Ganga Curriculum

An Environmental Case Study of the River Ganges

Part I - Water Quality

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The Ganga Curriculum provides a case study to topics presented in environmental science curricula for high school.

This pdf viewed **on-line** is interactive with the web site..

The three main sections are:
　　　Water Quality,
　　　Water Resource Management and
　　　Ecological, Economic, Spiritual and Cultural Values of Water

This a printable version of the curriculum which is found on the Ganga site. The links refer back to the curriculum site.

Each section begins with reference to specific broadcast segments that provide the introduction for the material and activities that follow. Discussion questions lead the students to consider both the issues associated with the Ganges River itself, and about water resource protection and management in general.

Classroom activities are practical exercises which can be performed in the field, the laboratory or on a computer.

Educational Resources provides links, glossary, articles etc

The list of key concepts covered in the project.

More information about the APES Curriculum and exam can be found at the College Board Website.

The GANGA curriculum can be covered effectively in five class periods, with additional time needed for completion of all activities.

Water Quality

Is Ganga a polluted river? As documented in this series, the question has no easy answer. Disagreements come from disputes about the effects of the waters on those dependent on them, different methods of assessing water quality, and philosophical differences in the understanding of pollution. Even the establishment of standards is problematic, dependent on the final use of the water, cultural norms and logistic issues that may limit the implementation of strategies to "clean" the water.

The Ganga Action Plan 20 Years Later
Varanasi and Kanpur

Link to audio clips (This is a real audio clip)

The Rape of Ganga

The Indian government has long recognized the pollution of Ganga as a serious problem and in 1986 Rajiv Gandhi launched the Ganga Action Plan (GAP) to improve the quality of the river. Tens of millions of dollars have been invested in water treatment and education with mixed results. These pages and audio clips attempt to document the successes and failures of GAP and discuss some of the political, social and economic issues that have affected the implementation of the plan.

The Special Properties of the Ganges Water
or The Mysterious Factor X

Link to audio clip (In real audio)

At the festivals of Kumbh Mela at the Allahabad millions bathe in the waters of Ganga with no apparent ill-effects despite the inflows of raw sewage, industrial wastes, agricultural run-off and a host of pollutants that cause the western tourist to pale at the prospect of immersion in the water. Yet, there is no evidence of any significant health risk associated with this exposure. The Indian people generally do not believe that the river is polluted although they are aware of the constant inflow of pollutants along the course of the river. There have been suggestions that there exist conditions in the Ganges that allow the river to purify itself; this section looks at factors that could allow a river to clean itself.

The Ganga Action Plan 20 years later:
Varanasi and Kanpur

Background
Discussion Questions
Responses
Further Resources

Background

When he launched the Ganga Action Plan (GAP) in Varnasi in June 1986, Rajiv Gandhi argued that while the sacred purity of the river could never be in question, its material nature could be compromised to a point where worshippers could get ill and even die from pollution. Pollution is caused by humans, whether from sewage or toxic wastes from factories, so humans can clean it up. Twenty years after the initiation of the GAP serious problems remain and questions surrounding the next steps persist.

Discussion Questions

1. What are the criteria for establishing standards for the water quality of a River?

2. What factors beyond discharge rates affect the levels of pollutants in a waterway and their effects on the populations exposed to them?

3. The technology exists to clean waste water to drinking water standards and yet frequently even the most basic treatment technologies fail in India. What are the reasons for this and is the situation in India comparable to that in Europe or the United States?

4. Would strict enforcement of primary treatment requirements lead to significant improvements in the quality of the Ganges? What environmental conditions or problems would justify full funding for the implementation of secondary treatment plants?

Responses

Question 1: The challenges of setting appropriate standards for water quality are manifold. Tens of thousands of pollutants may affect the quality of a river, with concentrations of the pollutants changing constantly. Scientists studying a river can reach dramatically different conclusions about the health of the system based only on differences in the location and timing of sample collection. Yet, economics dictate that sampling be limited in scope, which necessitates the adoption of conservative limits on many pollutants. Setting overly restrictive standards may unnecessarily restrict economic growth and may lead to many ignoring requirements for treatment.

Like many governments, the strategy to protect Ganga's water quality involves a three fold approach: reducing inflows from point and non-point sources, providing funds for

the construction of wastewater treatment plants and monitoring the quality of the river directly to determine if immediate action is needed to protect public health.

As discussed in the broadcast, there is disagreement about the criteria and standards established to evaluate the river's health at both Varanasi and Kanpur. Measurements of Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) are sensitive to slight changes in temperature and the short term appearance of organic matter in the River. While such parameters may provide an indication of the effects of sewage on the river, they do little to assess the likely concentrations of heavy metals, a potentially more serious problem. The selection of parameters to serve as "indicators" of the health of the river must reflect both the likely pollutants entering the river and must provide information about those pollutants most likely to cause health effects in the affected populations.

Question 2: Once discharged into a river, pollutants are immediately diluted, can be broken down or chemically changed, can settle into the sediments, can be absorbed by living organisms in the ecosystem or can persist as dissolved or suspended materials in the water. The fate of the pollutants is therefore a function of flow rates, the structure of the river and the structure of the ecosystem itself. Flow rates emerge as a significant issue in many areas.

Question 3: The effective implementation of treatment technologies depends on an understanding of the nature of the waste stream and the feasibility of consistently treating the waters reaching the Sewage Treatment Plant (STP). Plants must be designed to accommodate expected flows, personnel must be trained to monitor the treatment and consistent electrical power is needed to meet the 24 hour per day requirements of an STP. The treatment plants along the Ganges seem to fail in each of these three criteria at least some of the time. Plants designed to handle tannery waste were not designed to remove heavy metals, salaries are not paid eliminating qualified workers from the facilities, and power failures result in the predictable daily discharge of untreated wastes into the River. Industries do not follow the requirements that they remove certain toxins prior to the discharge to the sewers, all resulting in the continued discharge of all pollutants into the River despite the considerable investment into treatment technologies.

Question 4: Primary treatment is effective for the removal of much of the suspended material flowing into a STP. When coupled with chlorination or UV sterilization (a technique used in the United States and Europe to kill pathogens), such treatment can reduce the incidence of disease causing organisms, BOD and toxic materials bound to the particles that settle out of the water. Primary treatment is not effective at removing dissolved materials in the water, including nutrients, heavy metals and many organic toxins. Secondary treatment removes more of the suspended materials, however is again less effective at reducing the discharges of heavy metals, nutrients and other dissolved pollutants.

Other Resources
Maps of Varanasi and Kanpur
Sankat Mochan Foundation (SMF)

Classroom activities:

Predicting Water Quality
Using bioassessment and indicator pollutants to examine water quality
Assessing Water Quality

The Special Properties of the Ganges Water
or The Mysterious Factor X

Background Information
Discussion and Research Questions
Responses
Further Resources

Background Information

All rivers purify themselves. The sun volatilizes many organic compounds, bacteria break down waste products, sediments carry toxins to the bottom of the river and simple dilution reduces the concentrations of material to levels at which they have little effect on humans or the ecosystem. Other processes are less well understood: viruses attack bacteria, chemical reactions break down toxins, and light itself attacks pathogens. In one sense, pollution represents humans' ability to overwhelm these processes.

Given the difficulty and expense associated with wastewater treatment it is important to determine the maximum level of contamination that can safely be discharged to a river. With a goal of cleaning the Ganges, the Ganga Action Plan (follow this link for details on this initiative) defined requirements for treatment, relying heavily on western technology (follow this link for a more detailed discussion and a laboratory activity associated with wastewater treatment). The broadcast presented above suggests that Ganga may not behave like other rivers and that more study and discussion is needed before an effective treatment strategy can be developed. If untreated sewage is being dumped into the river at locations above the bathing festivals why is there no evidence of disease outbreaks?

Three answers suggest themselves: the diseases are being poorly reported, the bacteria in the river do not survive long enough to have an effect on human health, or the bathers have developed a tolerance to the organisms they encounter. Some combination of the three is certainly also possible.

Discussion and Research Questions

1. What are the challenges faced by governments trying to understand the consequences of people's use of a possibly contaminated river? Given the probability that Ganga's waters contain pathogens, including bacteria, viruses and protists, and toxic materials including toxic organic compounds and heavy metals. Prepare a table describing the probably human health effects of these materials.

2. Using the four steps of risk assessment, describe how a health organization could determine if the river was adversely affecting the health of the target populations.

3. How might scientists explain the results if the analysis suggested that few of the expected effects were evident in those exposed? How might the discharge of pollutants into a river occur with few problems? Would you feel it was safe to use the waters if this "no effect" outcome were found to be true? Why or why not?

4. How might bacteriophage populations reduce the levels of bacteria in the receiving waters? Are the suspected fluctuations in these populations consistent with the principles of population dynamics developed to describe predator-prey relationships?

1) What water pollutants are likely to play a significant part in the spread of water-borne illness?

2) What are the primary sources of these pollutants associated with both direct and indirect discharges to the river?

3) How can a River clean itself?

Responses
Question 1:

• Bacteria and viruses; diseases spread in this manner include cholera
• Microorganisms; including diseases like schystosomiasis and amoebic dysentary
• Inorganic chemicals; metals like mercury and chromium can cause serious neurological effects, birth defects and many other diseases
• Organic materials; solvents and other hazardous organics, oils

Question 2:

Pollutants reach a river either from point sources, flowing out of an identifiable discharge point, or non-point, flowing over land and entering the river from a variety of locations. Point sources include waste water treatment plants and industrial discharges, non-point sources include runoff from agricultural activities or runoff from streets and buildings in developed areas.

Question 3:

As discussed above, a river can clean itself. In the United States and Europe the introduction of legislation reducing the inputs of pollutants into a river has led to

dramatic improvements in the quality of the Nation's waters. More subtle and complex processes may also play a role in this. Why do apparently few Indians suffer from the adverse effects of exposure to the wide assortment of pollutants which occur in the river? This is a difficult question to answer, made unclear by the lack of good information on the extent of water-borne illness along the river and the difficulty associated with identifying specific causes and effects for many common health problems. If the incidence of water-borne disease is indeed low despite the tremendous exposure, one explanation is the development of a tolerance to the pollutants among the affected populations. Certainly a visitor to any country runs a risk of digestive problems associated with the ingestion of a new and unfamiliar group of pathogens. There may be differences in behaviors; native peoples may have developed strategies to reduce the ingestion of the disease causing organisms or in removing them after exposure.

As discussed in the broadcast, there is evidence to suggest that although the bacteria most closely linked to many of the most severe water-borne diseases occur in large numbers in Ganga, these bacteria are short-lived because of the activity of bacteriophages, viruses that specifically target the bacteria and reduce their numbers so quickly that they have little opportunity to infect the population. Persisting in a resting state during times when bacterial populations are low, the virus populations explode immediately upon the appearance of large numbers of bacteria, associated perhaps with a festival or a failure of a sewage treatment facility.

Predicting Water Quality Classroom Activity WQ1

Improving water quality depends on an understanding of both point and non-point sources of pollution which affect the water body or waterway. The identification of point sources is frequently straightforward although can be time consuming. Industrial discharges and wastewater treatment plants contribute known quantities of pollutants (in the United States such information is generally publicly available), or industry-wide averages are available through the EPA. Understanding the effects of non-point sources of pollution is more challenging, although again, much information exists to describe the effects of agriculture, urban runoff and other land covers within the watershed of the river or lake.

A point source and landscape analysis of the watershed is the first step taken by regulators to develop a program for testing the water quality of an aquatic system. This allows for a more efficient sampling strategy that will lead to a better understanding of the sources of pollution degrading the system.

Activity Module see Handout at the end of the section

Resources
Topographic maps: Topozone and USGS resellers.
Computer generated maps: ESRI; a search for "GIS Freeware"
Industry pollutants: Environmental Protection Agency's,
National Pollutant Discharge Elimination System
Effluent guidelines: EPA

Using bioassessment and indicator pollutants to examine water quality -WQ2

Background Information

Evaluating the water quality of any water body or waterway requires the development of a sampling strategy that reflects both the probably sources of pollution in the system and the ultimate uses of the waters. Activity WQ1 provides a means of identifying likely pollutants given good background knowledge of land covers and sources of pollution which occur in the drainage basin. A second approach involves sampling for a broad spectrum of indicator pollutants, characteristic of general classes of pollutants.

Many pollutants are quite easy to measure and can provide much information about the health of a system. Table 1 lists a set of pollutants and some of the possible sources of pollution than can affect the parameter's values

Table 1. Selected indicator pollutants and frequent sources within a watershed

Parameter	Possible source
pH	industrial discharge; lime (lawns & industry); acid precipitation
Conductivity	salts from highways; erosion from agricultural practices; industrial discharge
Nitrate	fertilizers; industrial discharge
Phosphate	fertilizers, industrial discharge
Iron	Industrial discharge, erosion
Copper	Industrial discharge; wastewater treatment
Coliform bacteria	sewage; wastewater treatment; agriculture
Fecal coliform bacteria	sewage; wastewater treatment; agriculture

This approach is frequently supplemented by the use of bioassessment, or using the life of the ecosystem as a means of determining water quality. Polluted systems tend to be less diverse than clean ones, and certain organisms are far less tolerant of pollutants than others. The use of bioassessment is spreading and much work is being done to further our understanding of the pollution tolerance of different taxa.

Water quality testing can be done using any number of systems. Two of the most comprehensive are have been developed by Lamotte and Hach. Both offer a variety of methods for testing water quality at a range of prices and precisions. Both also provide extensive resources on their web sites that assist in the development of site-specific protocols and with the interpretation of results. The United States Environmental Protection Agency also provides information that is suitable for use internationally.

The following links provide useful information about bioassessment practices:

United States Environmental Protection Agency
http://www.epa.gov/bioindicators/html/benthosid.html

Stround Water Research Center
http://www.stroudcenter.org/index.htm

A search of the internet using the region name and the word "bioassessment" will frequently provide specific information for a given locale. Particularly good information can be found at the "Missouri Stream Team" home page, which although regionally-biased provides links to many activities and much useful information.

Procedure

1. Identification of sampling sites
This can either be done using the techniques described in Activity WQ1 or by the instructor prior to a visit to the site. In all cases it is important to obtain permission from the landowner before proceeding, making public lands especially attractive for this type of work. Boat launches and docks are frequently convenient locations, however chemical pollution and repeated physical disturbance of the beds can create bias in the results.

2. Collection of water samples
Proper collection of water samples is critical to the success of the laboratory. In most cases this should be done immediately upon arrival at the sampling site to reduce the effects of students stirring up the sediments which will bias samples. For streams and rivers students must collect samples upstream from where they are standing, and must be adequately spaced to prevent contamination of the samples from upstream sources (primarily other groups disturbing the substrate).

Upon entering the water, students should rinse the sample container at least twice to remove any traces of nutrients and minerals left from the cleaning efforts. While one liter of sample water is sufficient to carry out all the tests described above, collection of a backup sample is advisable given the multiple opportunities for spillage and contamination between the waters and the testing site.

3. Testing of water samples
Conductivity, pH and turbidity data should be collected on site; other samples can be stored for 24 hours (depending on the testing procedures being used) and analyzed in the classroom.

4. Collection of organisms for bioassessment
Many techniques have been developed to sample aquatic macroinvertebrates for analysis. The three presented below are all likely to provide large numbers of organisms, and when used together allow for a defensible assessment of water quality. Selection of a technique depends on budget, number of times a site can be visited and regulations governing the collection of insects and other invertebrates.

i. Dipnetting
Far and away the easiest method of collecting aquatic insects, dipnetting allows for

many organisms to be collected during a single visit given adequate training of the students. Collection can be affected by weather conditions, and animals inactive during the day may be under-sampled.

ii. Minnow or other funnel traps
Traps allow for the collection of animals over longer periods of time, reducing the bias associated with differing periods of activity which affects results from single period sampling. Minnow traps can be obtained commercially from a variety of sources, or funnel traps can be constructed from two liter soda bottles with the top removed and inverted into the body of the bottle (Figure 1)

Care must be taken in the placement of the traps, especially if there is the potential for fish, amphibians or reptiles to be collected. If this is likely, traps should be placed so that a portion of the trap is above water to allow for animals to breath (Figure 2)

iii. Leaf pack systems
Developed by the Stroud Water Research Center , Leaf Packs have emerged as a viable technique for the biological assessment of water quality in different aquatic ecosystems.

5. Calculation of biotic indices for evaluation of bioassessment results

Most biotic indices are based on tolerance values determined from past studies that describe the probability of a species being found in a polluted system and on the diversity of a system. The indices assume that effluents and other stresses on the aquatic environment decrease aquatic life diversity, which is an "indicator" of a healthy aquatic ecosystem. Thus, when a pollutant is discharged into a stream, the numbers of species decline, with an increase in the populations of those organisms that tolerate such stresses.

Tolerance indices can take many forms, but all are based on categories similar to those given below:

Class I Organisms (Sensitive or Intolerant)
Organisms that are unlikely to be found in a polluted system because of their inability to survive or reproduce in polluted systems. This is frequently attributable to reduced oxygen concentrations associated with eutrophic conditions, but may also be the result of senstivity to salts or other toxic materials.

Class II Organisms (Facultative)
Facultative organisms can be found in both polluted and non-polluted systems, but have exhibited reduced population densities in degraded or polluted systems.

Class III Organisins (Tolerant)
Organisms found in all systems, apparently able to survive conditions with low oxygen or high levels of toxins.

Organisms collected are identified to the highest level of classification as possible, although a determination of order is generally adequate for this type of analysis. Once

the organisms have been sorted and identified, they are grouped and the number of taxa (not individuals) is recorded. The calculation below is for Beck's biotic index, which doubles the importance of sensitive organisms in the calculation of the index.

2*(number of Class I Taxa) + (number of Class II Taxa) = Biotic Index

The presence of only Class III organisms would yield a value of zero in this calculation. This provides a good opportunity for discussion: pollution does not necessarily lead to the absence of life, but to a change in the community.

6. Evaluation of Results

This laboratory work brings together many of the most important aspects of the study of water pollution in an AP Environmental Science curriculum. Looking at both the pollutants themselves and their direct effects on the ecosystem forces provides a greater understanding of the issues associated with the regulation of waste water discharges.

The large number of analyses possible with the data collected forces students to refine hypotheses and think through the logical relationships between dependent and independent variables. High levels of copper may not correlate to Biotic Index values if the organisms are not affected by the pollutants in the stream, while the unmeasured BOD, perhaps reflects in nutrient levels may correlate well with a drop in the Index values.

Classroom Activity WQ3
Assessing the Effectiveness of Wastewater Treatment

Outline of Page
Background Information
Materials
Procedure
Further Resources

Click here for a PDF handout of the laboratory

Background Information
Water treatment occurs in many ways, many of which can be modeled in the classroom. Preassembled kits are available from several suppliers (see resources), however it is also possible to produce the systems using less expensive materials. The exercise described below can be easily modified based on the availability of testing materials and other laboratory equipment. Students will explore two or three different types of treatment and investigate the relative benefits and efficacies of each of the technologies. The simplest system involves 24 hours of settling, the second adds filtration through a soil bed and the third filtration through a vegetative bed. None of these technologies depend on constant power or technology that may be beyond the reach of a developing country.

This activity draws on the material presented in the The Ganga Action Plan 20 Years Later and Varanasi and Kanpur broadcasts with the supplementary materials described on the Water Quality Home Page.

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Required Materials
Equipment Needed (per group)

- 2 Oil Drain Pans or other small bucket
- 20 cm Plastic Tubing
- Nitrate/Phosphate/Iron test kit
- Sterilized Potting Soil (no nutrients added)

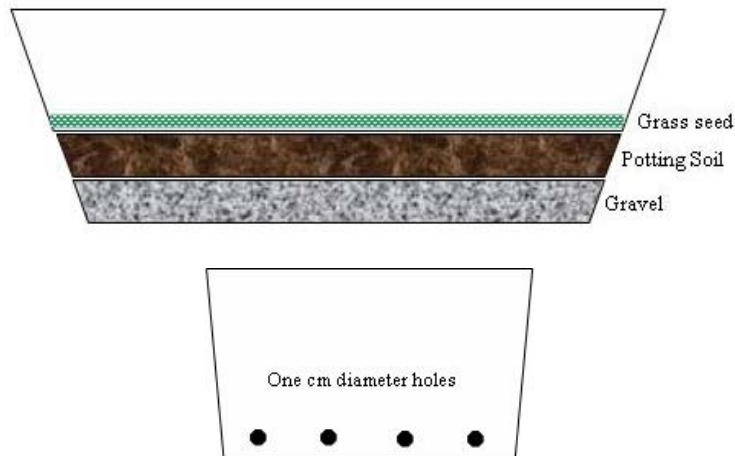- Optional: planting tray, grass seed

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Procedure
3 - 4 weeks prior to beginning lab:

Prepare a planting tray by drilling four holes at one end. Fill the planting tray with 1.0 cm of gravel and fill to within 1.0 cm of the top with a sterilized potting soil. Plant the grass or sedge seed as directed on the packet and cover to retain moisture (Figure 1)

Figure 1. Construction diagram for the planting tray.

Within one week of the laboratory in class:

Target pollutants

Phosphate
Nitrate
Iron

'Wastewater" production – To achieve greater consistency in results, a 20 liter batch of "wastewater" should be mixed for group use prior to beginning the lab (assuming about 3 liters are needed per group). The material should consist of both dissolved and suspended material, and should contain levels of material of sufficient concentration to allow for the test kits in use to determine any change. Organic fertilizers contain nutrients that will provide an excellent source of the necessary materials. Dissolve approximately three tablespoons of fertilizer per liter of water; this should form a cloudy solution with high concentrations of nitrate and phosphate. If desired, iron can be added with iron filings. Test the concentrations of the three pollutants prior to beginning the lab! Adjust as necessary to achieve the desired concentrations.

Preparation of Materials

Settling Tank - Drill a hole in the side wall of one of the oil pans or buckets, one cm above the bottom (Figure 2) that will allow the latex tubing to pass through it snugly. Place rubber washers on either side of the tubing and affix with a waterproof adhesive. Seal the area around the washers with silicone caulking material. Place a clamp on the latex tubing that will allow for the slow release of the water.
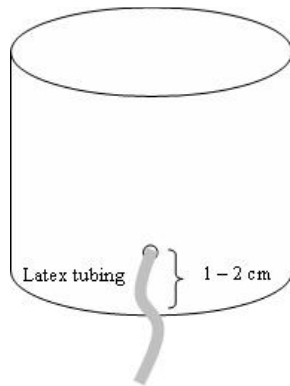
Figure 2. Construction diagram for the settling tank.

Soil Filtration – The structure for the soil filtration chamber is similar to that of the settling tank, with the discharge located at the bottom of the bucket. Approximately 4 cm of sterilized potting soil should be placed at the bottom of the bucket and a layer of paper towel placed over the soil (Figure 2).
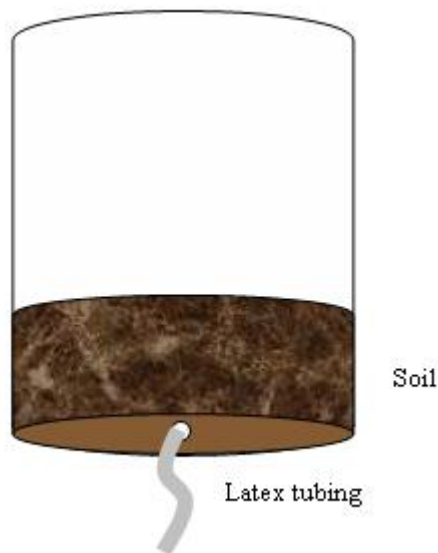
Figure 3. Construction diagram for the soil filtration tank.

Vegetative Filtration (tertiary treatment) – flow through an artificial wetland: The planting tray should be elevated about 2 cm from one end to the other. Make sure that this system is full saturated with distilled water prior to beginning the experiment, otherwise much of the sample water will be absorbed leaving little for analysis. It is also important to select inert potting soils as many seed starting and other mixes contain fertilizers that will confound the results.

Student Procedure

1. Settling

   Begin by stirring the "wastewater" to suspend the soil particles. Add three liters of water to the primary settling tank and record parameter values for all pollutants. Allow this tank to settle for 24 hours. Being careful not to disturb the sediments, remove as much water as possible above the drainage hole, reserving a sufficient amount of water to allow for sampling (50 ml should be adequate) and retest pollutant levels. Set the remainder of the collected water aside to for use in the next step of the experiment.

2. Soil Filtration

   Take the remaining water collected after settling and slowly pour it into the soil filtration tank (with the drainage tube clamped closed) taking care not to disturb the paper towel covering the soil. Open the clamp sufficiently to allow the water to trickle out at a slow rate. After 24 hours, most of the water will have been collected in the receiving vessel. Once again, collect 50 ml of water for testing, setting the rest aside for the vegetative filtration.

3. Vegetative Filtration

   24 hours prior to beginning treatment, the planting tray should be watered to saturation and allowed to drain. Failure to do this may result in excessive absorption of the water leaving too little to test. Connect the drainage tube to the distribution system and open the clamp to allow the water to slowly trickle into the planting tray. Restrict the flow such that there is no significant surface flow visible.

Evaluation of Results

   1. Calculate the percentage of material removed in each of the treatments using the formula:

$$\frac{(\text{Initial Concentration} - \text{Final Concentration})}{\text{Initial Concentration}}$$

   2. Do the results suggest that an Advanced Integrated Wastewater Pond System (AIWPS) system of ponds that allows for the treatment of wastewater at a lower cost than conventional wastewater treatment facilities would be an effective strategy for handling wastewater in developing countries?.

   3. The time that the water remains in each of the treatments is critical to the extent of removal of the pollutants. However, more time of residence requires greater area for the storage of the water and therefore greater expense. How would scientists determine the optimal area for treatment?

Further Resources

For additional information or assistance with this activity please contact David Black at dblack@groton.org.

Predicting Water Quality:
Understanding Sources of Pollution

Background Information

Rivers, streams, lakes and ponds are vulnerable to pollution coming from a variety of sources and the first step in a program of improving water quality depends on an understanding of both point and non-point sources of pollution. Point sources are those that can be traced to a single discharge point, and frequently straightforward although can be time consuming. If in compliance with the Clean Water Act, industrial discharges and wastewater treatment plants contribute known quantities of pollutants (in the United States such information is generally publicly available), or industry-wide averages are available through the EPA. Understanding the effects of non-point sources of pollution is more challenging, although again, much information exists to describe the effects of agriculture, urban runoff and other land covers within the watershed of the river or lake.

A point source and landscape analysis of the watershed is the first step taken by regulators to develop a program for testing the water quality of an aquatic system. This allows for a more efficient sampling strategy that will lead to a better understanding of the sources of pollution degrading the system. Conversely, water quality data can help identify likely sources and can allow regulators to take steps to prevent further contamination of the affected waters.

Frequently the most interesting results are those that compare different systems or different reaches within a stream or river. To do this researchers must study both the sources of pollutants and the characteristics of the waters. Large flowing systems can dilute wastes quickly; isolated pools can concentrate pollutants over a period of years. Rivers that are healthy during the spring floods can become dangerously polluted during the dry summer even if they receive similar discharges.

Procedure

Acquiring Base Maps

There are now several on-line resources that provide easy access to topographic maps, satellite images and land cover information. Students can delineate study areas, zoom to appropriate scales and save the maps, either for analysis using a computer program or as a base for producing a "pollutant loading map" using tracing paper.

Acquiring the base map using Google Earth

Google Earth version 4 has added some powerful features that allow for the production of good base maps with some possibility of analysis. This software allows for users to draw polygons on their maps representing different land covers, helpful in simplifying a complex landscape.

http://earth.google.com/

Acquiring the base map using ESRI's ArcExplorer (a powerful tool that will also allow for analysis of the map information)

Connect to ESRI's on-line GIS (Geographic Information System) for information about the products available for on-line use in the classroom.

http://www.esri.com/software/arcgis/arcgisonline/index.html

Navigate through to the ArcGIS online resource center linked in the sidebar to the left of the page. From here click on the link for ArcGIS Explorer maps and select "USA Imagery" if you are working in the United States or "Satellite World" for other countries. Note that ArcExplorer can either be used on stand alone machines after download or through a web-based server.

Acquiring Topographic Maps

All United States Geologic Survey maps are available at no charge through Topozone

http://www.topozone.com/

Analysis

Watershed delineation using tracing paper

Using a light table or a window, place the USGS map provided beneath a sheet of graph paper. Identify the river, stream, lakes or ponds that you will be analyzing and use a blue pencil to outline the banks of the water body or waterway.

You now need to determine the area of land that drains into the water body or waterway; this area is referred to as the watershed of the receiving water.. The topographic map provides you with all the information that you need to do this. Figure 1a shows a schematic topographic map with the high points identified with a star; look for the bulls-eye pattern in the topographic lines. Figure 1b shows these high points connected, with some guessed made about the location of the divide in between them. This is the preliminary delineation of the boundary of the watershed. Note other features: "V's" show stream channels with the water flowing from the angle to the opening. Straight lines suggest that humans have had a role in the transformation of the landscape, sometimes even creating new boundaries through the filling of large areas for highways or railroads. The delineation of the watershed required frequent assumptions and in the absence of field verification is only approximate. Nonetheless, this quick analysis provides good preliminary information about land covers and pollution sources potentially affecting a water body or waterway.
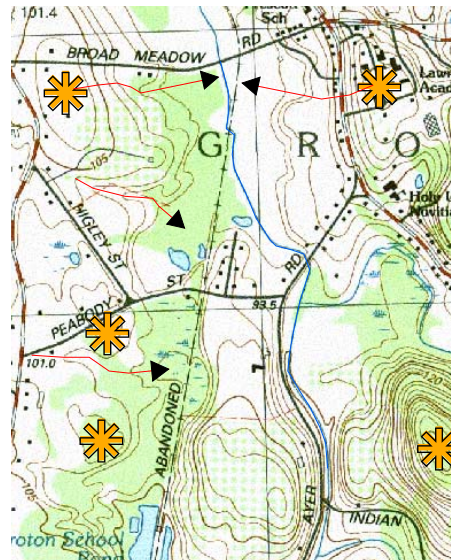

Figure 1a. Topographic map showing contours, high points and channels for water flow.
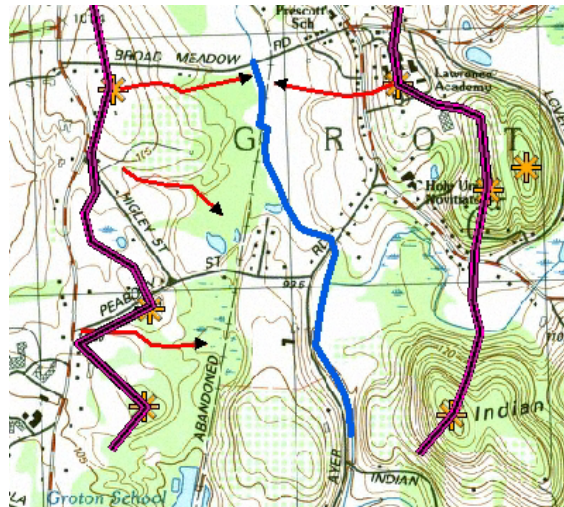
Figure 1b. Topographic map showing approximate watershed boundaries

Watershed delineation using image analysis software

There are several software products available for classroom use that will allow students to map land covers by drawing polygons which overlay the topographic maps and the aerial photographs. These are called Geographic Information Systems or "GIS".

A list of GIS providers and educational communities is provided at the end of this document.

Identification of pollutant sources

The next step in the analysis is the identification of land covers and point sources of pollution. Having the legend for the map is helpful in identifying the land uses, and some knowledge of the study are allows for a better understanding of point sources of pollution. Figure 2 is a topographic map of a rural area in central Massachusetts currently experiencing some residential, commercial and industrial development, while preserving some agricultural landscapes.

1. Prepare a table listing the types of land cover that exist in the watershed that you have mapped. You should include forests, grassy areas, open spaces like parks, agricultural fields, grazing lands (you may need to look at the aerial photos of the area to help determine the use of the area, and developed areas. For developed areas, classify the residential lands as rural (houses more than 300 m apart), suburban (houses between 100 and 300 m apart, urban (houses with 100 m of each other), and industrial (more than 50 percent of the area paved).

2. Using the topographic maps or the aerial photos, identify point sources of pollution within the watershed. These can include industrial sites, wastewater treatment facilities or other sources of pollution flowing out of a pipe.

3. Pick five to ten sites along the river (or several small pools or ponds) and predict the levels of the pollutants shown in Table 1. Your textbook and the information above provide the information needed to do this. For example, lead and mercury are likely to be associated with landfills and industrial area, whereas nutrients like phosphate and nitrate are likely to come from agricultural sources.

Table 1. Common pollutants and possible sources

Pollutant	Source
Turbidity	Runoff from streets, agricultural fields, possible industrial discharges.
pH	Industrial discharge, runoff from feedlots.
Conductivity	Associated with most types of pollution; high conductivity levels suggest that pollutants are reaching a water body, although naturally high levels can be found.
Nitrate	Industrial processes, fertilizers, feedlots.
Phosphate	Some detergents and cleaning agents, fertilizers
Iron	Industrial discharges and landfills; natural levels can very significantly.
Copper	Industrial discharges and landfills; natural levels can very significantly.
Lead	Industrial discharges and landfills; natural levels can very significantly.
Mercury	Industrial discharges and landfills; natural levels can very significantly.
Chromium	Industrial discharges and landfills; natural levels can very significantly.
Coliform Bacteria	Sewage disposal systems close to the water, feedlots and grazed areas, wastewater treatment plants that are not functioning properly.

4. Develop a sampling strategy to test your hypotheses. Testing of all possible pollutants in the environment is impractical both in terms of the level of effort required and the cost of the laboratory work. Over many years, scientists have developed lists of indicator pollutants that provide some information about the water quality in an area. Because some of the pollutants can come from a variety of sources, care must be taken in their analysis, but using the information above, rank concentrations of each of the pollutants below at each of the sampling stations

5. Go onto the next exercise and test your hypotheses! Move onto Water Quality Exercise 2: Assessing Water Quality.

For those wishing to look more closely at the situation in Kanpur, a map and aerial photograph of the area around the river can be found by following the links below:

GIS Providers and Educational Communities

ESRI (www.esri.com). ESRI produces the ArcMAP family of products, all of which are available for classroom use at discounted prices. The online community is active and can be found at http://edcommunity.esri.com/.

Google Earth (http://earth.google.com/). Beyond providing maps and images, Google Earth offers more advanced projects for analysis of spatial data. The Google Earth Community can be found at http://bbs.keyhole.com/ubb/ubbthreads.php/Cat/0.

IDRISI (http://www.clarklabs.org/). Less common in high school classrooms, IDRISI offers a comprehensive suite of GIS tools for analysis.

Using bioassessment and indicator pollutants
to examine water quality

Background Information

Evaluating the water quality of any water body or waterway requires the development of a sampling strategy that reflects both the probably sources of pollution in the system and the ultimate uses of the waters. Activity WQ1 provides a means of identifying likely pollutants given good background knowledge of land covers and sources of pollution which occur in the drainage basin. Once this step has been carried out researchers can involves sample for different indicator pollutants, characteristic of the sources that exist in the area.

Table 1 describes some of the indicator pollutants commonly used in this evaluation, although different areas may need to add specific pollutants of concern.

Table 1. Common pollutants and possible sources

Pollutant	Source
Turbidity	Runoff from streets, agricultural fields, possible industrial discharges.
pH	Industrial discharge, runoff from feedlots.
Conductivity	Associated with most types of pollution; high conductivity levels suggest that pollutants are reaching a water body, although naturally high levels can be found.
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Coliform Bacteria	Sewage disposal systems close to the water, feedlots and grazed areas, wastewater treatment plants that are not functioning properly.

This approach is frequently supplemented by the use of bioassessment, or using the life of the ecosystem as a means of determining water quality. Polluted systems tend to be less diverse than clean ones, and certain organisms are far less tolerant of pollutants

than others. The use of bioassessment is spreading and much work is being done to further our understanding of the pollution tolerance of different taxa (groups of plants or animals in the same taxonomic group: kingdom, phylum, order, family, genus, species).

Procedure

1. When you arrive at your sample site you must be very careful not to stir up the waters. This can frighten away many of the animals that you are trying to collect and the collection of large amounts of sediment makes the water quality testing more difficult and less reliable. Before doing anything look around your sample area to see if there are any factors that might affect your results. Are there large amounts of trash in the area? Abandoned cars? Do you see any pipes discharging into the waters? Are the banks particularly badly eroded? Make careful notes of this information.

2. Disturbing the bottom sediments as little as possible, immerse your sample bottle below the surface of the water, taking care not to collect water from the cloud of material that is appearing around your feet. When the bottle is half full, swirl the water and dump it out to remove any contaminants that may be inside. Repeat the process, filling the bottle to the top and capping it immediately.

3. Your teacher will have instructed you on the techniques being used to collect the organisms for assessment.

Safety Warning: Wear gloves and use tweezers or nets to handle all insects! Many of them can sting. Never handle snakes or turtles as all will bite!

As you collect the animals, transfer them to covered gallon jar provided, placing a small amount of water in the bottom to prevent them from drying out.

Back in the Laboratory or away from the water:

4. Dump the gallon plastic jar into the dishpan. First, place any bugs larger than two centimeters in length into a paper cup and sort them by species. Using tweezers, sort all of the other animals using the ice cube trays provided by your teacher. Identify the species using the key provided by your teacher.

5. Test the water samples using the materials provided by your teacher.

6. You will now calculate the biotic index values for your site and compare it to other sites sampled by other groups. Most biotic indices are based on "tolerance values" determined from past studies. These describe the probability of a species being found in a polluted system – species that are intolerant of pollution occur only in clean waters; species that are tolerant of pollution can be found anywhere and may be more abundant in lower quality waters. You will also look at the diversity (the total number

of different kinds of organisms, not the number of individuals) of the system as past studies have suggested that polluted waters support a lower diversity of life than more pristine systems.

Tolerance indices can take many forms, but all are based on categories similar to those given below:

Class I Organisms (Sensitive or Intolerant)
Organisms that are unlikely to be found in a polluted system because of their inability to survive or reproduce in polluted systems. This is frequently attributable to reduced oxygen concentrations associated with eutrophic conditions, but may also be the result of senstivity to salts or other toxic materials.

Class II Organisms (Facultative)
Facultative organisms can be found in both polluted and non-polluted systems, but have exhibited reduced population densities in degraded or polluted systems.

Class III Organisms (Tolerant)
Organisms found in all systems, apparently able to survive conditions with low oxygen or high levels of toxins.

Organisms collected are identified to the highest level of classification as possible, although a determination of order is generally adequate for this type of analysis. Once the organisms have been sorted and identified, they are grouped and the number of taxa (not individuals) is recorded. The calculation below is for Beck's biotic index, which doubles the importance of sensitive organisms in the calculation of the index.

2*(number of Class I Taxa) + (number of Class II Taxa) = Biotic Index

The presence of only Class III organisms would yield a value of zero in this calculation. pollution does not necessarily lead to the absence of life, but to a change in the community. Your teacher will provide you with a table showing the pollution tolerance of the aquatic insects found in your area.

Questions for discussion:

1. Were there differences in the water quality at different sites according to the chemical and biological testing? Were these differences what you expected based on your knowledge of the area?

2. What characteristics of a site might affect water quality beyond the amount of material discharged into it? Do any such characteristic seem to affect your results?

3. How might the discharge of nutrients such as phosphate and nitrate initially affect the diversity of a system (hint: think about limiting factors and changes in primary productivity)?