Susquehanna River Basin Commission

Susquehanna Large River Assessment Project

Publication 265
September 2009

Report by Tyler Shenk
Water Quality Specialist

www.srbc.net

SRBC • 1721 N. Front Street • Harrisburg, PA 17102 • 717.238.0423 • srbc@srbc.net

Printed on recycled paper

ABSTRACT

In 2002, the Susquehanna River Basin Commission (SRBC) conducted a pilot study to determine appropriate methods of biologically assessing the large rivers of the Susquehanna River Basin (basin). Based on the results of that survey, SRBC determined that a combination of rock basket samplers and traditional Rapid Bioassessment Protocol (RBP) methods was the most efficient and consistent collection method to sample the Susquehanna River. These methods were implemented in the 2005 Susquehanna Large River Assessment Project (Hoffman, 2006) at 25 stations on the mainstem Susquehanna River and at the mouths of its major tributaries: the West Branch Susquehanna River, the Juniata River, and the Chemung River.

The U.S. Environmental Protection Agency (USEPA) has developed a field operations manual for the National River and Stream Assessment (NRSA), detailing data collection methods for both wadeable and nonwadeable streams (USEPA, 2008). In 2007, SRBC adapted this protocol for the 25 stations previously sampled (Hoffman, 2008). In late summer 2008, SRBC staff collected data at 17 of the same stations following the NRSA protocols.

Composite benthic macroinvertebrate samples were collected at each station from three D-frame net sweeps at each of ten transects. Field and laboratory water quality samples and overall observations of the site also were collected at each site.

Two of the sites were designated as nonimpaired, ten sites were slightly impaired, and five sites were moderately impaired. Only 6.9 percent (28 of 408) of the water quality values exceeded their respective limits, indicating fairly good water quality in the Susquehanna River.

SRBC plans to continue to use the adapted NRSA river protocols in the future. Fish collection may be added to the protocol in subsequent years, and SRBC plans to develop protocols to properly assess the reservoirs near the mouth of the Susquehanna River.

INTRODUCTION

SRBC has been performing biological assessments throughout the basin since the late 1970s. When USEPA introduced the first version of the RBP manual (Plafkin and others, 1989), SRBC adopted those methods for use in its interstate stream monitoring program and its rotating subbasin surveys. However, neither the previous nor current RBP methods (Barbour and others, 1999) used by SRBC in the aforementioned surveys accurately depict the biological integrity of the basin's large rivers: the mainstem Susquehanna, Chemung, West Branch Susquehanna, and Juniata Rivers. Thus, in 2002, SRBC initiated a pilot project to determine proper methods of biologically assessing the large rivers in the basin. From this pilot project, staff determined that a combination of rock-filled basket samplers and traditional RBP methods was the most effective and consistent collection method for sampling the Susquehanna River (Hoffman, 2003).

In summer 2005, SRBC staff collected biological and water quality data at 25 stations on the mainstem Susquehanna River and at the mouth of its major tributaries using the methodology described above. In 2007, staff changed the methodology to mimic the methods drafted by USEPA for the NRSA (USEPA, 2008). These methods have been used for the past two years.

Although the NRSA data collection includes fish, physical habitat, toxicology, and other parameters in addition to benthic macroinvertebrates, SRBC staff chose to focus efforts on benthic macroinvertebrate sampling. Benthic macroinvertebrates were used to assess biological conditions for several reasons. Benthic macroinvertebrates are sensitive to a wide range of stressors, have a wide range of documented pollution tolerances, and are found in a wide variety of habitats throughout lotic systems (Flotemersch and others, 2001a). Additionally, SRBC has background macroinvertebrate data from various sites on the large rivers of the basin from subbasin surveys and interstate streams monitoring, as well as the previous river assessment studies.

Geography

The Susquehanna River Basin is the largest river basin on the east coast of the United States, draining 27,510 square miles. The Susquehanna River originates at Otsego Lake, N.Y., and flows 444 miles through New York, Pennsylvania, and Maryland to the Chesapeake Bay at Havre de Grace, Md.

This year's Large River Assessment stretched from Great Bend to Marietta, Pa., and encompassed a total of 17 stations: two in the Upper Susquehanna Subbasin; nine in the Middle Susquehanna Subbasin; one at the mouth of the West Branch Susquehanna River; four in the Lower Susquehanna Subbasin; and one at the mouth of the Juniata River. Downstream of Marietta, Pa., the river flows through a series of dams and reservoirs, which this protocol is not designed to assess.

Collecting macroinvertebrate samples at Wyalusing, Pa.

METHODS

Data collection

From September 16 through October 21, 2008, SRBC staff collected macroinvertebrate samples using D-frame nets on the mainstem Susquehanna River from Great Bend to Marietta, Pa., and at the mouths of the Juniata and West Branch Susquehanna Rivers. Field chemistry measurements were taken at each site, and chemical water quality samples also were collected for laboratory analysis. Macroinvertebrate samples were labeled with the site number, the date, and the number of bottles used.

Chemical water quality

Water samples were collected at each sampling site, with a depth integrated sampler, to measure nutrient and metal concentrations in the river. Field water quality measurements included water temperature, dissolved oxygen, conductivity, and pH. Temperature was measured with a field thermometer in degrees Celsius. Dissolved oxygen was measured with a YSI 55 meter that was calibrated at the beginning of every day when samples were collected. Conductivity was measured with a Cole-Parmer Model 1481 meter. A Cole-Parmer Model 5996 meter that was calibrated at the beginning of each sampling day and randomly checked throughout the day was used to measure pH.

A list of laboratory parameters is located in Table 2. Laboratory samples consisted of one 500-ml bottle of raw water, one 250-ml bottle preserved with nitric acid for metal analyses, and one 250-ml bottle was preserved with H_2SO_4 for nutrient analyses. Samples were iced and shipped to the Pennsylvania Department of Environmental Protection, Bureau of Laboratories, Harrisburg, Pa., for analysis.

Macroinvertebrates

Benthic macroinvertebrates (organisms that live on the stream bottom, including aquatic insects, crayfish, clams, snails, and worms) were collected for analysis during this survey. Staff collected benthic macroinvertebrate samples using a D-frame kick net with 500 µm mesh.

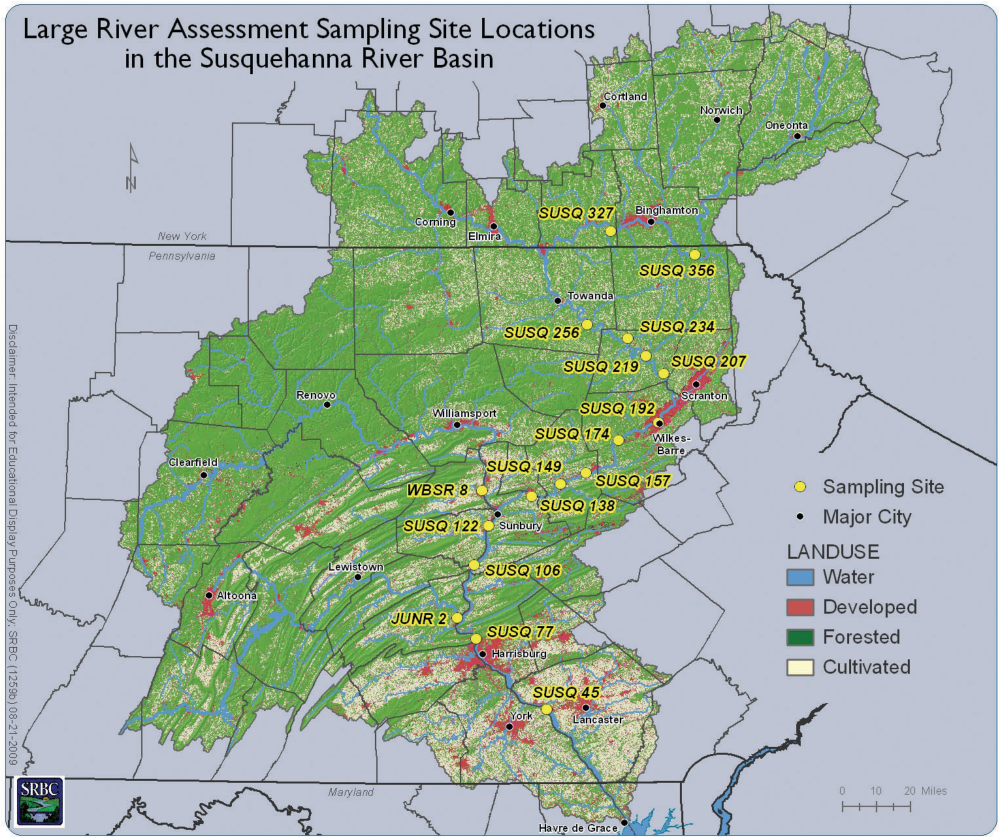

Figure 1. *Large River Assessment Sampling Site Locations*

Station Number	County/State	USGS Quad	Latitude	Longitude	Site Description
SUSQ 356	Susquehanna/Pa.	Great Bend, Pa.	41.9612	-75.6620	Susquehanna River near Oakland, Pa.
SUSQ 327	Tioga/N.Y.	Apalachin, N.Y.	42.0653	-76.1426	Susquehanna River near Apalachin, N.Y.
SUSQ 256	Bradford/Pa.	Wyalusing, Pa.	41.6705	-76.2786	Susquehanna River near Wyalusing, Pa.
SUSQ 234	Wyoming/Pa.	Meshoppen, Pa.	41.6099	-76.0509	Susquehanna River near Meshoppen, Pa.
SUSQ 219	Wyoming/Pa.	Tunkhannock, Pa.	41.5351	-75.9502	Susquehanna River near Tunkhannock, Pa.
SUSQ 207	Wyoming/Pa.	Ransom, Pa.	41.4594	-75.8524	Susquehanna River near West Falls, Pa.
SUSQ 192	Luzerne/Pa.	Kingston, Pa.	41.2500	-75.8845	Susquehanna River near Wilkes-Barre, Pa.
SUSQ 174	Luzerne/Pa.	Nanticoke, Pa.	41.1774	-76.1085	Susquehanna River near Shickshinny, Pa.
SUSQ 157	Columbia/Pa.	Mifflinville, Pa.	41.0405	-76.2945	Susquehanna River near Berwick, Pa.
SUSQ 149	Columbia/Pa.	Catawissa, Pa.	40.9935	-76.4369	Susquehanna River near Bloomsburg, Pa.
SUSQ 138	Northumberland/ Pa.	Danville, Pa.	40.9422	-76.6011	Susquehanna River near Danville, Pa.
SUSQ 122	Snyder/Pa.	Sunbury, Pa.	40.8182	-76.8420	Susquehanna River at Hummels Wharf, Pa.
SUSQ 106	Snyder/Pa.	Dalmatia, Pa.	40.6517	-76.9226	Susquehanna River at McKees Half Falls, Pa.
SUSQ 77	Dauphin/Pa.	Harrisburg West, Pa.	40.3358	-76.9125	Susquehanna River at Fort Hunter, Pa.
SUSQ 45	Lancaster/Pa.	Columbia West, Pa.	40.0365	-76.5239	Susquehanna River at Marietta, Pa.
JUNR 2	Perry/Pa.	Duncannon, Pa.	40.4258	-77.0159	Juniata River at Amity Hall, Pa.
WBSR 8	Northumberland/ Pa.	Lewisburg, Pa.	40.9679	-76.8797	West Branch Susquehanna River at Lewisburg, Pa.

Table 1. *Susquehanna River Station Locations*

SRBC staff collected various aquatic species for analysis, including clams and crayfish.

A three-kick composite sample, collected from representative habitat locations, was collected at each of ten equidistant transects along a one-kilometer sampling reach.

Alternating banks were utilized for transect sampling. For example, transects two, four, six, eight, and ten were sampled on the right bank, while transects one, three, five, seven, and nine were sampled on the left bank. Multiple habitats, including bottom substrate, woody debris, undercut banks, and macrophytes, were included in sample collection. Sampling was conducted in a 10 meter area surrounding each transect, to a depth of 0.5 meters.

Each sample was preserved in the field in 95 percent denatured ethyl alcohol. After sampling was completed at a given site, all equipment that came in contact with the sample was rinsed thoroughly, sprayed with 10 percent bleach solution, examined carefully, and picked free of algae or debris before sampling at the next site. Additional organisms that were found on examination were placed into the sample containers.

Subsampling and sorting procedures were based on the 1999 RBP document (Barbour and others, 1999). In the laboratory, composite samples were sorted into 300-organism subsamples, when possible, using a gridded pan and a random numbers table. The organisms contained in the subsamples were identified to genus (except Chironomidae and Oligochaeta), when possible, and enumerated.

Data Analysis

Chemical water quality

Chemical water quality was assessed by examining field and laboratory parameters. Limit values were obtained for each parameter based on current state and federal regulations or references for aquatic life tolerances (Table 3, Buda, 2008).

Macroinvertebrate analysis

A series of macroinvertebrate metrics was calculated for each sample, and assessments of the sites were performed. Benthic macroinvertebrate samples were assessed using procedures described by Barbour and others (1999), Klemm and others (1990), and Plafkin and others (1989). Using these methods, staff calculated a series of biological indexes at each station. The metrics used in this survey are summarized in Table 4. Metric 2 (Shannon-Wiener Diversity Index) followed the methods described in Klemm and others (1990), and all other metrics were derived from Barbour and others (1999).

A reference condition approach was used to determine impairment levels for each sample. This protocol entails determining the best score for each metric. The 300-organism subsample data were used to generate scores for each of the seven metrics. Scores for metrics 1-4 were converted to a biological condition score, based on the percent similarity of the metric score, relative to the best possible metric score. Scores for metrics 5-7 were based on set scoring criteria developed for the percentages (Plafkin and others, 1989; Ohio Environmental Protection Agency, 1987). The sum of the biological condition scores constituted the total biological score for the sample, and total biological scores were used to assign each sample to a biological condition category (Table 5).

RESULTS

Water Quality

In late summer and early fall 2008, water quality at most of the sampling sites met water quality standards. Only 6.9 percent (28 of 408) of water quality values exceeded their respective limits. The majority of these exceedances were for total sodium, total phosphorus,

Table 2. *Parameters for Laboratory Analysis*

Parameter	
Alkalinity, mg/l[a]	Total Suspended Solids, mg/l
Total Nitrogen, mg/l	Total Sodium, mg/l
Total Nitrite, mg/l	Total Chloride, mg/l
Total Nitrate, mg/l	Total Sulfate, mg/l
Total Phosphorus, mg/l	Total Iron, µg/l[b]
Total Orthophosphate, mg/l	Total Manganese, µg/l
Total Organic Carbon, mg/l	Total Aluminum, µg/l
Total Hardness, mg/l	Turbidity, NTU[c]
Total Magnesium, mg/l	Total Calcium, mg/l

[a] mg/l = milligrams per liter
[b] µg/l = micrograms per liter
[c] nephelometric turbidity units

Table 3. *Water Quality Limits and References*

Parameter	Limit	Reference Code
Temperature	> 25 °C	a,f
Dissolved oxygen	< 4 mg/l	a,g,i
Conductivity	>800 µmhos/cm	d
pH	<6.0	i
Alkalinity	< 20 mg/l	a,g
Nitrogen*	>1.0 mg/l	j
Nitrite	> 0.06 mg/l	f,i
Nitrate	> 1.0 mg/l	e,j
Phosphorus	> 0.1 mg/l	e,k
Orthophosphate	> 0.05 mg/l	l,f,j,k
TOC	> 10 mg/l	b
Hardness	> 300 mg/l	e
Magnesium	> 35 mg/l	i,l
Calcium	> 100 mg/l	m
TSS	> 25 mg/l	h
Sodium	> 20 mg/l	i
Chloride	> 250 mg/l	a,i
Sulfate	> 250 mg/l	a,i
Iron	>1,500 µg/l	a
Manganese	>1,000 µg/l	a
Aluminum	> 750 µg/l	n
Turbidity	> 150 NTU	h

Reference Codes and References

a: http://www.pacode.com/secure/data/025/chapter93/s93.7.html
b: Hem (1970) - http://water.usgs.gov/pubs/wsp/wsp2254/
c: Gagen and Sharpe (1987) and Baker and Schofield (1982)
d: http://www.uky.edu/WaterResources/Watershed/KRB_AR/wq_standards.htm
e: http://www.uky.edu/WaterResources/Watershed/KRB_AR/krww_parameters.htm
f: http://www.hach.com/h2ou/h2wtrqual.htm
g: http://sites.state.pa.us/PA_Exec/Fish_Boat/education/catalog/pondstream.pdf
h: http://www.epa.gov/waterscience/criteria/sediment/appendix3.pdf
i: http://www.dec.ny.gov/regs/4590.html
j:* http://water.usgs.gov/pubs/circ/circ1225/images/table.html
k: http://water.usgs.gov/nawqa/circ-1136/h6.html#NIT
l: http://www.epa.gov/waterscience/criteria/goldbook.pdf
m: based on archived data at SRBC
n: http://www.epa.gov/waterscience/criteria/wqctable

* *Background levels for natural streams*

total orthophosphate, and total nitrogen. Exceedances are summarized in Table 6 and Figure 2.

Biological Communities

Biological conditions are summarized in Figure 3. Nonimpaired biological communities were found at two of the 17 stations (12 percent), slightly impaired conditions were found at 10 sites (59 percent), and moderately impaired conditions were found at five sites (29 percent). No sites were rated as severely impaired.

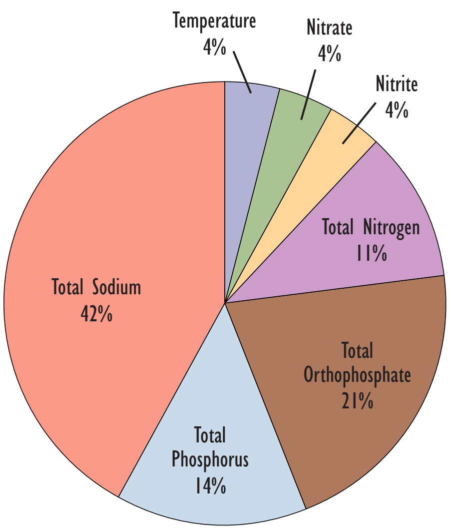

Figure 2. *Parameters Exceeding Water Quality Standards*

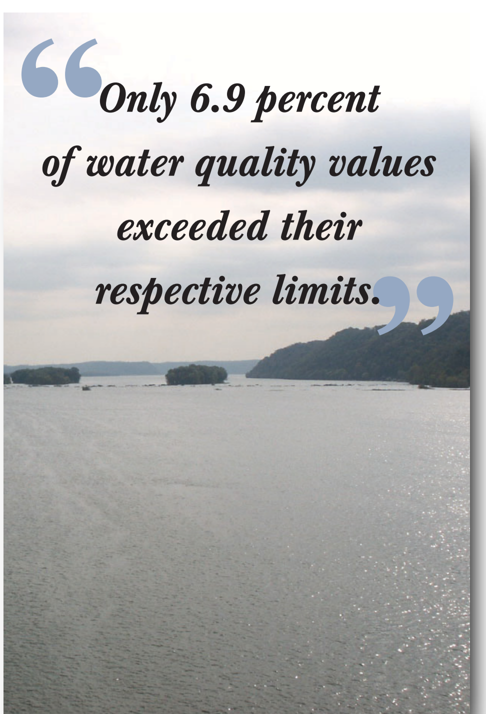

Table 4. *Summary of Metrics Used to Evaluate the Overall Biological Integrity of River Benthic Macroinvertebrate Communities*

Metric	Description
1. Taxonomic Richness (a)	The total number of taxa present in the 300-organism subsample. Number decreases with increasing disturbance or stress.
2. Shannon-Wiener Diversity Index (b)	A measure of biological community complexity based on number of equally or nearly equally abundant taxa in the community. Index value decreases with increasing stress.
3. Hilsenhoff Biotic Index (a)	A measure of the organic pollution tolerance of a benthic macro-invertebrate community. Index value increases with increasing stress.
4. EPT Index (a)	The total number of Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) taxa present in the 300-organism subsample. The index decreases with increasing stress.
5. Percent Ephemeroptera (a)	The percentage of Ephemeroptera in a 300-organism subsample. Percentage decreases with increasing stress.
6. Percent Dominant Taxa (a)	A measure of community balance at the lowest positive taxonomic level. Percentage increases with increasing stress.
7. Percent Chironomidae (a)	The percentage of Chironomidae in a 300-organism subsample. Percentage increases with increasing stress.

Sources: (a) Barbour and others, 1999 (b) Klemm and others, 1990

Table 5. *Summary of Criteria Used to Classify the Biological Conditions of Sample Sites*

SAMPLING AND ANALYSIS

↓

TOTAL BIOLOGICAL SCORE DETERMINATION

Metric	Biological Condition Scoring Criteria			
	6	4	2	0
1. Taxonomic Richness (a)	> 80%	79-60%	59-40%	<40%
2. Shannon-Wiener Diversity Index (a)	> 75%	74-50%	49-25%	<25%
3. Hilsenhoff Biotic Index (b)	> 85%	84-70%	69-50%	<50%
4. EPT Index (a)	> 90%	89-80%	79-70%	< 70%
5. Percent Ephemeroptera (c)	> 25%	10-25%	1-9%	< 1%
6. Percent Dominant Taxa (c)	< 20%	20-30%	31-40%	>40%
7. Percent Chironomidae (c)	< 5%	5-20%	21-35%	>35%
Total Biological Score (d)				

↓

BIOASSESSMENT

Percent Comparability of Study and Reference Condition Total Biological Scores (e)	Biological Condition Category
>83%	Nonimpaired
79-54	Slightly Impaired
50-21	Moderately Impaired
<17%	Severely Impaired

(a) Score is study site value/reference condition value X 100
(b) Score is reference condition value/study site value X 100
(c) Scoring Criteria evaluate actual percentage contribution, not percent comparability to the reference station
(d) Total Biological Score = the sum of Biological Condition Scores assigned to each metric
(e) Values obtained that are intermediate to the indicated ranges will require subjective judgment as to the correct placement into a biological condition category

Table 6. *Number of Exceeds per Parameter*

Parameter	Limit Concentration	# of Exceedances
Total Sodium	>20 mg/l	12
Total Orthophosphate	>0.05 mg/l	6
Total Phosphorus	>0.1 mg/l	4
Total Nitrogen	>1.0 mg/l	3
Total Nitrate	>1.0 mg/l	1
Total Nitrite	>0.06 mg/l	1
Water Temperature	>25 °C	1

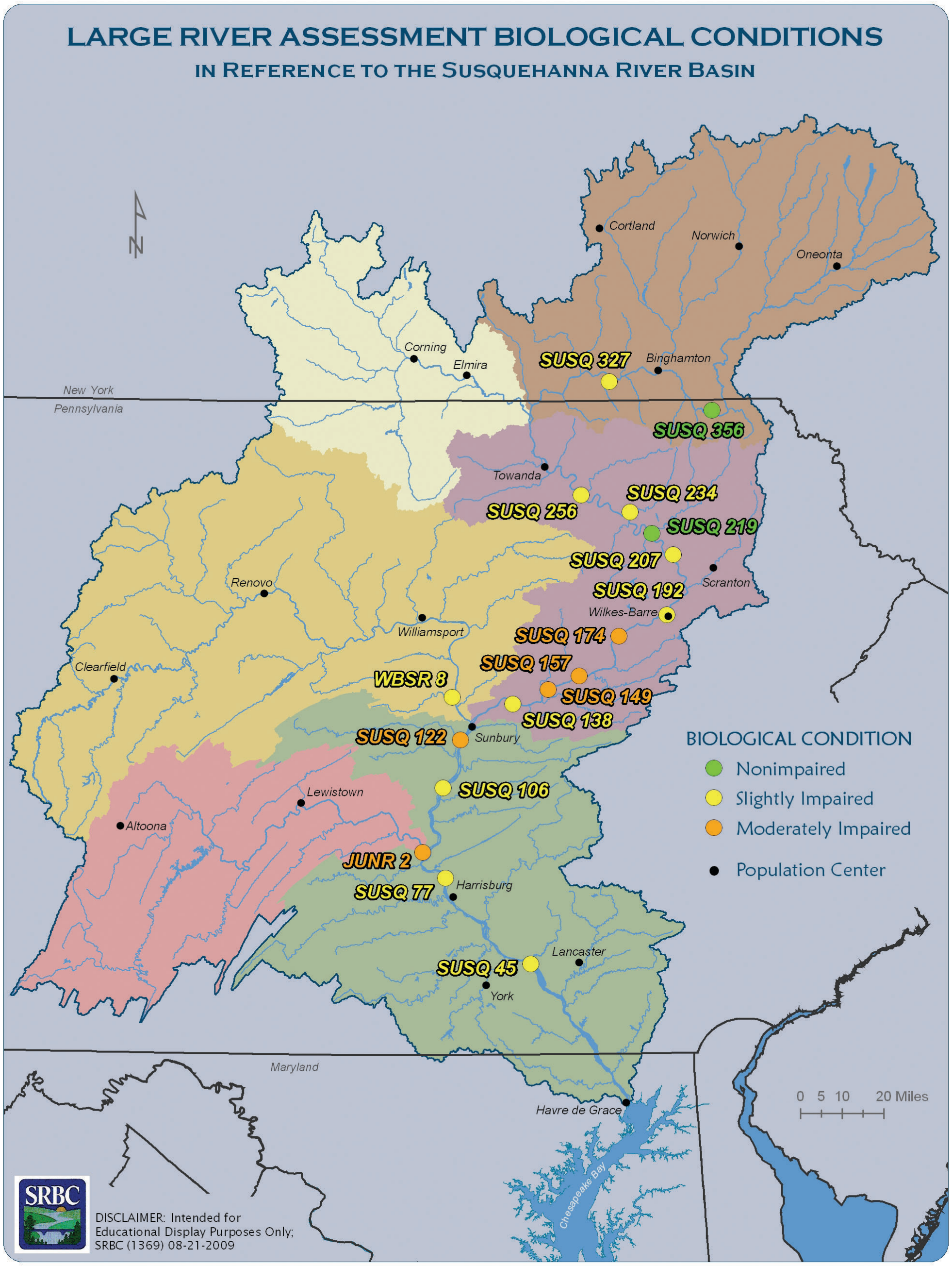

Figure 3. *Biological Conditions in 2008*

DISCUSSION

Water Quality

A comparison of water quality samples from the present large river assessment project (August-September 2007) to water quality samples collected for the most recent interstate streams survey (Steffy, 2007), Upper Susquehanna Subbasin Survey (Buda, 2008), Chemung Subbasin Survey (Buda, 2007), Middle Susquehanna Subbasin Survey (LeFevre, 2002), West Branch Subbasin Survey (LeFevre, 2003), Juniata River Subbasin Survey (LeFevre, 2005), and Lower Susquehanna Subbasin Survey (LeFevre, 2006) indicates that water quality conditions on the Susquehanna River between Sidney, N.Y., and Marietta, Pa., and at the mouths of its major tributaries, are stable and generally below limits, although temperatures were greater than 25 degrees Celsius at several stations and total sodium exceeded the level of concern in many samples. From the data analysis, it appears that the Susquehanna River, in the stretch encompassed by this study, contains fairly good water quality, with some slightly elevated parameters.

Macroinvertebrate Communities

Upper Susquehanna River

The upper Susquehanna River starts at Otsego Lake in Cooperstown, N.Y., and continues to the confluence with the Chemung River in Sayre, Pa. This is a fairly rural area that mostly consists of forest and agricultural land, with the exception of one large population center, Binghamton, N.Y. Only two sites were sampled this year in the upper Susquehanna due to weather and high flows. The most upstream site in the survey was at Great Bend, Pa. (SUSQ356), where the river flows south into Pennsylvania before turning north and back into New York. Great Bend was rated as nonimpaired, with the highest number of EPT taxa (16) and diversity of taxa (31) in the entire river; a condition that continued from the studies of 2005 and 2007. The site at Apalachin, N.Y. (SUSQ327), is located downstream of Binghamton, N.Y., and may show the effects of the population center. The site received a slightly impaired rating; due to a significant reduction in EPT taxa (9) and lower ratings for percent dominant taxa and taxonomic richness.

"Great Bend was rated as nonimpaired, with the highest number of EPT taxa (16) and diversity of taxa (31) in the entire river; a condition that continued from the studies of 2005 and 2007."

Middle Susquehanna River and the West Branch Susquehanna River

The middle Susquehanna River stretches from Sayre, Pa., to the confluence with the West Branch Susquehanna River at Sunbury, Pa. The northern part of the middle Susquehanna River is heavily forested with plots of agricultural land, which continues to the largely urbanized Scranton/Wilkes-Barre, Pa. This area was heavily mined in the past and abandoned mine drainage (AMD) is an issue from the Scranton/Wilkes-Barre area continuing downstream. Nine sites were sampled throughout the middle Susquehanna River for this survey.

The sites at Wyalusing (SUSQ256), Meshoppen (SUSQ234), and Tunkhannock (SUSQ219), Pa., were designated as slightly impaired as in previous years. All of the stations had low ratings for the number of EPT taxa, but received good to high ratings for all other metrics. SUSQ 219 received the highest rating for percent dominant taxa and Shannon-Wiener diversity. The last site in the heavily forested hill area is located in West Falls, Pa. (SUSQ207). This site was designated as nonimpaired and received the highest ratings for taxonomic richness, Hilsenhoff Biotic Index, number of EPT taxa, and percent Chironomidae.

The site at Wilkes-Barre, Pa. (SUSQ192), was rated slightly impaired with the number of EPT taxa dropping off significantly from the upstream site. The site at Shickshinny, Pa. (SUSQ174), was designated moderately impaired, with some of the lowest ratings for the entire study in many categories. The river is deeper at this station than at other sites, and sample collections were challenging, which may have negatively influenced the macroinvertebrate sample. Additionally, SUSQ174 is downstream of not only a heavily urbanized area but also severely AMD-impacted streams such as Solomons, Newport, and Nanticoke Creeks. All of these factors may play a significant role in the degradation of the site. The sites near Berwick (SUSQ157), Bloomsburg (SUSQ149), and Danville (SUSQ138), Pa., are located near developed and agricultural areas. SUSQ 157 and SUSQ 149 were both moderately impaired with low numbers of EPT taxa and some of the lowest ratings for percent dominant taxa in the study. SUSQ 138 had a low number of EPT taxa; however, many other metrics improved so the site was designated only slightly impaired.

The West Branch Susquehanna River drains approximately 6,982 square miles and is the largest tributary to the Susquehanna River. The watershed is very diverse, from huge areas of undeveloped forests, to areas of heavy mining activity causing many AMD-impacted streams in the headwaters, to some developed areas and agricultural lands towards the mouth. One site is located on the West Branch Susquehanna River near the mouth at Lewisburg, Pa. (WBSR8). The station was designated as slightly impaired with a high rating in Shannon-Wiener Diversity, but a low number of EPT taxa.

Lower Susquehanna River and the Juniata River

The lower Susquehanna River flows from the confluence with the West Branch and mainstem in Sunbury, Pa., to where the river meets the Chesapeake Bay in Havre de Grace, Md. This portion of the watershed contains a significant amount of agricultural land along with a few densely developed areas, including Harrisburg, Pa., which lies directly adjacent to the river. Four sites are located within this reach, with the most downstream site located 45 miles upstream from the Chesapeake Bay. Hydroelectric dams turn the river into a series of pooled reservoirs on this last stretch, which staff are unable to assess with the current protocols.

The site at Hummels Wharf (SUSQ122), Pa., was designated as moderately impaired with a low number of EPT and two of the worst metric ratings for taxonomic richness and Hilsenhoff Biotic Index. The last three sites on the river, McKees Half Falls (SUSQ94), Fort Hunter (SUSQ77), and Marietta (SUSQ45), Pa., were slightly impaired. The SUSQ94 Hilsenhoff Biotic Index rebounds to a higher rating than the upstream site, but the EPT taxa metric was still low. Higher quality streams such as Shermans, Clark, and Stony Creeks enter the Susquehanna River upstream of SUSQ77, possibly increasing the metrics ratings. SUSQ45 is a long-term interstate stream survey station, with a current and historical assessment of slightly impaired.

The Juniata River Watershed contains forested and agricultural land with a large population center in the headwaters at Altoona, Pa. One site at the mouth near Duncannon (JUNR2), Pa., was moderately impaired, with lowest ratings for percent dominant taxa and number of EPT taxa.

Future Goals

The assessments at the Susquehanna River sites are fairly consistent between this study and past studies. The 2007 and 2008 Large River Assessment projects used the same protocol with very similar end results, while staff used different protocols in 2005 with very similar results. Future studies will continue, conditions permitting, and expansion of the project will be investigated. SRBC is interested in collecting macroinvertebrate and water quality data in the last 45 miles of reservoirs as well as possible fish collection at the current stations.

Confluence of West Branch and mainstem Susquehanna Rivers.

References

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Buda, S.L. 2009. Middle Susquehanna Subbasin Survey: A Water Quality and Biological Assessment, June-September 2008. Publication 263. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

_____. 2008. Upper Susquehanna Subbasin Survey: A Water Quality and Biological Assessment, June-September 2007. Publication 260. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

_____. 2007. Chemung Subbasin Survey: A Water Quality and Biological Assessment, June - August 2006. Publication 251. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

Cooper, S.D. and L.A. Barmuta. 1993. Field Experiments in Biomonitoring. In Freshwater Biomonitoring and Benthic Macroinvertebrates. Ed. by D.M. Rosenbert and V.H. Resh. Chapman and Hall, New York. 488 pp.

Flotemersch, J.E., B.C. Autrey, and S.M. Cormier. 2000a. Comparisons of Boating and Wading Methods Used to Assess the Status of Flowing Waters. EPA/600/R-00/108. U.S. Environmental Protection Agency, Cincinnati, Ohio.

Flotemersch, J.E., B.C. Autrey, and S.M. Cormier, eds. 2000b. Logistics of Ecological Sampling on Large Rivers. EPA/600/R-00/109. U.S. Environmental Protection Agency, Cincinnati, OH.

Hoffman, J.L.R. 2008. Susquehanna Large River Assessment Project. Publication 261. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

_____. 2006. Susquehanna Large River Assessment Project. Publication 245. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

_____. 2003. Susquehanna River Pilot Study: Large River Assessment Project. Publication 228. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

Klemm, D.J., P.A. Lewis, F. Fulk, and J.M. Lazorchak. 1990. Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters. EPA/600/4-90/030. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio.

LeFevre, S.R. 2006. Lower Susquehanna Subbasin Survey: A Water Quality and Biological Assessment, June - November, 2005. Publication 247. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

_____. 2005. Juniata River Subbasin Survey: A Water Quality and Biological Assessment, July-November 2004. Publication 240. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

_____. 2003. West Branch Susquehanna Subbasin Survey: A Water Quality and Biological Assessment, July - November 2002. Publication 226. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

_____. 2002. Middle Susquehanna Subbasin: A Water Quality and Biological Assessment, July - September 2001. Publication 222. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

LeFevre, S.R. and D.L. Sitlinger. 2003. Assessment of Interstate Streams in the Susquehanna River Basin: Monitoring Report No. 16, July 1, 2001, through June 30, 2002. Publication 227. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

Parsons, M. and R.H. Norris. 1996. The effect of habitat-specific sampling on biological assessment of water quality using a predictive model. Freshwater Biology, 36: 419-434.

Resh, V.H. and E.P. McElravy. 1993. Contemporary Quantitative Approaches to Biomonitoring Using Benthic Macroinvertebrates. In Freshwater Biomonitoring and Benthic Macroinvertebrates. Ed. by D.M. Rosenbert and V.H. Resh. Chapman and Hall, N.Y. 488 pp.

Resh, V.H. and J.K. Jackson. 1993. Rapid Assessment Approaches to Biomonitoring Using Benthic Macroinvertebrates. In Freshwater Biomonitoring and Benthic Macroinvertebrates. Ed. by D.M. Rosenbert and V.H. Resh. Chapman and Hall, N.Y. 488 pp.

Steffy, L.Y. 2007. Assessment of Interstate Streams in the Susquehanna River Basin, July 1, 2005 - June 30, 2006. Publication 249. http://www.srbc.net/interstate_streams.

Steffy, L.Y. and D.L. Sitlinger. 2006. Assessment of Interstate Streams in the Susquehanna River Basin. Publication 244. Susquehanna River Basin Commission, Harrisburg, Pennsylvania.

United States Environmental Protection Agency. 2008. National Rivers and Streams Assessment: Field Operations Manual. Office of Water, Office of Environmental Information, Washington, D.C. EPA-841-B-07-009.

United States Geological Survey. Methods for Collecting Benthic Invertebrate Samples as part of the National Water Quality Assessment Program. Open File Report 93-406. http://water.usgs.gov/nawqa/protocols/OFR-93-406/inv1.html.