Indianapolis: City as a Living Laboratory

21 Urban Water Science Concepts Resource Handbook

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Overview

THE I/CALL PROJECT

The Indianapolis / City as Living Laboratory (I/CaLL) project is a civic collaboration that uses the city of Indianapolis as an informal science learning (ISL) environment. The project creates place-based science learning experiences in the city through curated, artistic interpretations of science at five parks connected to the urban water system. The project draws on four art forms (sculpture, music, poetry, and dance) to interpret scientific concepts, using inductive reasoning to promote learning, with media promotion.

I/CaLL leverages Reconnecting to Our Waterways (ROW), a collective impact partnership of over 100 public, private, and cultural institutions dedicated to changing the way science knowledge is nurtured in communities. I/CaLL is a collaboration among multiple organizations that to create I/CaLL spaces, engage with communities, and serve as research participants to support the understanding of how science literacy can be advanced in society. The scale of this project provides a full measure of informal science service learning at a city scale to create data that can change how science learning is measured and advanced.

In the first year of the project, the research team developed a list of 21 Urban Water Science Concepts relating to the science of sustainability and waterways in Indianapolis that are central to the overall project. These concepts ranged from riparian habitats to urbanization impacts on the water cycle, and human impacts on groundwater.

HOW TO USE THIS HANDBOOK

The 21 Urban Water Science Concepts Resource Handbook is designed for all people who are interested in exploring science topics related to urban waterways, particularly in Indianapolis. Specifically, educators, artists, and community members in Indianapolis may find this publication useful. With a small amount of extra research for examples in their area of interest, urban environmental educators across the country will also find utility in this handbook.

Each chapter introduces the key construct definitions, followed by an elaboration of the key concepts and ideas that support the core issue, and a description of the applications and implications of that topic to the Indianapolis watershed. These short, bulleted lists allow for quick reading and are designed to facilitate discussion.

To further support discourse, we include discussion questions relevant to the five themes emphasized at the sites: water infrastructure (Pogues Run), change over time (Pleasant Run), water and habitat corridor (Fall Creek), water in the atmosphere (White River), and water as a resource (Central Canal).

We also offer thoughts on how to better assess levels of understanding among both single and group users. These levels can be considered useful for those who are interested in increasing their knowledge. We also include a few key resources for further reading.

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Glossary

Adaptive Management – A resource management strategy that focuses on achieving a specific water quality goal (e.g., level of phosphorus in surface water). Monitoring is required to track movement towards the goal or determine whether the goal should be revised. This approach allows management teams to use incoming data to responsively manage a resource.

Aquifers – Areas that are hundreds of feet underground and may take centuries to recharge, including fossil water. Contrast with water tables.

Apparent Water Losses – Water losses that occur through theft, misuse, or inaccurate or nonfunctional meters. Contrast with Real Water Losses.

Biological Magnification – Toxicants become more concentrated as they move up the food web from plants to herbivores to predators to decomposers. Each level of the food web concentrates the toxicants that lower levels have consumed.

Brownfields – Abandoned or idle tracts of land that were used previously for industry or manufacturing and are now contaminated with low concentrations of hazardous substances. The contaminant (e.g., petroleum) poses a risk to human health or the environment, but expansion or redevelopment is possible once the substances are treated or removed.

Carbon, Hydrogen, Nitrogen, Oxygen, Phosphorus, and Sulfur (CHNOPS) – The six chemical elements making up most biological molecules on Earth, which are commonly tracked in nutrient cycling analyses.

Carcinogenic Chemicals or Carcinogens – Toxicants that increase the occurrence of cancer, often as a result of long-term exposure to low concentrations of the chemicals or of acute exposure of high concentrations. Carcinogens typically come from industrial and manufacturing sources.

Channelized Rivers or Drainage Systems – Waterways that are deepened through dredging, contained between levees, or paved canals. These features increase runoff water speed and volume leading to erosion, channel deepening, and topsoil loss, which clogs stream channels and damages habitat. Channelized rivers and streams may be unable to accommodate peak runoff volumes and support diverse aquatic ecosystems.

Clean Water Act – The primary US law that limits water pollution. The law aims to restore and maintain the chemical, physical, and biological integrity of US waters by preventing pollution, improving wastewater treatment, and maintaining the integrity of wetlands.

Combined Sewage Overflow (CSO) – Combined sewage systems are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe and transport it to a treatment plant. However, with heavy rainfall or snowmelt, the combined sewer system can exceed the capacity of the treatment plant and the collected liquids are discharged into nearby bodies of water with inadequate or no treatment. This overflow is a CSO.

Deep Rock Tunnel Connector (DRTC) – The first phase of the DigIndy Project that will store CSO outfalls and prevent millions of gallons of raw sewage from being discharged into Indianapolis waterways. Construction started in 2011 and is scheduled to be completed in 2017. The DRTC is 18 feet in diameter, over seven miles long, and upon completion, it will store 70 million gallons of raw sewage and remove 3.5 billion gallons of raw sewage entering the waterways through 2025.

Desalination – Using heat to produce freshwater from seawater by removing the salts to create water for drinking. This energetically demanding process will likely become more common in the future for coastal communities.

DigIndy Project – A deep underground tunnel system running parallel to four major waterways in Indianapolis – White River, Fall Creek, Pogues Run, and Pleasant Run – that is designed to store sewage overflows. This system will be 25 miles long and able to store around 250 million gallons of sewage. The DigIndy project is scheduled to be completed by 2025 at a total cost of $1.6 billion and will include significant upgrades to two wastewater treatment plants.

Ecohydrology – The study of how water moves through ecosystems. Often this field has the goal of managing water and improving the efficiency of urban regulatory processes related to hydrology.

Ecosystem Services – Benefits that emerge from the collective biological action of the plants and animals in a location.

Environmentally Persistent Pharmaceutical Pollutants (EPPPs) – Drugs and pharmaceuticals that are resistant to being broken down by human metabolism (biodegradation) and pass into waterways, are taken up by plants, and make their way into the food chain.

Erosion – The action of processes like water movement or wind that remove soil, rock, or dissolved material from one location and transport it elsewhere.

Escherichia coli (E. coli) – An innocuous species of bacteria found in humans' lower intestine. *E. coli* concentrations can indicate when there have been sewage spills in the environment; if *E. coli* is present, then it is likely that sewage is also present.

Eutrophication – When lakes or streams are simplified to only have one type of plant, excluding most other life. Eutrophication occurs when Nitrogen, Phosphorus, and Potassium are introduced into a waterway. These are the most important and limiting chemicals for plant growth. Elevated amounts of these nutrients may stimulate quick growing algal blooms that may suddenly deplete oxygen and suffocate all other life in the waterway.

Exotic, Introduced, or Non-Native Species – Species that are brought to a new location from elsewhere, usually by human action, and are not a native species in that location. These terms are more general than invasive species as they also may be used for species that have not necessarily become ecologically dominant.

Filter Strips – Long, narrow areas installed next to surface waters that act as buffers to filter and slow runoff, as well as reduce erosion.

Floodplains – Areas of land that border waterways and are inundated with water when flow rate is higher than normal. Floodplains provide many ecosystem benefits, including enhanced biodiversity, cleaner water, stored water surges, rejuvenated productive soils, and maintained fisheries.

Fossil Water – Water that is stored in aquifers hundreds of feet underground and may take centuries to recharge.

Greenfields – Land that does not have structures or contaminants on them and can be reused without further preparation.

Green Infrastructure for Water – Approaches to water management that use vegetation, soils, and natural landforms to contain water in depressions in the ground and increase absorption into the water table, thereby creating healthier ecosytems. Green infrastructure absorbs as much or more precipitation than the concrete and pavement often used to contain stormwater.

Green Roofs – Roofs that are partially or completely covered with growing plants to help cool the building and reduce the urban heat island effect.

Greyfields – Land that is overbuilt with unused concrete structures, but would only need to have the structures removed for the land to be reused.

Groundwater – Water that is stored below ground that can be divided into two main categories: the water table and aquifers.

Point Source Pollution – Pollution that has a clear source of production and output, such as a pipe from a sewage treatment plant.

Hormone Analogues – Toxicants that affect an organism by disrupting the normal growth and activity of organs and tissues, and typically come from agricultural or industrial and manufacturing sources. Impacts often result from long-term exposure to low concentrations of the chemicals or acute exposure to high concentrations.

Impervious Surfaces – Land covering that does not allow water to pass through it, often associated with urbanization in the form of concrete, asphalt, or buildings. Impervious surfaces alter how water moves through the water cycle.

Infiltration – The process by which water on the ground surface enters the soil through percolation or similar means.

Infiltration Trench Systems – Trenches filled with rocks that can hold water and make it easier to slowly enter the soil through infiltration.

Inorganic Matter – Material that is usually synthesized by geological systems.

Integrated Urban Water Infrastructure Strategies – An integrated and diverse set of approaches by cities to manage water use by combining built and green infrastructure to manage the collection, distribution, and storage of water. Ultimately, the goal is to keep as much water out of the sewage treatment plants as possible while ensuring that all water in an urban area is clean and healthy.

Invasive Species – Non-native species whose introduction by humans and subsequent massive population growth disrupt the local ecosystem and may cause harm to the economy, environment, and human health.

Material Flow Analysis (MFA) – A process that quantifies and assesses the movement of materials (e.g., water, food, excreta, and wastewater) and chemicals (e.g., nitrogen, phosphorus, and carbon) in a defined ecosystem.

Mitigation – The efforts that are involved in reducing loss of life and property by reducing the impact of a threat.

Mutagenic Chemicals or Mutagens – Toxicants that cause mutations in tissues, especially reproductive tissues. Impacts from these chemicals can be the result of long-term exposure to low concentrations of the chemicals or acute exposure to high concentrations. Mutagenic chemicals typically come from industrial and manufacturing sources.

Nativescaping – Replacing lawns with natural land cover comprised of native plants. These species typically do not need additional watering over what is normal for the environment in that area and thereby help land managers reduce water consumption.

Naturalized Species – Species that are non-natives that have been cultivated for human use (e.g., sweet clover for cattle forage). These are not usually considered invasive as they are largely dependent on human cultivation and care to thrive.

Nonpoint Source Pollution – Pollution that is more challenging to identify and typically have a broad, diffuse pathway of entry to the waterway, such as oil running off road surfaces during rain.

Nutrient Cycling – The use, movement, and recycling of chemical nutrients in the environment.

Organic Matter – Material that includes carbon and is usually formed by the metabolic processes of living organisms.

Pervious Pavement – Land cover that allows water to seep through it to reduce runoff and filter out pollutants.

Pharmaceuticals and Personal Care Products (PPCPs) – Drugs and non-pharmaceutical products (e.g., sunblock, fragrances) that enter waterways through stormwater runoff, septic tank leakage, CSOs, or treated grey water.

Point and Non-Point Pollution – Point source pollutants can be attributed to a single source, such as discharge from a particular factory or sewage outfall. Non-point source pollutants cannot be attributed to one source and include agricultural and urban runoff.

Rain Gardens – An area planted with native plants to help capture rainwater.

Real Water Losses – Water loss due to poorly designed or broken equipment, old and leaky water distribution infrastructure and evaporation during open-air transportation of water in canals. Contrast with Apparent Water Losses.

Recycled or Reclaimed Water – Water that has passed through the treatment procedures at a sewage treatment plant, but may be used multiple times before it reenters the natural water cycle to water landscaping, golf courses, and public parks. Some communities with advanced water treatment systems have begun to mix this water into the normal water supply system.

Riparian Zone – The interface between the land and a river or stream running through it. Riparian habitats are the types of habitats found along the banks of a river or stream.

Restoration – The process of converting an ecologically damaged or degraded area to a more natural state.

Runoff – The movement of water on the surface of land, typically from precipitation. Runoff occurs when precipitation amounts exceed the rate of infiltration into the soil. Runoff is one of the most important ways that watersheds are defined and connected.

Superfund Sites – Land that is severely contaminated with high levels of hazardous waste and pollution.

Sustainability – The ability to maintain something of the same level of quality into the future indefinitely.

Toxic Chemicals or Toxicants – Chemicals that are typically introduced to waterways from one of three human activities: industry and manufacturing, agriculture, or residential areas and can affect plants, animals, and humans living in or near the watershed.

Urban Heat Islands – A phenomenon wherein city growth alters the urban fabric by replacing cooler forest and natural cover with human-made features, such as asphalt roads and tar roofs. The heat concentrated in the human-made features is released at night, so that both the highest and the lowest temperatures in the city are elevated relative to the surrounding rural areas.

Urbanization – A process whereby undisturbed land becomes converted into human use, often involving the construction of roads, buildings, parking lots, recreational fields, and other human-centric edifices. Erratic and massive stormwater runoff events often result that can trigger changes in water and sediment quality, water temperature, and hydrology, which in turn affect habitat diversity and resources available to the waterway species.

Water Cycle or the Hydrological Cycle – The continuous exchange of water between land, water, and the atmosphere.

Watershed – An area where all the water running off the land drains into a specific body of water. Watershed size can vary based on the management approach. For example, the land that drains into a single stream can be a watershed at a small scale, while the land and streams that collectively drain into a river can comprise a larger watershed. Each watershed is an integrated system and must be treated as a unit.

Water Table – Water that is stored a few feet to dozens of feet below ground and quickly recharges with surface water, in contrast to aquifers.

Wellhead Protection – A process of reducing groundwater contamination around the wellhead, which is the land above and around wells. Polluted water in this area may seep into the ground to contaminate the water table and eventually the underlying aquifer. Sustainable planning identifies areas that are susceptible to contamination and generates measures to reduce this risk.

Concept 1: Brownfields

Definition

Brownfields are abandoned or idle tracts of land that were used previously for industry or manufacturing and are now contaminated with low concentrations of hazardous substances. The contaminant (e.g., petroleum) poses a risk to human health or the environment, but expansion or redevelopment is possible once the substances are treated or removed.

Figure 1. Engineering at a Brownfield Contaminated Site

Feb 23, 2010. Used with permission under Creative Commons.

Key Concepts & Ideas

1. Sites previously used for industry are classified by the effort required to prepare them for use. ***Brownfields*** are polluted sites that need improvement before they can be reused. ***Greyfields*** are overbuilt with unused concrete structures, but would only need to have the structures removed for the land to be reused. ***Greenfields*** do not have structures or contaminants on them and can be reused without further preparation.
2. ***Superfund sites*** are severely contaminated with high levels of hazardous waste and pollution. Typically, they are not considered to be brownfield sites because they cannot be readily improved without massive financial and time investments.
3. Brownfield contaminants can spread into waterways, depending on the proximity of the brownfield to surface water (e.g., stream), the depth the contaminant has been put or leached into the soil, and the distance from the groundwater table.
4. Factors influencing the spread of contaminants include:
   - Average rainfall, with more rain moving contaminants faster;
   - Topography, with hillier areas leading to more rapid lateral movement and flatter areas result in downward movement towards groundwater;
   - Proximity to water and the groundwater table, with closer proximity leading to faster movement around the landscape;
   - Soil type, with sandy soils allowing contaminants to move more quickly than clay soils;
   - Water-solubility, with high solubility allowing pollutants to move more quickly than if they were oil-soluble; and
   - Soil depth, with shallow soils allowing more lateral movement than deeper soils.
5. Leaching occurs at historically polluted properties, such as the Coke Plant, where the chemicals are dried or otherwise contained, but rainfall or surface water dissolves and enables the contaminants to move through the landscape.
6. Contaminants affect groundwater versus surface water differently. Groundwater cycles are slower than surface water cycles, so the impact of contaminants is greater. Quickly changing surface water systems like rivers and lakes are able to clear a contaminant from an area in a matter of hours or days. For example, Fletcher Park has contaminated groundwater due to the Circle City Complex nearby, which will likely impact the groundwater for decades to centuries if left to its natural cycle.
7. ***Mitigation*** is the effort to reduce loss of life and property by reducing the impact of a threat. Effective mitigation requires understanding all local risks and investing in the community's long-term well-being. Without mitigation, safety, financial security and self-reliance are jeopardized.

8. Remediation efforts reduce or eliminate contaminants. Remediation may use many methods, including:
    - Bioremediation, which uses living organisms (e.g., trees) to take up contaminants (particularly heavy metals) from the top layers of the soils and are then harvested and disposed;
    - In Situ Thermal approaches, which use heat to denature and destroy pollutants on the brownfield site;
    - Excavation and Pumping, which directly remove contaminated land and water from a site so that they can be treated off site;
    - Solvents, which are used on a site to encourage the chemicals to leach out of the soil for subsequent liquid extraction; and
    - Containment, which may occur when sites are contaminated with very viscous (thick) pollutants that can be completely contained and stored onsite safely and permanently.
9. Redevelopment or Reclamation occurs when communities are able to reuse brownfield land. Some communities restrict redevelopment to specific uses to minimize exposure to any pollutants that may remain. The redevelopment of brownfield sites is a substantial part of repopulating urban areas and often results in green spaces for recreational uses or housing.

Applications & Implications

Humans: Health & Communities

- Exposure to contaminants can have myriad health consequences for people in the area. Risks include groundwater poisoning or direct exposure to liquid pollutants, which can lead to illness or death;
- Brownfields often cause devaluation of buildings and decreased property values accompanied by severe economic losses, including loss of taxation for local communities; and
- The investment of time and money can be tremendous, with costs to the community, such as lost tax revenue.

Nature: Environment, Sustainability & Conservation

- Brownfields almost inevitably lead to loss of native biodiversity and therefore the loss of healthy and functioning ecosystems;
- When brownfields are untreated for many years or decades, the time to recovery may greatly increase. An area that has been dramatically degraded over a few years may take decades to return to ecological health; and
- Remediation can help to jumpstart the natural recovery process so that sensitive species and ecosystems may recover much faster than would be otherwise possible.

Discussion Questions

Water Infrastructure (Pogue's Run)

- How could the processes involved in remediation and redevelopment affect the infrastructure necessary for influencing the movement and actions of water in an area?
- Could those processes affect how we interact with water in our watersheds?

Change Over Time (Pleasant Run)

- Brownfields, by definition, change over time. How easily could you change your perception of a brownfield to instead view it as a park or residential area?
- How much time or what type of change would be necessary before you would be willing to use the land?

Water and Habitat Corridor (Fall Creek)

- Animals and plants can be found in an area regardless of how contaminated it is. Would the potential impact of the pollutants in a brownfield site on wildlife change how much you would advocate for remediation and reclamation?

Water in the Atmosphere (White River)

- We often think of rainwater as being pure and helping to clarify our waterways. How does the presence of brownfields affect rainwater?
- How does rain or snow affect the brownfield remediation process in a helpful way? How could it slow the process?

Water as a Resource (Central Canal)

- How much should our cultural and spiritual associations with an area influence our decisions about using water affected by brownfields as a resource?
- Where are brownfields and their effects usually located? Are there economic and social justice issues that need to be considered in advocating for brownfield remediation?

Figure 2. Restricted Land

Pavel P. February 26, 2014. Used with permission under Creative Commons.

Levels of Understanding

None

- Has heard of chemical spills and contaminants, but has not thought about long-term impact of contaminants on land;
- Unaware of how contaminants spread through the environment from a spill site;
- Assumes contaminants will always be present or will go away on own;
- Unaware of mediation and mitigation efforts; and
- Unconcerned with the long-term impacts of brownfields on local land values, human health, and biodiversity;

Low

- Aware of chemical spills and contaminants and has thought some about long-term impact of contaminants on land value and need for cleaning them;
- Aware that spills spread from the site of origin, but has minimal ability to predict effects of topography, soil, and bedrock on spread of pollutants;
- Aware that contaminants change locations and recognizes that they do not just go away on their own;
- Has heard of mediation and mitigation and has some understanding of what they mean; and
- Concerned with long-term impacts of brownfields on local land values, human health, and biodiversity, but does not know how brownfields will impact matters locally.

Intermediate

- Knows about chemical spills and contaminants, has thought about long-term impact of contaminants on land value, has wondered about the need to clean them up, and has some ideas for how to do so;
- Knows that spills spread from the site of origin, and is able to predict that topography, soil, and bedrock will influence the spread of pollutants from a site;
- Knows that contaminants will change location and will not just go away on their own, has a basic knowledge that they have needed to be cleaned up in the past, and can recollect ways in which this has been done in the past;
- Knows of mediation and mitigation, can differentiate between the two, and knows that they will help to recover land from damaged brownfields or greyfields; and
- Concerned about long-term impacts of brownfields on local land values, human health, and biodiversity and aware that brownfields will negatively impact the local area.

Advanced

- Knows about chemical spills and contaminants, has thought about long-term impact of contaminants on land value, has wondered about the need to clean them up, has ideas for how to do so, and has examples when it has happened in the past;
- Knows that spills spread from the site of origin, and confidently able to predict that topography, soil, and bedrock will influence the spread of pollutants from a site, with specific examples as to how this has happened in the past;
- Knows contaminants will change location and will not go away on own, knows that they have needed to be cleaned up in the past, can recollect ways in which this has been done, and has ideas for how to do this in the future;
- Knows of mediation and mitigation, can differentiate between the two, knows that they will help to recover land from damaged brownfields or greyfields, and can cite specific examples when this has happened; and
- Concerned with long-term impacts of brownfields on local land values, human health, and biodiversity, definitely aware that brownfields will negatively impact matters

locally, has observations about the mechanisms behind how all three are driven down by brownfields.

References for Further Reading

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Figure 3. Ohio Redevelopment Projects

Toledo-Plabell Rubber Company Property. December 30, 2008. Used with permission under Creative Commons.

Concept 2: Toxic Chemical Pollutants

Definition

Toxic chemicals are typically introduced to waterways from one of three human activities: industry and manufacturing, agriculture, or residential areas. These chemicals are collectively called toxicants. When not adequately treated, toxicants are directly or indirectly discharged into waterways and can affect plants, animals, and humans living in or near the watershed.

Figure 4. Smoke Trapped Between Wires

January 27, 2010. Used with permission under Creative Commons.

Key Concepts & Ideas

1. *Mutagenic chemicals* are toxicants that cause mutations in tissues, especially reproductive tissues. Impacts from these chemicals can be the result of long-term exposure to low concentrations of the chemicals or acute exposure to high concentrations. Mutagenic chemicals typically come from industrial and manufacturing sources.
2. *Hormone analogues* are toxicants that affect an organism by disrupting the normal growth and activity of organs and tissues. Impacts can result from long-term exposure to low concentrations of the chemicals or acute exposure to high concentrations. Hormone analogues typically come from agricultural or industrial and manufacturing sources.
3. *Carcinogenic chemicals* are toxicants that increase the occurrence of cancer, often as a result of long-term exposure to low concentrations of the chemicals or of acute exposure of high concentrations. Carcinogenic chemicals typically come from industrial and manufacturing sources.
4. *Runoff* is how most toxicants spread across a landscape, often during heavy rainstorms. Occasionally, toxicants are spread via a spill of a large container ship and the spill makes its way into the water system for widespread dispersal. Signage on residential drains (e.g., *Sewers Drain to Waterways*) can help prevent disposal of chemicals down storm drains in the street.
5. Industrial and manufacturing toxicants include nearly all toxicants that can be imagined or have been recorded. Solvents and petroleum derivatives are some of the most common industrial pollutants due to their widespread use in so many capacities. Because of the possibility of unplanned chemical releases, most cities have specific zoning restrictions on where industrial manufacturing can occur. As such, most brownfields tend to be concentrated in areas that are zoned for industry. Industrial and manufacturing toxicants tend to have relatively more types of hormone analogues than the other two sources.
6. Agricultural toxicants include pesticides, herbicides, fungicides, insecticides, and fertilizers. These are usually washed off agricultural fields into nearby waterways through runoff-caused soil erosion and can lead to significant ecological effects. In the case of fertilizers, this often takes the form of nutrient enrichment and sudden growth of one or a few species of algae, a process called eutrophication.
7. Residential toxicants are common, typically residing under our kitchen sinks. Some describe the typical home in America as one of the most toxic locations imaginable because of the pesticides, cleaners, bleaches, soaps, paints, oils, petroleum, lawn chemicals, drain openers, and other household products. Typically, these are present in small quantities (with the exception of lawn chemicals, which are often used in great quantities and have a dramatic effect on the surrounding ecosystems) and usually get into the waterways via runoff or the occasional decision to incorrectly dispose of them down a sink or storm drain.
8. *Point source pollutants* can be attributed to a single origin, such as discharge from a particular factory or sewage outfall. Non-point pollution cannot be attributed to one source and includes agricultural and urban runoff. Toxicants from point and non-point sources can get into the water table and spread underground as a large toxic plume that is difficult to trace.

9. *Biological magnification* is when toxicants become more concentrated as they move up the food web from plants to herbivores to predators to decomposers. Each level of the food web concentrates the toxicants that lower levels have consumed. As such, it may be dangerous to consume fish living in waterways with low concentrations of toxicants.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Think about where wealthy and poor housing tends is located relative to industrial areas of the city. Which neighborhoods do you think are most strongly affected by industrial toxicants?
- Where do residential and agricultural toxicants tend to be most commonly used: rural or urban areas?
- How could water infrastructure facilitate or inhibit the spread of toxicants in a community?

Change Over Time (Pleasant Run)

- Change is an essential factor to consider when removing toxins from the environment. How do you think the changes at Pleasant Run affect the ability to remove toxins?
- How do natural processes affect toxin removal?

Water and Habitat Corridor (Fall Creek)

- Are low levels of toxicants in our waterways a concern for wild animals? What about for plants?
- Are low levels of toxicants in our waterways problematic to humans? What about humans that interact with the water directly, by fishing for example?
- Would you be more or less likely to advocate for conservation if wildlife is or is not affected by toxicants in the environment?

Water in the Atmosphere (White River)

- How would rainfall at the White River affect how pollutants are taken out of the waterway?
- Do you think that snowfall and cold weather would affect the removal of pollutants? If yes, how?

Water as Surface Runoff (Little Eagle Creek)

- Given that runoff is the main way toxicants spread, would you be more or less likely to go fishing after a strong rainstorm? Why or why not?
- How does land use or coverage (e.g., pavement, gravel, grasslands, forest) affect the movement of toxicants?
- How does land use affect the speed toxicants enter waterways?

Water as a Resource (Central Canal)

- Do you live near a community that takes drinking water out of the waterways? Would you feel more or less safe about the presence of pollutants if the water comes from a natural river or from a constructed waterway like Central Canal?

Figure 5. Deepwater Horizon Response

July 4, 2010. Used with permission under Creative Commons.

Applications & Implications

Humans: Health & Communities

- Little is known about how many of these compounds affect human and ecosystem health. In general, it is thought that toxicants are mostly lethal, cause mutations, or may cause cancer in humans and animals.
- Toxicants tend to disproportionately impact poorer people because toxicants are more highly concentrated in communities close to industrial areas
- Toxicants are likely to affect people who rely on well water for drinking water because toxicants are likely to leech into well water sources.

Nature: Environment, Sustainability & Conservation

- Release of toxicants is ongoing, pervasive, diffuse, and often very difficult to control, which has many negative consequences for nature. Although it is illegal to dump most toxicants, contaminated sites that are decades old are still around and nearly impossible to clean thoroughly.

- Fish and other aquatic species appear to be the most vulnerable because they are immersed in water-borne toxicants.
- The long-term environmental consequence of toxicants may be dire, possibly leading to the extinction of species and imbalance of ecosystems.

Levels of Understanding

None

- Thinks all chemical toxicants act equally;
- Unaware of the impact of runoff on spread of toxicants;
- Unaware that different types of toxicants predominate in urban, agricultural, and industrial landscapes;
- Unaware of point versus non-point pollution; and
- Unaware of biological magnification.

Low

- Aware that different chemicals toxicants affect people differently and has some awareness of terms including mutagenic, carcinogenic, and hormone analogues, but not sure how they differ;
- Aware of the impact of runoff on spread of toxicants, but only in the most general sense;
- Aware that different types of toxicants predominate in urban, agricultural, and industrial landscapes;
- Aware of point and non-point pollution, but is not certain about the difference; and
- Aware of biological magnification, but does not know the meaning.

Intermediate

- Knows that different toxicants affect people differently, has heard of the terms mutagenic, carcinogenic, and hormone analogues, and can offer vague but accurate descriptions of how they differ from each other;
- Knows about the impact of runoff on the spread of toxicants, has given some thought to how to control disposal of toxicants to avoid spread of chemicals into the waterway;
- Knows that different types of toxicants predominate in urban, agricultural, and industrial landscapes, is aware of the different impacts of these toxicants on people, and has read about the abundance of different toxicants in their region;
- Knows about point and non-point pollution, is able to describe the difference between the two, and has some idea about implication differences for cleanup; and
- Knows that biological magnification means concentrating pollutants in the bodies of animals.

Advanced

- Knows that different toxicants affect people differently, has heard of the terms mutagenic, carcinogenic, and hormone analogues and can differentiate between them, and has some accurate explanations as to where some of those categories typically come from and how they act on people;
- Knows about the impact of runoff on differential spread of toxicants, has given extensive thought to how to control disposal of toxicants to avoid spread of chemicals into the waterway;
- Knows that different types of toxicants predominate in urban, agricultural, and industrial landscapes, is aware of different impacts of these toxicants on people and how they may interact with each other, and has read about the abundance of these different toxicants in their region;
- Knows about both point and non-point pollution, is able to describe the difference between the two, and, can talk about clear implication of differences for cleanup;
- Knows that biological magnification means concentrating pollutants in the bodies of animals that are higher in the food chain, and thinks this may be relevant to human wellbeing.

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Figure 6. Large Scale Farming

USDA. April 19, 2011. Used with permission under Creative Commons.

Concept 3: Water Contamination by Harmful Bacteria

Definition

Although all non-sterilized water has hundreds of harmless bacteria species in it, some of which are naturally found in the human digestive system, the presence of disease-causing strains of bacteria can cause a great number of human illnesses. These illnesses include intestinal infections, dysentery, hepatitis, typhoid fever, and cholera.

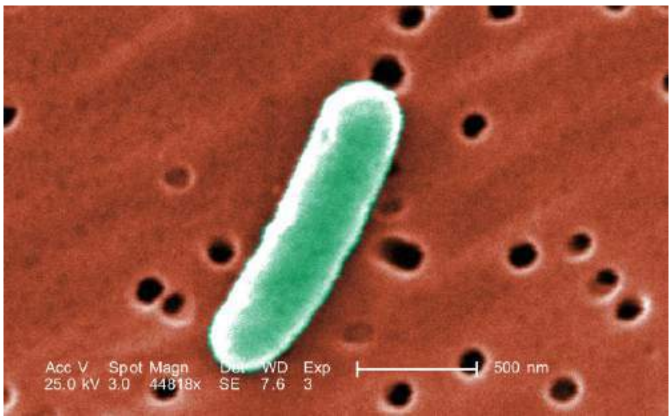

Figure 7. *E. coli* Bacterium

July 22, 2008. Used with permission under Creative Commons.

Key Concepts & Ideas

1. Bacteria are single celled organisms that do not have a true nucleus or other cellular organelles. There are tens of thousands of species of bacteria found in nature – a single teaspoon of soil contains more than a billion bacteria – and most of these do not pose human health risks. The weight of all the bacteria on the planet is greater than the weight of all plants and animals combined. Where there is water, there are bacteria.
2. ***Escherichia coli*** is one of many species of bacteria found in the human digestive system. *E. coli* is present in the lower intestine of humans as an innocuous strain that aids digestion and prevents other bacteria from colonizing our lower intestines. Because *E. coli* is exclusively present in humans and usually degrades when exposed to the environment, it is a useful indicator of when there have been sewage spills to the environment; if *E. coli* is present, then it is likely that sewage is also present.
3. ***Combined sewage systems*** are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Usually, combined sewer systems transport all collected runoff and sewage to a treatment plant where it is treated and discharged to a water body. However, with heavy rainfall or snowmelt, the combined sewer system can exceed the capacity of the treatment plant and the collected liquids will go into the water body with inadequate or no treatment, known as a ***combined sewage overflow*** (CSO). During these periods, it is usually unsafe to come into contact with the water body affected by the CSO due to high bacterial counts. Combined sewage systems are found in the Northeast, Great Lakes states (including Indianapolis), and the Pacific Northwest. In Indianapolis, even a light rainstorm can cause a CSO and pollute Indianapolis waterways.
4. Bacteria counts indicate the concentration of *E. coli*-like bacteria (i.e., fecal coliform bacteria) in water and provide a measure of sewage pollution in our waterways. Usually these counts are expressed as the number of colony forming units per milliliter of the sample. All non-sterilized water has bacteria in it, but only those that have been contaminated by human waste will have coliform bacteria in it.
5. Bacteria enter waterways from the surrounding land, stormwater runoff, septic tank leakage, or other animals and birds that are part of the local ecosystem. Most of these bacteria are either helpful to the human body or are killed off during the water treatment process by UV light, chlorination, or another sanitizing technique. People who drink water straight from the waterway do not have the benefit of water treatment, so they may consume harmful bacteria.
6. Antibiotic resistant strains of *E. coli* evolve when people use large amounts of antibiotics inappropriately or do not take the full prescribed dose. In both cases, the weakest strains of the bacterium are killed and leaving only those that are resistant to the antibiotic. These strains can be exceptionally difficult to treat using regular antibiotics and have the potential to become significant health concerns such as superbugs like MRSA (methicillin-resistant *Staphylococcus aureus*) and *Clostridium difficile*.
7. Boil-water advisories are issued when drinking water has been infected with fecal coliform bacteria. This water is not safe to drink unless it has been boiled for more than 3 minutes. Fecal coliform bacteria usually come from humans, but some can come from domestic animal associates such

as dogs and pigs. Before being transferred to people, contaminated water is usually held in reservoirs, rivers, or runs through pipes that have previously been contaminated.

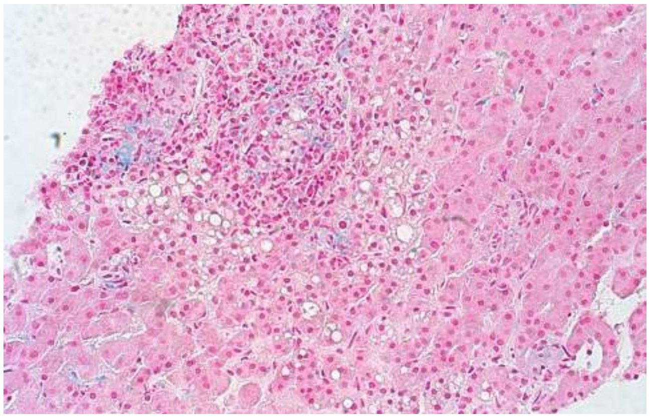

Figure 8. Mac Granulomatus Hepatitis Virus

Jeremy T. Hetzel. January 30, 2010. Used with permission under Creative Commons.

Applications & Implications

Humans: Health & Communities

- Increases of sewage, as detected by monitoring counts of fecal coliform bacteria, usually have negative health implications for humans living near waterways.
- Typically, these implications affect those who interact with the waterways, such as fishers, boaters, swimmers, and walkers, but can also involve the general public if drinking water contamination is involved.
- Often, reservoirs are affected by CSOs and other contamination by sewage spills, making boil-water advisories necessary.
- Most of the bacteria that are most harmful to humans, including *E. coli*, cannot live outside of human and animal bodies for long. As such, the impacts of a CSO or other contamination events tend to be relatively short-lived.

Nature: Environment, Sustainability & Conservation

- Increased sewage also has negative implications for the plants and animals living in waterways.
- Sewage acts as a fertilizer for bacteria and algae, causing them to grow rapidly and consume most of the oxygen in the water, leading to die-offs of fish and other animals.
- As a result, environmental threats from CSOs and sewage spills are caused by the nutrients in the sewage, rather than the harmful bacteria that can be there.

Discussion Questions

Water Infrastructure (Pogue's Run)

- CSOs happen in Pogue's Run because water infrastructure was designed and built many decades ago. How would you redesign the water treatment system to avoid CSOs?
- What are the relevant environmental justice issues, given that wealthy people do not usually live by the waterways where the combined sewage treatment plants are located?
- Where would you put the combined sewage treatment plants so they have the smallest impact on Indianapolis?

Change Over Time (Pleasant Run)

- Does the fact that harmful bacteria degrade quickly in the natural environment affect your perspective of our waterways? If yes, how?
- Given that Indianapolis built much of its infrastructure many decades ago, how challenging would it be to rework the combined sewage system? How long would it take and how would you get the public to advocate for this change?

Water and Habitat Corridor (Fall Creek)

- How might CSOs affect the rich biodiversity in Indianapolis in the long term?

Water in the Atmosphere (White River)

- Sometimes people say that the best way to treat harmful bacteria in the environment is to wait until the next rainstorm. Why would someone hold this perspective? Do you agree with it? Why or why not?

Water as Surface Runoff (Little Eagle Creek)

- Surface water flow through rainfall and snowfall can be followed by a sense of cleanliness in the air and on the land. Are there challenging consequences that come out of this event for the waterways? If so, what would they be?

Water as a Resource (Central Canal)

- A common assumption is that water is a renewable resource. Does understanding harmful bacteria influence your perspective on this assumption? If yes, how?

- Central Canal is a man-made waterway; would you prioritize the cleanup or treatment of a CSO that fed into the Canal over the cleanup of one that fed into a natural waterway?

Levels of Understanding

None

- Unaware of harmful bacteria and their health consequences;
- Has never heard of *E. coli*;
- Unaware of any aspect of sewage treatment and likely assumes that it is just dumped into the water or disappears;
- Assumes that all illnesses should be treated with antibiotics and over uses them regularly; and
- Unaware of the reasons for boil-water advisories.

Low

- Aware that bacteria pose health consequences for human well-being, but unaware of the fact that there are beneficial or even neutral bacteria from a human health perspective;
- Aware of *E. coli* but not certain how it can be acquired by people or from where it comes;
- Aware of how sewage is treated, has not heard of CSOs, and does not know how they work;
- Would prefer to treat all illnesses with antibiotics regardless of the cause; and
- Aware of the reasons for boil-water advisories but does not know how to follow them correctly.

Intermediate

- Knows the health consequences of bacterial contamination and is aware that some bacteria are harmful but that most are beneficial or neutral from a human perspective;
- Knows how *E. coli* spreads and can address contamination;
- Knows about CSOs, their impact, and why they happen, but not certain how they could be addressed;
- Knows about correct antibiotic usage and its benefits, but tends to assume antibiotics would help most illnesses; and
- Knows the reasons for boil-water advisories and follows them.

Advanced

- Knows the health consequences of bacterial contamination and is confidently knowledgeable that some bacteria are harmful but that most are beneficial or neutral to humans;
- Knows how *E. coli* spreads and can address contamination;
- Knows about of CSOs, their impact, and why they happen, understands how sewage is treated normally and has ideas for how CSOs could be addressed;
- Knows about correct antibiotic usage and its benefits, only rarely assumes antibiotics would help most illnesses; and
- Knows the reasons for boil-water advisories and follows them.

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Figure 9. Working on a New Cholera Vaccination

Department of Foreign Affairs and Trade. March 11, 2012. Used with permission under Creative Commons.

Concept 4: Pharmaceutical Pollutants

Definition

Pharmaceuticals are synthetic chemicals from many different chemical families. People use many thousands of types of drugs, so it is almost impossible to sufficiently study the myriad interactions that may occur in the environment and how humans and nature may be affected by all these chemical interactions.

Figure 10. Virginia Guard Assists DEA in Drug Destruction

The National Guard. October 12, 2012. Used with permission under Creative Commons.

Key Concepts & Ideas

1. Most drugs and pharmaceuticals are manufactured to be biologically active in living organisms and resistant to being broken down by our metabolism. These Environmentally Persistent Pharmaceutical Pollutants (EPPP) may pass through the animal digestive systems unaltered and remain biologically active for a long time. EPPPs can then enter the waterways, be taken up by plants, and make their way into the food chain.
2. *Pharmaceuticals and Personal Care Products (PPCP)* includes non-pharmaceutical products like sunblock and fragrances as well as pharmaceuticals. PPCPs enter waterways after being excreted from the body or when unused medication is flushed down the toilet through stormwater runoff, septic tank leakage, CSOs, or treated grey water. People who drink water straight from the waterway or from wells without water treatment may consume low levels of these pharmaceuticals.
3. *Biological magnification* is when pharmaceuticals become more concentrated as they move up the food web from plants to herbivores to predators to decomposers. Each level of the food web concentrates the chemicals that lower levels have consumed. As such, it may be dangerous to consume fish living in waterways with low concentrations of toxicants.
4. Impacts of pharmaceuticals in large doses and via interactions are diverse and affect animals in many ways, including hormone disruption, cancer, mutations, growth or development disruption, and many others. Usually the concentration of these substances in the environment is low, so the main way that humans are impacted is through chronic exposure. Aquatic animals are particularly likely to be affected because they are immersed in these water-borne pharmaceuticals.
5. *Drug take back programs* are a key way that communities have begun to address this problem by collecting and safely disposing of pharmaceuticals. These programs will help reduce the drug contaminants in the environment, but they have faced challenges from federal restrictions on the transfer of controlled substances.

Applications & Implications

Humans: Health & Communities

- Little is known about how these compounds affect human health. It is thought that they have genetic, developmental, immune and hormonal health effects, although this has not been conclusively demonstrated.
- The evolution of antibiotic-resistant microbes which may re-infect humans is a real concern. These microbes have already affected densely populated parts of India.

Nature: Environment, Sustainability & Conservation

- Pharmaceuticals are manufactured to be biologically active in living organisms and to have long half-lives. This makes them risky in nature. Release is ongoing, pervasive, diffuse, and impossible to control.
- Little is known about how these compounds affect ecosystem health.
- Fish and other aquatic species appear to be the most vulnerable. Male fish in the Potomac River near Washington, DC have been found with male and female sex organs, a mutation thought to be caused by exposure to pharmaceutical compounds.
- The long-term environmental consequence may be quite dire. Many EPPPs affect the reproductive systems of aquatic animals, possibly leading to the extinction of species and ecosystem imbalance.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Sewage treatment plants cannot treat or destroy (or denature) EPPPs without being extensively redesigned with additional chemical treatment structures. How willing would you be if you were asked to pay $10 to help create this? What if you were asked to pay $100 to do so? $1,000?
- How could you help address the federal legislation problems preventing a national drug take-back program?

Change Over Time (Pleasant Run)

- How may pharmaceuticals in the waterways change across seasons or years? Are there trends that may influence the abundance of drugs in the system? How could they provide hope for solving this problem?

Water and Habitat Corridor (Fall Creek)

- How do the concentrations of pharmaceuticals change as we move up the watershed? Why?

Water in the Atmosphere (White River)

- Rainwater affects pharmaceutical pollution in similar and different ways than it affects presence of sewage and fecal coliform bacteria. How would a strong rain affect both sources of pollution?

Water as a Resource (Central Canal)

- How do the concentrations of pharmaceuticals differ in river water and well water? Why?

Figure 11. A Variety of Pharmaceutical Pills

Miran Rijavec. June 24, 2011. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware that pharmaceutical pollutants are a problem;
- Unaware of biological magnification;
- Unaware of EPPPs or PPCPs; and
- Unaware of drug take backs as ways to safely dispose of unused medicine.

Low

- Aware that pharmaceutical pollutants are a problem, but not certain how they are problematic or how they enter waterways;
- Aware of biological magnification, but is not certain what it means;
- Aware of EPPPs and PPCPs, but is unaware that they are types of pharmaceutical pollutants; and
- Aware of drug take backs as ways to safely dispose of unused medicine, but does not see the value of participating.

Intermediate

- Knows that pharmaceutical pollutants are a problem, knows that they enter waterways, mostly through sewage treatment systems, and thinks that improper drug disposal into the sewage system likely plays a role;
- Knows that biological magnification refers to concentrating pollutants in the bodies of animals;
- Knows of EPPPs and PPCPs, is aware that they are types of pharmaceutical pollutants, and is aware that they may be problematic for wildlife and possibly also people; and
- Knows of drug take backs as ways to safely dispose of unused medicine, see the value of participating, wants to participate, but is uncertain about how to participate.

Advanced

- Knows that pharmaceutical pollutants are a problem, know that they enter waterways mostly through sewage treatment systems, knows that improper drug disposal into the sewage system likely plays a role, and has advocated for the proper disposal of medicines;
- Knows that biological magnification refers to concentrating pollutants in the bodies of animals higher in the food chain, and thinks that it may be relevant to human wellbeing;
- Knows of EPPPs and PPCPs, is aware that they are types of pharmaceutical pollutants, and is aware that they definitely are problematic for wildlife and also people; and
- Knows of drug take backs as ways to safely dispose of unused medicine, sees the value of participating, wants to participate and has successfully searched for how to do so.

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Concept 5: The Deep Rock Tunnel Connector

Definition

Indianapolis' Deep Rock Tunnel Connector (DRTC) will store CSO outfalls and thereby prevent millions of gallons of raw sewage from being discharged into the city's waterways. The stored sewage in the tunnel will be treated in the advanced sewage treatment plants, so that fully treated water will be discharged into the waterways.

Key Concepts & Ideas

1. *The DigIndy Project* consists of a deep underground tunnel system running parallel to four major waterways in Indianapolis – White River, Fall Creek, Pogues Run, and Pleasant Run – and is designed to store sewage overflows. This system will be 25 miles long and able to store around 250 million gallons of sewage. It will be part of the Long Term Control Plan as agreed to by Indianapolis and Marion County. The DigIndy project is scheduled to be completed by 2025 at a total cost of $1.6 billion and will include significant upgrades to two wastewater treatment plants.
2. The DRTC is the first phase of the DigIndy Project. The DRTC will run through the bedrock under southwest Indianapolis, 250 feet under Harding Street and Banta Road. The DRTC will be 18 feet in diameter, over seven miles long, store 70 million gallons of raw sewage, and remove 3.5 billion gallons of raw sewage entering the waterways through 2025. Construction started in 2011 and is scheduled to be completed in 2017.
3. Digging 250 feet under Indianapolis is not an easy feat. There are five vertical shafts that go down to the horizontal DRTC. These shafts go through many layers of earth: soil and living areas, parts of the upper horizons, the siltstone and shale layers of the water table, and the limestone and shale bedrock layers. A tunnel-boring machine is used to dig through these layers. The machine is 20 feet in diameter and is 450 feet long, and weighs 1.2 million pounds. This machine was previously used to bore the tunnel for the Second Avenue subway line in New York City.
4. *Combined sewage systems* are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Usually, combined sewer systems transport all collected runoff and sewage to a treatment plant where it is treated and discharged to a water body. However, with heavy rainfall or snowmelt, the combined sewer system can exceed the capacity of the treatment plant and the collected liquids will go into the water body with inadequate or no treatment. These *CSOs* pollute all Indianapolis waterways when it rains, adding 7.8 billion gallons of sewage to waterways annually. Once completed, the entire DigIndy Tunnel System will reduce the annual outfall to less than 414 million gallons, a 95% reduction.
5. Boil water advisories are issued when there has been infection of drinking water with fecal coliform bacteria and the water is not safe to drink unless it has been boiled for more than three minutes. Fecal coliform bacteria usually come from humans, but some can come from domestic animal associates such as dogs and pigs. Water that is contaminated is usually held in reservoirs, rivers, or pipes that had been contaminated. The DRTC and the larger DigIndy Tunnel System will help to reduce the number of boil-water advisories by removing untreated sewage from the waterways.

Applications & Implications

Humans: Health & Communities

- The implications of the DRTC for humans are dramatic and positive.
- Benefits for humans are: reduced occurrence and quantity of CSOs, reduced fecal coliform and bacterial counts, reduced quantities and types of pharmaceutical pollutants in the waterways, healthier fish for consumption, reduced stench coming from the water, fewer boil-water advisories, cleaner waterways for water sports and activities, and higher quality drinking water.

Nature: Environment, Sustainability & Conservation

- The implications of the DRTC for nature are also dramatic and positive.
- Benefits for nature are: reduced occurrence and quantity of CSOs, reduced bacterial counts, fewer nutrients entering the waterways reducing algal blooms and increasing oxygen levels, fewer fish die-offs, reduced quantities and types of pharmaceutical pollutants in the waterways, and healthier fish and aquatic animals.

Discussion Questions

Water Infrastructure (Pogue's Run)

- The infrastructure required for the DigIndy Project will eventually come to all five I/CaLL waterways and the benefits of these tunnels are numerous and diverse. Are there drawbacks to putting in the tunnels in the short term? What about over the long term? How might they be addressed?

Change Over Time (Pleasant Run)

- Once the DigIndy Project is completed in 2025, CSOs should dramatically decrease. How long will sewage, pharmaceuticals, and other pollutants from CSOs continue to have an effect?
- Which will deplete in our waterways faster: sewage, bacteria, pharmaceuticals, or other toxic pollutants from old CSOs? Why?

Water and Habitat Corridor (Fall Creek)

- Natural environments will benefit from the DigIndy Project. If you were a frog living in Fall Creek, what is the benefit that would matter most to you?
- Given that non-native species dominate heavily disturbed areas, how will a decrease in CSOs affect the presence and number of non-native species? Would non-native species increase or decrease with a decrease in CSOs? Why?

Water in the Atmosphere (White River)

- How will snowfall affect the ability of the DigIndy Project and the DRTC to control CSOs?

Water as a Resource (Central Canal)

- The Central Canal contains the river that runs through downtown Indianapolis. In many ways the Canal is an aboveground DRTC. How are these two systems similar? How are they different?
- Could the Central Canal and DRTC be used for other purposes? What challenges would you expect if you did so?

Figure 12. Tunnel Boring Machine

MTA Photos. February 21, 2012. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware of the existence of the DRTC;
- Unaware of CSOs and their implications;
- Unaware of boil water advisories and assumes that all water is safe to drink; and
- Unaware that the DRTC will benefit biodiversity locally.

Low

- Aware of DRTC, but unaware of its function;
- Aware of CSOs but not certain how they affect the local waterways or people;
- Aware of boil water advisories, has not heard of boil water advisories locally, and does not know how long to boil water to sterilize it; and
- Aware that the DRTC will benefit biodiversity locally, but not certain how.

Intermediate

- Knows of the DRTC, and can describe what problems it will address;

- Knows of CSOs and that they affect the local waterways or people, can name specific ways in which they harm people and the environment;
- Knows about boil water advisories, has heard of boil water advisories locally, and knows how long it should be done for to safely sterilize the water; and
- Knows that the DRTC will benefit biodiversity locally, can describe how, and can give some general idea about the species that it may benefit.

Advanced

- Knowledgeable about the DRTC, can describe what problems it will help address, and some of the details of its construction;
- Knows of CSOs and that they affect the local waterways or people, can confidently name several ways in which they harm people and the environment, and can name ways to address the problem;
- Knowledgeable about boil water advisories, knows of boil water advisories locally, knows exactly how long water should be boiled to sterilize it, knows the specific microorganisms that would be addressed; and
- Knows that the DRTC will benefit biodiversity locally, can describe how, can give specific ideas about the species that it may benefit, knows that CSOs tend to produce eutrophic water conditions that kill local species.

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Concept 6: Riparian Habitats

Definition

The riparian zone is the interface between the land and a river or stream running through it. Riparian habitats are the types of habitats found along the banks of a river or stream. Riparian habitats may be on land (terrestrial), in the water (aquatic), or at the water's edge (littoral). These habitats are of great value for local wildlife and plants, typically containing many more species than the surrounding lands.

Figure 13. Riparian Habitat

Merrill College of Journalism Press Release. December 1, 2010. Used with permission under Creative Commons.

Key Concepts & Ideas

1. ***Riparian areas*** have become increasingly important plant and animal habitat as humans continue to alter the natural environment. Even small riparian strips are of great value for animals as places to live, feed, and reproduce. Riparian habitat, however, is also threatened. A 1991 study[1] estimated that the conterminous United States has lost 53% of the wetland and riparian habitats that existed before European colonization. This estimate has likely grown with the doubling of human population growth since the study.
2. In urban and agricultural areas, biodiversity tends to be greatest in riparian habitats. Without these habitats, we would be less likely to see frogs, toads, newts, fish, many species of plants, and many bird species, especially migratory birds. In some dry areas of the west (e.g., southeastern Wyoming and Oregon), riparian zones comprise less than 1% of the land but over 75% of all terrestrial wildlife species are dependent on them for at least a portion of their life cycle[2].
3. Breeding areas for many species – especially amphibians, birds, insects, fungi, and aquatic plants – are exclusively in riparian zones, including urban riparian zones.
4. ***Riparian corridors*** also act as dispersal and migration routes, facilitating the movement of species across an otherwise hostile landscape. For many species, urban and agricultural areas do not have the resources necessary for the species to live, such as food, nesting materials or space, water, cover, or shelter. Riparian corridors allow individuals to move through these urban areas to more valuable habitat relatively safely.
5. The plants in riparian habitats often provide valuable ecosystem services. Ecosystem services are processes that emerge from the collective biological action of the species in the waterways. For example, plants stabilize riverbanks, decreasing erosion, filtering water, slowing floodwater movement, and reducing downstream flood peaks. Healthy riparian habitats help local aquifers recharge with water so

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[1] Dahl, T.E., and Johnson, C.E. (1991) Wetlands-Status and trends in the conterminous United States, mid-1970's to mid-1980's. Washington, D.C., U.S. Fish and Wildlife Service, 22 p.

[2] Chaney, E., W. Elmore, and W. S. Platts. (1990) Livestock grazing on western riparian areas. United States Environmental Protection Agency, Washington, D. C., USA.

that more groundwater may be available for human use during dry seasons.

6. The width of riparian zones determines their ecological value. A wide natural riparian zone provides area for a diversity of riparian habitats and a buffer zone, which insulates them from the effects of the urban environments like noise and chemical pollution, trash, and human traffic. As a consequence, wider riparian zones tend to be healthier and more biologically diverse than narrower one.
7. *Restoration* is the process of converting an ecologically damaged or degraded area to a more natural state. In riparian habitats, restoration is typically focused on expanding the width of the natural areas along the sides of waterways. This can be accomplished by allowing the sides of the waterways to regrow on their own, replanting the waterway banks, or some combination of the two. If the riparian zones are paved or otherwise altered by humans, removing construction materials will be necessary.

Applications & Implications

Humans: Health & Communities

- Ecosystem services benefit humans by reducing the impacts of flooding and pollutants in the short term and drought in the long term.
- Humans may also directly use riparian habitats by fishing, kayaking, canoeing, swimming, and enjoying the scenery.

Nature: Environment, Sustainability & Conservation

- Riparian habitats are valuable areas for plants and animals to live, especially in urban areas.
- The value of riparian habitats for species conservation increases as the area altered by human activity increases.
- Biodiversity in riparian areas depends on the features of the habitat. Areas with more hills leads to greater diversity in plant types (e.g., trees, bushes, grasses, forbs) and will tend to support more species of plants and animals.

Figure 14. Riparian Strip Cottonwoods

Lou Feltz. October 27, 2013. Used with permission under Creative Commons.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Areas that are more heavily built typically have fewer habitats for native species. How could you change built riparian areas so that they would be more valuable for biodiversity?
- Do your changes require more or fewer modifications of the environment?
- Can you restore riparian habitats without direct intervention?

Change Over Time (Pleasant Run)

- Does restoration of riparian habitats occur over months, years, or decades? Why?
- How does the speed of restoration compare to the speed in which humans alter riparian habitats?
- What could you do to speed up the process of restoration?

Water and Habitat Corridor (Fall Creek)

- Riparian habitats form a natural corridor through Indianapolis along which animals may move. Which animals do you think are using these riparian zones to live year-round? Which pass through during migrations?
- What data could you collect that would help you to distinguish between residents and migrants?

Water in the Atmosphere (White River)

- Aquifer recharging may happen faster in wider riparian zones. How would you advocate for widening the zone? How else could the recharging process be sped up?
- Are these actions more valuable in urban or rural areas? Why?

Water as a Resource

- Does the presence of water in a riparian zone always make the area more desirable for wildlife? Why? Consider human waste products

Levels of Understanding

None

- Does not know what a riparian zone is or its importance as habitat;
- Has never heard of an ecological corridor;
- Unaware of how riparian zones contribute to biodiversity;
- Unaware of the concept of ecosystem services; and
- Unaware of the value of restoring riparian zones.

Low

- Knows what a riparian zone is, but does not know its importance as habitat;
- Aware of the concept of an ecological corridor, but is not certain what it means or its significance;
- Aware that riparian zones contribute to biodiversity, but is not certain why;
- Aware of the general concept of ecosystem services, but not certain how riparian zones may provide any ecosystem service; and
- Aware of the value of restoring riparian zones, but is unclear how it would happen;

Intermediate

- Knows what a riparian zone is, can discuss its importance as habitat, and can name one or two species that live there;
- Knows the concept of an ecological corridor, is able to describe its significance, and can name one or two species would use a riparian zone for dispersal;
- Knows that riparian zones disproportionately contribute to biodiversity, understands why, and can describe how they impact biodiversity;
- Knows the general concept of ecosystem services and can provide examples, knows that riparian zones provide valuable ecosystem services, has a definite idea of what one might be, and explains it well; and
- Knows about the value of restoring riparian zones, has some ideas how it would happen, has seen it done, and is aware of the challenges and tradeoffs.

Advanced

- Knows what a riparian zone is, can discuss its importance as habitat, can name several species that live there, and can describe what habitats are unique to those species;
- Knows the concept of an ecological corridor and what the concept means, is able to thoroughly describe its significance, can name several species that use riparian zones for dispersal, and can describe how those animals would use it;
- Knows that riparian zones disproportionately contribute to biodiversity, understands why, can describe how and why these zones impact biodiversity;
- Knows about ecosystem services and can provide examples, knows that riparian zones provide valuable ecosystem services, and has a definite idea about a few and explains them all well; and
- Knows about the value of restoring riparian areas, has several ideas how it would happen, has seen it done, and is able to speak about the challenges or tradeoffs.

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Concept 7: Invasive Species

Definition

An invasive species is a non-native species whose introduction by humans and subsequent massive population growth may cause harm to the economy, environment, and human health.

Figure 15. Kudzu

U.S. Department of Agriculture. February 12, 2014 Used with permission under Creative Commons.

Key Concepts & Ideas

1. There are multiple terms for species that are not native to a given area. While they are often used interchangeably, they have slightly different meanings.
   - ***Exotic, Introduced, or Non-Native species*** are brought to a new location from elsewhere, usually by human action, and are definitely not a native species. These terms are more general than invasive species. Exotics and non-natives have not necessarily progressed to becoming ecologically dominant.
   - ***Naturalized species*** are non-natives that have been cultivated for human use (e.g., sweet clover for cattle forage). These are not usually considered invasive as they are largely dependent on human cultivation and care to continue.
   - ***Invasive species*** are non-native or exotic species that have become ecologically dominant in a given area, often outcompeting and crowding out native species.
2. Human actions have led to the introduction of most non-native species into a new area. Introductions occur by intentional releases (e.g., pigs), accidents (e.g., Emerald Ash boring beetle in shipping materials), escapes of cultivated species (e.g., Asian carp), or by humans modifying an environment so that non-native species can establish (e.g., purple loosestrife along the sides of US highways).
3. Human disturbances may allow species to become superabundant and progress to becoming invasive. Human disturbances may involve directly manipulating habitat (e.g., paving or dredging) or indirectly contributing to offsite disturbances (e.g., chemicals in the runoff from streets). Both may contribute to changes in species abundance.
4. Habitat change often accompanies the proliferation of exotic species, such as with the invasion of the common reed along slow-moving waterways. Often plants such as the common reed will grow so densely that they can choke a river and convert a free-flowing waterway into a stagnant pond.
5. Species diversity declines often accompany superabundant invasive species. Invasive species will outcompete all other species in the area and cause native species populations to decline until they become locally extinct. As these species become dominant in a riparian area, the overall vegetative diversity decreases. This can also result in the absence of key resources and habitats for some wildlife species, including those of value to hunters and fishers.
6. Water quality may be negatively affected by the presence of invasive species along waterways. For example, invasive algae species grow quickly and may consume most of the oxygen in the water, resulting in huge fish die-offs due to lack of oxygen. Also, native organisms in the water may not be able to decompose dead plants as quickly as they are produced, so that they start to rot and spoil the water (often giving off a smell of rotten eggs).
7. The natural spread of invasive species does occur, but it has been estimated that the frequency of human-assisted spread of species is several thousand times greater than natural spread[3]. As a result, most biologists assume that new species showing up in an area are due to human activities.
8. It is better to prevent the introduction of new species than to try to remove it once it has become invasive. Similarly, if an

[3] Lockwood, J.L., M.F. Hoopes, M.P. Marchetti. (2013). Invasion Ecology, 2nd Edition. Wiley-Blackwell. 466 pages.

introduction is detected early when the population of the possibly invasive species is small, it is much cheaper, more effective, and less damaging to the environment to eradicate it immediately, rather than waiting. As such, monitoring for problematic species and then quickly removing them when they are detected is the single most effective strategy for controlling the spread of invasive species.

Applications & Implications

Humans: Health & Communities

- Most invasive species found near or in waterways only inconvenience nearby people, typically by changing how the waterway functions or smells.
- If stream flow becomes slowed or stagnant, such as can occur in an invasion of densely growing reeds, the water may allow for the breeding of mosquitoes. Proliferations of mosquitoes may facilitate the spread of mosquito-borne illness, such as West Nile Virus.

Nature: Environment, Sustainability & Conservation

- The ecological dominance of species once they become invasive often leads to the local extinction of natives.
- Although it would be best avoid invasive species altogether, once they are present and ecologically dominant, it is costly and likely ecologically damaging to remove them. Conservation biologists disagree about whether removing them is worth the cost and damage.

The best way avoid invasive or non-native species is to prevent their spread by monitoring for the presence of new pest species. Volunteering to help monitor and remove invasive species is a great way to help maintain the health of your local waterways. If an invasive is detected early enough, it is possible to remove it cheaply and with little ecological damage.

Figure 16. Zebra Mussels on a Shopping Cart

USFWS Pacific Region. September 26, 2012. Used with permission under Creative Commons.

Discussion Questions

Water Infrastructure (Pogue's Run)

- What are some ways that invasive species may negatively affect the built environment?
- What are some ways that invasive species can improve the water infrastructure in Indianapolis?

Change Over Time (Pleasant Run)

- Many non-native species are present in ecosystems in very low numbers for years or decades before human activities cause their numbers to increase rapidly. Are there human disturbances around Pleasant Run that may promote the proliferation of a plant or animal species?
- What are some traits that make a species' population size likely to increase in response to human disturbances?

Water and Habitat Corridor (Fall Creek)

- Habitats comprise a limited resource for species along a natural waterway. What are some ways that invasive species may increase the number and diversity of habitats by coming in and growing in abundance? Think about plants of many heights that may become established along a waterway and offer different nesting habitats.
- Are you interested in volunteering to help monitor for possibly invasive species and help to remove them? What would make you want to do this?

Water in the Atmosphere (White River)

- How might longer and colder winters affect the establishment of new species that may otherwise become invasive locally? Would it help or hinder their establishment?
- Would more or deeper snow help or hinder establishment of new species. Might the snow act like a protective blanket?

Water as a Resource (Central Canal)

- Water is a resource for many species. Would you support the decision to dredge a waterway to remove an invasive species if it harmed native species in the short term?

- What if the impacts of the dredging to remove the invasive were very short and modest? At what point would you change your mind to not support the dredging?

Levels of Understanding

None

- Unaware that invasive species are an ecological problem;
- Unaware of the role of humans in the introduction and spread of invasive species;
- Unaware of the impacts of invasive species on local communities and species;
- Unaware that invasive species may negatively affect water quality; and
- Unaware of the best time to try to remove a non-native species.

Low

- Aware that invasive species are an ecological problem, but not certain of difference between invasive versus non-native species;
- Aware of the role of humans in the introduction and spread of invasive species, but is not certain how this happens;
- Aware of the impacts of invasive species on local communities and species, but does not know how invasive species may negatively affect other species;
- Aware that invasive species may negatively affect water quality, but not certain how; and
- Aware that it is easiest to remove non-native species soon after their arrival when population sizes are small.

Intermediate

- Knows that invasive species are an ecological problem, knows difference between invasive versus non-native species, has several examples and maybe a few ways to remove them;
- Knows about the role of humans in the introduction and spread of invasive species, knows that humans have helped to introduce species in many locations and modified the environment to make it easier for them to establish and spread;
- Knows about the impacts of invasive species on local species, is able to discuss some of the mechanisms for how invasive species may negatively affect other species, but is not certain of the scope of impact globally;
- Knows that invasive species reduce plant and animal diversity, thereby decreasing water quality and hindering ecosystem functioning; and
- Knows that it is easiest to remove non-native species soon after their arrival when population sizes are small and has some idea about how to do so for one or more species.

Advanced

- Knows that invasive species are an ecological problem, knows difference between invasive versus non-native species, can provide many example species, and several ways to remove them;
- Knows about the role of humans in the introduction and spread of invasive species and knows that humans have helped to introduce species in many locations and modified the environment to make it easier for them to establish and spread;
- Knows about the impacts of invasive species on local species, is able to discuss many of the mechanisms for how invasive species may negatively affect other species, and know that impact of invasive species globally is huge;
- Knows that invasive species reduce plant and animal diversity, thereby decreasing water quality and hindering ecosystem functioning, and understands ecosystem functioning; and
- Knows that it is best to remove non-native species soon after their arrival when their population sizes are small and has some idea about how to do so for one or more species.

Figure 17. Eucalyptus Grove

Kent Kanouse. July 30, 2005. Used with permission under Creative Commons.

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Concept 8: Nutrient Cycling in an Urban Environment

Definition

Nutrient cycling describes the use, movement, and recycling of chemical nutrients in the environment. In an urban setting, there are many forces that directly and indirectly alter nutrient cycling processes and have consequences for health of natural biodiversity, urban tree health, water quality, pet waste disposal, and water runoff patterns.

Figure 18. Fungi

Vik Nanda. September 23, 2006. Used with permission under Creative Commons.

Key Concepts & Ideas

1. *Nutrient cycling* refers to the movement of organic and inorganic matter back into the production of living matter. As such, nutrient cycling can be thought of as a form of natural recycling of nutrients from one form into another. This process can involve biological, geological, and chemical processes. While nutrient cycling is often treated as equivalent to biogeochemical cycling, nutrient cycling tends to be contained within a given ecosystem whereas biogeochemical cycling typically involves a much larger geographical area.
2. All matter consists of atoms of elements bound into molecules that may then be combined into compounds. These compounds and molecules typically need to be decomposed and broken down into smaller molecules before plants, fungi, and animals can use it.
3. *Carbon, Hydrogen, Nitrogen, Oxygen, Phosphorus, and Sulfur (CHNOPS)* are the chemical elements making up most biological molecules on Earth and are commonly tracked in nutrient cycling analyses. These elements are recycled at different rates.
4. *Organic matter* includes carbon and is usually formed by the metabolic processes of living organisms. *Inorganic matter* is usually synthesized by geological systems. Organic and inorganic matter cycle differently.
5. Biological activity is usually required to break down dead organic matter and make the nutrients available for uptake and recycling by organisms. The recycling of dead organic matter may be slower in urban areas than in natural areas because there are fewer decomposers and insect-eating animals present.
6. Smelly water is a frequent consequence of the slow rate with which organic matter is recycled in urban waterways. Odors may be particularly strong in small bodies of stagnant water that are also breeding grounds for biting flies that may bite people and spread diseases.
7. Nutrient flow pathways are affected by different factors in an urban versus natural environments. These factors include the urban heat island effect (pavement retains heat longer than does open soil), atmospheric pollutants from exhaust and industry, anthropogenic disturbances, soil and lawn fertilization and irrigation, and planting and cultivation of non-native plant and animal communities.

Applications & Implications

Humans: Health & Communities

- Nutrient cycling, and particularly slower organic decomposition, has consequences for human wellness, particularly for those who interact closely with waterways.
- Consequences include noxious odors from stagnant water, high nutrient loads in the water, which kill most insect-feeding animals but leave mosquitoes, increased rates of mosquito and fly-borne diseases, and decreased water quality on surface waterways and underground wells.
- In the past, people in many urban areas, including Indianapolis, did not view the waterways as important parts of their communities. Poorer people tended to live near the

waterways and have suffered most from decreased nutrient cycling in those urban areas.

Nature: Environment, Sustainability & Conservation

- Urban influences will decrease local biodiversity, which in turn slows nutrient cycling.
- As the environment is degraded, many native species are lost and opportunistic species become ecologically dominant. The loss of native species often results in population increases in pest insects.
- Removing urban influences from our waterways is challenging, but possible. Many communities have made concerted efforts to crack down on polluters, clean up debris, and help riverbanks return to a natural state. These changes have increased the ecological health of many waterways, including those in Indianapolis.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Are there improvements that you think would help to return the waterway to ecological health?
- Why does a paved streambed slow nutrient cycling? Are there easy ways to restore the paved streambed to a more natural streambed?
- How might a waterway with slow nutrient cycling cause human disease?

Change Over Time (Pleasant Run)

- A person might say that time can heal all wounds. Do you think that nature and natural processes would eliminate the effects of people on the waterways?
- How could you accelerate the process of changing a strongly urbanized waterway back to a more natural state?
- How could you accelerate the process if little money was available to do so? What are some small activities that would prompt change?

Water and Habitat Corridor (Fall Creek)

- Urban waterways tend to have slower nutrient cycling because of the strong ecological changes that come from being in an urban setting. What could we do to this waterway to make it more natural and therefore more of a viable habitat for local species?
- Are there native species already here? How do you know?
- How do native and non-native species affect nutrient cycling? Point out a few species and suggest how you think that they may affect the decomposition of dead organic matter.

Water in the Atmosphere (White River)

- Does rain slow or speed up nutrient cycling in urban areas? Why or why not?
- How do snow and ice affect nutrient cycling?

Water as a Resource (Central Canal)

- Slower nutrient cycling in urban waterways may lead to water being made stagnant and smelly. How might this outcome may affect our use of the water?
- The water table, where we get our well water, often has very different properties and cycling patterns than surface water in our waterways. How might this strict separation break down, such as during a heavy rainstorm?

Figure 19. Soybean Field with Healthy Soil

USDA NRCS South Dakota. July 10, 2013. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware of the concept of nutrient cycling;
- Unaware of the differences in movement of materials in urban relative to natural settings;

- Unaware of differences in biodiversity in urban relative to natural settings;
- Unaware of differences in decomposition rates in urban relative to natural settings; and
- Unaware of major chemical elements in organic materials and has not thought about differences between inorganic and organic materials.

Low

- Aware of the concept of nutrient cycling, but is not certain of any details;
- Aware that the movement of materials in urban settings must be different than natural settings, but has not given it much thought;
- Aware of differences in urban and natural biodiversity, but is not certain how they differ;
- Aware of differences in decomposition rates in urban and natural settings, but is not certain how they differ; and
- Aware of major chemical elements in organic materials, but cannot name them and has not thought about differences between inorganic and organic materials.

Intermediate

- Knows of the concept of nutrient cycling, knows that material is cycled through the atmosphere, soil, and water, and has an idea that animals and plants are involved;
- Knows that the movement of materials in urban settings is different than natural settings and can discuss a few possible reasons for why;
- Knows about differences in biodiversity in urban and natural settings and offers an explanation for the difference;
- Knows about differences in decomposition rates in urban and natural settings and offers an explanation for the difference; and
- Knows major chemical elements in organic materials, can name most of them, knows the difference between inorganic and organic materials, and suspects that presence of carbon may be the key difference.

Advanced

- Knows about nutrient cycling, knows that material is cycled through the atmosphere, soil, and water, knows that animals and plants are involved in the breakdown and conversion of materials to other states;
- Knows that the movement of materials in urban settings is different than in natural settings, identifies urban heat islands, runoff, and pollution as possible reasons;
- Knows about differences in biodiversity in urban and natural settings, has clear facts about the ways in which urban diversity is depressed, and offers a few clear explanations for the difference;
- Knows about differences in decomposition rates in urban and natural settings, has clear facts about how urban decomposition is slowed, and offers a few clear explanations for the difference; and
- Knows major chemical elements in organic materials, can name all of them, has thought about differences between inorganic and organic materials, and knows that presence of carbon is the key difference.

Figure 20. Mushrooms

Rene Mensen. October 27, 2013. Used with permission under Creative Commons.

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Concept 9: Material Flow Analysis

Definition

Material Flow Analysis (MFA) is the quantification and assessment of the movement of materials (e.g., water, food, excreta, and wastewater) and chemicals (e.g., nitrogen, phosphorus, and carbon) in a defined ecosystem. MFA tracks the path a material or chemical takes through the system.

Figure 21. Surveying Methods

U.S. Army Corps of America. September 24, 2010. Used with permission under Creative Commons.

Key Concepts & Ideas

1. MFA is a systematic assessment of the flows and stocks of materials within a system. The process can identify problems and quantify the impact of human activity on resource recovery and environmental pollution.
2. MFA has many applications, including:
   - Controlling and optimizing the paths materials take in industry processes;
   - Tracking energy usage patterns in a system, including natural systems like waterways;
   - Identifying an industry or product's environmental impact on a waterway or ecosystem;
   - Helping find solutions for hazardous waste sites and sewage treatment problems, such as CSOs; and
   - Monitoring nutrient levels in waterways affected by urbanization, pollution, or waste, and planning treatment.
3. MFA allows scientists and other governing bodies to quantify the nutrient and chemical makeups of different waterways, where these substances go, and how they vary over time.
4. MFA can help determine how to allocate funds to repair or re-engineer damaged waterways in urban ecosystems. Comparing the environmental and financial impacts of different options, such as the diversity of sanitation technologies, can inform decision-making.
5. Material flows are expressed in kg/year or kg/capita/year.
6. When conducting a MFA, it is important to determine the system boundaries to effectively close a system and measure the flows. These boundaries may be as small as the septic system on a single house, or as large as a watershed.

Applications & Implications

Humans: Health & Communities

- MFAs benefit human health by enabling us to evaluate multiple approaches to solving environmental problems, such as CSOs or stagnant bodies of water.
- Developing countries and economically disadvantaged US communities have used MFAs to detect environmental problems early and develop appropriate solutions.

Nature: Environment, Sustainability & Conservation

- MFA can be used to determine how an ecosystem has been or will be affected by a pollutant.
- MFA can also inform policies for managing hazardous substances, nutrients in watersheds, and sanitation.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Would it be easier to conduct an MFA in a heavily built waterway or in an undisturbed, natural waterway? Why?

Change Over Time (Pleasant Run)

- How might the MFA approach differ for materials that do not readily decompose, versus those that do?

Water and Habitat Corridor (Fall Creek)

- MFAs ideally occur in a closed system. What factors would you have to consider for an MFA of a river that flowed through many counties? What about for one that flowed through many states?
- Is a lake a closed system? Are there processes that connect lakes to the surrounding landscape?

Water in the Atmosphere (White River)

- Does rain or snow affect whether a system can be considered as closed?
- Can you imagine ecosystems or habitats that are completely closed to outside influences?

Water as Surface Runoff (Little Eagle Creek)

- Water that flows along the surface of the ground connects landscape features that would otherwise be separate from each other. How might surface runoff similarly connect features? Can you think of situations where this has happened in your community?

Water as a Resource (Central Canal)

- If you are responsible for a waterway, what sort of information would you need to do an MFA?
- How frequently would you need to check the material flows in and out of your system to make sure that your resource is maintaining the same flow rates?

Figure 22. Water Monitoring

Nexen Energy. May 9. 2012. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware of MFAs;
- Unaware that people track the progress of water infrastructure projects; and
- Unaware that people need to clearly define the boundaries of a system when tracking materials.

Low

- Has not heard of the term MFA, but is able to intuit what it means;
- Aware that people track the progress of water infrastructure projects and can describe the value of this process; and
- Aware that people would want to clearly define the boundaries of a system when tracking materials, but not exactly certain why.

Intermediate

- Knows of MFA and is able to describe its value for tracking the movement of materials through a system;
- Knows that people use MFA to track the progress of water infrastructure projects and can describe the value of this process; and
- Knows that people would want to clearly define the boundaries of a system when tracking materials, knows that not doing so would lead to diffuse tracking and lack of clarity, and thinks that there are other consequences.

Advanced

- Knows about MFA and is able to thoroughly describe its value for tracking the movement of materials through a system;
- Knows that people use MFA to track the progress of water infrastructure projects and can skillfully describe the value of this process; and
- Knows that people would want to clearly define the boundaries of a system when tracking materials, knows that not doing so would lead to diffuse tracking and other consequences, such as loss of money or materials.

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Figure 23. Measuring River Flow

Aug 3, 2008. Used with permission under Creative Commons.

Concept 10: Urban Water Cycle

Definition

The water cycle, also known as the hydrological cycle, is the continuous exchange of water between land, water, and the atmosphere. Impervious surfaces associated with urbanization alter the amount of water that takes each route. The consequences of this change are a decrease in the volume of water that permeates the ground and an increase in volume and decrease in quality of surface water. These hydrological changes have significant implications for the quantity of fresh, clean water that is available for use by humans, fish, and wildlife.

Figure 24. Raining Night

January 17, 2007. Used with permission under Creative Commons.

Key Concepts & Ideas

1. The ***water cycle*** tracks the movement of water around the planet. Approximately 97% of the earth's water is seawater. The remaining 3% is freshwater, most of which is stored in the polar ice caps, so that only 0.61% of all water on the planet is consumable by people. Precipitation can follow several routes: water can evaporate and return to the atmosphere, water may seep into the ground and go into the water table or even deeper into the underlying aquifer, or water may stay on the surface of the Earth, traveling to oceans by the terrestrial waterways.
2. Urban water cycles are different than those in more natural areas because so much of the land is covered by ***impervious surfaces*** (e.g., pavement, buildings, channelized waterways, artificial playing surfaces). These surfaces prevent water from seeping into the ground and recharging the water table or the aquifer that provides long-term water storage.
3. In urban settings, the percentage of precipitation that goes into evaporation, ***infiltration***, and surface runoff differs based on the percentage of ground with impervious cover. In settings with more natural cover, 10% of precipitation goes to runoff, 40% to evaporation, and 50% penetrates the earth to recharge the aquifer and water table. In cities, these numbers are almost reversed: 55% goes to runoff, 30% to evaporation, and only 15% penetrates the ground.
4. Flooding risk is greater in urban settings because of the increase in intensity and size of water surface flows. In cities, as much as half of all precipitation becomes runoff, which is collected into fewer waterways as it moves down the watershed. Consequently, even relatively small rainfall events can lead to flooding in low-lying areas.
5. ***CSOs*** tend to be more frequent in urban areas with more impervious cover. As a result, the amount of untreated sewage water also tends to increase with urbanization.
6. There is more ***erosion*** in urbanized areas than in natural areas because more precipitation goes to runoff. As a result, topsoil is lost faster in urban areas and the waterways are silted up more quickly. Similarly, vegetation cover is lost on stream banks near and downstream from urban settings because of increases in surface water flows.
7. Water quality is lower in urban settings for several reasons. First, more pollutants and trash enter the waterway. Second, the treated water coming from wastewater treatment plants still has many PPCPs dissolved in it. Third, more erosion and faster movement of surface runoff contribute to the spread of harmful products in the runoff.
8. Water tables and aquifer levels drop with more urbanization and impervious ground cover because more precipitation becomes runoff. Wells in areas with more than 10% impervious cover become non-productive very quickly. Areas with dropping water tables and aquifers are also prone to sinkholes, which can bury homes and property.

Applications & Implications

Humans: Health & Communities

- Cities with more impervious ground cover, including paved waterways, tend to have more floods and erosion, lower water quality, more sinkholes, less groundwater recharging, drier wells, and more frequent and severe CSOs.

- Some cities have begun to reduce the amount of impervious groundcover to mitigate these harmful effects. This effort has been particularly focused on the banks of waterways in urban areas.

Nature: Environment, Sustainability & Conservation

- For more natural aquatic ecosystems, there are serious threats that more erosion will scour out entire plant and animal communities on the sides of waterways.
- More surface flow will also bring many more pollutants, human waste, and trash into the waterways and decrease the quality of the water for the animals and plants living in it. Species that are sensitive to these substances may experience population or go locally extinct.
- Restoring natural streambeds will help some native species to return to the area. Unfortunately, the new ecosystem may be quite different if non-native plants and animals have taken up residency. Native species may not be able to compete with these outsiders.
- Humans must make efforts to replant native plant species. Native animals that rely on those plants will often reestablish on their own.

Figure 25. Flooded Street Corner

Paul Jerry. June 4, 2010. Used with permission under Creative Commons.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Pick one aspect of the waterway infrastructure. What are the core functions of that infrastructure and what is not necessary?
- What features could be removed to improve the naturalness of the area while keeping the core functions of the infrastructure?

Change Over Time (Pleasant Run)

- Restoring urbanized areas takes time. How can we speed up this change along waterways?
- Why would people want to remove pavement around their homes? How might we encourage people to do this?

Water and Habitat Corridor (Fall Creek)

- In urban systems, large volumes of water are channeled into waterways, which can overflow and destroy habitat along the riverbanks. What can the city do to slow the frequency and volume of these pulses of water?
- How can we use built structures to slow erosion and beautify the community and waterways?

Water in the Atmosphere (White River)

- Rain washes oil and other chemicals from the pavement and channels them into the waterways, which may poison animals and plants. What are small actions that people can take to minimize this problem?
- What messages work best for you? Does effective messaging differ by neighborhood or by target age groups?

Water as a Resource (Central Canal)

- A key way to increase water quality is to reduce the amount of water that flows off the land and into the storm drains. Would you be willing to collect water around your home that would otherwise flow into the drains and then out to the waterways? What can you could do with the water that you collect?
- People who live in very dry places often collect rainwater from their roofs to use in their homes. How could you help to ensure that water is drinkable? How would you treat it over the long term to keep it clean and healthy?

Levels of Understanding

None

- Unaware of the water cycle;
- Unaware that water moves through urban areas differently than through natural areas;

- Unaware of differences in flooding rates and scale in urban areas relative to natural areas;
- Unaware of CSOs; and
- Unaware that rivers become more contaminated as they enter urban areas.

Low

- Aware of the water cycle, but is not clear on the details;
- Aware that water moves through urban spaces differently than through natural spaces, but is not certain how;
- Aware that flooding rates and scale in urban areas differs from natural areas, but is not sure how;
- Aware of CSOs, but is not certain what they are; and
- Aware that rivers are more contaminated as they enter urban areas, but not certain how.

Intermediate

- Knows what the water cycle is, has most of the details correct, but is missing a few key components, (e.g., unaware that all water eventually enters the oceans);
- Knows that water moves through urban spaces differently than through natural spaces, knows that more water moves through runoff, knows that more of urban areas are covered with impervious surfaces, may have an idea that this will mean that less water enters groundwater;
- Knows that more flooding happens in urban areas than in natural areas, thinks that it may be because of impervious cover;
- Knows about CSOs, understands why and when they occur, and is aware of the connection between rainfall and raw sewage discharge; and
- Aware that rivers are more contaminated as they enter urban areas, knows that they become contaminated with runoff byproducts from land, thinks that these runoffs contain chemicals from industry and agriculture, but is not certain what that means.

Advanced

- Knows what the water cycle is, has the details correct for the entire process, and is aware that all water eventually enters the oceans and becomes re-circulated;
- Aware that water moves through urban spaces differently than through natural spaces, knows that more water moves through runoff, knows that more of urban areas are covered with impervious surfaces, knows that this means that less water enters groundwater;
- Knows that more flooding happens in urban areas than natural areas, knows that it is due to impervious cover;
- Knows about CSOs, confidently explains why and when they occur, knows the connection between rainfall and raw sewage discharge, and can explain the physical structure of sewage treatment plants that lead to this; and
- Knows that rivers are more contaminated as they enter urban areas, knows that they become contaminated with runoff byproducts from land, and knows that these runoffs contain chemicals from industry and agriculture, suggests that household chemicals are also a large factor.

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Concept 11: Urban Heat Island Effect

Definition

Urban heat islands are created when city growth alters the urban fabric by replacing forest with manmade features, such as asphalt roads and tar roofs. Trees provide shade and cool the air through evaporation, but the hard, dark surfaces that replace them store heat during the day. This heat is released at night, so that both the highest and the lowest temperatures in the city are elevated relative to the surrounding rural areas.

Figure 26. Melted Streets

Orin Zebest. June 16, 2006. Used with permission under Creative Commons.

Key Concepts & Ideas

1. The ***urban heat island effect*** is most intense in large cities without adequate green space. Dark pavement, cement, tarmac, stone, and glass are effective at holding heat, so areas with a greater concentration of these materials will have more intense heat island effects. Green spaces dissipate heat in surrounding areas, acting as a sink that drains heat away from built areas. In contrast, urbanization may cool desert cities if development introduces grass and other irrigated vegetation that hold moisture.
2. Urban heat island effects can be up to 22°F (12°C) warmer at night than surrounding rural areas. During the day, the effect is smaller; the annual mean air temperature of a city with one million people or more can be 1.8–5.4°F (1–3°C) warmer than its surroundings.
3. The heat island effect is greatest in the center of the city than at urban-rural borders. Parks, open land, and bodies of water can create cooler areas within a city.
4. The impact of urban heat island can include greater energy consumption for cooling, increased air pollution and greenhouse gas emissions, reductions in human health and comfort, and lower water quality in natural areas due to the elevated temperature of runoff.
5. On a larger scale, urban heat islands can also change weather patterns and rainfall. Weather patterns can be affected because thunderstorms break over heat islands due to the increased temperature, which keeps water in the atmosphere and inhibits the water cycle. This effect may also create thunderstorms at unusual times, such as after midnight. As heat is generated and trapped in a city, hot air rises and forms a heated column over the city, which in turn brings in cooler air and creates wind. The dome of heated air generates convective clouds that may bring rain and thunderstorms.
6. It is possible to reduce the urban heat island effect in many ways, including planting more trees, installing green roofs, painting roofs a light or reflective color, and replacing pavement with surfaces that do not hold the heat. These mitigation activities have multiple benefits, including cleaner air, improved human health and comfort, reduced energy costs, and lower greenhouse gas emissions.

Applications & Implications

Humans: Health & Communities

- The most common consequence of the urban heat island effect is that cities become less comfortable places to live, especially in warmer months.
- The city is hotter, has more dangerous air pollutants, and it requires more electricity and energy to cool homes than the surrounding rural areas.
- In extreme cases, heat waves in combination with the elevated urban heat island effect have led to waves of heat-related deaths among the elderly in cities.
- Most consequences of the urban heat island effect can be reduced by introducing more green space or by painting the roofs of buildings white or another reflective color.

Nature: Environment, Sustainability & Conservation

- Aquatic ecosystems can become stressed because of quickly changing temperatures resulting from warm water running off of pavement.
- Sustained warmer temperatures can decrease reproduction in some aquatic or semi-aquatic species.
- In summer, when the urban heat island effect is particularly strong, some heat-sensitive species may be more likely to die in greater numbers.
- Some migratory species may remain in warmer urban areas for longer periods and may get stranded in cities late in the year. Some species may be unable to successfully complete their migration south after remaining in cities for too long.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Areas that are heavily developed will have the greatest urban heat island effect. If you were designing a city, how could you distribute infrastructure to minimize the heat island effect?

Change Over Time (Pleasant Run)

- City size and development history will affect the magnitude of the urban heat island effect. Compare Indianapolis and Chicago; at what point in development would the heat island effect have been noticeable in both cities?
- Which is more effective at dissipating the heat island effect: bodies of water or farmland? Think about Chicago's location next to Lake Michigan versus the rural areas surrounding Indianapolis.

Water and Habitat Corridor (Fall Creek)

- Some urban waterways have elevated temperatures due to the heat island's effect on water runoff. What species will be most heavily impacted by this change?
- How would you characterize those species? Where do they tend to live? What ecological and morphological features do they share?

Water in the Atmosphere (White River)

- Rainfall patterns differ in large cities with great urban heat island effects because cities radiate heat upwards. How would rainfall patterns change throughout the year?
- Are there urban heat island effects in the winter? Think about snowfall in Indianapolis. Do you have more or less snow in the city than in the surrounding rural areas?

Water as a Resource (Central Canal)

- Water is a finite resource, as all of the water that has ever existed on Earth is all that will exist. How does the urban heat island affect the geographical distribution of water across a landscape? Why?
- How does the heat island effect change the distribution of water in any given area through time? Would areas closer to the city center or farther out at the suburban edge be more affected? Why?

Figure 27. A Roof Covered in Plants

Barry Pousman. August 29, 2011. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware of urban heat island effect;
- Unaware of geographic differences in heat island effect;
- Unaware of the impact of cities on local weather patterns; and
- Unaware of connection between trees and the heat island effect.

Low

- Aware of urban heat island effect, has some general and vague understanding what it means;
- Aware of geographic differences in heat island effect, aware that it is concentrated in cities;
- Aware of the impact of cities on local weather patterns, but is not certain how they have an impact; and
- If asked, would suggest that more trees would likely reduce the heat island effect.

Intermediate

- Knows about the urban heat island effect, knows at least one ecological and economic impact;
- Knows about geographic differences on heat island effect, knows that it is strongest in areas with the greatest concentration of buildings and pavement, often in the city center, and wonders about the impact of large city parks;
- Knows that cities impact local weather patterns, knows that the column of rising heat alters rainfall during the day; and
- Knows that more urban trees would reduce the heat island effect, aware that replanting is desirable, and would support reforestation campaigns in the city.

Advanced

- Knows about the urban heat island effect, skillfully explains what it means, knows several ecological and economic impacts, and can explain the larger significance;
- Knows about geographic differences in heat island effect, is able to clearly describe that it is strongest in areas with the greatest concentration of buildings and pavement, often in the city center, and knows that large city parks help to absorb some heat;
- Knows that cities impact local weather patterns knows that the column of rising heat alters rainfall during the day; and
- Knows that more urban trees would reduce the heat island effect, knows that replanting is desirable, and has considered supporting reforestation campaigns in the city.

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Concept 12: Stormwater Management

Definition

When stormwater is absorbed into the ground, it recharges the water table, and replenishes aquifers. In developed areas, however, impervious surfaces such as pavement and roofs prevent precipitation from soaking into the ground. Instead, the water runs rapidly into storm drains, sewer systems, and drainage ditches.

Figure 28. Sewer Overflow

Cameron Wong. March 26, 2011. Used with permission under Creative Commons.

Key Concepts & Ideas

1. Poor drainage and flooding often are a result of impervious surfaces that force rainwater directly into the drainage system. In most urban areas, a lack of sufficient sewers and drainage also results in standing water or flooded streets and basements.
2. The proliferation of ***impervious cover*** in urban areas prevents water from penetrating the soil and recharging the water table and underlying aquifer. As a consequence, much more water runs into the waterways.
3. Stormwater surges have a great number of ecological impacts, including downstream flooding, stream bank erosion, increased muddiness created by stirred up sediment, habitat destruction, and dramatic changes in the flow rate of a stream over a period of time. Water trapped on impervious surfaces can collect residual toxins, chemicals, and other substances that can harm humans and other organisms in the ecosystem. These ecosystem changes affect land structure and function.
4. The effects of stormwater surges impact people in urban areas as well. Chief among these are CSOs, which send raw sewage into the waterways. Additionally, surges may damage infrastructure. Both factors may lead to contaminated streams, rivers, and coastal water.
5. Many urban neighborhoods encounter chronic flooding in streets and yards. In Indianapolis, there is an average of 20,000 stormwater-related complaints filed each year, highlighting the need to improve the stormwater system.
6. Stormwater management solutions are summarized in The Marion County Stormwater Master Plan, which includes a total of $81 million in projects to help problem areas through 2018. Almost all of the projects included reducing the amount of impervious cover or providing additional storage capacity for containing stormwater surges. Specific plans include adding:
   - ***Rain gardens*** - area planted with native plants to help capture rainwater;
   - ***Pervious pavement*** - allows water to seep through it to reduce runoff and filter out pollutants;
   - ***Green roofs*** - partially or completely covered with growing plants;
   - ***Filter strips*** - narrow, long areas installed next to surface waters that act as buffers to slow runoff and reduce erosion;
   - More storm sewers and drains;
   - Hybrid ditch systems - pipes which draw water away from homes and into the ground;
   - Road resurfacing to direct standing water into the ground;
   - ***Infiltration trench systems*** - trenches filled with rocks that can hold water as it slowly enters the soil; and
   - New storm sewer pipes and manholes.
7. People can reduce stormwater runoff using rain gardens, pervious pavement, green roofs, and rain barrel water collection at their homes.

Applications & Implications

Humans: Health & Communities

- Inadequate stormwater management has significant implications for the wellbeing of people in urban areas. Chief among these are decreased water quality, flooding, power outages, and property damage.
- There are many things that people can do to reduce the amount of stormwater that runs off their land, most of which entail changing the amount of impervious cover on their land or collecting and using rainwater.

Nature: Environment, Sustainability & Conservation

- Impacts of stormwater surges on the environment can be dramatic, and mainly include flooding and erosion. Additionally, pollutants coming from CSOs can harm natural communities.
- Infrequent, but intense stochastic events can restructure riverbanks and waterways and uproot entire trees, as well as other plants and animals.
- Fortunately, many cities are focusing on engineering better solutions for flood control and stormwater management. Indianapolis's efforts include the Deep Rock Tunnel and planting natural vegetation on top of containment swales.

Discussion Questions

Water Infrastructure (Pogue's Run)

- What stormwater infrastructure is located in your neighborhood?
- Are there places to install additional infrastructure along banks of the waterway? What about in parking lots?
- What is the biggest obstacle to installing new stormwater management systems?

Change Over Time (Pleasant Run)

- Storm surges can have large effects on ecosystems and human infrastructure. How would you design a streambed to slow a storm surge?
- How much money and time would you spend for infrequent storm surges (e.g., once every 100 years)? What about for frequent storm surges (e.g., once every five years)?
- Erosion is thought to happen very slowly, almost imperceptibly. How does your understanding of storm surges change how you think about erosion? Does erosion happen differently in urban, suburban, and natural areas?

Figure 29. Sewer Flooding

Doug Zeiser. March 3, 2010. Used with permission under Creative Commons.

Water and Habitat Corridor (Fall Creek)

- How do increasingly frequent stormwater surges affect native versus invasive species? What about trees versus smaller plants? What about plants that regrow from roots versus those that regrow from seeds?
- What are the ecological characteristics of the species that colonize waterways with frequent stormwater surges?

Water in the Atmosphere (White River)

- What time of year are stormwater surges most frequent? Does type of precipitation (e.g., rain, snow) affect the frequency and intensity of stormwater surges? Why?
- Does rainfall affect residences near waterways differently from those that are uphill from waterways? How?

Water as a Resource (Central Canal)

- Stormwater is a valuable resource. How can we use natural areas to contain and purify the water that runs off our land?
- Aquifers are thought to be some of the slowest water storage structures to recharge, often taking centuries. What are some creative ways to get stormwater underground so that it will recharge aquifers more quickly?

Figure 30. Outflow

March 25, 2014. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware of the term impervious surface and has no idea about effect of impervious surfaces on waterways;
- Unaware of CSOs;
- Unaware of differences in flooding rates and scale in urban areas relative to natural areas;
- Unaware that cities are doing anything to better manage stormwater; and
- Unaware that a private citizen can do anything to help manage stormwater.

Low

- Aware of impervious surfaces, knows that impervious surfaces may not be universally good, and has some vague idea that there are alternatives to impervious cover;
- Aware of CSOs, but not certain what they are;
- Aware that there are differences in flooding rates and scale in urban areas relative to natural areas, but is not certain how they differ;
- Aware that cities are trying to better manage stormwater, but is not certain what they are doing; and
- Aware that individuals may be able to help better manage stormwater, but is not certain what is possible.

Intermediate

- Knows what an impervious surface is, is aware of the values and threats posed by impervious surfaces, and is able to describe at least one solution that will increase infiltration;
- Knows about CSOs, understands why and when they occur, and is aware of the connection between significant rainfall and raw sewage discharge;
- Knows that more flooding happens in urban areas than in natural areas, is aware that it may be because of impervious cover;
- Knows that cities are trying to better manage stormwater, including keeping stormwater from entering the waterways, and is aware that they are putting in more green infrastructure to absorb water into the ground; and
- Knows that individuals are trying to manage stormwater by preventing it from exiting their property, is aware that they are putting in more green infrastructure to absorb water into the ground, and has some general ideas about other methods.

Advanced

- Knows what an impervious surface is, knows about the values and threats posed by impervious surfaces, and is able to describe alternatives that will lead to infiltration;
- Knows about CSOs, confidently describes why and when they occur, knows the connection between significant rainfall and raw sewage discharge, and can explain the physical structure of sewage treatment plants that lead to this;
- Knows that more flooding happens in urban areas than in natural areas, knows that it is due to impervious cover;
- Knows that cities are trying to better manage stormwater, knows that they are trying to keep stormwater from entering the waterways, is aware that they are putting in more green infrastructure to absorb water into the ground, and can explain why; and
- Knows that individuals are trying to manage stormwater by preventing it from exiting their property, aware that they are putting in more green infrastructure to absorb water into the ground, and has some specific ideas about other methods.

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Figure 31. Stormwater Interceptor

Aug 7, 2009. Used with permission under Creative Commons.

Concept 13: Human Impacts on Groundwater

Definition

Human activity commonly affects the distribution, quantity, and chemical quality of water resources, and this is particularly acute in urban areas. These actions will typically reduce the amount of water that makes its way into the water table, resulting in a slower movement of water into aquifers. The net result is that there will be less and lower-quality groundwater for humans and the environment.

Figure 32. Oil on Pavement

Pete Birkinshaw. May 17, 2007. Used with permission under Creative Commons.

Key Concepts & Ideas

1. Human activities may affect the quantity and quality of water resources on multiple spatial and time scales. Immediate effects result from opening a floodgate and longer-term changes include depleting an aquifer that has taken centuries to fill up.
2. *Groundwater* can be divided into two main categories. The *water table* is a few feet to tens of feet below ground and quickly recharges with surface water. In contrast, *aquifers* are hundreds of feet underground and may take centuries to recharge, hence the term *fossil water*.
3. Pollutants that enter groundwater may also be divided into two main categories. *Point sources* have a clear source of production and output, such as a pipe from a sewage treatment plant. *Nonpoint sources* are more challenging to identify and typically have a broad, diffuse pathway of entry to the waterway, such as oil running off road surfaces during rain. The progress that we have been able to make in eliminating point source pollution has made it apparent that nonpoint source pollution and habitat degradation are the nation's biggest water quality challenges.
4. Surface-water irrigation redistributes water from confined riverbanks all across the landscape. Agricultural irrigation changes the infiltration of water into the ground and runoff characteristics of the land surface. These changes influence how quickly groundwater gets recharged and the delivery of water to aboveground waterways. These processes affect the movement of surface water into groundwater.
5. Dam systems affect the recharging of groundwater in two ways. First, like irrigation, dams redistribute water to other locations. In addition, they confine water to smaller areas than it would be found naturally. Some dam systems may be located over bedrock that prevents surface water from moving into the groundwater.
6. Flooding may result from impervious surfaces that force rainwater directly into an inefficient drainage system. Most urban areas also lack sufficient sewers and drainage, which results in standing water or flooded streets and basements.
7. The clearing of trees and other vegetation and the simultaneous proliferation of impervious surfaces in urban areas prevent water from percolating into the soil and recharging the water table and the underlying aquifer. As a consequence, much more water runs off into the waterways.
8. Runoff increases and water table and aquifer levels drop with increasing urbanization and more impervious ground cover. Wells in areas with more than 10% impervious ground cover become non-productive very quickly.
9. Overdrawing groundwater results in a lower water table and less water in lakes and streams. This reduction may have profound consequences for plants and animals in the waterway ecosystem.
10. Areas with lower water tables and drier aquifers are prone to sinkholes, in which the land may suddenly collapse, potentially taking homes and property underground.
11. Water quality usually decreases in urban settings because surface runoff picks up extra pollutants and trash and

treated water may contain chemicals from pharmaceuticals and personal care products.

Applications & Implications

Humans: Health & Communities

- Precipitation that falls in urban areas disproportionately leaves in the form of runoff rather than recharging the water table, so there may be less water available to people who rely on wells.

Nature: Environment, Sustainability & Conservation

- Natural communities may be affected negatively by storm surges, which can lead to flooding and erosion. These intense stochastic events can restructure riverbanks and waterways and uproot entire trees, as well as other plants and animals in the area.
- Pollutants in the runoff can also harm natural communities.

Discussion Questions

Water Infrastructure (Pogue's Run)

- What types of infrastructure would help recharge groundwater more quickly?
- How might this infrastructure affect the rate of erosion? How will it affect natural communities? What types of infrastructure might have a smaller impact on natural communities?

Change Over Time (Pleasant Run)

- Sustainability is defined as the ability to maintain something into the future. Is our current water use sustainable?
- What are the long-term impacts on groundwater, and on aquifers in particular, if we continue to use water at the current rate?

Water and Habitat Corridor (Fall Creek)

- When we talk about using water sustainably, we usually do not think about nature and environmental processes. What are the best ways to ensure that there is enough water in our waterways for nature to be able to function as it has?
- Are nature and human use of a resource like groundwater always in conflict?

Water in the Atmosphere (White River)

- Climate change will alter the frequency, quantity, and distribution of rain and snowfall. How are moisture patterns expected to change in central Indiana?
- What measures can Indianapolis take to ensure that it has enough water for its residents in the face of these changes?

Water as a Resource (Central Canal)

- Does Indianapolis use water sustainably? If not, what could be done to increase sustainability?
- How can we better store and retrieve water? How might we better use aquifers?
- What risks might be involved in these processes?

Figure 33. Urban Stormwater Drainage

April 6, 2011. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware that there are multiple types of groundwater;
- Unaware of point and nonpoint pollution;
- Unaware of how surface structure affects water movement; and
- Unaware of the impact of urbanization on water quantity or quality.

Low

- Aware that there are multiple types of groundwater, but is not certain what they are;
- Aware of point versus nonpoint pollution, but is not certain how they differ;
- Aware that surface structure may affect water movement, but not sure how; and
- Aware that urbanization impacts water quantity and quality, but is not sure how.

Intermediate

- Knows that there are multiple types of groundwater, and is able to name them as water table and aquifers, and is able to describe some ways in which they differ;
- Knows of point versus nonpoint pollution, knows how they differ, and is aware that they are addressed differently;
- Knows that surface structure affects water movement and can infer how; and
- Knows that urbanization reduces water quantity and quality and has clear examples of how that happens.

Advanced

- Knows that there are multiple types of groundwater, is able to name them as water table and aquifers, is able to say how they differ, and is able to describe how they recharge at different rates and are accessed differently;
- Knows of point versus nonpoint pollution, knows how they differ, can deftly define how they do, and is aware that there are consequences for how the two are addressed and can describe these differing consequences;
- Knows that surface structure affects water movement, can describe how;
- Knows that urbanization reduces water quantity, has clear examples of how that happens, and has some ideas for how to address this reduction in supply; and
- Knows that urbanization degrades water quality, has clear examples of how that happens, and has some ideas for how to address this degradation.

Figure 34. Mountain Spring

April 14, 2008. Used with permission under Creative Commons.

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Concept 14: Water Distribution and Loss

Definition

Water distribution across urban areas relies on a system to control freshwater flowing through cities, providing water to buildings and keeping it out of areas where it should not be. Systems are rarely perfectly efficient and water is lost through leaks in the plumbing and misuse.

Figure 35. Water Flow Through Cement Channels

November 21, 2014. Used with permission under Creative Commons.

Key Concepts & Ideas

1. Departments of Public Works are responsible for managing water in urban areas. Pipes connected to underground water mains provide water to residential, agricultural, and industrial locations. Containment structures, such as levees and underground treatment and holding facilities, keep water out of areas where it is not wanted.
2. Nearly all water is chemically treated in the same way before entering the water distribution system, so water used to water lawns is the same quality as water for drinking. A few US communities have separate infrastructure for treating wastewater used in industry and agriculture and that used in residential areas. These efforts save money in the long term because not all water is treated as much as drinking water.
3. Water loss is a normal part of water distribution infrastructure. A detailed audit of 47 California water utilities found an average loss of 10 percent[4], with a range of 5 to 30 percent. One industry study reported losses of more than 45 percent leakage in some very old urban systems[5].
4. Water loss from urban infrastructure costs every city money. Most communities in the US use a single plumbing system to transport water, all of which is drinkable quality. Water lost after treatment represents money lost. In large cities, like New York City, detecting and repairing leaks can save millions of gallons of water per day. This challenge is particularly daunting because New York City has over 7,000 miles of underground water mains.
5. Causes of water loss include poorly designed or broken equipment, old and leaky water distribution infrastructure and evaporation during open-air transportation of water in canals. These causes are referred to as ***real losses***. Minor leaks invariably become larger leaks if not repaired.
6. Water losses also occur through theft or misuse. Unauthorized people sometimes tap into pipelines and use water that they have not paid for, which drains the system. Similarly, inaccurate or nonfunctional meters mean that water managers cannot accurately track water used. In addition, people who are careless about their water use present an unnecessarily burden on the system by overwatering lawns, leaving taps open, and running partially filled washers. These causes are referred to as ***apparent losses*** and additional costs are usually passed to customers.
7. Chronic leaks can damage roads and buildings. Typically, this damage occurs when undetected, long-term leaks slowly erode soil until a road or building collapses into a sinkhole. Identifying and repairing leaks will increase water conservation, reduce financial losses, and to protect against expensive lawsuits.

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Figure 36. Plumbing Repair

Rick Walter. February 20, 2013. Used with permission under Creative Commons.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Water distribution and loss is integrally connected to water infrastructure. What human-caused processes might lead to water losses?
- What natural processes may lead to damages to the water infrastructure and eventually to water losses?

Change Over Time (Pleasant Run)

- Aging pipes is one of the lead causes of water loss, whether they are clay, plastic, or metal. Can you think of ways to slow the aging of pipes before they are installed?
- What could be done to existing pipes to slow their aging?

Water and Habitat Corridor (Fall Creek)

- Construction can damage the environment. How might leaky pipes be treated to minimize construction damage?
- How might cities slow the speed of water in canals to reduce siltation in natural waterways?

Water in the Atmosphere (White River)

- How does rainfall affect the aging of our water distribution infrastructure?
- How does snow affect the aging of our water distribution infrastructure? Is the effect the same or different than rain?

Water as a Resource (Central Canal)

- Water losses have a significant financial impact on communities. How can people help the utility companies detect leaks?
- What would motivate people to want to help?

Applications & Implications

Humans: Health & Communities

- Water losses and resulting infrastructure damage can have large financial consequences for communities, which must pay for repairs.
- Communities may have to deal with erosion, gullying, or other environmental damage on public lands or property. Favored landscapes may become degraded.
- Individuals can suffer personal property damage, inconveniences of road or building damage, and flooding.

Nature: Environment, Sustainability & Conservation

- Natural communities will be affected directly through erosion, siltation, unnecessary construction to repair damaged water mains, and loss of water that is channeled to human use.
- Construction has a dramatic and long-lasting impact on natural communities. For example, soil takes many years to recover from digging, repairing, and covering underground pipes.

Figure 37. Urban Reservoir

Vincent Desjardins. February 2, 2011. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware of the purpose of a water distribution system;
- Has never thought about water treatment;
- Unaware that there are systematic water losses in city infrastructure;

- Unaware that people steal water; and
- Unaware that chronic leaks can damage city infrastructure.

Low

- Aware that the purpose of a water distribution system is to control the flow and availability of water in a landscape;
- Has thought about water treatment, but does not know there are many levels of water treatment;
- Aware that there are systematic water losses in city infrastructure, but does not know details;
- Aware that people steal water, but not certain how or how large of a loss it is; and
- Aware that chronic leaks can damage city infrastructure, but is unsure of the magnitude of the problem.

Intermediate

- Knows that the purpose of a water distribution system is to control the flow and availability of water in a landscape, mentions components of a system, and is able describe their roles;
- Knows about water treatment, knows that there is only one level of water treatment for most communities, and is aware that some communities use reclaimed water;
- Knows about systematic water losses in city infrastructure, knows that these losses represent substantial quantities of water, and has some ideas about the need for retrofitting and replacement;
- Knows that people steal water, knows than it is an important source of loss, and has some ideas about how water is stolen; and
- Knows that chronic leaks damage city infrastructure, knows that this damage can be substantial, and can think of an example when this might happen.

Advanced

- Knows that the purpose of a water distribution system is to control the flow and availability of water in a landscape, mentions most components of a system and their roles, is able to mention the benefits and drawbacks of each;
- Knows about water treatment levels, knows that there is only one level of water treatment for most communities, speaks knowledgeably about how some communities use reclaimed water, and understands the need for a secondary distribution system;
- Knows about systematic water losses in city infrastructure, knows that it is an important loss of substantial quantities of water, and has clear ideas about the need for retrofitting and replacement;
- Knows that people steal water, knows than it is an important source of loss, and knows that it is stolen by disabling water meters and tapping pipes; and
- Knows that chronic leaks damage city infrastructure, knows that the damage can be substantial, and can describe at least one example illustrating this problem.

Figure 38. Water Leak

Joshua Works. September 2, 2007. Used with permission under Creative Commons.

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Concept 15: Integrated Urban Water Strategy

Definition

An integrated urban water resource management plan covers the entire urban water cycle, including rainwater, desalination, ground and surface water, storage and distribution, treatment, recycling, disposal, use, water loss, and protection and conservation of water resources. This approach draws on the diversity of water management options available to urban planners, including the built infrastructure as well as the natural landscape. Managing human water use allows cities to conserve the quantity and quality of freshwater as well as the terrestrial ecosystems that provide services to humans and all living things. When it is most successful, this approach creates more sustainable livelihoods in cities and empowers communities to be involved in ensuring access to safe water and hygienic living conditions.

Figure 39. Urban Rainwater Barrels

June 19, 2010. Used with permission under Creative Commons.

Key Concepts & Ideas

1. *Integrated urban water infrastructure strategies* use built and green infrastructure to manage the collection, distribution, and storage of water. Ultimately, the goal is to keep as much water out of the sewage treatment plants as possible while still ensuring that all water in an urban area is clean and healthy.

12. *Ecohydrology* approaches strive to use ecosystem properties to manage water and improve the efficiency of urban regulatory processes related to hydrology. The solutions must be well integrated with each other and with the city system to be effective.

13. *Green infrastructure* uses vegetation, soils, and natural landforms to contain water in depressions in the ground and increase absorption into the water table, thereby creating healthier environments. Green infrastructure absorbs as much or more precipitation than the concrete and pavement often used to contain stormwater.

2. Many processes and features are part of green infrastructure, including: rainwater harvesting, rain gardens, planter boxes that retain rainwater, bioswales or small channels created to hold water, permeable pavements, and replacing pavement with green land cover.

3. Controlling where water does and does not go is a large challenge for departments of public works. These teams use underground water mains and pipes to distribute water across communities. Containment structures, such as levees, storage reservoirs, underground treatment and holding facilities (such as the Deep Rock Tunnel in Indianapolis), and sewage treatment facilities ensure that water does not flow where it is not wanted.

4. Surface-water irrigation redistributes water from rivers all across a landscape. Agricultural irrigation changes the runoff characteristics of the land surface, which influences how quickly groundwater is recharged and delivered to above ground waterways.

5. Dam systems, the reservoirs that form behind dams, and levees affect the recharging of groundwater in similar ways. Like irrigation, these human-created features redistribute water to other locations. In addition, they confine water to smaller areas. Some of these areas may be located above bedrock, which is less permeable to water, slowing movement into groundwater.

6. Causes of water loss include poorly designed or broken equipment, old and leaky water distribution infrastructure, and evaporation during open-air transportation of water in canals. These causes are referred to as *real losses*. Minor leaks invariably become larger leaks if not repaired.

7. Water losses also occur through theft or misuse. Unauthorized people sometimes tap into pipelines and use water that they have not paid for, which drains the system. Similarly, inaccurate or nonfunctional meters mean that water managers cannot accurately track water used. In

addition, people who are careless about their water use present an unnecessarily burden on the system by overwatering lawns, leaving taps open, and running partially filled washers. These causes are referred to as ***apparent losses*** and additional costs are usually passed to customers.

8. Controlling water demand and use is crucial an integrated water management strategy and is as important as physically managing the flow of water. Providing incentives to reduce water consumption, such as compensating for removal of water guzzling landscaping can be an effective approach.

Figure 40. Rainwater Collection Tank

ReUse Action. June 30, 2009. Used with permission under Creative Commons.

Applications & Implications

Humans: Health & Communities

- An integrated urban water strategy has benefits human wellbeing because it ensures that people will have enough high quality water.
- Individuals can contribute to this strategy in many ways, including: collecting rainwater to water their lawns and gardens, ***nativescaping*** their lawns, properly disposing of chemical and solid trash rather than allowing them to enter the waterways through runoff, installing green roofs, and trying to reduce water consumption in their daily lives.

Nature: Environment, Sustainability & Conservation

- People can reduce the impact on nature by trying to reduce water consumption in their daily lives, making more water available for natural ecosystems.

Discussion Questions

Water Infrastructure (Pogue's Run)

- What do you know about the Integrated Urban Water Strategy? Do you notice any of the infrastructure?
- What infrastructure might work against the Strategy? How could that impact be reduced?

Change Over Time (Pleasant Run)

- In the last few decades, city planners have started to integrate more than just the pipes and levees that have long comprised water management strategies, but also the diversity of green infrastructure and ecohydrology approaches discussed earlier. Why has this change has happened only recently?
- What changes in community water management do you expect to see in the near future? What problems will they help to address?
- What changes do you expect to see in the long term?

Water and Habitat Corridor (Fall Creek)

- If people use less water, there will be more water flowing in the waterways and natural ecosystems around Indianapolis. What species would benefit from more water being available in these systems?
- Can you see residues of past water levels along your waterways? These residues may look like rings in a bathtub (e.g., around reservoirs) or differently structured ecosystems, depending on the amount of time that has passed.
- How do you think that water use strategy has changed in your local ecosystems?

Water in the Atmosphere (White River)

- Rain brings life, particularly to agricultural areas. What do most city dwellers think of rain? How does this perspective affect how they would like rain to be treated in a future Integrated Urban Water Strategy?
- How could you, as an advocate for healthy waterways, change the urban perspective of rain? What would you emphasize?
- Why might people not care about healthy waterways in the context of an Integrated Urban Water Strategy?

Water as a Resource (Central Canal)

- Responsible resource management is the ultimate goal of an Integrated Urban Water Strategy. What are the challenges of using any of the approaches described above? How might you overcome these challenges?
- Water quality is equally as important as water quantity, but is often thought of as only a component of the larger process. What actions would be particularly likely or unlikely to affect water quality? Why?

Levels of Understanding

None

- Unaware of the concept of an integrated urban water strategy;
- Unaware of green infrastructure;
- Unaware of how water is distributed in an urban setting;
- Assumes that all water from storage facilities makes it to people with no loss; and
- Unaware that most water companies want consumers to use less water.

Low

- Aware of the concept of an integrated urban water strategy or of the idea that all processes at work in a watershed could or should be considered together, but does not know how that is done or what it really means;
- Aware of green infrastructure and can infer or describe what it is;
- Aware of how water is distributed in an urban setting, has heard about reservoirs and wells, but cannot describe what they are;
- Aware that there is regularly system loss of water in the urban infrastructure; and
- Aware that most water companies want consumers to use less water, but is not certain why.

Intermediate

- Knows about the concept of an integrated urban water strategy and of the idea that all processes at work in a watershed could or should be considered together and has a few ideas about how that could be done;
- Knows about green infrastructure and can mention a few aspects of what is involved;
- Knows about how water is distributed in an urban setting, can locate several reservoirs and wells, knows about the water table and aquifers;
- Knows that there is regular system loss of water in the urban infrastructure, can mention several examples, and how to correct them; and
- Knows that most water companies want consumers to use less water, knows that they want this to reduce stress on infrastructure and has ideas for how to do so.

Advanced

- Knows about the concept of an integrated urban water strategy and of the idea that all processes at work in a watershed could or should be considered together, and has robust understanding of how that could be done;
- Knows about green infrastructure and can mention several aspects of what is involved in it and how these might affect urban water strategies;
- Knows about how water is distributed in an urban setting, can locate several reservoirs and wells, and knows about the water table and aquifers;
- Knows that there is regular system loss of water in the urban infrastructure, can mention many examples and how to correct them, knows approximately how many gallons are lost on a regular basis; and
- Knows that most water companies want consumers to use less water, knows that they want this to reduce stress on infrastructure, and has several ideas for how consumers and industry can do so.

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Concept 16: Physical Impacts of Urbanization on Waterways

Definition

Urbanization changes the physical, chemical and biological environment in our waterways. Physical changes include altering riverbank structure, waterway channel, flow rate, turbidity, and wastewater inputs. Erratic and massive stormwater runoff events can trigger changes in water and sediment quality, water temperature, and hydrology, which in turn affect habitat diversity and resources available to the waterway species.

Figure 41. Flooding

Global Water Partnership. June 30, 2009. Used with permission under Creative Commons.

Key Concepts & Ideas

1. ***Urbanization*** around watersheds may cause many changes in stream hydrology, water quality, physical habitat, and water temperature that have profound effects on waterway aquatic and riverbank communities of plants and animals.
2. Negative impact is greatest as degree of urbanization moves from low to moderate intensity. As urbanization increases from moderate to high to very high, many of the negative impacts do not increase (i.e., threshold effect).
3. In urban settings, the percentage of that goes into evaporation, infiltration, and surface runoff differs greatly based on the percentage of ground with impervious surfaces. In settings with more natural cover, only 10% of precipitation goes to runoff, 40% is lost through evaporation, and 50% penetrates the earth to recharge the aquifer and water table. In cities, these numbers are almost reversed: 55% goes to runoff, 30% is lost to evaporation, and only 15% penetrates the ground.
4. Flooding risk is highest in urban settings because water surface flows increase in intensity and size. As much as half of all precipitation may turn into runoff in urban settings which is concentrated into fewer waterways than were present before urbanization, due to land conversion, as it moves down the watershed. Consequently, in intensely urban settings with a lot of impervious cover, even small rainfall events can lead to flooding in low-lying areas. In more natural settings, runoff is about one-fifth of that in urban areas, so surface flows and the intensity of floods are lower.
5. The physical shape of urban waterways can change during episodic floods, even in areas where waterways are relatively natural (i.e., not lined with concrete, no man-made dams or impoundments). In areas with a lot of impervious surfaces, runoff increase, and the width, depth, and speed of water movement in the waterway also increases. These changes can lead to increased riverbank erosion and deposition patterns.
6. Chemical concentrations in a waterway will change with increasing urbanization. The amount of carbon, nitrogen, and phosphorus is usually greatest in urbanized waterways and may be several times the levels found in forest and agricultural streams. These are three of the most important and limiting chemicals for plant growth. Elevated amounts of these nutrients may have dramatically negative consequences downstream for lakes and oceans by promoting quick growing algal blooms that may deplete oxygen and suffocate all other life, a process called ***eutrophication***.
7. Many organic contaminants increase with watershed urbanization and change dramatically with water flow in urban waterways. These chemicals include toxic agricultural and industrial by-products such as polyaromatic cyclic hydrocarbons, organochlorine pesticides, and polybrominated diphenyl ether flame-retardants. Some of these chemicals are ***carcinogenic*** and of great concern for the well-being of people and nature.
8. Elevated concentrations of organic matter in urban streams originates from a variety of sources including terrestrial runoff, sewage, and changes in how in-stream chemical

processes take place. CSOs are a key problem in increasing organic matter in urban waterways because untreated sewage is directly discharged into waterways.

Figure 42. Water Eutrophication

Gary L. Wamer May 9, 2010. Used with permission under Creative Commons.

Applications & Implications

Humans: Health & Communities

- Cities that have more impervious cover and channelized or paved waterways tend to have more floods and erosion, decreased water quality, more sinkholes, decreased rates of groundwater recharging, drier wells, and more CSOs.
- There is more organic material in the water because of changes in runoff patterns, leading to changes in water chemistry and foul smells near waterways.
- Cities are making efforts to reduce the amount of impervious cover, especially around waterway banks.

Nature: Environment, Sustainability & Conservation

- Increased erosion can scour out entire plant and animal communities on the sides of waterways.
- Similarly, greater surface flow will also bring pollutants, human waste, and trash into the waterways and decrease water quality. Animals and plants that are sensitive to these pollutants will experience dramatic losses in population sizes and some may become locally extinct.
- Restoring natural streambeds will help some native species to return. Unfortunately, the modified ecosystem may include new non-native plants and animals, which may outcompete the native species.
- In addition to active restoration of natural streambeds in urban areas, it is often necessary for humans to take an active role in replanting native plant species. Native animals that rely on those plants will often reestablish on their own.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Human water-management activities that change the permeability of waterways (e.g., lining channels with concrete, creating dams and impoundments) can alter water movement. What changes might you expect to see?
- Can you think of any examples of human-altered waterways?

Change Over Time (Pleasant Run)

- What are the short and long-term effects of increasing the permeability of a waterway on the width, depth, and speed of the waterway? On water quality?

Water and Habitat Corridor (Fall Creek)

- Compare two locations along a waterway or waterways, one with lots of tree cover and plants growing all along the banks and the other with cleared or cut vegetation. How many birds do you see in these two areas? How many beetles? How many other animals? Does one location consistently have more animals than the other? Why?
- Are there differences in the availability of plants? What about climate? How might these differences be related?

Water in the Atmosphere (White River)

- Big storms can bring large quantities of water into a city in a relatively short time. How far from the city would you expect to see changes in a waterway? Why?
- What percentage of the warehouse region in the neighborhood is covered with impermeable surfaces? Use Google Maps or Google Earth to make a rough calculation. How close was your initial guess? What effect might his type of land coverage have on the waterway?

Water as a Resource (Central Canal)

- Waterways provide resources for the plants and animals living in and around them. Healthier waterways will be able to support more wild species. What are some species that you would encounter in or around healthy waterways that you might not see near an unhealthy waterway?

- How could you use these species in a public relations campaign to reduce urbanization impacts on waterways? How might the species you choose affect the success of the campaign?

Levels of Understanding

None

- Unaware that water moves through urban areas differently than though natural areas;
- Unaware of differences in flooding rates and scale in urban areas relative to natural areas;
- Unaware that river shape changes in urban areas;
- Unaware that river chemistry changes in urban areas; and
- Unaware rivers become more contaminated in urban areas.

Low

- Aware that water moves through urban areas differently than through natural areas, but not certain how;
- Aware of differences in flooding patterns in urban areas relative to natural areas, but is not certain how they differ;
- Aware that river shape changes in urban areas, but is not certain how;
- Aware that river chemistry changes in urban areas, but is not certain how; and
- Aware that rivers become more contaminated in urban areas, but is not certain how.

Intermediate

- Knows that water moves through urban areas differently than through natural areas, knows that more water moves through runoff, knows that urban areas contain more impervious surfaces, and may have an idea that this will mean that less water enters groundwater;
- Knows that more flooding happens in urban areas relative to natural areas, is aware that it may be because of impervious cover, thinks that floods may be larger;
- Knows that river shape changes in urban areas, knows that they are more open, suspects that they may move faster and be deeper, thinks there may be other differences;
- Knows that river chemistry changes in urban areas, knows that rivers contain more fertilizers and waste, and suspects that there may be other chemicals in there too; and
- Knows that rivers become more contaminated in urban areas, knows that contaminants run off from the land, thinks that there are likely more petrochemicals and maybe other agricultural chemicals.

Advanced

- Knows that water moves through urban areas differently than through natural areas, knows that more water moves through runoff, knows that urban areas contain more impervious surfaces, knows that this means that less water enters groundwater;
- Knows that more flooding happens in urban areas relative to natural areas, knows that it is due to impervious cover, knows that floods will be larger;
- Knows that river shape changes in urban areas, knows that they are more open, knows that they may move faster and are deeper, thinks that they may have deeper scouring;
- Knows that river chemistry changes in urban areas, knows that they have more fertilizers, due largely to more human waste, mentions the elements nitrogen, carbon, or phosphorus; and
- Knows that rivers are more contaminated as they enter urban areas, knows that contaminants run off from the land, knows that there are likely more petrochemicals, other agricultural chemicals, and household chemicals.

Figure 43. Flooded Streets

Horst Kieche. November 8, 2011. Used with permission under Creative Commons.

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Concept 17: Urban Stream Restoration

Definition

Restoration is the effort to reestablish the pre-disturbance physical, chemical, and biological characteristics of a waterway and the related functions. The ultimate goal of stream restoration is to return the stream to its original undisturbed condition. Restoration efforts should also increase the diversity and population size of waterway plant and animal species.

Figure 44. Wetlands Restoration

Massachusetts Department of Environmental Protection. June 15, 2010. Used under the permission of the Creative Commons.

Key Concepts & Ideas

1. *Urbanization* and agriculture decrease the health of waterways by clearing plants from the stream banks, changing the path and quantity of runoff and the shape and speed of streams, enhancing erosion, and introducing pollutants and nutrients.
2. Lower waterway health results in habitat loss for fish and other aquatic species, poor water quality, downstream flooding, and the spread of non-native potentially invasive species. Restoration reduces human impact on the waterway, so that nature benefits.
3. *Restoration* efforts usually begin by studying the waterway to learn about its original state, what caused it to change, and how we can rebalance the ecosystem. A well-designed restoration project will usually also involve restoring the riparian zone adjacent to the waterway.
4. In urban systems, restoration efforts target erosion and sedimentation, nutrient loading (because of CSOs), and bacterial contamination. Restoration provides hope for the future of these waterways and shows that we have the skills and knowledge to improve the environment.
5. Restoration methods are almost as varied as the environmental challenges they address and depend on how badly the area needs help and the specific objectives of the restoration. Objectives may include slowing the speed of the water moving in the waterway or changing how the stream is structured. Restoration methods include removing causes of the damage by closing pipes carrying the pollutants and CSO outfalls, stabilizing a heavily eroded bank to stop further erosion, removing dams or reshaping the stream, and replanting the streamside corridor and riparian zones.
6. A challenge for all restoration projects is determining if the restoration was successful. Scientists debate whether it is possible to restore a heavily degraded waterway to its pre-disturbance state. Some argue that a degraded ecosystem will carry remnants of the degradation for decades, longer than restoration projects can be realistically implemented.
7. Restoration usually relies on human efforts in addition to natural processes. Typically, humans will start the restoration process, particularly by removing the acute source of the problems (e.g., impervious cover, CSOs and pollutant spills), and then step back and hope that nature will further improve the health of the waterway.
8. IndyParks and IUPUI's Center for Earth and Environmental Science are leading a restoration project at Pleasant Run with the help of Citizens Water. This project focuses on improving water quality by adding plants along the waterway to make the stream more stable and reduce erosion. The restoration team is also using techniques to change the flow of water, including altering the width of the stream and reintroducing buffer zones with rocks, logs, or other debris to slow the water flow and reduce erosion.

Applications & Implications

Humans: Health & Communities

- A successful restoration project reduces many problems that people face from directly interacting with contaminated or unhealthy water.

- Restoration can reduce bad smells emanating from stagnant water in degraded waterways as well as reduce the number of mosquitoes that can spread diseases.
- Importantly, restoration projects provide hope to communities by demonstrating that there are people and organizations devoted to correcting environmental problems.

Nature: Environment, Sustainability & Conservation

- Restoration of natural waterways may allow some native species to come back to the area, although they may have to compete with new non-native plants and animals that colonized the area in their absence.
- In addition to active restoration of natural waterways in urban areas, it is often necessary for humans to replant native plant species. The native animals that rely on those plants will often reestablish on their own.
- People can help alleviate the impact on nature in urban settings by reducing water consumption to make more water is available for natural ecosystems.
- Disruptions from natural cycles lead to problems in ecosystems including the spread of non-native, possibly invasive species.
- It is also important to replant stream banks near the waterways. More plant cover leads to more shade, more stable temperatures, and less heat stress on native species. Also, vegetation surrounding the waterways can absorb pollutants that would otherwise reach the waterway, and keep runoff-borne sediment on land.

Figure 45. Animal Life at a Restoration Site

March 29, 2011. Used with permission under Creative Commons.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Problems affecting waterways are usually caused in part by human water infrastructure. Can you think of any infrastructure near where you live that negatively impacts the waterway? How could you could redesign it to reduce the environmental impact?
- How could you alter a channelized or built-up waterway (e.g., rocks piled along banks) to provide additional habitat for plants and animals? What are the trade-offs in doing so?

Change Over Time (Pleasant Run)

- Restoration is rarely accomplished by human activity only; natural processes are a key component of restoration. How might you take advantage of natural processes to reduce the amount of money needed for restoration projects?
- How might that balance differ based on the waterway?

Water and Habitat Corridor (Fall Creek)

- Would you spend more money on restoring a waterway in a suburban or an urban setting? Why?
- What about one that is heavily degraded versus only slightly degraded? Why?
- Would the fact that some areas are of greater value to certain wildlife species affect your priorities?

Water in the Atmosphere (White River)

- When a restoration project is in process, the ground is often highly disturbed and a heavy rain can greatly disrupt the work and possibly jeopardize the project. What are some actions that would reduce the impact of rain on a restoration construction site?
- Typically restoration work is done in the warmer months when the ground is not frozen. What are some benefits of doing restoration in the winter? What are the challenges?

Water as a Resource (Central Canal)

- Restoring waterways can affect the human communities who use it. What are some ways that you might you use a natural waterway differently than a canal? Why?

Levels of Understanding

None

- Unaware of the value of restoring waterways;
- Thinks that restoration should not be hard to do;
- Thinks that restoration is like a construction project and nature would play no role in the process; and
- Thinks that restoration is done the same way everywhere.

Low

- Aware of the value of restoring waterways, but is unclear how it would happen;
- Aware that restoration is challenging, but not sure why;
- Thinks that restoration is like a construction project, but that nature may also play a role in the process; and
- Aware that restoration is not done the same way everywhere because waterways vary, but is not able to describe how those differences affect the process.

Intermediate

- Knows about the value of restoring waterways, has some ideas how it would happen, has seen it done, and is aware of the challenges and tradeoffs;
- Knows that restoration is challenging, is able to explain several reasons why, but is unable to offer solid explanations for how to overcome the challenges;
- Knows that restoration is not like a construction project, that nature plays a role in the process, and can offer several reasons why this human-nature collaboration is helpful; and
- Knows that restoration is not done the same way everywhere because waterways vary, and is able to describe how those differences might affect the process for a few waterways.

Advanced

- Knows about the value of restoring waterways, has several ideas how it would happen, has seen it done, and is able to skillfully speak about the challenges and tradeoffs;
- Knows that restoration is challenging, is able to explain many reasons why, and is able to offer solid explanations for how to overcome several of the challenges;
- Knows that restoration is not like a construction project, that nature plays a prominent role in the process, and can offer several reasons why this human-nature collaboration is essential; and
- Knows that restoration is not done the same way everywhere because waterways vary, is able to describe how those differences might affect the process for several waterways, and is able to describe specifics for one waterway in particular.

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Concept 18: Health of Urban Waterways

Definition

In general, urbanization and agriculture decrease the health of the waterways by clearing plants from stream banks, changing the path and quantity of runoff, altering the shape of streams, furthering erosion, and introducing pollutants and nutrients. Many urban communities are making efforts to address these problems and improve the health of local waterways.

Figure 46. Water Runoff

April 20, 2008. Used under the permission of the Creative Commons.

Key Concepts & Ideas

1. Urban design can fundamentally affect the health of local waterways. Historically, cities have used the waterways to remove waste, a process that was halted with the passage of the Clean Water Act in the United States in 1972. Since then, nearly all urban waterways in the US have seen marked improvements in their health and water quality[6].
2. Nonetheless, ***urbanization*** has a profound effect on waterways by changing the path and quantity of runoff, the amount of sediment, and the shape of streams. The latter occurs by paving the streambeds and channelizing waterways. Typically, restructured waterways have an increased flow rate, deeper scouring, and more erosion. Because of higher rates of flow, urban waterways are usually deeper and straighter than natural waterways. All of this has the net effect of reducing the diversity of habitats available for native species.
3. Different waterways respond differently to the same uses of land. Much of the response depends on the condition of the waterway prior to the changes, such as whether the area had been disturbed previously.
4. Urbanization increases the amount of ***impervious surfaces*** such as pavement, cement, and buildings. These surfaces prevent the soil under them from collecting water. Consequently, surface runoff increases, water flows are dramatic and irregular, and the amount of erosion and sediment transported into streams increase. Impervious surfaces also increase the diversity and amounts of chemicals, pesticides, and nutrients added to the water, degrading the health of the waterways.
5. There are two general categories of pollutants distinguished by how they reach the waterway. ***Point sources*** have a clear source of production and output, such as a pipe from a sewage treatment plant. ***Nonpoint sources*** typically have a broad, diffuse pathway of entry to the waterway, such as oil running off road surfaces during rain. The progress made in eliminating point source pollution has made it apparent that nonpoint source pollution and habitat degradation are the nation's biggest water quality challenges.
6. Waterway health is often estimated based on the diversity and abundance of insects, mollusks, crustaceans, and fish, as these species are sensitive to ecosystem changes.
7. Healthier streams typically have more green area surrounding them, including trees along their banks and more open vegetated area surrounding the waterway. Green spaces reduce the impacts of urbanization by slowing and filtering surface runoff of the pollutants, nutrients, and sediment that would otherwise reach the waterway.
8. Development age, density, location, and type (e.g., industrial versus residential) and the surrounding ***water infrastructure*** will mediate the effect on nearby waterways. Sprawling industrial developments have a greater negative effect on waterways than compact residential developments. Damaged waterways have difficulty

[6] American Rivers. (n.d.). Protecting the Clean Water Act. Retrieved from http://www.americanrivers.org/initiatives/pollution/clean-water-act/.

providing healthy habitats, naturally filtering out pollutants, and with drainage of excess water.

9. *Integrated urban water infrastructure strategies* use built and *green infrastructure* to manage water collection, distribution, and storage. The goal is to keep as much water out of the *sewage treatment plants* as possible while still ensuring that all water in an urban area is clean and healthy.
10. *Ecohydrology* efforts strive to use all ecosystem properties to manage water and improve the efficiency of urban regulatory processes. Solutions must be well integrated with each other and into the city system to be most effective.

Applications & Implications

Humans: Health & Communities

- Urban waterways have lower water quality than natural waterways, which affects urbanites who interact with the waterways for extended periods of time (e.g., fishers, boaters, swimmers, and people with wells).
- The impacts of urban areas on waterway health are generally a consequence of city planning decisions, which are often outside the purview of individual community member. However, community members can take organize to lobby for the city government to take action.
- Some individual-level actions can increase the health of the urban waterways, including: using rainwater to water yards and gardens, *nativescaping* yards instead of planting grass, properly disposing of chemical and solid trash so they don't enter the waterways through runoff, installing green roofs, and reducing water consumption.

Nature: Environment, Sustainability & Conservation

- Low water quality and clarity, high temperature because of runoff over hot pavement, and changes in physical traits of waterways negatively affect native species.
- People can reduce human impact on nature in urban settings by trying to reduce water consumption, thereby making more water available for natural ecosystems.
- Replanting areas near waterways leads to more shade, more stable temperatures, and reduces heat stress of native species. Also, this vegetation absorbs pollutants and keeps runoff-borne sediment on land.

Discussion Questions

Water Infrastructure (Pogue's Run)

- How would you change the local water infrastructure to decrease human impact on the waterways? Why?

Change Over Time (Pleasant Run)

- Most waterways have become healthier since the passage of the Clean Water Act in 1972. What are some changes that may have contributed to that recovery? Can you think of some waterways that have not yet been cleaned up?
- What can your community do to accelerate that recovery?

Water and Habitat Corridor (Fall Creek)

- Some waterways around Indianapolis are more natural than others. What features differ?
- How do you think biodiversity will change as these features change? Is it a linear change? Why or why not?

Water in the Atmosphere (White River)

- Generally, water that falls from the sky is cleaner and healthier than that which has absorbed chemicals and features from the Earth. What are some factors that could contaminate rain or snow as it falls? How might those factors contribute to larger environmental problems?
- What changes can you make to reduce aerial pollutants? How might those changes affect your personal health?

Water as a Resource (Central Canal)

- Fishers, boaters, swimmers, and people with wells are likely to be particularly affected by contaminated water. How might membership in one of those groups affect how much you are willing to advocate for clean waterways?
- If you are a regular user of waterways, how could you convince non-users to care about cleaning waterways?

Figure 47. Algal Bloom

August 22, 2010. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware of the effects of urbanization on waterway health;
- Unaware of the effect of impervious surfaces on waterways;
- Unaware that increasing green spaces in cities may lead to healthier waterways;
- Unaware that development characteristics impact waterway health; and
- Unaware of point versus non-point pollution.

Low

- Aware of the effects of urbanization on waterway health, but unaware of ways to increase waterway health;
- Aware of impervious surfaces, knows that impervious surfaces may not be universally good, has some idea that there are alternatives to impervious surfaces;
- Aware that increasing green space in cities may lead to healthier waterways and thinks it may have something to do with absorbing runoff;
- Aware that development characteristics impact waterway health, is able to infer at least one relationship; and
- Aware of point versus non-point pollution, but is not certain of the difference.

Intermediate

- Knows about the effects of urbanization on waterway health, is able to describe some aspects of the relationship, aware that there are ways to increase waterway health;
- Knows about impervious surface, is aware of the problems posed, can describe at least one method to increase infiltration;
- Knows that increasing green spaces in cities leads to healthier waterways, knows that green spaces absorb runoff and may have some idea that it may remove pollutants before they get to the waterways;
- Knows that development characteristics impact waterway health, is able to describe at least one relationship; and
- Knows about point and non-point pollution, is able to describe the difference between the two, and has some idea about the implications for cleanup.

Advanced

- Knows about the effects of urbanization on waterway health, skilled at describing the causal relationship, is able to discuss at least one way to increase waterway health;
- Knows about impervious surfaces, knows about the problems posed, can describe methods to increase infiltration;
- Knows why increasing green spaces in cities leads to healthier waterways, knows that green spaces absorb runoff and may have some idea that it may remove pollutants before they get to the waterways;
- Knows that development characteristics impact waterway health, is able to describe some of the relationship; and
- Knows about point and non-point pollution, skillfully describes the difference between the two, and can talk about the implications for cleanup.

Figure 48. Bridge Next to an Urban Waterway

Olof S. May 13, 2008. Used with permission under Creative Commons.

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Concept 19: Politics of Urban Watershed Management

Definition

Watershed management generates many legal and political issues as organizations and individuals create and implement plans and projects to sustain and enhance watershed functions. Legal and political conflict is evident when competing interests seek to determine who gets how much water, of what quality, where it should drain, how to handle stormwater runoff, how to settle claims to water rights, and how to use and maintain waterways. Landowners, land use agencies, stormwater management experts, environmental specialists, water use surveyors and communities all play an integral part in watershed management.

Figure 49. Water Distribution Channel

Lesley Ross. May 7, 2013. Used with permission under Creative Commons.

Key Concepts & Ideas

1. A ***watershed*** is an area where all the water running off the land drains into a specific body of water. Watershed size can vary based on the management approach. For example, the land that drains into a single stream can be a watershed at a small scale, while the land and streams that collectively drain into a river can comprise a larger watershed. Each watershed is an integrated system and must be treated as a unit. Collectively, the world's watersheds comprise all land on Earth and all eventually connect to the oceans.
2. Watersheds are interconnected. Activities that impact one watershed are likely to impact another one downstream. As a result, problems like contaminated drinking water and soil erosion can affect people who are not near the original problem site.
3. Watershed management is essential because all people depend on a clean, well-functioning watershed. Watershed and resource managers, politicians, lawyers, and conservation organizations help the public make decisions that affect the environment and our health.
4. One recent scientific review[7] suggested that there were seven major barriers to sustainable urban water management: (1) uncertainties in performance and cost of the projects, (2) a lack of engineering standards and guidelines, (3) lack of clarity in terms of who is responsible for certain projects, (4) lack of institutional capacity, (5) lack of legislative mandate, (6) lack of funding and effective market incentives, and (7) resistance to change on the part of the community and their leaders.
5. Local governments have a large role in protecting urban natural areas. Government passes legislation and laws that require municipalities to develop and implement plans that conform with planning standards. Standards typically prioritize conserving open space, protecting natural and historic resources, and protecting natural areas.
6. Watershed management teams work to ensure the long-term sustainability of watersheds. They are subject to federal mandates that public lands be open to all kinds of activity, including resource extraction, recreation, wildlife preservation, and development. Teams must consider myriad competing factors in management decisions, such as environmental stability, economics, and regulations.
7. Watershed residents can be the watchdogs of the watershed by reporting flooding, contamination, and illegal dumping to government authorities. Residents are the best stewards of their own watershed.
8. At the community level, individuals can join groups that advocate for the protection and restoration of watersheds. One successful community group is Ducks Unlimited, which realized long ago that conserving the wetland habitat is essential to ensure hunting opportunities in the future.

[7] Roy, A., S. Wenger, T. Fletcher, C. Walsh, A. Ladson, W. Shuster, H. Thurston, and R.R. Brown. (2008). Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management: Lessons from Australia and the United States. Environmental Management 42: 344–359.

Applications & Implications

Humans: Health & Communities

- Many people are involved in the creation and implementation of a sustainable watershed management plan, so political conflicts inevitably arise. People often disagree on the best priorities and methods for watershed management. Conflicts can delay project implementation and in the meantime, watershed health will continue to degrade.
- Although well-designed public works projects benefit communities, the biggest impact that watershed politics have on human wellness are delays, despite the need for immediate action.
- Compromises made between groups with competing interests may reduce the effectiveness of the project. Mission clarity is difficult to maintain when many are involved.

Nature: Environment, Sustainability & Conservation

- As with human wellness, the greatest threats to the natural environment posed by management and the resultant politics are delays in project implementation.
- Most public works projects that are involved in creating a sustainable urban watershed lead to improvements in the natural world as well.

Figure 50. Irrigation

March 14, 2008. Used with permission under Creative Commons.

Discussion Questions

Water Infrastructure (Pogue's Run)

- How would you define sustainability with regard to watershed management?
- Would you define sustainability differently in another location with more or less infrastructure?

Change Over Time (Pleasant Run)

- How do you define sustainability with regard to watershed management? What is the most sustainable watershed feature in your neighborhood? How would you characterize that feature?
- What is the least sustainable watershed feature? Why? How could you improve this feature? How much money and time would it take to ensure that it is sustainable?

Water and Habitat Corridor (Fall Creek)

- Humans' impact is particularly high near urban areas. What interventions would you recommend to reduce human impact on waterways in your neighborhood?
- How prominent is erosion in your neighborhood? Is it caused by human activities or not? If so, where? What can watershed managers do to reduce erosion?

Water in the Atmosphere (White River)

- Snow and rain pose different challenges for watershed managers. What factors must they consider to ensure adequate drinking water for Indianapolis in the winter?
- What times of year does the city have the greatest shortages of water? Why? Consider both supply and demand.

Water as a Resource (Central Canal)

- If you were the manager of one component of the infrastructure here (e.g., the nearest sewage treatment facility), how would you define sustainability differently from the manager of another nearby infrastructural component (e.g., the canal)?
- How would you come to an agreement that is acceptable to you both?
- Try doing a role-playing game with some friends where each of you represent a different stakeholder involved in water management decisions. Engage in a discussion where you

collaborate to plan a water management project. Was it challenging to come to a consensus? What were your key obstacles? Were there key points of opportunity for collaboration?

Levels of Understanding

None

- Unaware of what a watershed is;
- Unaware of sustainable watershed concept, unaware of the need for management of the water supply, does not know who the stakeholders are;
- Unaware that politics are involved in watershed management sustainability; and
- Unaware of roles that citizens can play in improving management.

Low

- Aware of what a watershed is and has a general idea what it means;
- Aware of sustainable watershed concept, aware of the need for this management for sustainable water supply, does not know who the stakeholders are;
- Aware that politics are involved in sustainability and is able to describe a few relevant user groups; and
- Aware of a few roles that any citizen can play to improve management and is able to mention at least one way that citizens can help reduce use and contamination.

Intermediate

- Knows what a watershed is and has a clear idea about what it means, is able to clearly describe its relationship to municipal water supply, and has some idea that it needs to be managed;
- Knows about sustainable watershed concept, is able to describe the need for this management for sustainable water supply, and has an idea about the diversity of stakeholders involved in the process;
- Knows that politics are involved in sustainability, is able to describe some of the important user groups to involve in discussion, is unable to articulate the perspectives of most groups; and
- Knows the roles that citizens can play in improving management and is able to mention several ways that citizens can help reduce use and contamination.

Advanced

- Knows what a watershed is, has a clear idea about what it means, is able to describe its relationship to municipal water supply, and explains at length why it needs to be managed;
- Knows about sustainable watershed concept, is skilled at describing the need for this management for sustainable water supply, and is able to describe the diversity of stakeholders in the process;
- Knows that politics are involved in sustainability, is able to describe the perspectives of each user group; and
- Knows about the roles citizens can play in improving management and can describe many ways that citizens can help reduce use and contamination.

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Concept 20: Sustainable Urban Water Supply

Definition

A sustainable urban water supply has become more important as increasing consumption and contamination reduce the availability of clean water. Urban areas must identify new sources of water and reduce the environmental pollution that is threatening existing supplies. A sustainable water plan will include reductions in water use, better environmental regulations and enforcement, and minimal system leakage. Although US cities are beginning to address these problems, they have a lot to learn from water supply networks in developing countries, which have dealt with population increase, water scarcity, inadequate infrastructure, and environmental pollution for many years.

Figure 51. Dam

Nicholas A. Tonelli. April 20, 2007. Used with permission under Creative Commons.

Key Concepts & Ideas

1. City water usually comes from multiple sources, including surface water and ***groundwater***. Surface water comes from rivers, creeks, streams, aqueducts, and reservoirs. Groundwater comes from rain, snow, sleet, and hail that have seeped into the ground. This water collects in pockets underground between sand, gravel or pores and may be drawn from shallow wells that tap into the ***water table*** or deeper ones that tap into the aquifer.
2. Indianapolis draws its water from three reservoirs - Morse, Geist, and Eagle Creek - and several wells that are tapped into the water table. Additionally, four groundwater stations - Geist Station, Harding Station, South Wellfield, and Ford Road - pump water from underground aquifers. All of this water is sent to the four treatment plants before being distributed to consumers.
3. In most cities, water sources often extend beyond city limits. Urban areas cover only around 2-4% of the Earth's land surface, but draw their water from sources that cover 41% of the Earth's land surface[8]. Importing water is especially common in areas with low rainfall, such as desert areas across much of the Southwestern US. For example, San Diego County imports approximately 80% of its water from sources that are hundreds of miles away via extensive aqueducts that traverse the state[9].
4. ***Adaptive management*** focuses on achieving a specific water quality goal (e.g., level of phosphorus in surface water). Monitoring is required to track movement towards the goal or determine whether the goal should be revised. This approach allows management teams to use incoming data to responsively manage a resource.
5. ***Wellhead protection*** reduces groundwater contamination. A wellhead is the land above and around wells that is drilled into an aquifer. Polluted water in this area seeps into the ground to contaminate the water table and eventually the aquifer. Sustainable planning identifies areas that are susceptible to contamination and generates measures to reduce this risk.
6. Sustainable plans ensure diverse sources of uncontaminated sustainable urban water. In many communities, Indianapolis included, there are plans to eliminate septic tanks and connect residences to the sewage system. These measures prevent bacteria from failed septic

[8] McDonald, R. (2014). Urban Water Footprint: Extensive and Expensive. Retrieved from http://blog.nature.org/science/2014/06/04/urban-water-footprint-extensive-and-expensive/.

[9] San Diego County Water Authority. (n.d.). San Diego County's Water Sources. Retrieved from http://www.sdcwa.org/san-diego-county-water-sources.

tanks from entering the water system. Most cities are also interested in better regulating the industrial wastewater that flows into the sewer system to protect the treatment plants.

7. There are many ways to more efficiently use existing water supplies, regardless of the new water system developments. Key components of this optimization can be achieved by reducing per capital water use such as through efficiency in use, reductions in water use, demand management, conservation, and plumbing code changes to use better materials.

8. Some coastal communities in the US and around the world are beginning to use water desalination plants to remove the salts from ocean water and create fresh water for drinking. ***Desalination*** will likely become more common in the future, but at present the technology is still in its infancy and requires a lot of energy to boil the water. For some cities, like those in the United Arab Republics, oil is not as expensive and the economic barriers to desalination are lower. For most of the world, however, the financial and environmental costs (e.g., emission of greenhouse gases) are prohibitive.

9. ***Recycled or reclaimed water*** is becoming more commonly used in the US. This water has passed through the treatment procedures at a sewage treatment plant, but may be used multiple times before it reenters the natural water cycle. Normally wastewater is treated and then discharged into a nearby waterway. In contrast, many communities have created a separate water distribution piping network, often painted lavender or light purple, to supply recycled water for watering landscaping, golf courses, and public parks. Some communities with advanced water treatment systems have begun to use this water to mix into the normal water supply system. In reality, nearly all water that is used by humans is recycled, because much of the water taken from waterways has already been used, treated, and then released back into the waterway by communities upstream. We all live downstream.

10. ***Green infrastructure*** (e.g., bioswales, green roofs, runoff holding ponds, biofiltration wetlands) will help cities increase the supply of high-quality water. Green infrastructure increases stormwater absorption, so less is channeled to sewage treatment plants, reducing treatment costs. Green infrastructure also increases water quality in rivers and streams. It is therefore essential for reducing the effects of ***CSOs***, pollutants from runoff, untreated industrial wastes, agricultural runoff, and unsafe waste disposal by urban residents.

11. Some key parts of the water infrastructure system must be retrofitted or redesigned to better function. Removing old, leaky sewer mains is costly, so is usually done only after they break. A strategy to replace sewer mains before they break could reduce waste and environmental impact, but may be expensive and inconvenience community members.

12. Many contemporary problems like climate change, sea level rise, earthquakes, and public mandates to reduce environmental impacts have substantial and sometimes unpredictable consequences for the water supply. For example, climate change will change where water falls and accumulates across the landscape. Sea level rise can introduce saltwater into freshwater supplies in coastal communities and degrade the water quality for many years. Earthquakes and other natural disasters can disrupt piping and contaminate the water supply when breaks allow other materials to enter the system. Planning for all of these challenges must be a part of any integrated urban water supply plan that emphasizes sustainability.

13. There are many ways to better use our existing water supplies and a key component is reducing per capital water use. Cities can reduce water use by improving management, promoting conservation, and altering plumbing codes to incorporate longer-lasting materials.

Applications & Implications

Humans: Health & Communities

- The solutions that comprise the creation of a sustainable urban water supply provide hope for the future. However, public misconceptions about the quality of the water from non-traditional sources may lead to political conflicts and delays in implementing the improvements.
- The greatest challenge that humans face with respect to creating a sustainable urban water supply is being receptive to novel water solutions, particularly with green infrastructure when they occur away from the waterways and with recycling water after it has already been used once.
- Planning for the future is a challenging task for city water planners and the diversity of tasks that lie ahead are daunting, particularly when considering regional and global changes, like climate change and natural disasters.

Nature: Environment, Sustainability, & Conservation

- Nature will greatly benefit by the creation of a sustainable water supply in that it will reduce the quantity of water extracted by the environment, as well as the quantity of wastewater discharged into the waterways.
- Most public works projects that are involved in creating a sustainable urban water supply lead to improvements in the natural world as well.

- Humans impact nature and this is particularly true in urban areas. As such, humans need to change how they interact with nature for it to improve and better cope with our presence.
- Forces such as climate change and sea-level change, particularly for coastal ecosystems, are influenced by human impacts on nature. Even if a city has created a plan for the future, there are many outside factors that will need to be taken into account during implementation.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Should existing cities build more water infrastructure? Do more pipes and construction improve the likelihood that your community will have a sustainable water supply? Why or why not?
- Do some research to find out where Indianapolis gets its water. How many miles of pipes are involved?
- What is the environmental impact on of this construction and piping? What are some ways to reduce the impact of construction on the natural world?
- Planning for the future may require extra water infrastructure in your neighborhood. How would you react to being inconvenienced because of repairs or modifications to the water infrastructure?
- Some water infrastructure developments may require returning built areas to a more natural state, such as converting a parking lot to a bioswale that can be used to filter water. Would you support this change if it required you to walk a half block further to find a parking spot?
- How much of an inconvenience would you tolerate in the short term if it benefitted you in the long-term?

Change Over Time (Pleasant Run)

- Small cities can more easily and sustainably get their water from nearby areas than can large cities. What are some threats to the water supply in small cities that large cities might avoid?
- Climate change has already begun to affect water systems all over the world, including in Indiana. How do rising temperatures change the amount of water available locally? Do some research online to compare your ideas to scientists' predictions.
- Humans are reusing water more frequently to mitigate increasing human demands on the Earth's water. How might reuse affect planning for the future? Are there any problems with reusing water?
- How could we increase the time between our use of the water and its eventual reentry into the global water cycle?

Water and Habitat Corridor (Fall Creek)

- Why are the headwaters of most water catchment areas protected from development? Is this valuable to you?
- How much do you think it would cost for your community to source and treat all its water from a polluted or degraded waterway? Look up a case study in which New York City saved millions of dollars by protecting watersheds in the nearby Catskill Mountains instead of building new treatment centers. How did they achieve this?
- Does a similar system operate in Indianapolis? If not, do you think it could work?
- Many assert that the needs of nature should be a part of our plans for the future of water use in cities. Do you agree or disagree?
- How would you vote if you were asked to support protection of the headwaters of a watershed that would benefit your community's water source? What about if that area was protected for reasons that did not directly benefit you (e.g., to protect the habitat of an endangered species)?

Water in the Atmosphere (White River)

- Rain and snow provide most of the water that we consume. Do you know where your drinking water comes from? Have you been to the river or reservoir that collects and funnels it to your treatment plant?
- Have you ever visited the headwaters of the river at the start of the watershed that provides your water? Is it protected by a conservation easement to ensure that the water catchment area remains intact?
- All water that has ever existed on Earth is the same water that exists now. Does this fact affect how you think about the purity of water?
- Which do you think is purer – falling rain or falling snow? Why? How might seasonal differences in pollution affect the purity of precipitation?

Water as a Resource (Central Canal)

- Using water sustainably is a relatively new concern for most people. How could help your community achieve sustainability? What are some actions that you could take today?

- Planning for the future is an exercise in deferred gratification and rewards, and there is no shortage of requests for short-term solutions. If you were the head of the water department for your community, how would you balance long and short-term goals?
- Would you use a different approach to get people to use water more economically than for the getting people to dispose of wastes safely?
- Would you use a different approach to make industries change their water usage or discharging effluents than to get private citizens to change their behavior?
- Calculate how many gallons of water you could save if you made some lifestyle changes to reduce water use. What do you save if you change your behavior for a week? A month? A year? A decade?

Figure 52. Water Management System

September 22, 2010. Used with permission under Creative Commons.

Levels of Understanding

None

- Unaware of the sources of drinking water;
- Unaware of alternative sources of water like reclaimed or desalinated water;
- Unaware of local pollution sources and how they impact drinking water;
- Unaware of the impacts of climate change and how it affects water supply; and
- Unaware that there are efficiency gains to be made in their own residence and across the city more generally.

Low

- Aware of the sources of their drinking water, has not thought about the repercussions of water supply and sustainability;
- Aware of alternative sources of water like reclaimed or desalinated water, but is not certain what they are;
- Aware of local pollution sources and how they impact drinking water;
- Aware the impacts of climate change and how it affects water supply; and
- Aware that there are efficiency gains to be made in personal residences and across the city, but is not certain how.

Intermediate

- Knows the sources of their drinking water, has thought about some of the repercussions of water supply and sustainability, is aware of tradeoffs needed for sustainability;
- Knows of alternative sources of water like reclaimed or desalinated water and what they mean, is aware of some of the costs and benefits of these water sources;
- Knows about local pollution sources and how they may impact drinking water, is well informed about pollution sources, and has some idea about routes that pollutants take to the waterways;
- Knows about the impacts of climate change and how it affects water supply, and has some idea how it might affect the local area; and
- Knows there are efficiency gains to be made in their own residence and across the city, is able to explain several ways how they could increase efficiency, and has a general idea about water losses in city infrastructure.

Advanced

- Knows about the source of drinking water, has thought about the repercussions of water supply and sustainability, and is knows of several tradeoffs needed for sustainability;
- Knows about alternative sources of water like reclaimed or desalinated water and what they mean, and is aware of many of the costs and benefits of these water sources;
- Knows about local pollution sources and how they impact drinking water, is well informed about pollution sources, and can clearly describe routes that pollutants take to the waterways;

- Knows about the impacts of climate change and how it affects water supply and has good understanding about how it will affect local area; and
- Knows that there are efficiency gains to be made in personal residences and across the city, is able to explain several ways they could increase efficiency, and has a clear idea about water losses in city infrastructure.

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Concept 21: Urban Water Engineering

Definition

Many cities were founded on waterways, but today, the unpredictability and intensity of flooding has made these locations more challenging to live in than in the past. Floods can cause extensive property damage and make it difficult to maintain normal urban functions. Large-scale engineering projects, like dams, are essential to control the movement and availability of water and these projects must be implemented in an environmentally sensitive fashion to minimize harm and maximize benefits.

Figure 53. Dam

November 2013. Used with permission under Creative Commons.

Key Concepts & Ideas

1. In the past, engineering strategies have focused on using cement construction to alter how water flows through urban ecosystems. Projects like floodwalls, levees, river channels, river canals, dams, locks, paved stream banks, and piping aim to protect property from flooding.

14. ***Floodplains*** border waterways and are inundated with water when flow rate is higher than normal. Floodplains provide many ecosystem benefits, including enhanced biodiversity, cleaner water, stored water surges, rejuvenated productive soils, and maintained fisheries. Stretches of rivers without healthy floodplains push wave energy further downstream, impacting aquatic life and more distant communities.

15. Hydrological engineering approaches historically have disconnected waterways from floodplains, which increase the speed and volume of water in the waterway and disrupts natural waterway morphology.

16. Waterway speed increases with ***impervious cover*** and ***channelized drainage systems*** because these features increase runoff. Higher water speed and volume leads to ***erosion***, channel deepening, and topsoil loss, which clogs stream channels and damages habitat. ***Channelized rivers*** and streams may be unable to accommodate peak runoff volumes and support diverse aquatic ecosystems.

17. Over-engineering waterways disrupts natural meandering in larger streams and riffles, runs, and pools in smaller streams. Over-engineering also dramatically reduces wildlife diversity because of direct habitat loss through clearing or paving, increases in average stream temperatures, increases in flow rates, loss of vegetation on the bottom of the waterways, and low dissolved oxygen concentrations.

18. Engineering projects around waterways often allow landowners to build on land that was historically floodplain.

19. After decades of extensively modifying waterways and controlling flow, waterway engineers now also strive to repair past degradations and plan for the future. The discipline has moved toward predicting the response of the system to planned alterations by considering how water moves in response to surface structuring.

20. Engineers will draw on knowledge about how water moves through open channels, sediment transport, hydrology, physical geology, and riparian ecology to understand how waterways change their form over time.

Figure 54. Water Channel

Lesley Ross. May 7, 2013. Used with permission under Creative Commons.

Applications & Implications

Humans: Health & Communities

- The health of human communities is generally improved as a consequence of urban waterway engineering. Benefits to humans include decreased likelihood of property damage or loss from floods, increased predictability of waterway influences, drainage of standing water, and enhanced waterway navigation.
- Negative consequences of aggressive engineering along waterways include decreased aesthetic value and perceived naturalness, disconnectedness from the community waterway, noxious odors from polluted waterways, and an inability to easily access the waterway.

Nature: Environment, Sustainability & Conservation

- Waterway engineering almost always has a negative effect on nature.
- Disruptions to a natural ecosystem will invariably pose problems for native species. For example, even a slight increases in water temperature may prevent some species from laying eggs and rearing offspring.
- Engineered waterways frequently create entirely novel ecosystems. Engineered artificial ecosystems tend to be dominated by non-native or invasive species, which can outcompete native species.

Discussion Questions

Water Infrastructure (Pogue's Run)

- Is it possible for a small town to have all of its water needs met using a natural waterway without any pavement, concrete, rocks, or restructuring of the land? In what size community would this no longer be possible?
- What are the effects of a large city completely subverting all the natural functions of a waterway? What are the consequences for downstream communities?

Change Over Time (Pleasant Run)

- Fully engineered riverbanks will change through time as the waterway works against it. What types of engineered riverbanks will last longest: those with large rocks on them (i.e., rip-rap), pavement, earthen levees, or some other kind? Why?

Water and Habitat Corridor (Fall Creek)

- What types of riverbanks do you think are most attractive: artificial or natural? Why? What could be done to your less preferred type to make them more attractive to you?

Water in the Atmosphere (White River)

- Precipitation acts differently in engineered landscapes in the winter than it does in the summer. How and why?

Water as a Resource (Central Canal)

- Water is a valuable resource for people and nature. The tradeoffs involved in parceling out water to people and to nature are complex, but let us start by thinking about your neighborhood. How much of your community is paved and how much is natural?
- How might those percentages be used to allocate the total amount of water that is available in your community? How could you reallocate this important resource?
- Does this exercise change how you think about how much of the surrounding land where you live should be open space and how much should be paved? Why or why not?

Levels of Understanding

None

- Unaware that waterways have been engineered to benefit humans;
- Unaware of floodplains;
- Unaware of channelization and may assumes that is the way the river has always been;
- Unaware of the impact of engineering on biodiversity; and
- Unaware that engineering has changed its focus to include considerations about sustainability.

Low

- Aware that waterways have been engineered, but unaware that it is to benefit humans;
- Aware of floodplains, but is not certain how they relate to people;
- Aware of channelization and likely assumes that it is the way the river has always been, but wonders whether it has moved around in the past;

- Aware of the impact of engineering on biodiversity, but not certain what that would be; and
- Aware that engineering has changed its focus, but is not certain how or that it includes considerations about sustainability.

Intermediate

- Knows that waterways have been engineered, is aware that it is to benefit humans, and can name a few reasons why it is useful;
- Knows about floodplains and how they relate to people and can name a few ways that humans have changed them;
- Knows about channelization, its impact, and why it is used in the past, but is not completely certain how it could be reversed or that it would be useful;
- Has thought about the impact of engineering on biodiversity, thinks it is generally negative, and has some idea how to reverse it; and
- Knows that engineering has changed its focus, to include considerations about sustainability, but is unaware that it is for environmental conservation.

Advanced

- Knows that waterways have been engineered to benefit humans, and is confidently knowledgeable of several ways it has helped people;
- Knows about floodplains and how they relate to people, can confidently name ways that humans have changed them, and knows that they are of value in their undisturbed state;
- Knows about channelization, its impact, why it was used in the past, and why and how to reverse it;
- Has thought about the impact of engineering on biodiversity, thinks it is generally negative, and has several nuanced ideas how to reverse it; and
- Knows that engineering has changed its focus to include sustainability goals, and is aware that it is to include environmental conservation.

References for Further Reading

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