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Evaluating and Mitigating Stormwater Runoff Contamination

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by Sally Cannizzaro

Introduction and Rationale

September 2005 was a devastating month for the citizens of New Orleans. Those who survived Hurricane Katrina had to immediately brave the perils of the floodwaters, and for anyone watching news coverage of the flood, it appeared that people had to wade through a toxic mess of various chemicals and contaminants. We were told all about the chemical plants, petroleum refining facilities, Superfund sites, service stations, pest control businesses, dry cleaners, old lumber sites, and flooded automobiles that contributed to the environmental toxicity in the water, not to mention the biological waste from humans and animals. While experts ultimately determined that "the toxic 'witches brew' reported in the media."[1] wasn't as impactful as everyone suspected, the picture of absolute environmental devastation was clearly painted for viewers.[2]

Fast forward to May and June of 2019, when most of Oklahoma was deluged with heavy rain. As a result, many areas along the Arkansas River experienced 200-year flooding events. Portions of Tulsa were flooded for nearly a month, and the creeks and other watersheds feeding the Arkansas River were flooded as well. While most of my students generally lived far enough away from the river to not have their lives upended by the flooding, the event and its aftermath dominated the news. At one point, two unmanned barges carrying fertilizer broke free on the river and careened toward a lock and dam. Local TV stations dedicated helicopter coverage to a dramatic "will they or won't they" scenario before the barges did eventually crash into the dam and sink, fortunately without compromising the dam. Similar to the post-Katrina news coverage, this prompted discussions about what (besides the 3,800 pounds of phosphate fertilizer on the barges) was going into the river during the rain and flooding, as well as the impact it would have.[3]

Both of these occasions were opportunities for people to watch TV and speculate what had been washed into the water, as well as where the contaminants came from. These events were only two of many natural or man-made disasters that have caused people to be concerned about what exactly is being washed into the river. However, students aren't given opportunities to grapple with these concerns and determine how founded they are. It is important for students to understand what is in our stormwater, at what level its nonpoint source pollutants become problematic, and how we can reduce its negative impacts. Therefore, this unit looks to address these speculations by providing an opportunity to observe and systematically analyze rainwater and stormwater so that students are better informed, and by allowing students to design and implement solutions for any negative environmental impacts they observe.

School Profile and Student Academic Needs

The two Tulsa, Oklahoma middle schools I teach at have students who are historically underidentified for Gifted and Talented (GT) services. While the district averages around a 12% overall identification rate for GT students, one of my schools, Monroe Demonstration Academy (in which nearly half the students are Black—twice the district average—and with one-third as many white students as the district average) has a 3% identification rate. The other school, Hale Junior High (which is nearly 50% Hispanic, as opposed to the district average of roughly one-third) has a 4% GT identification rate. English Language Learners (ELLs) are also historically underidentified, and that is true for both of my schools: each school has just one currently-identified ELL student (both are Hispanic) and each school has four or five students who formerly required ELL services. It should be noted that this is not a matter of which students attend the schools; my buildings also have the highest rates of newly-identified Gifted and Talented students for middle schools in the district. This means that I serve populations of students who, for some reason or another, were not identified as needing these GT services and access to a more challenging curriculum until several years after their age-peers in other schools were.

As a result of not having been properly identified or served for so many years, many of my students have missed out on literal years of appropriate levels of classroom rigor and challenging intellectual problems. Therefore, each unit they complete with me needs to be interesting enough to overcome their learned intellectual apathy, and ideally also be an opportunity to hone their inquiry skills, which tend to be sorely underemphasized in schools with traditionally underserved populations. Practically speaking, this means it is important that I have engaging, inquiry-based lessons whenever possible, and that I provide topics that will allow students' positive contributions to the world to be the focus.

When they are interested in a topic, GT students tend to become completely engrossed in it. "The environment" is already of interest to several of my sixth through eighth grade students, though what this exactly means varies greatly, so providing an inquiry-based learning opportunity will potentially help them discover and/or hone their budding passion. Additionally, the two middle schools I teach at have principals who have been intentionally working to increase student connection to their school and community. Learning about and designing a solution for an observable environmental issue that will positively impact their school and community is a classic "win-win."

Background

Unit Content

This unit is divided into several sections. The first section provides basic information about stormwater runoff, watersheds, and their path through Tulsa. The second section discusses the impacts of stormwater, nonpoint source pollutants, and the Clean Water Act. The third section discusses the process, rationale, and current methods of stormwater runoff containment and mitigation. After grasping the basics, students will have the opportunity to evaluate current mitigation techniques, then will either improve upon an existing technique or create a mitigation of their own design, which will eventually be implemented.

Stormwater Runoff Basics

Stormwater Runoff Management

As a concept, stormwater is straightforward: when it rains, or when snow melts, it runs off permeable, semipermeable, and impermeable surfaces and eventually (often directly via storm drains) makes its way to streams and rivers.[4] The methods for managing stormwater runoff vary from city to city. Older cities (which includes over 700 cities in the United States) use a combined sewer system, in which stormwater and sewage flow through pipes together and travel to a sewage treatment plant. The very significant disadvantage with combined systems is that hard rains overwhelm the treatment systems and require that the excess untreated stormwater/sewage mix be discharged directly into local rivers and estuaries, into the local watershed system.[5]

Tulsa's system is new enough that it has storm drains and collection systems separate from the sanitary sewer system, which nearly eliminates untreated sewage from entering the watershed. However, there are homes and neighborhoods in Tulsa that chose not to tie into the city sewer system and will occasionally have system flooding problems with their septic tanks during heavy rains as a result. Those areas, fortunately, are few and far between. Tulsa storm drains flow directly or via a system of smaller watersheds to either Bird Creek or the Arkansas River.[6] Overall, Tulsa is fortunate to not have the issues that older cities with combined sewer systems experience. Unfortunately though, this means that untreated stormwater enters our natural watershed.

Watersheds

When imagining water pollution, watersheds are frequently the physical area being discussed. "Watershed" is a broad term that refers to an area of land on which all the rain and snow, etc. that falls on it flows. The size of these areas varies greatly, depending on their location. There are varying standards of quality of water and watersheds; the EPA's goal is to have them be minimally "swimmable and fishable." "Watershed management," then, is a similarly broad term; it refers to all the "plans, policies, and activities used to control water and related resources and processes in a given watershed."[7]

The U.S. Environmental Protection Agency's (EPA's) Watershed Protection Approach is carefully integrated and holistic in that it focuses on all water quality aspects, "including chemical water quality (toxics and conventional pollutants, e.g., fecal coliform and total phosphorous), physical water quality... habitat quality... and biodiversity."[8] This unit will focus on the chemical water quality aspect, since this aspect of water quality is one that students can easily observe and more directly impact.

Tulsa's Watershed System

Oklahoma has seven major watershed basins and nearly 7343,000 acres of freshwater wetlands. These include rivers, streams, lakes, reservoirs, and ponds.[9] In Tulsa, watersheds can be as small as a person's yard or as large as the Arkansas River, which is the 9th largest watershed in the United States as shown in Figure 1.[10] The stormwater that washes into Tulsa's storm sewers generally flows into one of many storm drains or creeks before being discharged into either Bird Creek or the River. Monroe Demonstration Academy's watershed area is Flat Rock Creek, which breaks away from Bird Creek. Hale Junior High's watershed is Mill Creek, which flows into Mingo Creek and through a large area of sunken land used as drainage ditches on its path (which is otherwise used as a soccer field complex in drier seasons.)[11]

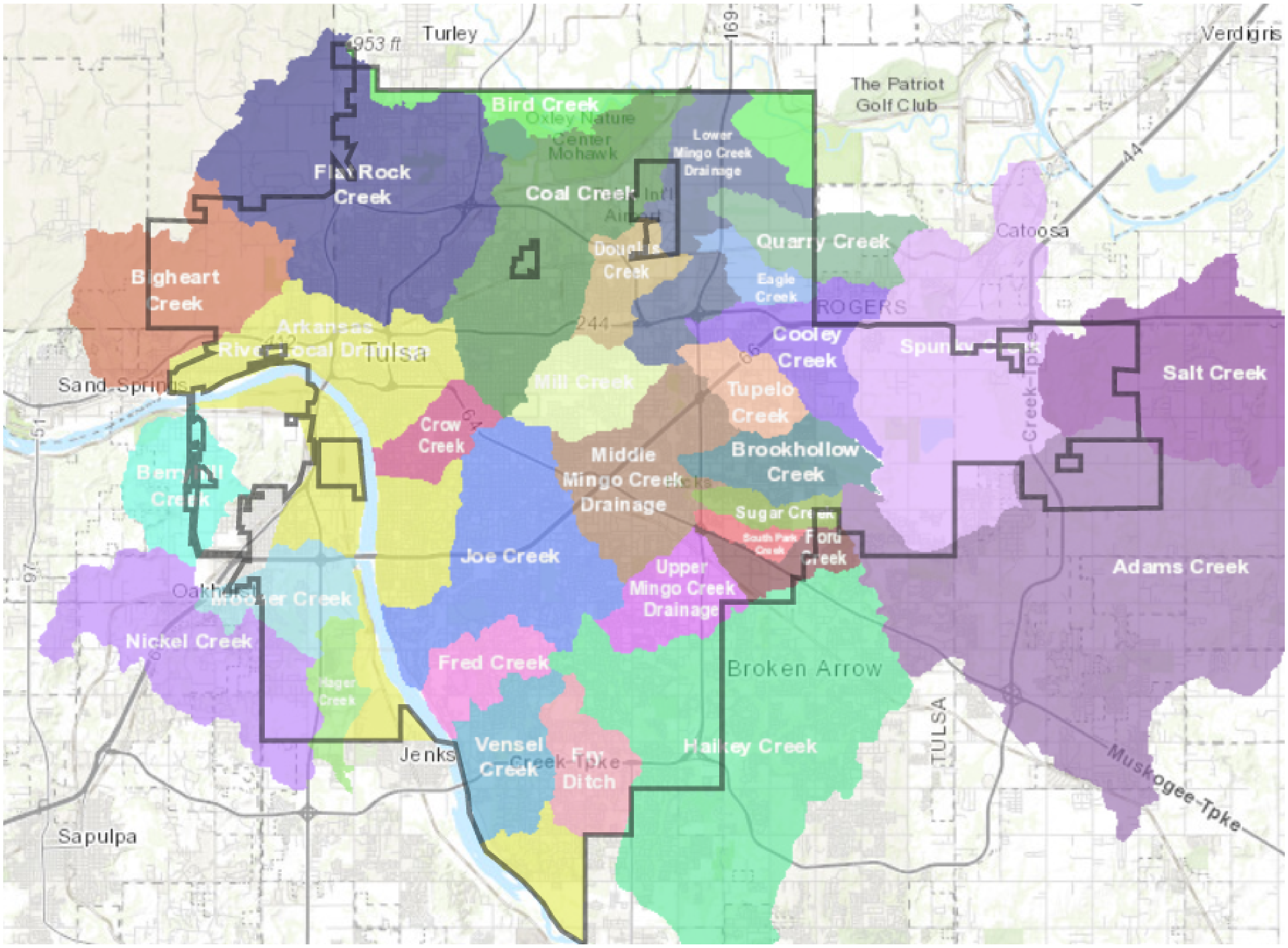

Figure 1: A map of the major streams comprising Tulsa's watershed system.[12]

Impact of Stormwater

The Clean Water Act

The major federal regulations for water pollution were signed into law in the early 1970's. The Clean Water Act is what we tend to think of when considering regulations concerning water quality. The Clean Water Act of 1972 (CWA) expanded the 1948 Federal Water Pollution Control Act and specifically addressed industry wastewater standards, the need for permits to discharge pollutants into navigable waters, and water quality criteria. An initial goal was to have "fishable and swimmable" waters, which meant that fish, shellfish, and wildlife needed to be protected, and that humans could enjoy recreation in and on the water. The CWA was further amended in 1987 to include more sources of impairments, including stormwater,[13] and Section 208 specifically requires the control of nonpoint source pollution in stormwater.[14] While the goal of 100% fishable and swimmable waters has not yet been met, there has been roughly a 20% improvement in the quality of our waterways since the CWA was passed.[15]

Nonpoint Source Pollution

Whenever precipitation falls or snow melts, its runoff carries pollutants of generally unknown origin through the watershed. All these "substances of widespread origin which run off, wash off, or seep through the ground are called nonpoint source pollutants." Common nonpoint source (NPS) pollutants include eroded soils, nutrients (such as fertilizers and grease,) acids and salts, heavy metals, toxic chemicals, pathogens, and even heat.[16] Historically, NPS pollutants have proven to be difficult to eliminate. Several years after the CWA was passed, point source pollutants (wastewater, industrial discharges, etc.) were noticeably lower, but various NPS pollutants were still collectively responsible for most waterway contaminants.[17, 18]

Stormwater, and urban stormwater runoff in particular, is problematic because it discharges NPS pollutants into a variety of receiving water bodies. Both aquatic life and raw drinking water may be affected, depending on how far removed the water body is from the stormwater runoff discharge and the type and amount of pollutants discharged.[19]

Pollutants

This unit will focus on the analysis and mitigation of a select few pollutants, chosen by the ease that students can observe them. For this unit, students will be measuring nitrates, total coliforms (which include fecal coliforms and E. coli,) and turbidity, and they will also observe petroleum sheen. The EPA has set standards for acceptable levels of these and many other water pollutants, which can vary depending on the water's intended use. For our purpose, we will use the EPA's established levels of contaminants in drinking water. This allows students to answer the very clear question of whether or not a particular water sample is safe for drinking.

Nitrates aren't problematic for most of the public to consume, but when they are present in drinking water above the EPA's drinkable standard of 10 mg/L infants under six months can become seriously ill, and potentially die.[20] Nitrates can be problematic in watersheds not intended to be drinking water, as well. Since the nitrates injected into a watershed come via fertilizer , livestock waste, and septic tank leakage, it would at first glance appear that they would have a positive impact on a watershed. After all, fertilizers accelerate plant growth. "However, nitrate can unbalance ecosystems in large amounts, fueling rampant growth by plants and algae. Their subsequent decomposition by bacteria can pull so much oxygen out of the water that it causes hypoxia, which can stress fish and other marine creatures. In the worst cases, dead zones and red tides can result."[21]

"Total coliforms" refers to a group of related bacteria, most of which are generally not harmful to humans, but several bacteria, parasites, and viruses can potentially be harmful if they are ingested. The total coliform count is considered to be a useful indicator of overall water health, and it has a maximum contaminant level of 5.0%. Of particular note are fecal coliforms and E. coli, which should not be present in drinking water at any level.[22] Discussing the possibility of finding coliforms in stormwater runoff and/or the watershed system has an "ick" factor that makes it an appealing pollutant for middle school students to track.

Water turbidity refers to how cloudy a water sample is due to soil runoff and is a good general indicator of how well water is being filtered. If water is conventionally filtered, its level of turbidity cannot exceed 1 Nephelometric Turbidity Unit (NTU), and 95% of samples collected monthly cannot exceed 0.3 NTUs. If other filtration systems are used, turbidity cannot exceed 5 NTUs. Higher levels of turbidity are correlated with higher levels of viruses, parasites, and some bacteria. There are a couple different approaches to measuring turbidity that are fairly easy for students to make, and observations and measurements can be taken independently, should school continue to be in distance learning at the time of this unit.[23]

A water's sheen is not a specific contaminant that has an EPA-imposed limit for drinking water. If an iridescent or color sheen is observed on water, it can indicate the presence of either a petroleum or bacteria substance, and it is another observation that students can easily make independently if needed. If the student drops a rock into water sheen or pokes it with a stick and the sheen breaks into platelets, it is likely caused by bacteria. If the sheen tries to reform, it could be from petroleum source. This is useful to check a day or two after it rains so that students can observe oil and gas runoff that likely washed from parking lots and roads. Its presence gives students an easy visual indicator of how stormwater runoff travels.[24]

Regardless of the type or amount of these particular NPS pollutants students find in stormwater runoff around their school or community, the larger point around taking measurements of them is that students see what contaminants are being injected into otherwise natural watershed areas. Ideally, observations lead to questions about how and why the contaminants come from, and what is and can be done to mitigate their negative effects.

Stormwater Contaminant Treatment

Background

Initially, the entire purpose of stormwater systems was to bring water away from developed areas quickly and without causing flooding.[25] This philosophy became problematic when it was observed that, "In some cases, the ability of the wetlands to naturally remove pollutants became overwhelmed by pollutant loadings from stormwater."[26] This means that so much water and pollutants are discharged via stormwater runoff that nature can't keep up anymore. A national water quality inventory in 1994 showed that "nearly 40 percent of surveyed waters in the US remain too polluted for fishing, swimming, and other uses."[27] This was overwhelmingly due to these nonpoint source pollutants, underscoring the importance of mitigating the negative impacts of stormwater runoff.

Surface Permeability

A major contributing factor for the hindered ability of wetlands to naturally remove pollutants is the increase in urbanization. Natural landscapes are permeable and allow rainwater and snowmelt to filter slowly into the ground, even acting as a filter for some pollutants. Urbanization has resulted in both a reduction in these permeable surfaces and an increase in impervious surfaces such as building roofs, roads, and parking lots (Figure 2). The increase in these nonporous surfaces means that there is more water flowing directly into storm drains, and at a faster rate. Not only does this increase in impermeable surfaces actually increase the risk of flooding, its resultant stormwater also picks up harmful pollutants like trash, road salts, chemicals, oils, bacteria and viruses, and sediment and carries them to the watershed. Fish, wildlife, vegetation, and humans are all impacted by increased pollutants due to urban stormwater runoff.[28, 29] Figure 3 shows Tulsa County's land cover, and how it has been affected by urbanization.

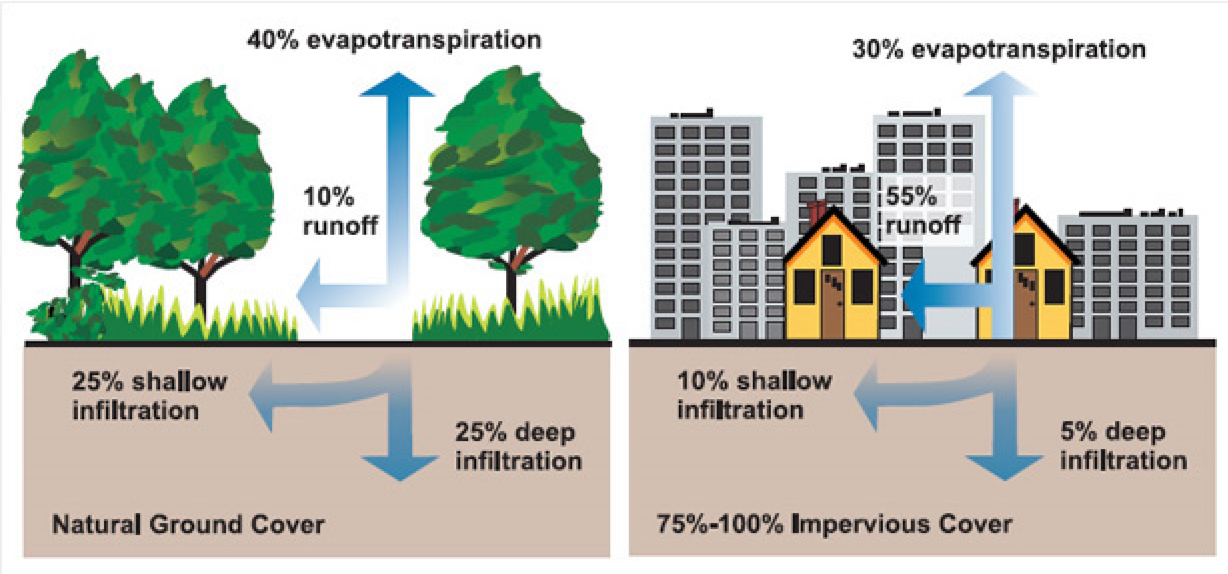

Figure 2: The difference in stormwater runoff due to urbanization.[30]

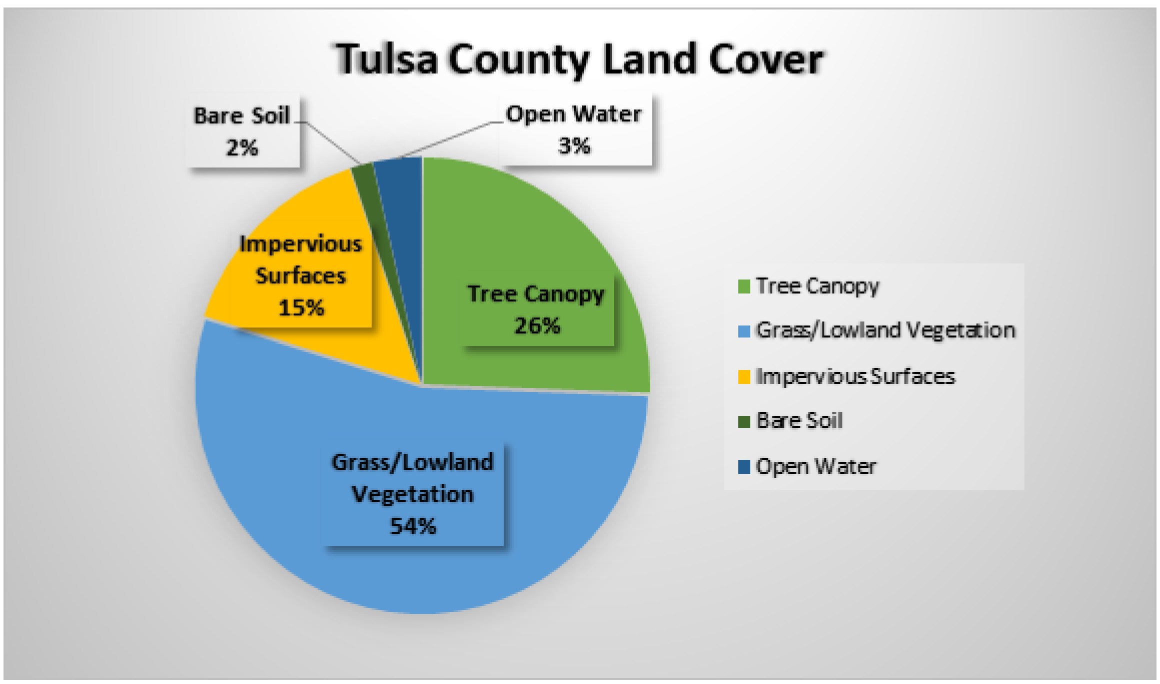

Figure 3: The type of land cover for Tulsa County's 391,148 acres (Author-created using information from Davey Resource Group.[31])

Mitigation

In order to design, create, and implement their own method of mitigating the negative effects of stormwater runoff, students need to understand current practices. Urban development doesn't have to be antithetical to responsible watershed management. A shift toward "green infrastructure" has incorporated infrastructure needs with the desire for urban green spaces at the same time there has been an increase in the amount of concern for aesthetics in urban construction. Incorporating plants and other specific landscape design choices into urban planning to mitigate stormwater runoff has become more aesthetically pleasing, and therefore more popular.[32]

On a global scale, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services noted several interventions that are applicable to stormwater runoff and would help sustain freshwater, including slowing and reversing de-vegetation of catchments, mainstreaming practices that reduce erosion, sedimentation, and pollution run-off, decentralized rainwater collection, and integrated management of surface and groundwater.[33]

Many storm drainage systems serve multiple functions and provide multiple benefits while having value aesthetically. These systems can improve water quality while providing recreational opportunities and improving wildlife habitat. Some of these include:

- stormwater gardens and other bioretention areas, which are simply depressed areas that are planted with vegetation that helps retain water and slow its likelihood of runoff while having the benefit of being aesthetically pleasing. They also cleanse pollutants to varying degrees, depending on design, and reduce demands on potable water for landscape irrigation;
- infiltration areas, which are similar to stormwater gardens but are deliberately connected to downspouts, driveways, and other impervious areas, and provide for groundwater recharge (if downspouts aren't eliminated entirely;)
- natural areas that are kept undeveloped and can reduce runoff volume while enhancing wildlife habitat;
- passive park areas, which can provide for infiltration and/or extended detention (Wenk)
- green roofs have been covered with a growing medium and vegetation on top of a waterproofing membrane on a roof, to absorb rainwater and reduce runoff from its source;
- rain barrels and cisterns, which are connected to gutter downspouts, which allow rainwater to be used for other nonpotable purposes, such as watering lawns and gardens;
- permeable pavements are an excellent alternative to impermeable asphalt and cement and help increase rainwater infiltration through porous areas, reducing runoff;
- riparian buffers are natural vegetation planted along stream banks, and help slow and prevent runoff into streams;
- constructed wetlands are artificial wetlands designed to mimic natural wetlands. They help treat stormwater and other types of wastewater using vegetation, filtering sediments, and microorganisms;
- Sediment control practices at construction sites to minimize the injection of eroded soils into watersheds; and
- street sweepers remove debris from gutters and lessen the amount that enters storm drains. [34, 35, 36, 37, 38, 39, 40]

While this is by no means an exhaustive list of interventions that can mitigate the negative effects of stormwater runoff, the diversity of these ideas can help students consider a variety of points along stormwater's route that they can potentially intervene.

Teaching Strategies

Standards and Practices

The National Association of Gifted Children (NAGC) Programming Standards, which are used to guide Gifted education, call on teachers to "provide opportunities to promote lifelong personal and social responsibility through advocacy and real world problem-solving."[41] This unit is an opportunity to have GT students refine their interest in "the environment" and allow them to positively contribute to the community. This unit heeds the NAGC's call to create opportunities for students to be advocates and problem-solvers by asking students to speculate about and examine stormwater, learn about its impacts on the environment, and create and implement a solution that addresses a specific problem they observe. Students will learn about nonpoint source pollution and why it is of environmental concern, as well as learn about current interventions to clean and mitigate stormwater runoff. Then they will then design and create an intervention that addresses a stormwater runoff issue of their choosing.

It is also important that GT students work at a level that is above their age peers, commensurate with their ability. Therefore, this unit will work to meet Oklahoma's high school Environmental Science Oklahoma Academic Standards, for which students will be working to reduce the impact of human activity on stormwater by modifying or creating a solution for it.

While the content is above grade-level, this unit is written to serve middle school students, and therefore needs to also meet these standards and objectives. In order to meet the NAGC standards on learning, and ensure that students are active participants in their learning, this unit uses two dimensions of the Next Generation Science Standards (NGSS) framework for middle school: Science and Engineering Practices (SEPs), and Disciplinary Core Ideas (DCIs). Of the SEPs, students ask questions about stormwater runoff and define problems associated with it. After investigating and gathering information on existing stormwater runoff mitigation techniques, students will analyze and interpret their data, and engage in an argument of which method shows the most promise for implementation at their school, with appropriate modifications. In order to directly address DCIs, students will explicitly define the engineering problem, test and modify possible solutions, and optimize the solution they ultimately decide to develop. For this unit, we will not be specifically addressing Crosscutting Concepts, though it is possible that the products of this unit will be referenced in the students' regular science classes and vice versa.

Engineering Design Process

The Engineering Design Process is similar to the Scientific Method but focuses on building a solution to a problem. There are several versions, but they all tend to include a variation of Ask, Research, Ideate, Create, Test, and Improve. We will use an Iterative Engineering Design methodology, which emphasizes the cyclical nature of engineering, and is pictured below (Figure 4). Once one has improved upon a design, it's time to ask questions about it and start the process again.

Figure 4: An illustration of the particular iterative Engineering Design Process this unit will use.

Depth and Complexity Strategies

The Depth & Complexity framework was created to challenge advanced learners and teach them to "think like disciplinarians in a deeper manner about content." The framework features eleven components, including eight Dimensions of Depth and three Dimensions of Complexity. The goal of increased Depth is to move students toward expertise while striking a balance with content coverage, and the idea behind Complexity is to challenge students to make connections across disciplines, over time, and between disciplines.[43] Using strategies from this framework will ensure that this unit is sufficiently challenging for my GT students. (D: Language-terminology; Rules-within the discipline, measurement, data systems, etc.; C: Over Time)

Classroom Activities

Since I serve more than one site as a pull-out academic support service, I see my students once or twice a week, unlike my core area counterparts who see their students daily or every other day for full class periods. This coming school year will be different for everyone, in that our school district has just announced that we will begin the year virtually, with a re-evaluation of that decision every 9 weeks, due to COVID-19. These conditions necessitate this unit be very flexible in its implementation. Several portions may have to be taught virtually with students completing their background research and experiments individually. Fortunately, chunking the unit according to where it is in the iterative Engineering Design Process works with this kind of schedule uncertainty.

Tulsa gets the most predictable rain in late Spring, so regardless of in-person vs. virtual learning, this unit will begin in March and is ideally complete by April 20th, to coincide with Earth Day. This time frame also means that if students had the opportunity to have learned material while physically in school, they would then have Spring Break to extend their learning opportunities at home and perform self-guided experiments. Additionally, I would like to see my students submit their final stormwater mitigation product to a Science Fair (our local-area Science Fairs are in the Spring) or a competition of some kind so that they can have recognition for their creativity and hard work.

Ask

Students must first determine where "the beginning" of the Engineering Design Process is before they can begin. For our purpose, to underscore the iterative nature of the Process, students will start this unit at the (physical) end by viewing a picture of the Arkansas River. We will have a discussion about the river, with a variety of specific prompts from NGSS's middle school framework to facilitate conversation. These prompts will range from questions focusing on EPA water quality levels, such as what students would want to know before deciding whether to swim or fish in it, to what is in the water, such as speculating on where various water contaminants originated. The goal of this discussion is that students are able to identify specific problems surrounding stormwater they want to address, which are ideally kept communally on a dedicated chart in the classroom. In the event of online learning, public responses in a class forum would serve this purpose.

Research

Once they are asking questions, students need to obtain an appropriate background in the topic of stormwater runoff so that they can have a clearer picture of what they are going to be asked to design. This requires that students first understand what Depth & Complexity calls "Language"—that is, students need to know terms and concepts appropriate to the discipline. Commonly used terms, such as watershed, wetlands, stormwater runoff, urbanization, nonpoint source pollution, permeability, riparian buffer, mitigation, "swimmable and fishable," as well as the specific types of pollutants nitrate, coliforms, turbidity, and sheen will be explicitly taught so that a common background can be assumed. In addition to a word wall, labeling and annotating a drawing of the school grounds or a neighborhood with the path of stormwater picking up various pollutants on its route will be helpful to retain this knowledge (Figure 5.) This can also be done using a digital annotation tool on top of a picture. This step in the process is another opportunity for students to foresee points at which they can potentially intervene.

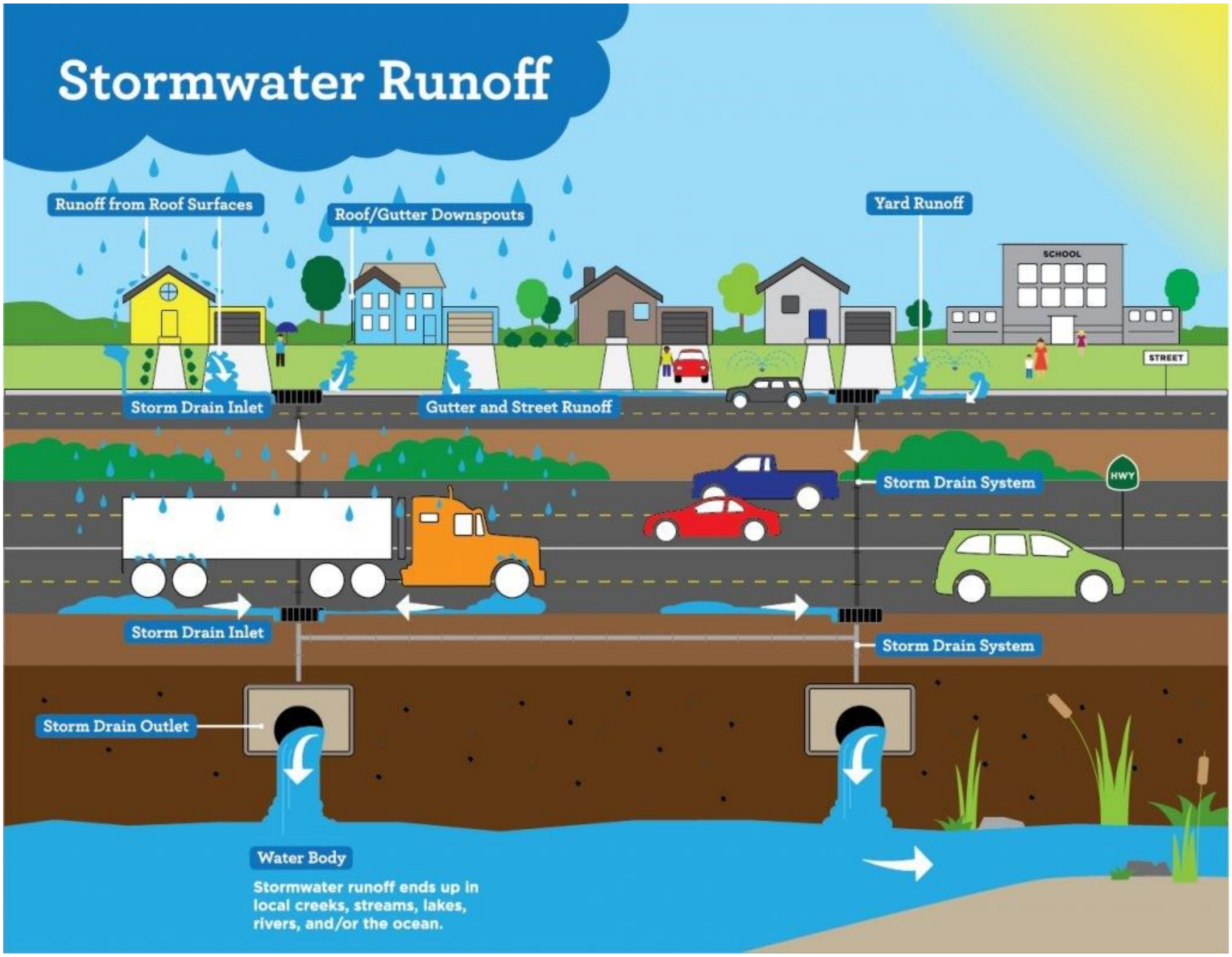

Figure 5: A neighborhood drawing that students could annotate with specific pollutants they anticipate.[44]

Students need to comprehend how water flows through their local watershed system. To ensure this, they will complete one or more of a variety of brief activities/experiments demonstrating how water moves, how water flows over permeable and impermeable surfaces, and/or the ability of various surfaces to filter water. Each of these activities/experiments will be as low-stakes, safe, and accessible as possible so that if students need to complete these independently due to virtual or extension learning, they are more likely able to.

Videos with explanations of the function of stormwater treatment plants, street sweepers, etc. will be made available to students as well, so that whether we are meeting in-person or virtually, they will have additional resources to help them grasp various concepts.

It is important that students appreciate the current state of their local watershed in order to develop a mitigating solution for it. Therefore they will use local topographic and road maps to trace the path of stormwater from the school’s roof to its discharge point in either Bird Creek or the Arkansas River. Samples of stormwater from various locations will be taken and analyzed for specific pollutants, including nitrates, fecal coliforms, turbidity, and sheen. These particular pollutants were selected because of their relative ease to test, and because of their abundance in Tulsa’s and Oklahoma’s waterways, which students will learn.[45] Ideally these activities/experiments are all completed in-person during a walking field trip with samples coming from downspouts, mud puddles, the parking lot, storm drains, and Bird Creek and the Arkansas River. It is possible that we will be meeting virtually; packets of test strips can be made available for pickup at the school so that students can independently obtain and analyze samples and record their results in a digital forum.

To make this unit as inquiry-focused as possible, the more in-depth background information regarding the history of EPA regulations and the Clean Water Act, the current state of Oklahoma's watershed system, and various contributing factors to nonpoint source pollution will be kept aside for students (likely in labeled physical folders for in-person learning and/or in a digital binder for virtual learning or learning extensions) who seek answers to questions they generate as they learn about stormwater runoff.

Ideate

The next step in the Engineering Design Process is to brainstorm ways of solving problems associated with stormwater runoff contamination. Again, this is an iterative process, so it is natural and expected that students cycle back through the Ask and Research steps as they explore solutions. It is important that students understand what Depth & Complexity refers to as Rules as they generate ideas—that is, students will need to clearly relate potential solutions to the specific questions they're asking and the problems they're hoping to ameliorate. This requires students to identify which measurements and data systems, etc. will be used to determine if their solution meets the expected level of effectiveness. The Ideate step can be done either in-person or virtually, but it is important that there is an element of collaboration and refinement during this process so that students are able to create the best possible solution they can.

It is also during the Research and Ideate steps that students differentiate any potential solution they propose to existing interventions. Students will read articles, look at photographs and diagrams, and watch videos that highlight the impacts of construction sites, building roofs, and choices that homeowners make, such as installing gutters and french drains, what plants and landscaping to incorporate, and determining how pervious their concrete should be. The EPA has a Windows-based Stormwater Management Model computer program that can be downloaded and used to help students see how stormwater runoff quantity and quality varies with each of these intervention methods. The modeling program can account for a variety of pollutant loads, types and amounts of hydrologic processes, and types of stormwater control strategies and practices, so it would be a great tool for students to use, whether they are in class or at home.[46]

Create

After students have ideas on how to mitigate the negative impacts of stormwater runoff, they will physically create their solutions. This step can take many different forms and will likely need to occur (at least partially) outside of class regardless of in-person or virtual meetings. The materials and tools required will vary greatly, depending on exactly what students propose to build, and it students will need to build a model or prototype before executing their final plan. There will be various measuring tools, found items, and standard craft and office items available for students to use, and there is also potential for local organizations to contribute materials or money to help students construct their design, as well. This step is purposefully left ambiguous, since the goal is to have students discover a problem and create an innovative solution. It would be counterproductive to dictate the type of solution that GT students could undertake, and it would stifle their potential to limit the type of solution they decide is best. For a more formal learning situation, such as a high school Environmental Science class, it may be appropriate to give students some parameters, such as creating a solution that would benefit their school building.

Test

It may not be possible for students to test their design at its intended point of insertion if we are fully participating in virtual school options, but every effort will be made for students to implement their design to see how well it meets their stated objectives. This may require field trips of varying lengths and/or collaboration with local regulatory agencies or the school district, depending on the solution proposed. Regardless of where or how students test their product, they will be asked to evaluate its effectiveness based on the parameters they previously set for their work. Students will be frequently reminded of their goal of mitigating the impacts of stormwater runoff contamination so that they stay on task.

Improve

Students need to go through the DCI and SEP steps of testing and modifying their possible solutions and analyzing and interpreting data they collect in order to arrive at the best possible solution. It is between this step and circling back to the Ask step that students will be presented with additional Depth & Complexity steps to ensure deep thinking and reflection. Specifically, students will be asked to speculate what would happen if one or more of their observed problems changes, or if variables such as the season or amount of rainfall could affect the outcome. They will also be asked to predict how effective their solution will be over time, and what modifications they will need to make to ensure its longevity. The iterative nature of the Engineering Design Process will again be emphasized so that students keep the idea of revisiting problems to improve solutions at the forefront of their evaluations.

Appendix on Implementing District Standards

NAGC Standards

Learning and Development

1.1. Self-Understanding. Students with gifts and talents recognize their interests, strengths, and needs in cognitive, creative, social, emotional, and psychological areas.

1.4. Awareness of Needs. Students identify and access supplemental, outside-of-school resources that support the development of their gifts and talents (e.g., families, mentors, experts, or programs).

Maybe? (Engineers Without Borders, TU/ TRSA connections, etc.)

1.6. Cognitive Growth and Career Development. Students with gifts and talents identify future career goals that match their interests and strengths. Students determine resources needed to meet those goals (e.g., supplemental educational opportunities, mentors, financial support).

Curriculum Planning and Instruction

3.6. Resources. Students with gifts and talents are able to demonstrate growth commensurate with their abilities as a result of access to high-quality curricular resources.

Learning Environments

4.3. Responsibility and Leadership. Students with gifts and talents demonstrate personal and social responsibility.

4.3.3. Educators provide opportunities to promote lifelong personal and social responsibility through advocacy and real world problem-solving, both within and outside of the school setting.

Programming

5.3. Career Pathways. Students with gifts and talents create future career-oriented goals and identify talent development pathways to reach those goals.

NGSS

MS-ETS1-1.	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2.	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3.	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4.	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Oklahoma Academic Standards (OAS)

EN.LS2.7 Ecosystems: Interactions, Energy, and Dynamics: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Depth & Complexity:

For this unit, we will use and focus on the following Depth and Complexity Dimensions: Language of the Discipline, Ethics, Rules, Within the Discipline, and Over Time.

Endnotes

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