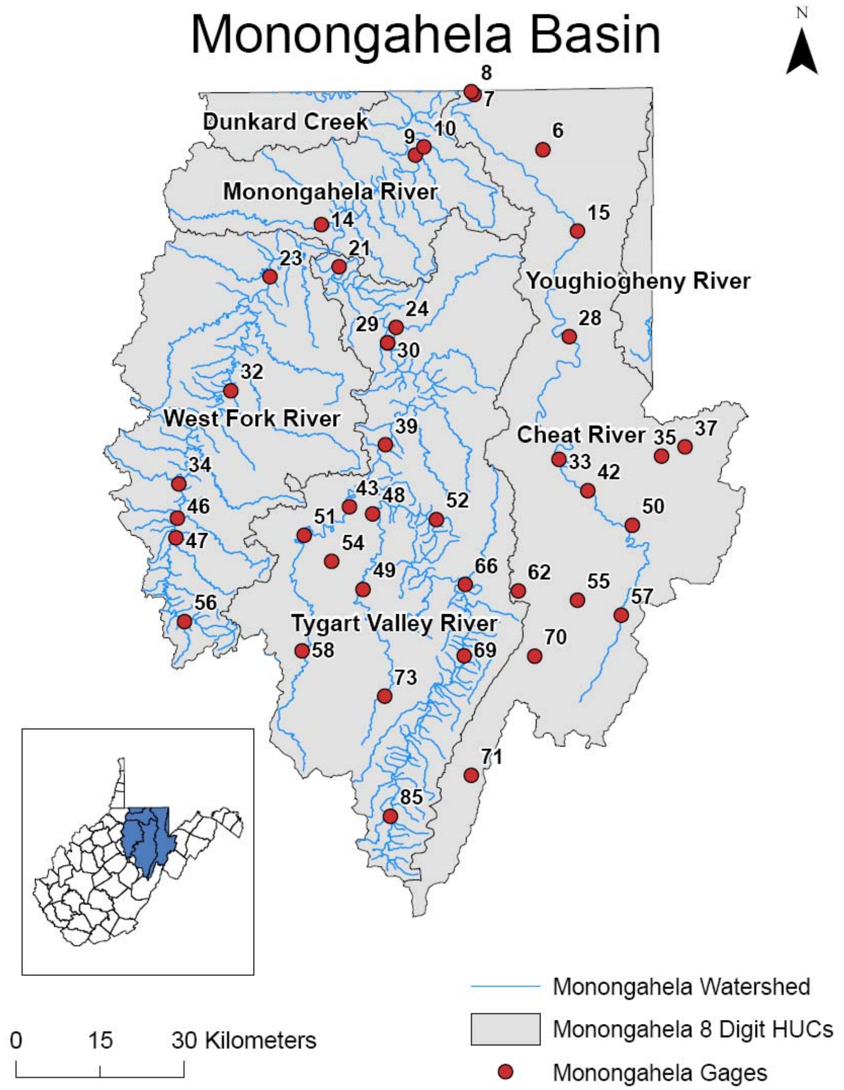
Big Sandy River
125
130
138
144
145
143
146
Tug Fork River
Big Sandy Gages
Big Sandy 8 Digit HUCs
Big Sandy Watershed
0
12.5
25 Kilometers


Guyandotte Basin
N
101
Lower Guyandotte River
127
133
Upper Guyandotte River
137
136
134
141
139
Guyandotte Gages
Guyandotte 8 Digit HUCs
Guyandotte Watershed
0
12.5
25 Kilometers


Monongahela Basin
N
Dunkard Creek
Monongahela River
Youghiogheny River
West Fork River
Cheat River
Tygart Valley River
8
7
9
10
6
14
15
21
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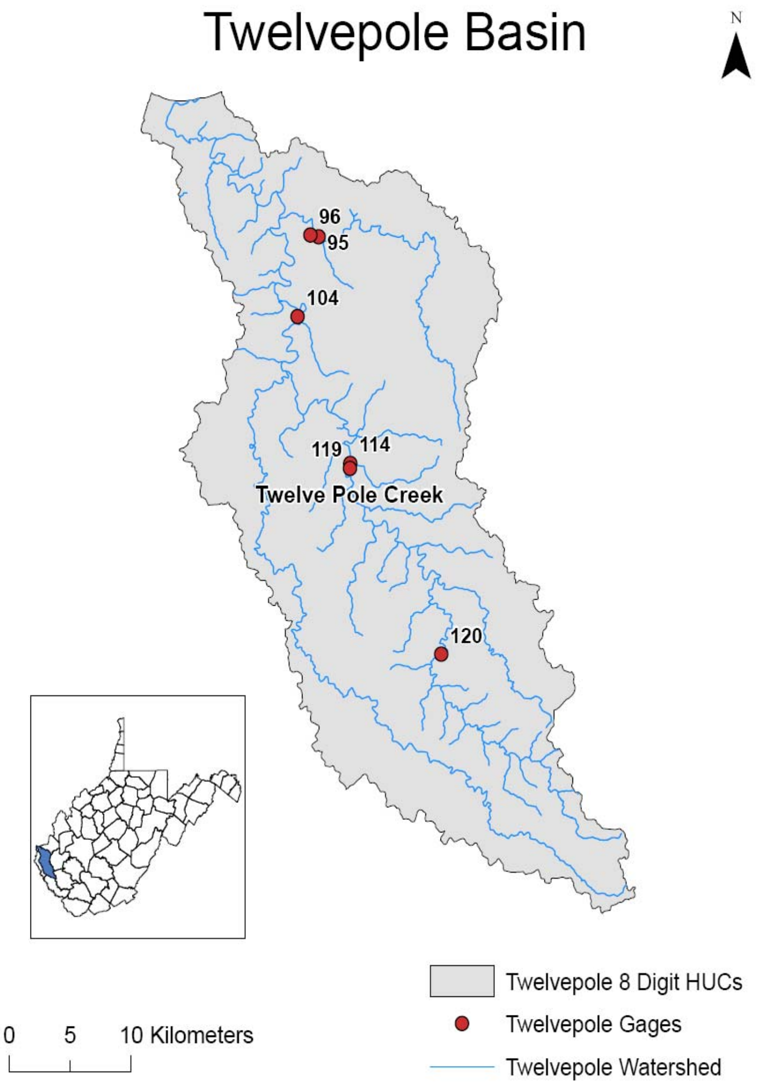
85
0 15 30 Kilometers
Monongahela Watershed
Monongahela 8 Digit HUCs
Monongahela Gages


Twelvepole Basin
N
96
95
104
119
114
Twelve Pole Creek
120
0 5 10 Kilometers
Twelvepole 8 Digit HUCs
Twelvepole Gages
Twelvepole Watershed

Chloride Sorption to Acid Mine Drainage Solids (WRI-84)

Basic Information

Title:	Chloride Sorption to Acid Mine Drainage Solids (WRI-84)
Project Number:	2006WV81B
Start Date:	3/1/2006
End Date:	2/28/2008
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Water Quality, Treatment, Surface Water
Descriptors:	
Principal Investigators:	Louis M McDonald, Paul Ziemkiewicz

Publication

Final Report: Chloride Sorption to Acid Mine Drainage Solids

Project Number: 2006WV81B

Louis M. McDonald

Division of Plant & Soil Sciences

West Virginia University

Introduction

Reports suggest that chloride concentrations are increasing in mine water and surface waters affected by mining operations. Chloride concentrations above the in-stream limit of 250 mg L^{-1} would require treatment, but chloride is a particularly difficult ion to remove from aqueous solution. The results of this project would be of interest to the State Department of Environmental Protection, Coal Operators and others interested in meeting existing and emerging water quality standards.

Stated Nature, Scope and Objectives

Because of the need to control experimental conditions, all experiments will be conducted in the laboratory using fully characterized solutions and solids. Chloride and sulfate sorption to AMD solids will be characterized using competitive sorption isotherms. Experimental conditions will span the range of anticipated field conditions. The objectives are 1) to quantify chloride sorption to AMD solids as a function of sulfate concentration, pH, and the absence and presence of the specifically sorbing cation Mn^{2+}. Aluminum will be included because it often occurs in AMD. 2) To determine the extent to which chloride is part of the occluded water in AMD precipitates.

Actual Nature, Scope and Objectives

An earlier WVWRI had suggested that chloride could be removed from AMD by sorption to precipitating solids. However, before proceeding to the full experiments described above, preliminary experiments were conducted to confirm these results.

Materials and Methods

One liter of each experimental solution was prepared as shown in Table 1. Iron was added as $Fe(NO_3)_3$, sulfate as $Na_2(SO_4)$, chloride as NaCl. Sodium nitrate ($NaNO_3$) was added as an indifferent electrolyte to control ionic strength. The remaining solution was adjusted to approximately pH 2 and then titrated to pH 10 with NaOH in nine increments using an Accumet pH meter (Model No. 15, Fisher Scientific, Pittsburgh, PA) and a Ross Sure-Flow combination electrode (Fisher Scientific, Pittsburgh, PA). At each pH increment, visible absorbance at 450 nm was determined with a fiber-optic dip probe attached to a spectrophotomer (Cary 50 UV-Vis, Varian Inc., Palo Alto, CA) to determine the onset of precipitation. Chloride activity was determined at each titration point using a chloride specific electrode (Accumet, Fisher Scientific, Pittsburgh, PA). Maximum chloride removal was calculated by difference and assuming that all initial iron in solution precipitated.

Table 1. Ion concentrations and ionic strength for each experimental solution.

Solution	Iron (III)	Chloride	Sulfate	Nitrate	Sodium	Ionic Strength
		---------------------- mM ----------------------				------- M -------
A	10	1.7	10	30	21.7	0.047
B	10	1.7	0	60	31.7	0.047
C	10	1.7	20	30	41.7	0.077
D	10	1.7	0	90	61.7	0.077

Results

For all solutions precipitation was essentially complete by pH 3 (data not shown). When comparing solution A to B and Solution C to D (Table 2), it is apparent that the presence of sulfate in solution depressed chloride removal. The average maximum amount of chloride removed from solution, under these experimental conditions was 0.046 mg per gram Fe(III) precipitated.

Table 2. Maximum chloride removed at constant ionic strength.

Solution	I	Sulfate	Chloride Removed
		------- mM -------	-----mg Cl/g Fe -----
A	0.047	0	0.044
B	0.047	10	0.038
C	0.77	0	0.060
D	0.77	20	0.040

Conclusions

A second year of funding to investigate AMD flocs as a removal technology for chloride was not requested. In our preliminary work with iron-sulfate flocs, using a chloride selective electrode for chloride determinations, the average chloride removal was 0.046 mg chloride per g iron precipitated, an amount considered too low for a practical treatment technology. In addition chloride removal was strongly inhibited by the presence of sulfate.

Information Transfer Program

West Virginia Water Conference 2006

Basic Information

Title:	West Virginia Water Conference 2006
Project Number:	2006WV75B
Start Date:	3/1/2006
End Date:	1/1/2007
Funding Source:	104B
Congressional District:	WV 1st
Research Category:	Not Applicable
Focus Category:	Water Quantity, Water Use, Water Quality
Descriptors:	None
Principal Investigators:	Tamara Vandivort

Publication

State:	WV
Project Number:	WRI-79
Title:	West Virginia Water Conference 2006
Project Type:	Information Transfer
Focus Category:	Water Quantity, Water Quality, Water Use
Keywords:	Water, Conference, Policy, Research, Education, Economics
Start Date:	3/1/06
End Date:	2/28/07
Congressional District:	WV 1st
PI:	Tamara Vandivort Email: tvandivo@wvu.edu
Co-PI's:	None

Goal

The ultimate goal of this conference was to encourage discussions and networking amongst West Virginia's water resources stakeholders to work towards ways to ensure protection and quality of the State's water resources.

Methods, Procedures, Facilities

The West Virginia Water Research Institute served as lead for the conference. The WV Department of Health & Human Services and the National Environmental Education & Technology Center co-sponsored the event. The West Virginia Advisory Committee for Water Resources assisted with conference planning, identifying a theme, topics, and agenda development.

Conference Planning Committee

This committee was comprised of members of the West Virginia Advisory Committee for Water Resources. Committee members are comprised of individuals from the following organizations:

- WV Department of Environmental Protection
- U.S. Geological Survey
- WV Chamber of Commerce
- WV Coal Association
- U.S. Environmental Protection Agency
- U.S. Department of Energy - National Energy Technology Laboratory
- U.S. Army Corps of Engineers
- WV Division of Natural Resources
- WV Department of Health & Human Services
- Federal Bureau of Investigation
- WV Farm Bureau
- West Virginia University

Communications included physical meetings, conference calls, and email. This group worked together to achieve the following:

- Developed a theme
- Created an agenda
- Selected a location
- Selected and invited moderators and speakers
- Enhanced the mailing list from the previous conferences
- Selected avenues for promoting the conference

The theme of the 2006 conference was *Ensuring Water Resources for West Virginia's Future.* The following is the final agenda:

Agenda

West Virginia Water Conference 2006...
Ensuring water resources for West Virginia's future
October 11-13, 2006
Stonewall Resort, Roanoke, WV

Agenda

Wednesday, October 11, 2006
8:00 AM Registration
9:00 AM Session I. Setting the Stage

Welcome and introduction of keynote speakers
Paul F. Ziemkiewicz, Director, West Virginia Water Research Institute

Keynote address: WVU's role in helping to develop and protect the state's water resources
Gerald Lang, Provost/Vice President, Academic Affairs, West Virginia University

Keynote address: Highland Action Plan: How it will benefit West Virginia's watersheds
Ed Hamrick, State Liaison, Mid-Atlantic Highlands Action Program

Keynote address: How are research findings and technology translated into policy?
Stephanie R. Timmermeyer, Cabinet Secretary, West Virginia Department of Environmental Protection

10:30 AM Break

11:00 AM Session II. Program Updates; what's new; what's hot

Moderator: John Quaranta, Associate Director, West Virginia Water Research Institute

Water research program for West Virginia; responding to policy, environment, and economic needs
Paul F. Ziemkiewicz, Director, WVWRI

11:30 AM Lunch provided

1:00 PM Session II. Program Updates *continued*

Moderator: John Quaranta, Associate Director, West Virginia Water Research Institute

Status of the State Water Survey
Mike Stratton, Environmental Resource Program Manager, West Virginia Department of Environmental Protection

U.S. Department of Energy - National Energy Technology Laboratory (USDOE-NETL) Water Program
Barb Carney, Chemical Engineer, USDOE-NETL

2:00 PM Break

2:30 PM Session III. The Value of Water: the Land Use-Water Connection

Moderator: William Toomey, Manager, Source Water Assessment Program, West Virginia Department of Health & Human Resources

Resource valuation–fairness, equality, and allocation
Donald Outen, Natural Resource Manager, Baltimore County Department of Environmental Protection

Water resources impact on business placement decision making
Tim Mallan, Environmental Affairs Manager, Appalachian Power

3:30 PM Break

3:45 PM Session III. The Value of Water: the Land Use-Water Connection *continued*

Moderator: Todd Petty, Assistant Professor, Forestry, West Virginia University

How Morgantown, West Virginia is protecting its water resources while undergoing vast urban development
Tim Stranko, General Council, Morgantown Utility Board

The challenges of development in karst terrain
Mark Kozar, Project Leader, U.S. Geological Survey

Sustainable logging in a watershed: optimizing logging while protecting our watersheds through sediment control
Jingxin Wang, Associate Professor, Forestry, West Virginia University

5:15 PM Closing Remarks and Adjourn

Paul F. Ziemkiewicz, Director, West Virginia Water Research Institute

Thursday, October 12, 2006
8:00 AM Session VI. Panel: From Watershed to the Tap: Trends and examples of effective water management

Moderator: Teresa Koon, Assistant Director, West Virginia Department of Environmental Protection

Watershed program
Jennifer Pauer, Watershed Basin Coordinator, West Virginia Department of Environmental Protection

Source Water Protection Program
William Toomey, Manager, Source Water Assessment Program, West Virginia Department of Health & Human Resources

Chesapeake Bay Program
Carla Hardy, Watershed Program Specialist, Department of Agriculture

Indian Creek Watershed/Monroe County Planning Commission
Craig Mohler, Monroe County Commissioner

9:30 AM Break

10:00 AM Session V. Watershed Approaches

Moderator: Brady Gutta, Research Associate, West Virginia Water Research Institute
River of Promise Ten Years Later
Keith Pitzer, Director, Friends of Cheat

West Virginia Watershed Network: Coordinating water quality improvement

Jennifer Pauer, Watershed Basin Coordinator, West Virginia Department of Environmental Protection

11:30 AM Lunch provided

1:00 PM Session VI. Panel: Water Quality Trading

Moderator: Rick Herd, Program Coordinator, West Virginia Water Research Institute

National perspective on water quality trading
Mark Kieser, Sr. Scientist, Kieser Associates

Miami Conservancy District
Dusty Hall, Program Development Manager, Miami Conservancy District

Connestoga River Trading
Ann Smith, Program Analyst, Pennsylvania Department of Environmental Protection

2:00 PM Session VII. Innovative Watershed Initiatives

Moderator: Jennifer Fulton, Research Associate, West Virginia Water Research Institute

Great Green Opportunities
Joseph Hankins, Vice President and Director, Freshwater Institute, The Conservation Fund

Deckers Creek Watershed Analysis
Alyse Schrecongost, Research Associate, West Virginia Water Research Institute

Potomac Headwater Initiative
Brian Moore, Project Director, Trout Unlimited

3:00 PM Break

3:30 PM Session VIII. Panel Session: Gages... who cares? Who uses them?

Moderator: Danny Bennett, Wildlife Biologist, West Virginia Division of Natural Resources

U.S. Geological Survey perspective
Ron Evaldi, Assistant Director, U.S. Geological Survey

U.S. Army Corps of Engineers perspective
Tom MacFarland, Chair, Water Management Section, U.S. Army Corps of Engineers

West Virginia Division of Homeland Security and Emergency Management (WVDHSEM) perspective
Jim Steele, Flood Warning Technician, WVDHSEM

West Virginia Rivers Coalition (WVRC) perspective
Liz Garland, Executive Director, WVRC

5:15 PM Closing Remarks and Adjourn

Paul F. Ziemkiewicz, Director, West Virginia Water Research Institute

Friday, October 13, 2006

8:00 AM Sesssion IX. Infrastructure Needs

Moderator: William Toomey, Manager, Source Water Assessment Program, West Virginia Department of Health & Human Resources

What and how POTW's analyze and treat the water they use for drinking water
Marc Mills, Risk Management Research Laboratory, U.S. Environmental Protection Agency

Drinking water and our aging infrastructure
Jefferson Brady, Executive Director, West Virginia Department of Health & Human Resources

Infrastructure needs, demographics in watersheds; needs assessments
Scott Simonton, Associate Professor, Environmental Science & Safety, Marshall University

Failing septic systems–the latest on the state's efforts to address this issue
Rick Hertges, Onsite Sewage Program Coordinator, West Virginia Department of Health & Human Resources

9:45 AM Break

10:00 AM Session X. Contaminants–Occurrence, Transport, Fate and Effects

Moderator: Clement Solomon, Projects Director, National Environmental Services Center

Environmental questions and community concerns: the role of public health research
Alan Ducatman, Director, Institute of Occupational and Environmental Health

Cryptosporidium in rural water from upstream users
Billie Suder, Water Quality Specialist, West Virginia American Water

Sampling for potential endocrine disrupting compounds, South Branch of the Potomac
Doug Chambers, Biologist/Water Quality Specialist, U.S. Geological Survey

Exposure to mercury in West Virginia
Barbara Smith, Investigator, Agency for Toxic Substances and Disease Registry, -Cooperative Partners Program, West Virginia Department of Health & Human Resources

12:00 PM Closing Remarks and Adjourn

Paul Ziemkiewicz, Director, West Virginia Water Research Institute

West Virginia Water Research Institute

NRCCE National Research Center for Coal and Energy

West Virginia University

NEETC

Office of Environmental Health Services
West Virginia Department of Health and Human Resources

USGS science for a changing world

WILDLIFE West Virginia Division of Natural Resources

Facility

The Stonewall Resort & Conference Center in Roanoke, West Virginia was selected as the venue for this conference due to its location and availability.

Registration and Materials

On-line registration was developed and handled by the WV Water Research Institute. Lunches and materials were provided to approximately 100 attendees. Materials included a newly revised brochure on the activities of the WVWRI and a natural resource guide provided by the WVDNR free of charge to all participants.

Exhibits

Approximately 5 exhibitors participated in the conference including an exhibit on the WVWRI.

Publicity/Technology Transfer

The conference was publicized in a number of ways as follows:

- Press releases to television, newspapers, and radio.
- West Virginia University and WVWRI web sites.
- Post cards mailed to WVWRI conference mailing list.
- Announcements provided to all on planning committee to distribute via their own agency web sites and mailing lists.
- The conference agenda, directions to the facility, an on-line registration form were all accessible via the WVWRI web site.

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	0	0	0	0	0
Masters	3	0	0	0	3
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	3	0	0	0	3

Notable Awards and Achievements

Publications from Prior Projects

None