

Sediment-al Journey:

Measuring Metal Concentrations in Soils Beside Urban Waterways



Photo courtesy of K. T. Belt

Meet the Scientists



◀ **Dr. Daniel Bain**, Hydrologist: My favorite science experiences generally involve one of three things: (1) finding a clear pattern from data I have collected, (2) working in an urban stream or soil pit and having a local resident come up and ask a question or share an insightful observation about the area, and (3) contributing technical data to challenges created by interactions between humans and natural systems within neighborhoods.

▶ **Mr. Ian Yesilonis**, Soil Scientist: Did you know more living individual organisms are in a tablespoon of soil than people are on Earth? Usually people don't know a lot about soil, and without it, our lives on Earth would be very different. Soil is important to our daily health and holds the evolving history of our planet. Soils do a lot of things, like provide footing for

plants to grow, homes for worms and insects, and filtration for water.

I enjoy playing in, learning from, and unlocking the mystery of soils. My favorite science experience is when I am out in a field, with a soil corer in hand; ready to discover something new about soil. Often, I feel like a detective, investigating the soil structure below the surface to search for the unique story it has to tell. To figure out the story, I first survey the area and look at the landscape for markers like hills; I look at the rocks to see what they are made of; I look at the plants, the streams, and the rivers. All of these first insights give me an idea of how the soil developed and how it interacts with the current environment.

Next, I get out my **auger**, dig out a soil sample from the Earth, and lay the samples down **systematically** to create a soil profile on a ground cloth. Then, I feel the soil, look at its color, and shape, and sometimes I even smell it. Combined, this information can tell me a lot about the soil. Using the soil profile, I can identify (1) if erosion took place hundreds of years ago, (2) if the area has been farmed or plowed, (3) how quickly water may or may not move through it, (4) if worms or mammals have made it their habitat, and (5) if the soil is old or young. For me, the best experience is going out into the field with my auger, on a nice sunny day, prepared to uncover the secrets of the soil.



◀ **Dr. Richard Pouyat**, Urban Ecosystem Ecologist: For me, science is most exciting when I have made a new discovery! If you practice science long enough, you too will make a discovery. One of my first scientific discoveries was when I found an **invasive species** of earthworm living in a forested park in New York City—a worm species from Asia! How did it get there? Why was this worm species not noticed before? Was it changing the soil? The species was probably brought to the United States with **exotic** plants and has had a dramatic effect on **nutrient cycling**.

Nobel-prize winner and Hungarian scientist Albert Szent-Gyorgyi (aul bərt sent gərj ē) once said, "Discovery is seeing what everybody else has seen and thinking what nobody else has thought." Using his definition, every discovery you make is your own!



Did You Know?

Dr. Pouyat found an earthworm that was an invasive species from Asia that was living in New York City parks. He was interested how it affected the environment. The same earthworm species was found hundreds of miles away in Georgia. Scientists in Georgia conducted research to find out how this invasive species affected the ability of native earthworms to survive.

To learn more about these earthworms, read the *Natural Inquirer* Monograph "Worming Their Way In." It can be found online at <http://www.naturalinquirer.org/all-issues.html>.

What Kinds of Scientists Did This Research?

hydrologist: This scientist studies the distribution, movement, and quality of Earth's waters.

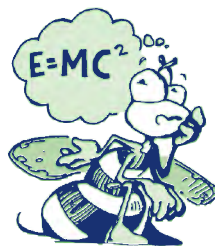
soil scientist: This scientist studies soils as one of Earth's natural resources.

urban ecosystem ecologist: This scientist studies the interactions of people and other organisms with each other and with nonliving parts of urban environments.

Thinking About Science

In 1980, the National Science Foundation created a network of research locations to study how ecosystems change over a long period of time. This network is called the Long Term Ecological Research (LTER) Network.

The United States has 26 of these areas, which includes one in Puerto Rico and two in Antarctica. The research being done at these locations is unusual because it focuses on changes that are happening over a long period of time. From a scientific perspective,



long-term research provides information that is impossible to discover in any other way.

One of these research locations is the Baltimore Ecosystem Study. Scientists working with the Baltimore Ecosystem Study seek to understand **metropolitan** Baltimore as an ecological system. The Baltimore Ecosystem Study involves scientists from the biological, physical, and **social sciences**. The LTER network enables a variety of scientists to work together. By working as a team, these different scientists can provide a much more complete picture of what is happening over time and why it is happening.

What Is the National Science Foundation?

The National Science Foundation (NSF) is an independent Federal agency created by Congress in 1950. The NSF provides funding for scientific research. This research promotes scientific progress; advances national prosperity, health, and welfare; and aids in national defense. For more information, visit <http://www.nsf.gov>.



Glossary words are **bold** and are defined on page 70.

One goal of the Baltimore Ecosystem Study is to understand how urban and suburban ecosystems change over a long period of time. In this study, you will learn what scientists are

discovering about changes in the **riparian** areas that drain into Baltimore's Middle Branch of the Patapsco River. This body of water is also known as Baltimore Harbor (**figures 1 and 2**).

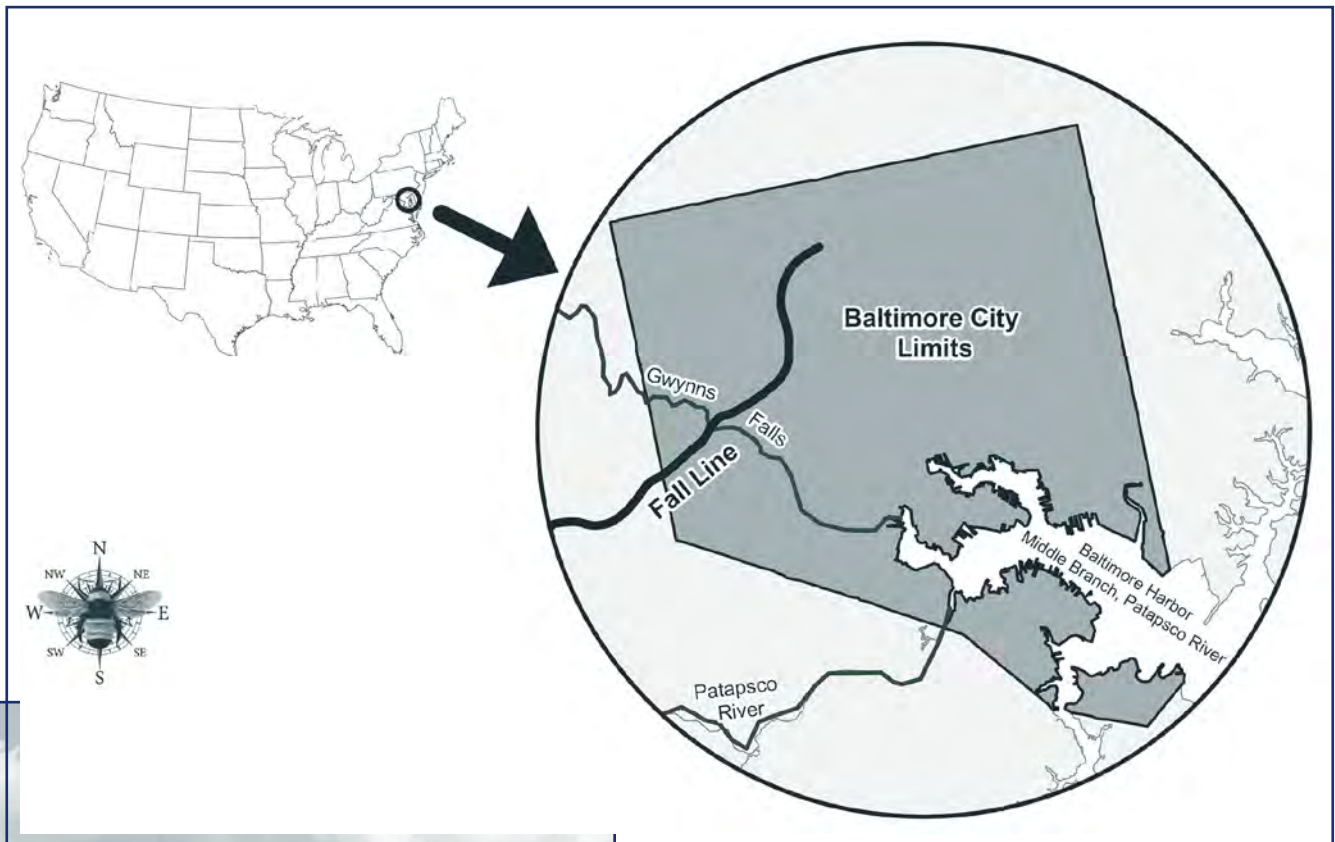


Figure 1. Baltimore is a large city in Maryland. Locate Baltimore Harbor on this map. Map by Lindsay Gnann.



Figure 2. People enjoy water sports in Baltimore Harbor. Photo courtesy of K.T. Belt.

Thinking About the Environment

Riparian areas are **transition** areas between waterways and land (**figures 3 and 4**). Riparian areas are ecologically important. They provide habitat for wildlife species and for plant species that grow in wet areas. When streams flow into rivers, the streams carry **sediment** into the rivers. Sediment is created by soil **erosion**. Soil erosion is caused by heavy rainfall from both



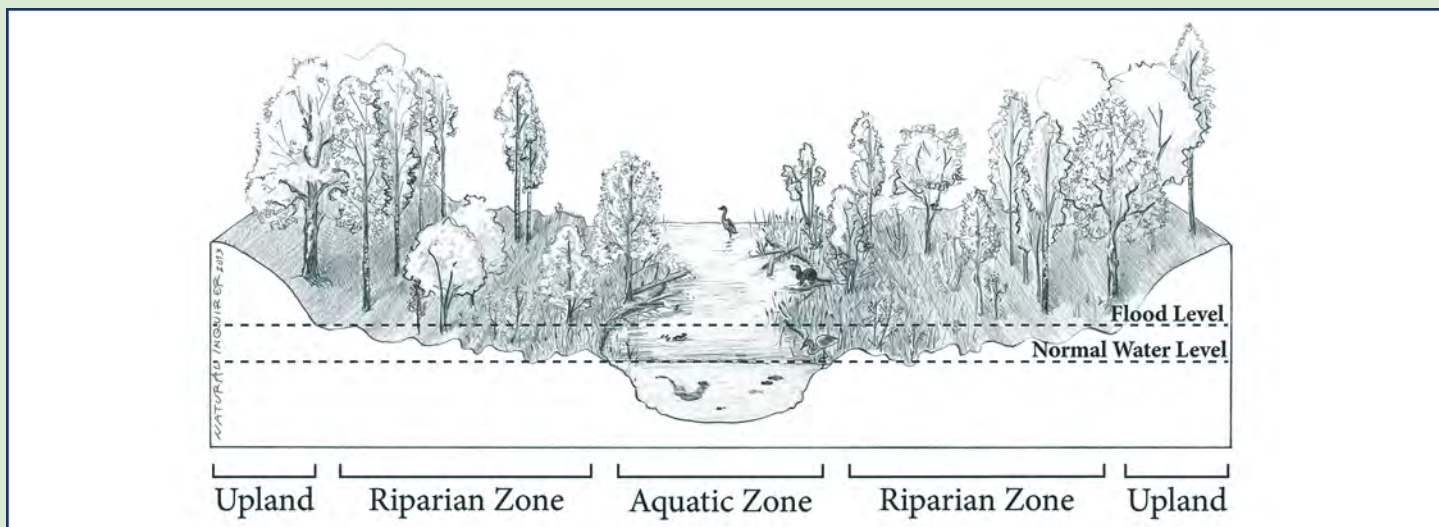


Figure 3. Riparian areas are found along waterways. When water levels are high, these areas may become flooded. When riparian areas are flooded, sediment being carried by the waterways is deposited onto the riparian area. Illustration by Stephanie Pfeiffer.

the lands through which streams and rivers flow and the riverbanks of the waterways themselves. Riparian areas protect waterways from too much soil erosion and **sedimentation**, and they protect upland areas from flooding.

Urban areas have a large amount of impervious (im **pər** vē əs) surface area. Concrete and asphalt are examples of impervious surfaces. Water cannot drain through impervious surfaces. Following rainfall or snowfall in urban areas, impervious surfaces cause rainfall or melted snow to enter waterways more quickly than it does in nonurban areas. Managers often take

action to slow the rate of runoff into waterways and to protect streambanks from erosion (**figure 5**).

In this study, the scientists wanted to learn about changes in urban riparian areas in **metropolitan** Baltimore. The scientists studied the sediment that is deposited onto riparian areas during high streamflows. They wondered about the sediment's **chemical** content, including trace chemicals like lead and plant nutrients like calcium. The scientists wanted to discover what the sediment's chemical content indicates about urban **land use**.



Figure 4. This riparian area is located in metropolitan Baltimore. Photo courtesy of K.T. Belt.



Figure 5. Rocks may be placed along urban streambanks or riverbanks to protect waterways from soil erosion. This photo is of Silver Creek in Illinois. Photo courtesy of ENCAP, Inc., <http://www.encapinc.net>.

Introduction

Most urban areas include places that contain chemicals from automobile and truck emissions, industrial processes, and urban development. Two chemicals found **abundantly** in urban areas are calcium and lead. Calcium is abundant in urban areas because concrete contains calcium (**figure 6**). Lead is released to urban areas by industrial processes, from oil-based fuels, battery acid, and vehicle exhaust fumes, among other sources. Chemicals that bind to soil particles, such as calcium and lead, can be washed into waterways during periods of high rainfall (**figure 7**). Waterways carry this sediment downstream. When flooding occurs, the sediment is deposited on the riparian areas along the waterways (see “Thinking About the Environment”).

The scientists in this study wanted to answer the following questions: What is the chemical content of riparian sediment samples across an urban-suburban **gradient**? What does the chemical content tell us about urban land use?



Figure 6. Concrete is abundant in urban areas. Concrete is used for sidewalks and for building and bridge foundations. Photo courtesy of K.T. Belt.



Figure 7. Storm drains may carry chemicals from urban areas into waterways. Photo courtesy of Babs McDonald.

Reflection Section



- ❖ Concrete is used for many building projects, including bridges, sidewalks, and buildings. Concrete is made from calcium. What part of your body contains calcium? Does this body part need to be strong? Why or why not?
- ❖ Based on what you have read so far, would you expect to find more calcium and lead in riparian sediment closer to or farther away from the city center? Why?

What Is the Urban-Rural Gradient?

Urban areas are not uniformly developed. City centers are areas with large buildings and a lot of people. Industrial sites are often found near city centers. In general, the farther away an area is from the city center, the less developed it is. Suburban areas are areas away from a city that have more homes and

open space. Beyond suburban areas are small towns and rural areas. These areas have fewer people, more farms, and more forests. This change from urban city center to suburban land use, and then to rural areas, is called the urban-rural gradient (**figure 8**).

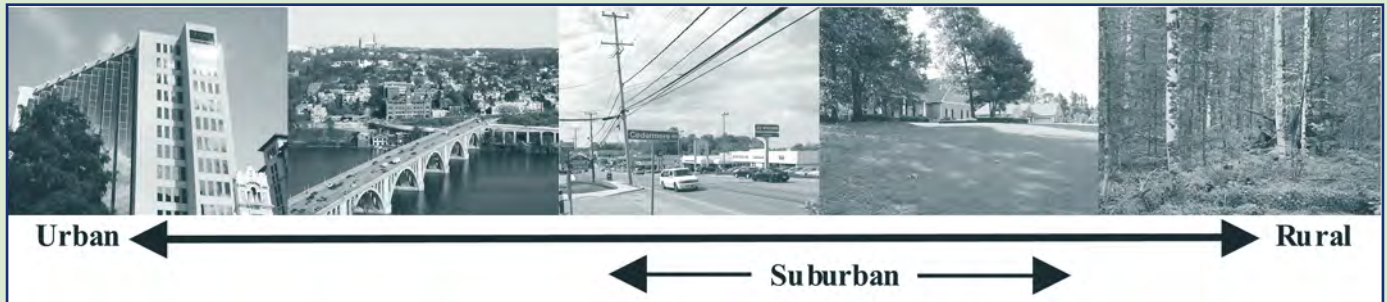


Figure 8. Urban areas have a lot of large buildings, roads, and people. Suburban areas have homes, shopping centers, and more open space. Rural areas are primarily open space. Photos courtesy of Babs McDonald.

Methods

The scientists studied riparian areas within the Gwynns Falls watershed (**figures 9 and 10**). Many scientists involved with the Baltimore Ecosystem Study are studying this watershed. During the study period, the headwaters of the Gwynns Falls watershed were less urban than the waterways downstream. This watershed, therefore, followed an urban-suburban gradient. The Gwynns Falls watershed does not include rural lands.

Another feature of the Gwynns Falls watershed is that it straddles a fall line (**figure 11**). This geographic feature is important, because it indicates a change in the types of underlying rock.

The scientists collected 26 soil samples from Gwynns Falls watershed riparian areas (**figures 12 and 13**).



Figure 9. A watershed includes an area that drains to a common waterway, such as a stream, lake, estuary, wetland, aquifer, or even the ocean. The headwaters of a watershed is the area where water enters the watershed. Illustration by Stephanie Pfeiffer.

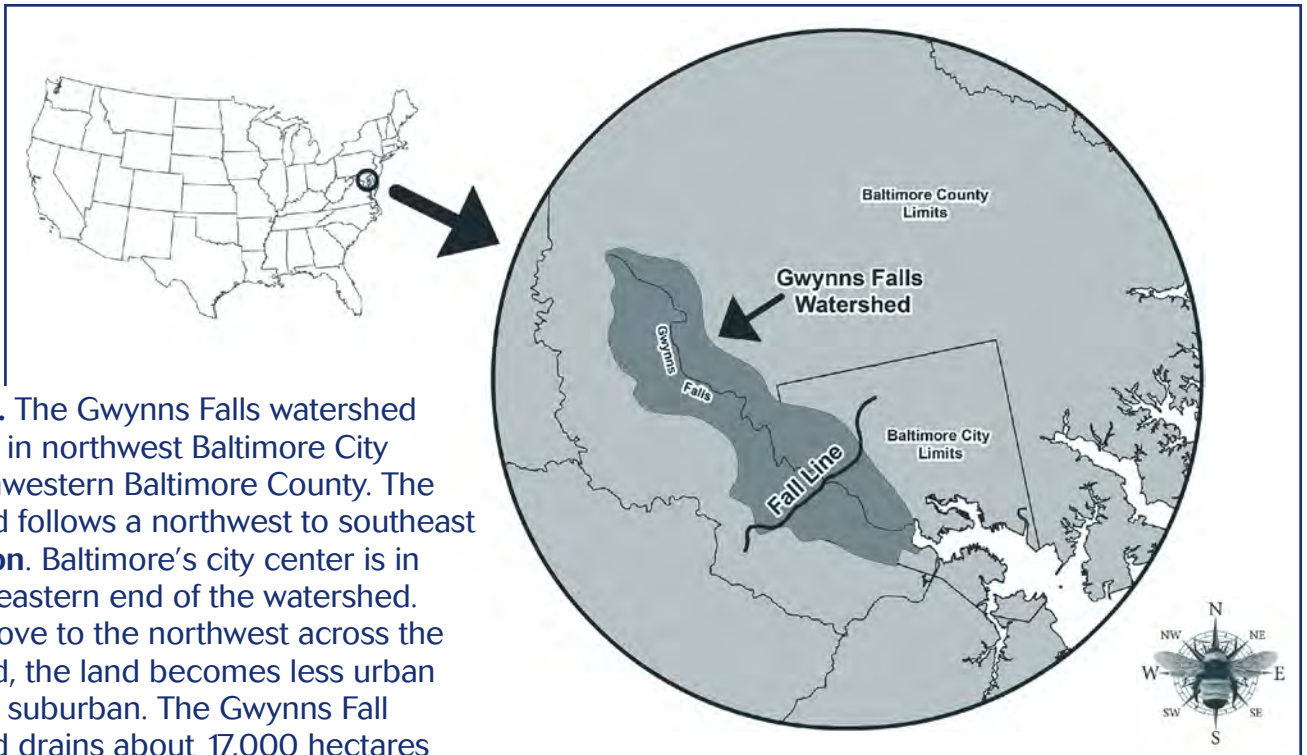


Figure 10. The Gwynns Falls watershed is located in northwest Baltimore City and southwestern Baltimore County. The watershed follows a northwest to southeast **orientation**. Baltimore's city center is in the southeastern end of the watershed. As you move to the northwest across the watershed, the land becomes less urban and more suburban. The Gwynns Fall watershed drains about 17,000 hectares of land. Map by Lindsay Gnaan.

Number Crunches

- 🍁 How many acres is 17,000 hectares? Multiply the number of hectares by 2.47 to find out.
- 🍁 How many square kilometers is 17,000 hectares? Divide 17,000 by 100 to find out.

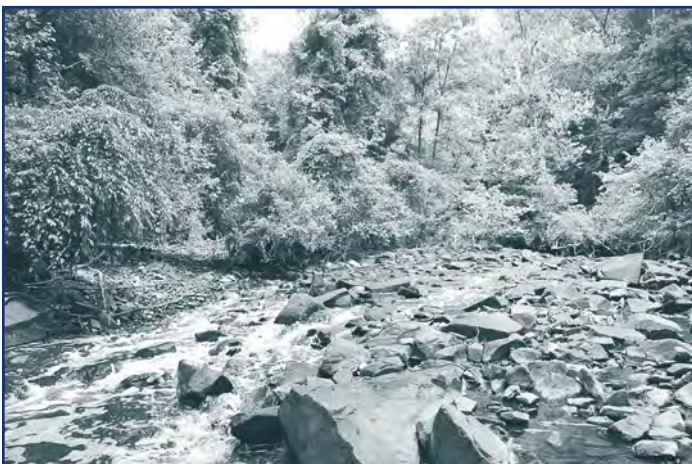


Figure 11. The Gwynns Falls watershed straddles a fall line. A fall line is not really a line but an area where rolling hills meet the flatter Coastal Plain. Photo courtesy of K.T. Belt.

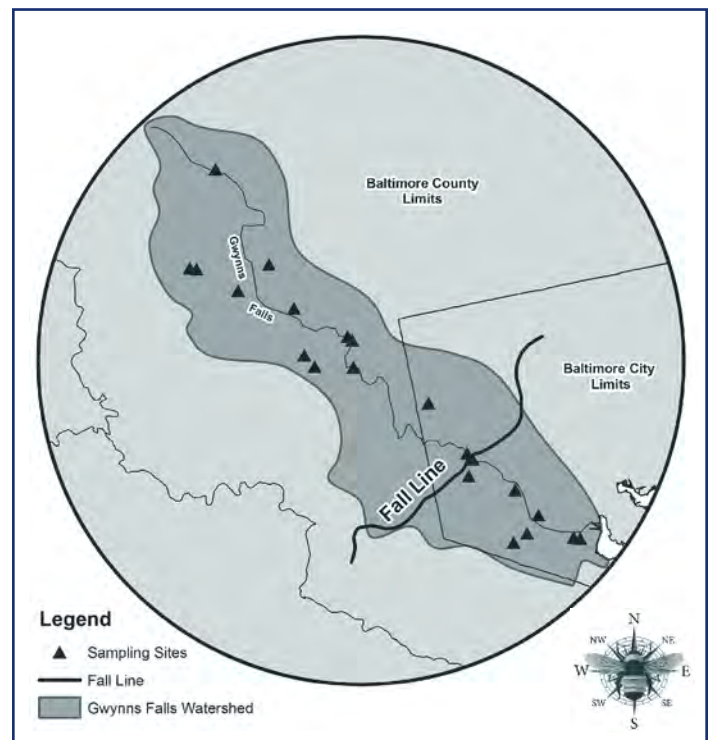


Figure 12. The scientists took soil samples from areas near Gwynns Falls waterways. Each triangle on this map represents one of the areas from which a soil sample was taken. Why do you think some of the triangles are not close to the Gwynns Falls River? (Hint: What is missing on this map?) Map by Lindsay Gnaan.

Each sample was taken 10 meters from the water's edge. The soil samples were taken between 0 and 15 centimeters from the soil surface. The scientists analyzed these samples for chemical content (**figures 14 and 15**).



Figure 13. Scientists take a soil sample in a suburban area. Photo courtesy of Dr. Richard Pouyat.



Figure 14. Scientists examine soil samples in the laboratory. Photo courtesy of Dr. Richard Pouyat.



Figure 15. The scientists used a Perkins-Elmer ELAN 6000 ICP-MS to analyze the sediment samples. This equipment enabled the scientists to identify a wide variety of chemical concentrations in the sediment samples. Photo courtesy of Dr. Daniel Bain and the University of Pittsburgh.

What Is a Fall Line?

A fall line is the place where an upland region of rolling hills ends and the flatter Coastal Plain begins. The upland region of rolling hills is called the Piedmont. The underlying rock of the Piedmont is harder and the underlying rock of the Coastal Plain is softer. Waterfalls, or a series of rapids, mark the fall lines. On the U.S. east coast, the Atlantic Seaboard Fall Line is 900 miles (1,400 kilometers) long. This fall line stretches from Massachusetts to Alabama. Is the Gwynns Falls watershed a part of the Atlantic Seaboard Fall Line? How do you know? If you do not know, look at a map that includes the Eastern United States.

Number Crunches

- How many feet are equal to 10 meters?
Multiply 10 by 3.28 to find out.
- How many inches are equal to 15 centimeters?
Multiply 15 by .3937 to find out.

Reflection Section

- Observe figure 12. Why did the scientists take samples across the entire watershed, from northwest to southeast?
- Why did the scientists take every sample 10 meters from the water's edge?



Findings

The underlying rock structure changes at a fall line. The chemical nature of naturally occurring sediment, therefore, is usually different above and below fall lines. This difference is because the underlying rock above and below the fall line contains different chemicals. These chemicals are washed into the water and deposited onto riparian areas. When analyzing soil samples, scientists expect to see a change in the types of naturally occurring chemicals found in sediment above and below a fall line.

The scientists found that the level of calcium and lead in the soil samples increased as soil samples were pulled near increasingly urbanized land. The level of calcium did not change suddenly at the fall line, as it would have if it was occurring naturally. Instead, the scientists found an increase in calcium across the entire watershed from the northwest to the southeast (**figures 16 and 17**).

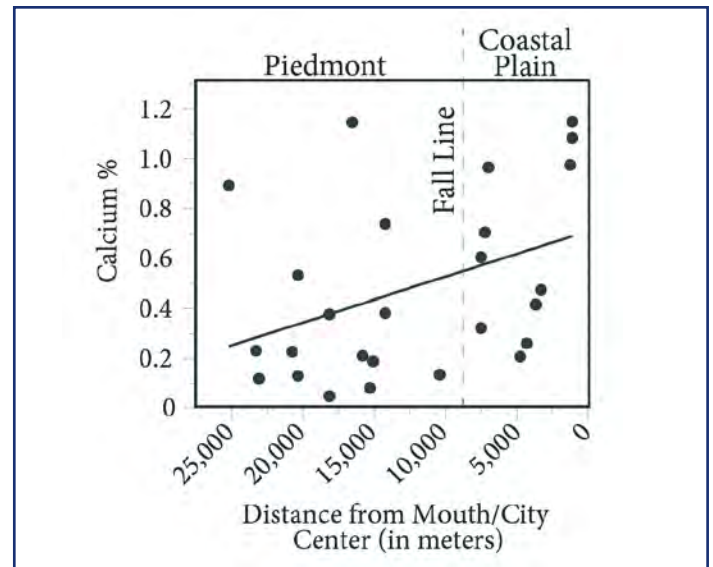


Figure 16. The percent of calcium found in the sediment samples was greater in areas closer to the city center. Each dot on this scatter plot represents a sampling site. When data are displayed in a scatter plot, scientists calculate an equation that shows a straight line. This straight line is mathematically determined to minimize the sum of the distances between the points and the line.

This line is called the line of best fit. A line of best fit shows the general trend of the data. A line of best fit may pass through some points, just one point, or all the points on a scatter plot. It is possible, but not likely, that a line of best fit will not pass through any of the points. Does the line of best fit in this figure pass through any of the points? Explain in your own words what the line of best fit in this scatter plot is showing about the calcium content across the urban-suburban gradient. Illustration by Stephanie Pfeiffer.

The scientists also tested the sediment samples for copper and zinc. These trace chemicals are often found in urban areas. Trace chemicals are chemicals found in small quantities. The scientists found that these chemical amounts also increased across the watershed's urban-suburban gradient from the northwest to the southeast (**figure 18**).



Figure 17. Urban concrete could be a source of the increased calcium measured in riparian sediment samples. Photo courtesy of K.T. Belt.

The scientists discovered something surprising about the amount of trace chemicals in the sediment. At four of the sampling sites, the amounts of trace chemicals were two to three times higher than those found at the other sampling sites. When comparing the sampling sites with maps of the watershed, the scientists observed something interesting. They observed that areas close to three of these four sampling sites were land areas created by adding fill dirt to existing low-lying land areas (**figure 19**). The scientists discovered that where these fill areas were created, high amounts of trace minerals were deposited onto nearby riparian areas.

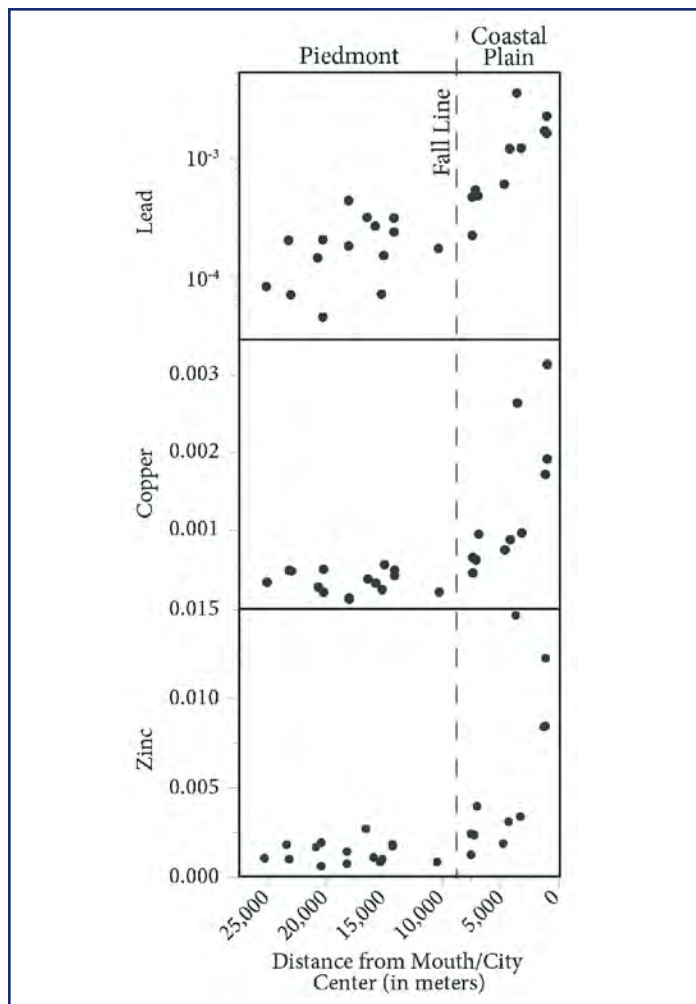


Figure 18. The increase in concentration of the trace metals lead, copper, and zinc shows a strong relationship with the most urbanized areas of Baltimore. Compare this scatterplot with the map of Gwynns Falls watershed (figure 12). Illustration by Stephanie Pfeiffer.



Figure 19. Fill dirt is sometimes used to create land areas that are suitable for development. Look carefully at this photo. Why might high rates of soil erosion be associated with fill dirt? Photo courtesy of Babs McDonald.

Reflection Section



Scientists prefer to use measurements to describe conditions. For example, rather than describing a day as hot, a scientist would prefer to report that the temperature is 94 °F (34 °C). Based on this study's results, what measure might one day be used to describe the amount of an area's urbanization? What is one advantage of using this measure?

The scientists found a relationship between higher levels of trace chemicals in riparian sediment and nearby artificially created land areas. If that same relationship is found in other studies, what might you conclude about one consequence of using fill dirt to create new areas of land?

Elements and Symbols in the Periodic Table

Symbols of elements (chemicals) are written by capitalizing the first letter. Symbols are derived from names of the elements, name of the discoverer, place of discovery, or other characteristic.

In this research, the following elements, or chemicals, were studied:

Element	Symbol
Calcium	Ca
Lead	Pb
Copper	Cu
Zinc	Zn

To examine a portion of the periodic table of elements, see page 50 in the "Caribbean Cruise" article of this *Natural Inquirer* journal.

Discussion

The scientists identified three important potential streamflow processes within urban watersheds. First, urban streams deposit sediment onto riparian areas. This sediment may contain chemicals found in roadways, industrial areas, and other developed areas. Second, the flooding of urban riparian areas during heavy rains may cause roadway, industrial, and development-related trace chemicals to enter waterways. Third, the process of creating new land areas from fill dirt placed in low-lying wet areas may introduce trace chemicals directly into waterways.

The scientists noted that little is known about the effects of increased chemical sediment deposited on riparian areas. Because urban riparian areas appear to have greater percentages of urban-related chemicals, this area deserves more scientific research.

Reflection Section



Do you agree with the scientists that more research is needed about urban-related chemical sediment deposits? Why or why not?

Baltimore is just one urban area among thousands of urban areas across the globe. If the findings of this study were true for all urban areas with nearby waters, what long-term change might you expect to find in these waters, such as rivers, lakes, and coastal bays around the world? What impact would this change have on global health? (Hint: Reread the first sentence of the last paragraph in the "Discussion" section).

Glossary

abundantly (ə **bun** dənt lē): Marked by great plenty.

auger (ò gər): A sharp tool that is used for making holes.

chemical (kə mi kəl): A substance, such as an element or compound.

erosion (i rō zhən): The process or state of wearing or washing away.

exotic (ig ză tik): Strange, different, or foreign.

gradient (grā dē ənt): An ordering of something according to a value. In this article, the urban-rural gradient is an ordering of landscapes according to the number of buildings and population size.

invasive species (in vā siv spē shēz): Any plant, animal, or organism that is not native to the ecosystem it is in, and is likely to cause harm to the environment, the economy, or human health.

land use (land yūs): How people are using the land.

metropolitan (me trə pā lə tən): Of, or relating to, a large city and the surrounding cities and towns.

nutrient cycling (nü trē ənt sik lɪŋ): The uptake, use, release, and storage of nutrients by plants and their environments.

open space (ō pən spās): Undeveloped land that is accessible to the public.

orientation (òr ē ən tā shən): Position or direction relative to other points or directions.

riparian (rə per ē ən): Areas along streams and rivers.

sediment (se də mən): Soil particles carried along in streams and rivers, some of which may settle to the bottom.

sedimentation (se də mən tā shən): The natural process in which material (such as soil, stones, and sand) is carried to the bottom of a body of water.

social sciences (sō shəl sī ən(t)s is): Particular areas of study that relate to human behavior and society.

systematically (sis tə mā tik lē): Marked by thoroughness or regularity, or according to a system.

transition (tran si shən): The act or process of passing from one condition, form, or place to another.

Accented syllables are in **bold**. Marks and definitions are from <http://www.merriam-webster.com>. Definitions are limited to the word's meaning in the article.

What's in a Name?

The title, "Sediment-al Journey," was taken from a popular song called "Sentimental Journey." This song was written by Les Brown and sung by Doris Day in the mid-1940s.

Adapted from Bain, D.J., Yesilonis, I.D., and Pouyat, R.V. 2012. Metal concentrations in urban riparian sediments along an urbanization gradient, *Biogeochemistry*, 107: 67–79. <http://www.treesearch.fs.fed.us/pubs/40667>.



Time Needed

One class period

Materials (for each student or group of students)

- Table on page 72
- Four blank pieces of graph paper (page 123)
- Pencils
- Rulers

The question you will answer in this FACTivity is: What is the relationship between the level of chemicals in a city's soils and level of the same chemicals in the city's riparian areas?

Methods

Examine the table on page 72. This table contains actual data provided to you by the scientists in this study. The table presents the median and mean (average) levels of chemicals found in the Gwynns Falls watershed's riparian areas. The table also presents the median and mean level of chemicals in Baltimore city soils.

You will construct bar graphs based on the data in table 1 to help you understand the data. You can use the graph paper on page 123 to help you construct your bar graphs. You will have to understand the difference between the mean, or average, and the median. The mean is the value of all the values summed and divided by the number of values. The median is the middle value in a list of values, ordered from the smallest value to the largest value.

Your teacher may hold a class discussion about what these two values represent. Both values are summary values, intended to give you a feel for the entire list of values. The average, however, is sensitive to values that may be very different from most of the other values. The median, on

the other hand, is not influenced by values that are very different from most of the other values.

- First, construct a bar graph for the mean value of the chemicals expressed as a percentage of a volume. Include both the Gwynns Falls Riparian Sediments and the Baltimore City Soils. Label the x-axis and y-axis.
- Next, construct a bar graph for the mean value of the chemicals expressed in ppm. Include both the Gwynns Falls Riparian Sediments and the Baltimore City Soils. Label the x-axis and y-axis.

How Much Is 1 PPM?

1 part per million (ppm) is roughly equal to:

1 inch in 16 miles
1 second in 11.5 days
1 minute in 2 years

- Now, observe your two bar graphs showing mean values. What do you notice about the amount of chemicals in Baltimore City Soils compared with the amount of chemicals in the riparian areas? What explanations do you have for your results?
- Now, construct a bar graph for the median value of the chemicals expressed as a percentage of a volume. Include both the Gwynns Falls Riparian Sediments and the Baltimore City Soils. Label the x-axis and y-axis.
- Next, construct a bar graph for the median value of the chemicals expressed in ppm. Include both the Gwynns Falls Riparian Sediments and the Baltimore City Soils. Label the x-axis and y-axis.

Blank graph paper is located on page 123.

- Now, observe your two bar graphs showing median values. What do you notice about the amount of chemicals in Baltimore city soils compared with the amount of chemicals in the riparian areas? What explanations do you have for your results? How do the two pairs of graphs compare? Did each statistical measure (mean and median) lead you to the same explanations?

What do you conclude about using different statistical measures? Your teacher will lead a class discussion about your class explanations and the effect of using different statistical measures to represent and summarize data.

Chemical	Symbol	Gwynns Falls Riparian Sediments		Baltimore City Soils		Unit of Measurement (ppm = parts per million)
		Median	Mean	Median	Mean	
Aluminum	Al	1.9	1.8	1.4	1.4	%
Calcium	Ca	0.29	0.46	0.025	0.043	%
Copper	Cu	20	30	35	45	ppm
Iron	Fe	2.2	2.0	2.2	2.3	%
Magnesium	Mg	0.39	0.39	0.22	0.27	%
Manganese	Mn	450	440	420	470	ppm
Lead	Pb	35	76	89	231	ppm
Zinc	Zn	63	120	81	141	ppm
Cadmium	Cd	54	170	89	106	ppm
Cobalt	Co	11	12	12	15	ppm
Chromium	Cr	32	31	38	72	ppm
Potassium	K	0.12	0.14	0.076	0.090	%
Molybdenum	Mo	35	97	300	500	ppm
Sodium	Na	150	150	96	120	ppm
Nickel	Ni	26	40	18	27	ppm
Phosphorus	P	300	330	460	530	ppm
Titanium	Ti	110	110	197	282	ppm
Vanadium	V	31	33	31	37	ppm

Table 1. Chemicals Measured in Gwynns Falls Watershed Riparian Areas and Baltimore City Soils. Parts per million, or ppm, is a measure of how concentrated the chemical is in water. Percentage is a measure of the percent of a particular volume of liquid that contains the chemical.

Natural Inquirer Connections

You may want to reference these *Natural Inquirer* articles for additional information and FACTivities:

- “Green Means Clean” on page 7 of this edition of *Natural Inquirer*. The FACTivity demonstrates the difference between runoff in vegetated, agricultural, and paved areas. You can modify this FACTivity by eliminating the agricultural option and assuming that the oil represents chemicals in the water.
- “Food for the Soil” *Natural Inquirer* monograph. The FACTivity simulates how water flows onto streambanks during a flood and deposits materials on the streambanks.

These resources can be found at: <http://www.naturalinquirer.org/all-issues.html>.

If you are a trained Project Learning Tree educator, you may use “Water Wonders,” “Field, Forest, and Stream,” and “Soil Stories” as additional resources.



Web Resources

The U.S. Geological Survey (USGS) Water Science School: Runoff

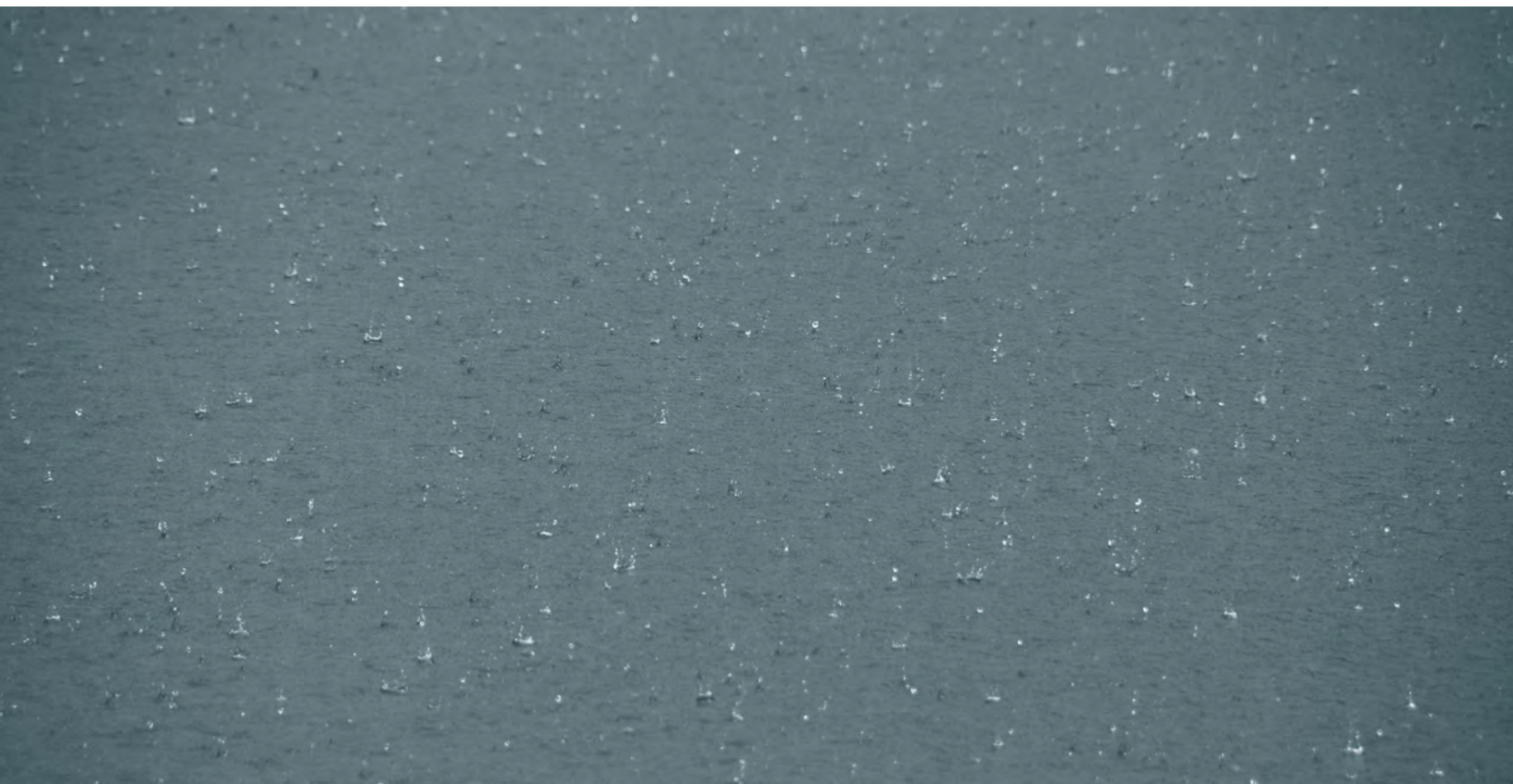
<http://water.usgs.gov/edu/runoff.html>

The U.S. Geological Survey (USGS) Water Science School: Sediment

<http://water.usgs.gov/edu/sediment.html>

When It Rains It Runs Off: Runoff in Urbanized Areas in Arizona

<http://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1542.pdf>



How does this scene relate to what you learned in this article?