Exploring Watersheds in Baltimore

Ecology Education Fellow
Martin Schmidt, McDonogh School

Contributing Scientists
Dr. Peter Groffman
Microbial Ecologist
Institute of Ecosystem Studies
Baltimore Ecosystem Study
Co-Principal Investigator

Dr. Lawrence E. Band
Geographer
University of North Carolina
BES Co-Principal Investigator

Gary T. Fisher, P.E.
Surface-Water Specialist
US Geological Survey
BES Co-Principal Investigator

Dr. Neely Law
Hydrologist
Center for Watershed Protection

Module Editors
Janie Gordon, ScM
BES Education Coordinator
Institute of Ecosystem Studies
Parks and People Foundation

Dr. Alan R. Berkowitz
Head of Education
Institute of Ecosystem Studies
Baltimore Ecosystem Study Co-Principal Investigator

Draft 2 – 3.21.07

Baltimore Ecosystem Study

Janie Gordon, Education Coordinator
800 Wyman Park Drive, Suite 010
Baltimore, Maryland 21211
T - 410-448-5663 ext. 125 F- 410-448-5895
Email - janie.gordon@parksandpeople.org
Website - www.beslter.org

Alan Berkowitz, Education Team Leader
Institute of Ecosystem Studies
PO Box R, Millbrook, NY 12545
T - 845-677-7600 ext. 311 F - 845-677-6455
Email – berkowitza@ecostudies.org
Website – www.ecostudies.org

Overview of Module

This module is designed to have students examine stream study data to understand some of the factors that affect the amount and quality of water in a stream. It uses data collected by the Baltimore Ecosystem Study (BES) on a specific watershed in the Baltimore, MD, region; but it can also serve as an example of the types of data that could be collected, and questions that could apply to, any watershed.

The entire lesson could be completed in 2 to 3 class periods if all the data is presented to the students, instead of the students preparing any of the data themselves; some time may also be added for discussion of the findings. Alternately, the lesson can be longer if it includes the students developing the skills to make their own charts, which they can then use for analysis. Having learned those skills, students can extend the lesson by doing analysis of other data from the BES work. The lesson could be further extended by students applying these skills to new watersheds - such as where their home or school is located - and doing analysis of that data. These and other ideas for extensions are described in the section titled Watershed Lesson Extensions.

Using the materials

The Module includes the following parts:

1. Teachers' Guide (filename: **Watersheds Module – Draft 2 – Teachers' Guide**)
    a. Introduction to Module
    b. List of maps, tables and charts
    c. Learning Objectives and Applicable Standards
    d. Introduction to Watersheds - Background for the teacher
    e. Glossary of Terms
    f. Resources for Additional Information
    g. Answers to problems in student lessons
    h. In-Class Extensions
    i. Lab and Field Extensions

2. Student Handouts
    a. Student Lesson (filename: **Watersheds Module – Draft 2 – Student Lessons)**
    A series of lesson assignments designed to be copied and handed to the students as an exercise; their answers would go on separate paper
    b. Background readings for students.
    c. Students' Guide to Using Excel (filename: **Watersheds Module – Draft 2 – Students' Guide to Using Excel)**
    Directions, to be copied and distributed to students if they are going to be developing charts themselves and are not familiar with the techniques needed to make these charts.

3. PowerPoint Visuals File (filename: **Watersheds Module – Draft 2 – Powerpoint File)**

This file contains all of the maps and charts needed to do the lesson. This file may be projected for all students to use, or printed out (one slide per page) and copied for students to use on paper. Most of these will still be effective if printed in black & white; a few may need extra labeling.

4. Data Files
   Excel spreadsheets that contain the data and charts referred to in the lesson, including:
   a. Discharges data (filename: **Watersheds Module – Draft 2 – Discharge Data.xls)**
   b. Chloride data (filename: **Watersheds Module – Draft 2 – Chloride Data.xls)**
   c. Nitrate data (filename: **Watersheds Module – Draft 2 – Nitrate Data.xls)**

   NOTE: If a class is using the paper charts, these Excel files will not be needed. If a computer video projector is available, or individual computers for students or lab groups, these Excel files could be another way to simply view the charts, with the advantage that the user can put the cursor over a point and find its value (not possible in PowerPoint). If the data files will be used for student practice on making Excel graphs, the teacher should open an original Excel file, delete the chart(s) that the students will create, and save the Excel file with a new name - this will then be the file the students begin with.

List of maps, tables, & charts

NOTE: all found in the Powerpoint File (filename: **Watersheds Module – Draft 2 – Powerpoint File)**

☐ Map A = Major watersheds in the Baltimore region.
☐ Map B = Gwynns Falls watershed and its streams, and subdivides the watershed to show the watersheds of several tributaries.
☐ Map C = BES stream study sites and their watersheds.
☐ Map D = As Map C with land use/land cover.

☐ Table 1 = Characteristics of the 7 study watersheds.

☐ Charts 1-3 = Hydrographs of streams, grouped by low, moderate, & high discharges.
☐ Chart 4 = Flow multiples for Pond Branch, Carroll Park, & Dead Run.
☐ Chart 5 = Flow multiples for Carroll Park, Villa Nova, and Gwynnbrook.
☐ Chart 6 = Chloride graph for period of record for Villa Nova, Dead Run, & Carroll Park.
☐ Chart 7 = Chloride graph for period of record for Pond Branch & McDonogh.
☐ Chart 8 = Same as Chart 6, with snowfall data added.
☐ Chart 9 = Nitrate graph for McDonogh, Gwynnbrook, & Pond Branch, for 1/1/00-12/3/02 (mostly because McDonogh didn't start until Dec 99).
☐ Chart 10 = Nitrate graph for the 4 Gwynns Falls sites (Glyndon, Gwynnbrook, Villa Nova, and Carroll Park), for period of record.

Learning objectives & applicable standards

Students using the Investigating Watersheds in Baltimore Module will address the following standards from the Core Learning Goals (CLG) for the state of Maryland:

1. Analyze data to draw conclusions (CLG 1.4.2). If applicable, also organizing the data into graphs (CLG 1.4.1).
2. Formulate and test a hypothesis (CLG 1.2.3 & 1.2.4).
3. Using computers to produce graphs, if the teacher decides to have students use the data in this way. (CLG 1.5.3).
4. Looking at examples of how natural and man-made changes in environmental conditions will affect individual organisms and populations (CLG 3.5.3).
5. Consider how consequences and/or trade-offs between technological changes have an effect on the individual, society, and the environment (CLG 3.6.1) when applied to watersheds.
6. Examine the interrelationship between humans and water quality and quantity (CLG 6.3.2).
7. Examine surface water processes. (CLG 2.4.2).
8. This lesson would also be included in the goals of the NRC National Science Education Standards in Content Standards F (Science in Personal and Social Perspectives), which includes study of changes in environments (K-4), environmental degradation (5-8), and environmental quality (9-12).

An Introduction to Watersheds

All life on Earth needs water to live. In some places like deserts, life struggles to find enough quantity of water to use, while other places the amount available is ample. But even when we have enough quantity, the quality or purity can be a concern, that is, whether the water is useable for a particular purpose. Thus, we need to pay attention to both quantity and quality of water around us - this study is called hydrology.

In eastern North America, the main water we see in nature is rain & snow falling, then collecting & running off into streams and rivers. For any given stream, there is an area of land from which rain and snowmelt flow downhill into that stream - this area of land is called the watershed for that stream. Since all of the water flowing into that stream flows over or through the watershed, it makes sense that the conditions in the watershed will have an effect on the water.

Though we are mainly aware of the water that collects and flows on the surface, some of the precipitation falling in the watershed also soaks into the ground, and so becomes groundwater. This groundwater saturates layers under the ground surface, much like water fills a sponge; this water also flows slowly downhill and in places flows out of the ground and back to the surface. This can happen in springs, where water visibly flows out of the ground, or less visibly when groundwater flows into a stream from the streambed itself. Thus, a complete study of a watershed will also take into consideration what happens to the groundwater of that watershed. Though we will not directly study groundwater in the Gwynns Falls study, we may see some of its effects.

Another factor included in a complete watershed study is a consideration of water in the air - especially rainwater that evaporates and water vapor given off by plants, called transpiration. Hydrologists consider these together, calling them evapotranspiration, or ET for short. This can have substantial effect on a water budget accounting for where all the water goes: in Baltimore, about 50% of the annual precipitation is returned to the atmosphere by ET. We mostly "see" ET process by their effects - for example, ET is why streams often run higher in the winter than in summer (because more water evaporates in the warmer summer), and ET is why there are more and bigger streams in the humid eastern U.S. than in the arid western U.S. (because in the west, nearly all the water evaporates, leaving little to flow in streams). Also, in cities, ET has a cooling effect, as the water absorbs significant amounts of heat as it evaporates. Values for ET in our area won't be part of this study, but it is a factor that has effects.

There are many things that affect the quantity and quality of the water in a watershed. First, there are factors that relate to the land. For example, the steepness of the watershed in general affects the water flows, so mountain watersheds will have different characteristics compared to flatter ones. The rock types and the resulting soil are also important, with the latter being affected by the climate. The climate is the second major part, after the land itself, and includes both temperature and amounts of precipitation. The temperature affects how much precipitation falls as rain compared to snow. The amount of precipitation is important both in how many inches fall during a year, and how it occurs over time, for example, whether more happens in a rainy season or is it spread out over the year. The climate also controls the vegetation types in the watershed, which in turn affect how much water runs off compared to how much can soak into the ground. It's important to also note that watersheds are connected to one another - a stream flowing from the mountains to the ocean flows through many watershed areas, so what happens in one affects others, and it is useful to see how they are related to each other.

Then there are many ways humans affect watersheds & the water in them. If people change the vegetation from what is naturally there - for example, change a forest into a farm field or a lawn - we change how the water will act in that watershed. When humans remove vegetation to build houses, roads, and parking lots, we create what are called impervious surfaces where water cannot soak in at all; these surfaces increase runoff water, which is the water flowing in surface streams, while decreasing groundwater. Humans also add new chemicals to a watershed, such as fertilizer or household and industrial chemicals, and these chemicals can be picked up by rain and so be added to the streams and rivers. Humans take water from rivers and wells (which get their water from groundwater) for drinking and other purposes, and return water to streams after use; this returned water may be good enough quality to reuse, or it may not.

Hydrologists measure both quantity of water in a stream and its chemical quality. The quantity of water is called discharge, and is the amount of water flowing in the stream per unit time; in the U.S., it is usually measured in cubic feet per second (abbreviated "cfs"). To measure quantity of water in a stream, the concept is to measure a cross-sectional area of the stream (which will be in square feet), and multiply that by the velocity of the water movement (in feet per second), to get cubic feet per second. Doing this requires measuring the width of the stream, its depths in several places, and the stream velocity in several places.

Water quality is measured by taking samples of the water in the stream and using chemical analysis methods to find the concentrations of substances in the water. Sometimes we are looking for toxic substances, and other times looking for materials which are useful because they are nutrients for plants and animals, but may cause a problem if found in high concentrations in the water. An example of the latter is the nitrate (NO_3^-) ion. Nitrogen is necessary for plant and animal life and nitrate is a highly soluble (plant-available) form of nitrogen, so it is considered a nutrient; humans use nitrogen compounds that are converted to nitrate as fertilizer on crops and lawns. It is also a waste product of plant decomposition, and in manure & sewage - all of this nitrate eventually flows to streams. Nitrate also forms from burning fossil fuels such as gasoline; this nitrate is deposited from the air or washed out of the air by rain, so it reaches streams as well. When nitrate flows into streams, it serves once again as a nutrient to plants in the water, which can result in blooms of algae and other vegetation in streams or in the Chesapeake Bay. When this vegetation decays, however, it can consume oxygen in the water, killing fish and other animal life in the water. These types of effects are why we monitor nitrate, and other nutrients such as phosphate.

Urban watersheds add complications. Impervious surfaces not only change the quantity of water, but also allow nutrients or other pollutants to run off quickly, as there is no place for them to soak into soil. Rainwater that flows into storm drains may go directly into streams, or may go into groundwater if the stormwater sewers are leaky - which occurs determines how fast the nutrients reach the stream. Meanwhile, nutrients can flow out of leaking sanitary sewage pipes on a continuing basis (this system is usually separate from the stormwater sewer pipes) and into streams or into groundwater. On top of any continual leaks, stormwater and sanitary sewage can get mixed in high-rainfall events, or when a sanitary sewer becomes clogged and overflows. Because Baltimore has been in existence a long time, its sanitary sewer system has aged and is known to need repair & replacement in many places, so this is likely source of nutrients in Baltimore watersheds. Nutrients can be removed from sewage at wastewater treatment plants (depending on the capabilities of the plants - there are plans to upgrade Baltimore's plants), but if the sewage leaks out of the pipes before reaching the plant, their nutrients can reach streams and the Chesapeake Bay.

Overall, a watershed is characterized by a set of many factors, and systems that interlock to affect one another. Thus, hydrologists studying watersheds look at many different aspects, to understand how they come together to create the particular characteristics we find in any chosen watershed.

Glossary of Terms

base flow - The normal discharge of a stream, unaffected by, for example, a recent rain or drought conditions.
divide - The upper or outside boundary of any watershed.
discharge - Quantity of water flowing in a stream per unit time; usually measured in cubic feet per second (abbreviated "cfs").
groundwater - Water which saturates and moves through the soil underground, much like water in a sponge.
hydrology - The study of all aspects of water, in this case, in a watershed. This can include studying the discharge and other physical characteristics, as well as chemistry of the stream
impervious - Description of any material which does not allow water to pass through it. Specifically, a land use is impervious when it will not allow water to soak into the ground beneath that land use; examples would be roads, parking lots, sidewalks, and any building roofs. Some land uses, such as residential, are a combination of pervious surfaces like lawns, and impervious surfaces like houses and driveways. Commercial and industrial land is usually largely impervious due to buildings and parking lots.
land use/land cover - A classification of what is on the land. Land uses are usually human-created, such as residential, commercial/industrial, or cropland; land covers, such as woods, water, or grasses, are natural. Of course, in an urban or suburban area, nearly everywhere is controlled by human land use decisions, even if it is woods or grass.
runoff - Water from precipitation (rain or melted snow) which travels on the surface to a stream, where it is carried away.
stream gage - A device in a stream to measure & record the height of the water level in the stream. When calibrated, this can tell us the discharge of the stream at the time the water level height is measured.
study site - A location on a stream where a stream gage is located and samples are taken to study water quality.
watershed - An area of land over which all of the surface runoff from precipitation drains to a particular stream.

Resources for Additional Information

Organizations

If your school or students which to become active concerning their own watershed, they might contact these organizations:

Gwynns Falls Watershed Association
Jones Falls Watershed Association
Herring Run Watershed Association
Trib Teams

Water-related websites (Current as of 16 July 2004)

http://waterontheweb.org/

Water on the Web (WOW) helps college and high school students understand and solve real-world environmental problems using advanced technology. WOW is a complete package containing two sets of curricula, data from many lakes and rivers nationwide, extensive online primers, data interpretation and Geographic Information System Tools, and additional supporting materials.

http://www.awwa.org/Advocacy/learn/education/WaterEducationResources.cfm

American Water Works Association
Links for Water Education

http://www.projectwet.org/

Project WET (Water Education for Teachers) is a nonprofit water education program and publisher for educators and young people ages 5-18. The program facilitates and promotes awareness, appreciation, knowledge, and stewardship of water resources through the dissemination of classroom-ready teaching aids and the establishment of internationally sponsored Project WET programs.

http://www.wetcity.org/

WET in the City engages K-12 youth in hands-on activities that creatively explore the science of water, its cultural context, and complex issues surrounding its management and stewardship. The program is delivered at the local level, city by city, and targets urban educators with relevant, localized water education through a network of city partners

http://water.usgs.gov/education.html

Water Resources Information for Students and Teachers
http://wwwga.usgs.gov/edu/
Welcome to the U.S. Geological Survey's (USGS) Water Science for Schools web site! We offer information on many aspects of water, along with pictures, data, maps, and an interactive center where you can give opinions and test your water knowledge.
http://www.groundwater.org/

The Groundwater Foundation is a nonprofit organization dedicated to educating and motivating people to care for and about groundwater

http://www.epa.gov/water/kids/watered2.html

Sites that contain lesson plans or projects. Information aimed at educators.

http://www.epa.gov/safewater/kids/wsb/

The Water Sourcebooks contain 324 activities for grades K-12 divided into four sections: K-2, 3-5, 5-8, and 9-12. Each section is divided into five chapters: Introduction to Water, Drinking Water and Wastewater Treatment, Surface Water Resources, Ground Water Resources, and Wetlands and Coastal Waters.

http://www.adopt-a-watershed.org/

Adopt-A-Watershed is a K-12 school-community learning experience using a local watershed as a living laboratory in which students engage in hands-on activities, making learning applicable and relevant to their lives. The program weaves education with the community, developing collaborative partnerships and reinforcing learning through community service.

http://www.uwex.edu/erc/eypaw/

Educating Young People About Water (EYPAW) guides and water curricula database provide assistance for developing a community-based, youth water education program. These resources target youth and link educators to key community members to build partnerships to meet common water education goals.

http://www.wef.org/WefStudents/
Welcome to the Water Environment Federation on the Web. Founded in 1928, WEF is a not-for-profit technical and educational organization. Our members are from varied disciplines and they collaborate with staff to realize the WEF vision of preservation and enhancement of the global water environment. The WEF network includes water quality professionals from 79 Member Associations in over 30 countries.
http://www.aquaventurer.org/

A Global Timeline and Database of Water Use, Abuse and Treatment. *(Interactive!)*

http://www.fi.edu/city/water/

Information on water basics, water science, Philadelphia waterways, worldwide waterways, references and activities.

http://destiny.mbhs.edu/riverweb/

Welcome to the Water Quality Simulator, a proof-of-concept, web-based, interactive learning environment designed to engage students in authentic problem-solving about physical, chemical and biological processes affecting water quality. *(Interactive!)*

http://kids.earth.nasa.gov/water.htm

How NASA Studies Water

References

Law, N.L. 2004. Analysis of water quality trends in urban-suburban watersheds. Ph.D Dissertation. University of North Carolina, Chapel Hill.

Law, N.L., L.E. Band, and J.M. Grove. In press. Nutrient input from residential lawn care practices. Journal of Environmental Management.

Law, N.L., L.E. Band, P. Groffman, K. Belt, and G.T. Fisher. Submitted. Water quality trends and determinants in developing urban-suburban watersheds. Hydrological Processes.

Answers to questions in student exercise

Activity I - Where is the watershed we will study?

1. The regional view.
    a. The Gwynns Falls is located in the Patapsco River watershed.
    b. Yes, the Patapsco & the Gwynns Falls both drain to the Chesapeake Bay.

2. The watershed view.
    a. There are 7 subwatersheds on Map B.

b. Though it does not empty into the flowing river section of the Patapsco, the Gwynns Falls flows into the estuary of the Bay known as the Patapsco River, and therefore it is considered to be in the Patapsco watershed.

c. In the city, water often drains to the storm sewers, and flows through the underground pipes, so no stream is visible at the surface to put on a map. Before the city and its storm sewers were built, there were surface streams in these watersheds.

Activity II - What are the conditions in various parts of the Gwynns Falls watershed?

3. Using maps.

a. The 7 study sites we will use are: Glyndon, Gwynnbrook, Villa Nova, and Carroll Park coming down the Gwynns Falls itself; McDonogh and Dead Run are tributaries that flow into Gwynns Falls; and Pond Branch is in a separate, nearby watershed.

b. In order by increasing size, the watersheds are: McDonogh, Pond Branch, Glyndon, Gwynnbrook, Dead Run, Villa Nova, and Carroll Park.

c. We would probably expect more development and more dense development as we move from the upper parts of the watershed to the areas in the city. As a result, there would be more grass and trees in the upper parts of the watershed, and more paved (or roofed) impervious areas as we got to the city. This would be true of other watersheds in the region as well, and around other cities that are on a coast or on a river, so streams drain toward the city.

d. Students should be able to tell that McDonogh is mostly agricultural, and Pond Branch is mostly forest. The others are largely residential, with more urban areas as you move down the watershed.

e. The watersheds in descending order of percent impervious area (highest first) are: Dead Run, Carroll Park, Glyndon, Villa Nova, & Gwynnbrook; both McDonogh and Pond Branch have 0 impervious areas. This is not a simple progression with the "most downtown" automatically the most impervious. This has multiple causes, including 1) there is quite a bit of development all through the watershed; 2) the residential land use classification is vague and doesn't do a great job distinguishing between new low density suburbs in the headwaters and older, denser suburbs closer to downtown; and 3) the "nested" nature of the sites along the Gwynns Falls itself, so that the calculation of percent impervious in each watershed is not separate, but also includes the watersheds above it.

f. Using Table 1, the classifications are:
Forest - Pond Branch

Agriculture - McDonogh
Urban - Dead Run and Carroll Park (2 highest in impervious surfaces)
Suburban - Glyndon, Gwynnbrook, Villa Nova

But Glyndon could also be considered urban based on its high total percentage of land classified as urban-open and urban-other.

4. Other characteristics that might be studied are (and this is not an exhaustive list):
a) Geology - Nearly all of the Gwynns Falls is metamorphic rock, and so similar in characteristics, but there are local differences in permeability & chemistry.
b) Soils - Soils are made from the underlying rock, and so can reflect the geology. Soils also vary with topography, so hilltops, slopes, and valleys will vary. In the Gwynns Falls watershed, there are more natural soils in the upper half of the watershed, and more disturbed (moved by humans) soils in the lower part of the watershed.
c) Slope affects runoff, so if a watershed has more land in slope, it may have different hydrologic characteristics compared to another watershed with less slopes.
d) Vegetation - Different vegetation will cause different runoff rates, as well as differing evapotranspiration rates.
e) Land use practices - Given a certain land use classification, the actions of people using it may change the hydrology.
f) Subterranean actions - In addition to human actions visible on the surface and reflected in the land use classification, humans can also affect the hydrology with underground construction such as sewer and stormwater piping systems.
Most of these aspects have not been extensively studied yet for the Gwynns Falls, but may enter discussions later in this lesson.

Activity III - How and why does the discharge vary in this watershed?

5. a. The streams do not have a constant flow. They have higher discharges when it rains or there is melting snow, and they have lower discharges in dry conditions.

b. Yes, the pattern of variation is similar because they all rise when it rains (or snow melts), and fall when it is drier.

c. Reasonable values for base flows should be around these values: McDonogh = .02 cfs; Pond Branch = .09 cfs; Glyndon = .1 cfs; Gwynnbrook = 2 cfs; Dead Run = 1.5 cfs; Villa Nova = 22 cfs; Carroll Park = 40 cfs.

d. The maximum values for each stream are: McDonogh = .25 cfs; Pond Branch = 1.1 cfs; Glyndon = 12 cfs; Gwynnbrook = 151 cfs; Dead Run = 432 cfs; Villa Nova = 1590 cfs; Carroll Park = 3520 cfs. These values are from the original data; values read from graphs should be close to these. Since these maximum values are many times the base flow values, there is a good bit of variation in the flows.

e. A large flow would be a flood, and may affect people living near the stream. Large flows can erode the banks, changing the vegetation around the stream. Very low flows can kill animals that live in the water. Many other effects could be mentioned.

f. Graphing all 7 streams on the same chart would result in a confusing array of lines. Also, the discharges of the 7 streams are so different that if a Y-axis scale is set up to plot the values that occur with the high-discharge streams, the hydrographs for the lower-discharge streams would be essentially horizontal lines at that scale, and their variation would not be apparent.

6. a. In order of increasing flashiness: Pond Branch, Carroll Park, Dead Run.

b. An important characteristic that contributes to flashiness is the amount of impervious surfaces, because rain & snowmelt run off of these surfaces quickly. Conversely, pervious surfaces allow rain & snowmelt to soak into the ground, so this water flows more slowly to streams via groundwater, and the stream discharge is more even. The order of the streams found in 6a matches their order of increasing amount of impervious surfaces, providing a sensible explanation of their behavior. Point out to students that this impervious-flashiness connection is considered a usual principle in hydrology of streams.

c. In general, we would expect streams to become more flashy as development increases the amount of impervious surfaces. Since increasing flashiness creates problems (floods, erosion, and general unpredictability), this might be a reason to limit growth, or at least plan the growth in a way that minimizes increases in impervious surfaces. This is one example of how human decisions have an impact on the streams and ecosystems around us.

7. a. Similar to Chart 4, Chart 5 also shows the multiple of base flow for 3 streams, and for the same time period as Chart 4. But Chart 5 is for 2 streams not in Chart 4.

b. In increasing order of impervious surface proportion, the 3 streams are: Gwynnbrook (17%), Villa Nova (19%), and Carroll Park (27%). Based on question 6, students would probably predict this is also the order for increasing flashiness, and make a general rule that increasing imperviousness causes increasing flashiness.

c. With some regularity, there are higher peaks for Gwynnbrook than for Carroll Park, suggesting Gwynnbrook is almost as flashy as Carroll Park, and Gwynnbrook is often more flashy than Villa Nova; this order does not match their imperviousness order. Explanations are an open subject and could be the subject of future investigations. Note that Gwynnbrook is highest in the watershed of these 3; the lower 2 might show less flashiness because as discharge increases downstream, it's harder to make significant changes to the amount of water. Gwynnbrook might also be noticeably different from the other 2 watersheds in some of the other characteristics mentioned in question 4 above.

d. The rule might become "Increasing imperviousness causes increasing flashiness in general, but other factors may also affect flashiness in a particular watershed."

Activity IV - How and why does the water chemistry vary in this watershed?

8. a. On Chart 6, the chloride concentrations range from near 0 to over 4500 mg/L, with the highest values occurring in the winter and early spring months.

b. On Chart 7, the chloride concentrations range from around 2 mg/L up to about 9 mg/L. These concentrations are much lower than those in question 8a.

c. The streams in Chart 6 are developed suburban and urban watersheds, while the streams in Chart 7 do not contain any developed areas, only forest or agricultural lands.

d. Knowing that salt is NaCl, and so provides Cl^- in solution, and that salt is used to melt snow & ice on roads in the winter, it would be sensible to hypothesize that this Cl^- comes from road salt. This is also supported by the lack of Cl^- in the watersheds (in Chart 7) where there are no roads. To further support this hypothesis, we could look at when the Baltimore area had snowfalls to see if they coincide with the times of high amounts of Cl^-.

e. Chart 8 shows snowfalls that coincide well with the increases in Cl^- concentration, thus supporting the hypothesis that the Cl^- comes from road salt.

f. Though at the highest reading in this data, the Cl^- concentration is only about a fourth the concentration found in seawater, students should appreciate what would happen if the only water they had to drink were salty. From this, they can probably understand that this salinity could have a negative effect on freshwater plants and animals in these streams. A particular problem is the extreme variability of the Cl^- concentrations: plants and animals can adapt to high or low Cl^- levels when those concentrations are relatively constant, but when Cl^- levels change by factors of 100 or even 1000, it is very hard to adapt.

The pros & cons should be a student discussion, and might include various aspects, such as: The use of road salt is good for the convenience and safety of drivers and passengers, but bad for the stream ecosystems. Use of road salt could be reduced if there was less demand for clear roads because people stayed home when it snowed or used other transport (such as trains or subways); but people need to go to work to earn a living, and clear roads may still be needed for emergency vehicles. Other chemicals that may have less pollution effects can be used to melt ice on roads, but these chemicals cost more than NaCl - are they worth paying extra for? Again, humans' choices, as in question 6c above, do have an effect on the ecosystem, and the Cl^- example is a very clear, direct effect; students should begin to see a trend here.

9. a. The highest nitrate concentrations are found in the agricultural land use (McDonogh), and the lowest are in the forest land cover (Pond Branch); the 2 urban/suburban watersheds (Gwynnbrook and Dead Run) are intermediate.

b. The higher nitrate concentration in the agricultural watershed is probably from fertilizer applied to crops. The nitrate in urban/suburban watersheds is from lawn fertilizer, septic tanks (where there are no sewers), and leaking sewer pipes. The nitrate in forested watersheds is from slow decomposition of plants & animals.

c. The urban/suburban watershed has the larger amount of imperviousness. This would suggest that watersheds with more impervious surfaces might be likely to have elevated nitrate levels, though less nitrate than agricultural watersheds.

10. a. The nitrate concentration is generally highest in the winter, then declining the rest of the year; there are exceptions to that trend. A major reason this might occur: Cold temperatures in winter mean plants are not growing and absorbing nutrients, so nitrates run off in the streams, while in the growing season months, the nutrients are taken up by plants.

b. As we go down the watershed, the nitrate concentrations generally decline. This does not agree with the relationship found in question 9c, as we generally get more imperviousness as we move down the watershed, yet the nitrate levels decline. Also, the patterns are variable: while the levels of decrease in nitrate generally follow the downstream order (Glyndon, Gwynnbrook, Villa Nova, Carroll Park), the order of increasing imperviousness (Gwynnbrook, Villa Nova, Glyndon, Carroll Park) is not the same. Dead Run is high in imperviousness, yet lower in nitrate levels. It is almost as correct to reverse the original relationship and say that more imperviousness results in less nitrate runoff, though there are exceptions to this as well (e.g., Glyndon - high in both imperviousness compared to other suburban watersheds, but also high in nitrate). It seems other factors in addition to imperviousness need to be considered to explain nitrate levels.

c. The nitrate concentration could decline as we go downstream simply because there is more water downstream, so some of this can be a dilution effect; however, in order for dilution to occur downstream, there must be less added nitrate flowing into the streams than was occurring upstream, so we still must explain why there is less nitrate added downstream. Nitrate in the upper, suburban areas of the watershed can come from (1) lawn fertilizers, (2) release of agricultural fertilizer on land which was previously cropland (in newer subdivisions), and (3) septic tanks and leaking sewer pipes. Runoff from suburban areas is also affected by watering of lawns, changing both the amount of nitrate flowing to the stream and the amount of water in the stream. Nitrate in the urban areas can come from (1) runoff from impervious surfaces of air- or rain-deposited nitrate, and (2) leaking sewer pipes.

d. Yes, humans are increasing nutrient levels in streams in many ways. Actions to be taken can generate good discussion. Some examples of actions and pros & cons: Agricultural fertilization provides needed food, but may need to be limited to reduce nutrient runoff. Forests provide land with low nutrient runoff, so removal of forests for development or wood harvesting should be considered with care. Lawn fertilizers may make lawns which are considered attractive but may also damage the wider environment, and using less fertilizer not only doesn't cost anything, it actually reduces costs. Note also that use of lawn fertilizer is a practice occurring in the watershed, not a land use characteristic, so actions taken on the land can be as important as its land use classification. But adding nitrate-removal systems to septic tanks, and fixing leaking sewer pipes, is costly. And, as in question 6c, this can be another negative effect of increasing imperviousness in a watershed, and so a factor in considering the effects of growth of roads & buildings. Sewage treatment plants can be successful at removing nutrients, but may cost tax dollars to make and keep them effective. Clearly there are many human choices that affect nutrient levels in streams.

11. a. The three conversion factors ($28.32 \times 86400/1 \times 10^6$) equal 2.4468, so it's easiest to multiply (flow x concentration x 2.4468) for each station. These values have been rounded to 3 or fewer significant digits, which is reasonable for this use and for the accuracy of the original data.

Station	Discharge - cfs	Nitrate concentration - mg/L	Total nitrate load- kg/day	Load added downstream - kg/day
Glyndon	0.1	2.27	0.56	0.56
Gwynbrook	2	2.07	10.1	9.54
Villa Nova	22	1.33	71.6	61.5
Carroll Park	40	1.14	112	40.4
Dead Run	1.5	0.6	2.20	-----------
McDonogh	0.017	4.1	0.17	-----------
Pond Branch	0.09	0.02	0.0044	-----------

b. Values for nitrate added downstream are shown in the above table.

c. The nitrate load clearly increases as we move downstream in the Gwynns Falls. At over 100 kg of nitrate per day, the load at Carroll Park contributes a fairly large amount of nitrate to the Bay (though, of course, many larger streams contribute more, and there are many streams flowing into the Bay).

d. Villa Nova (that is, the area between the Gwynbrook station and the Villa Nova station) adds the largest amount of nitrate. This is a suburban watershed. This data suggests that we might not

be surprised to find more nitrate from a suburban watershed than an urban one, even though this may seem a little counterintuitive (that is, we often think of urban watersheds contributing more pollutants than suburban ones). This is why we collect data - to see if things happen as we expect, or not.
e. Dead Run does not seem to contribute much nitrate to the Gwynns Falls.
f. Despite its high concentration, the total load of nitrate from the McDonogh tributary is small.
g. As expected, the nitrate load contribution of Pond Branch is very small.

Activity V – Overall Summary

12. a. Watersheds and stream systems tend to be complex, with multiple interacting factors that determine their characteristics.

b. Yes, humans do affect the amount and chemistry of water in streams, and many of these affects can be controlled by human choices.

In-Class Extensions to Watershed Lessons

Most of these extensions are keyed to each the 4 main activities of the module - so they are mostly independent of each other, and teachers can do as much or as little of an extension for each activity as time and wishes allow. Thus, some activities can be short (using just the presented materials), while others may be long (as students develop their own materials) - emphasize whatever parts you choose. Many extensions relate to computer use, especially to prepare the data for analysis, so computers and their availability may determine some choices. The large amount of data in this study makes computer practice for the students especially relevant.

One extension that applies to all activities is that of doing a study similar to the basic lesson for a new watershed - presumably the one where your school is, or, if different, where students live. This will require looking for additional information, but hopefully would be interesting and relevant for the students. Sources of information on other watersheds are included below.

Activity I - Where is the watershed we will study?

1. For all maps in Activity I & II, the maps can viewed on computers, especially using geographic information systems (GIS) software. In this case, the maps would probably come from the BES web site, but other data could be added as well. This does allow more flexibility on map use (e.g., zooming in or out, turning on certain layers when needed), but is more complicated to set up.
2. The location of other regional watersheds can be explored at the Chesapeake & Mid-Atlantic from Space site, <http://chesapeake.towson.edu/>. You can determine what watershed you are in at EPA's <http://cfpub.epa.gov/surf/locate/index.cfm>, though this will tell you a major watershed, not a local one. In Maryland, you can locate your watershed (and lots of other information) at <http://md.merlin.net/>.
3. If you use GIS software, you can download a MD state watershed map at <http://dnrweb.dnr.state.md.us/gis/data/index.html>.
4. Instead of starting with a watershed map, students can delineate a watershed themselves. There are various approaches:
    a. On a map which shows streams, students can draw lines between the streams - these lines will be the approximate location of the watershed boundaries; this simple exercise may help students realize what a watershed is. Of course this does not use the elevations that create the watershed, but is fairly easy. A map to do this for the Baltimore region - with the Gwynns Falls watershed in the center - is included in the visuals for the lesson. Users of that map will need to ignore some extra lines in the Bay, and work around some stray unconnected streams.
    b. If students understand topographic contour lines, they can delineate the watershed following the watershed divide using the elevations. Paper topographic maps can be obtained from the US Geological Survey, perhaps starting at <http://geonames.usgs.gov/pls/gnis/web_query.gnis_web_query_form>, where you can type in a place name and it will tell you what quad you are on. To get the entire Gwynns Falls watershed would need 4 1:24,000 scale quadrangles. You can view topographic maps online at

<http://terraserver-usa.com/>, and these can be printed, and/or downloaded to your GIS; thus, the delineation could be done on paper or on a computer.

c. If you go to <http://seamless.usgs.gov/>, you can view a shaded relief picture of a digital elevation model (DEM) - this may be helpful for students to visualize a watershed, and does not require them to understand contour lines. These views can be downloaded, and the watershed delineated using the elevations. DEMs can also be downloaded from EPA BASINS data, at <http://www.epa.gov/waterscience/basins/b3webdwn.htm>, but these require GIS software, and it will take some perseverance to prepare the DEMs for use.

Activity II - What are the conditions in various parts of the Gwynns Falls watershed?

1. For any watershed that has been delineated on a map, it is possible to overlay a grid of squares of known size copied onto clear plastic, and to count the squares to find the area of the watershed. Or, using GIS software, one can draw a polygon that includes the entire watershed and have the computer calculate its area.
2. A source of land classification for other areas of Maryland and all of the states that are part of the Chesapeake Bay watershed is available at a website mentioned above, <http://chesapeake.towson.edu/>. This includes percent impervious figures for some major watersheds.
3. Information on the geology of various areas of Maryland can be found at the Maryland Geological Survey website, <http://mgs.md.gov/>.
4. Some information on soils is in paper format, and some may be available at web sites. A place to start looking for information is <http://www.md.nrcs.usda.gov/technical/soils.html>.
5. If the information can be located, students could use aerial photographs to examine how a watershed's land use/land cover has changed over time, and how that may have affected water quality.

Activity III - How and why does the discharge vary in this watershed?

1. For all graphs used in Activities III and IV, students can look at the original graphs in Excel, instead of graphs on paper or in PowerPoint. One advantage is that the students can place the pointer over points on the graphs and learn the actual date and value of that point. They also can stretch graphs vertically or horizontally in order to see more detail in the graph, and look at the properties of the graphs as examples of how to set them up. Finally, they can alter graphs (perhaps copying & pasting the original to a new location and altering the copy while leaving the original untouched) to investigate different aspects.
2. The stream discharge for many USGS stream gages is available at <http://water.usgs.gov/>. Students could obtain data for some of the BES stream study sites for years not included in the lesson data, or obtain data for other watersheds. Once downloaded, the data can be graphed in order to interpret it; more detailed instructions for doing that using Excel are given in another part of this lesson. This, and the extensions mentioned under Activity IV below, is a good application for students to learn the useful skill of being able to graph spreadsheet data, and to apply that skill to explore a wide variety of questions. Using land use/land cover data mentioned above, other watersheds could be compared to the findings found for the BES watersheds.

3. If there is a source of rainfall data for your area, such as at the NWS station at Sterling, VA, at <http://www.erh.noaa.gov/er/lwx/climate.htm> (has BWI Airport weather data), students can download rainfall records and graph this information with stream discharge, to see the effects of particular amounts and timing of rainfall in a watershed. They can do the same graphs for other watersheds and see if the effects are the same or different. Rainfall data can also be obtained from the National Climatic Data Center (NCDC) at <http://lwf.ncdc.noaa.gov/oa/ncdc.html>; however, this data only comes as a graph for free, and numerical data must be purchased. In the future, there may be some weather data recorded by BES weather stations posted on the BES website.

Activity IV - How and why does the water chemistry vary in this watershed?

1. There is more water chemistry data on each of the BES study sites that could be graphed; this is a good extension because students can ask similar questions to those in the basic lesson, and compare their answers to the water chemistry conclusions they drew already. Other chemistry data covers total N, phosphate, total P, and sulfate. Students can get lots of practice on spreadsheet graphing skills using this data, while each student or student group graphs a different set of data, so they can be investigating their own question. Results of a wide variety of graphs could then be reported to the class. Use the Excel graphing directions in this lesson for help on this skill.
2. There is some water quality data for some of the streams found on the USGS site, <http://water.usgs.gov>. This could be used to compare watersheds if enough data can be located.
3. For Baltimore City, the City Department of Public Works will try to provide data to schools for a specific request, for example, for a particular stream or area for a particular period of time. Other county governments may provide data for your local area. This can allow a study of a watershed where your school is located, comparing the results to those in the BES watersheds.
4. It is possible to combine the discharge data and the water chemistry data to calculate the total amount of a particular nutrient or other ion in the stream. This procedure is described in the Excel directions.
5. Students can collect their own water chemistry data using inexpensive water quality kits (from Hach or LaMotte) or other water testing methods (e.g., tests designed for an aquarium for fish). They can work through many of the questions found in the lesson for their own watershed and see how their stream's chemistry compares to the BES sites. Even taking a limited number of samples can make a more personal connection to the water chemistry subject for the students. Taking tests periodically, such as every month or every few months, over as long a time as possible, such as year to year, could provide increasingly interesting data.

Field and Lab Extensions for the Watershed Lessons

If students are able to measure stream characteristics that they also work with in the BES data, the data will probably mean more to them. So, if possible, it would be good if students can measure stream discharge and do some water chemistry tests on a stream near their school. Because every school & stream situation is different, it is hard to give detailed directions for this field and lab work. Instead, sources of information and materials are given below, and teachers can decide what they are able to purchase and/or accomplish in this matter.

A. Measuring stream discharge

Measuring stream discharge requires access to a safe stream, and is likely to require wading in the stream to make depth measurements (sometimes these can, and in the case of large stream, must, be done from a bridge). Therefore, teachers will have to decide if this exercise can be done or not; if not, the general procedures could still be described to make the measurement data more relevant.

A good description of how to measure stream discharge using a current meter is at <http://www.ecy.wa.gov/programs/wq/plants/management/joysmanual/5meter.html>. If you don't have a current meter, how to measure discharge using a float is at <http://www.ecy.wa.gov/programs/wq/plants/management/joysmanual/5float.html>, though you will need to read the description above for the current meter, as that is where the calculations are explained.

Other descriptions of this process are also at <http://ga.water.usgs.gov/edu/measureflowdetail.html> and at <http://math.bhsu.edu/eps/Gaging.htm>. Detailed manuals on stream gaging are at <http://www.cee.mtu.edu/peacecorps/documents_november_02/ measuring_river_discharge.pdf> and at <http://www.cof.orst.edu/cof/teach/fe434/pdf/Discharge_Chapter_USFS_RM245.pdf>.

Current meters used by hydrologists are usually fairly expensive. Less expensive current meters can be obtained from various science education suppliers of sensors (in this case usually called a flow rate sensor), such as Vernier <www.vernier.com> or Pasco <www.pasco.com>.

B. Measuring water quality

There are many test kits for testing water quality. A basic type is meant for testing fish aquariums, which might be purchased at an aquarium store or some pet supply stores - these can be a simple way to test pH, nitrate, and more. Scientific kits for many types of water quality measurements can be obtained from LaMotte (a Maryland company, at <www.lamotte.com>), Hach <www.hach.com>, or from many science education suppliers such as Ward's <wardsci.com> or Forestry Suppliers <www.forestry-suppliers.com>. Costs will vary, and directions for using each kit will be part of the kit. Note that for students to compare their test results to BES data, they will need to be in the same units, usually milligrams/liter (except phosphate and total phosphorus are in micrograms/liter).