Yale National Initiative
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Curriculum Units by Fellows of the National Initiative
2020 Volume IV: Solving Environmental Problems through Engineering

Investigating Surfaces and Water Runoff in Urban Areas

Curriculum Unit 20.04.09, published September 2020
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Introduction:

I hate spring in Chicago. As measured by the number of days of precipitation, spring in Chicago is the wettest time of the year in the city. It is at this point on the calendar that winter and summer begin to converge. Up above the clouds, strong streams of air still hold their winter frost. Down below on the ground, the spring sun begins to warm the surface area of water, and earth. The warm air rising meets up with the cold air which leads to precipitation. The months of April (with 12.6 days of measurable precipitation) and March (with 12.4 days of measurable precipitation) lead the way in rainfall.

As a homeowner living in Chicago I've come to dread rainy days. The prospect of waking up in the morning and finding water on my basement floor was frustrating and maddening. A couple of years back after a devastating downpour, our basement looked like a small lake. We hired a plumber who promptly ripped out our basement floor, replaced our soaked drywall with moisture resistant sheetrock , dug out rusted, rotted out water pipes with new ones, and replaced a broken water sump pump with a new fancy one thinking we were now in the clear. Then we hired workers to excavate the perimeter of our house digging a good four of five feet down to the foundation patching and filling cracks on the building's walls with tar and sealers of all sorts. Nope. The water still came, in trickles through the walls and up through the drains on the floor. Sometimes it is pointless fighting with Mother Nature. Thousands of homes in the Chicago area of affected by flooding caused by storm water runoff yearly. Flood losses in the city and suburbs cost taxpayers $1.8 billion in subsidized grants, loans, and insurance payments between 2004 and 2014, according to a report released by the National Academy of Sciences. Only hurricane ravaged areas of coastal Louisiana, New York and Texas received more federal flood aid during the decade.[1] As climate change impacts the world, the effect of broadening use of impervious surfaces throughout the area and record breaking rainfall contribute to increases in storm water runoff flooding will continue to be a major challenge in Chicago. The region remains vulnerable despite $3.8 billion spent on one of the most expensive public works projects in the country: the Deep Tunnel, a labyrinth of cavernous underground pipes connected to massive reservoirs intended to "bottle up rainstorms" and keep Chicago and Cook County suburbs dry.[1] The tunnel project is still not finish, having begun construction in the 1970's with an approximate completion date of 2029. According to the National Climate Assessment, in the Midwest part of the United States precipitation has increased with more severity and frequency since 1901 and is to continue until the end of this century. Over the past two centuries Chicago has been challenged in the way it manages flooding. To begin with, the city was built upon swamps and as plains of soil and pasture were replaced with pavements and other impervious surfaces such as concrete and asphalt continued increases in water runoff contributed to flooding. As precipitation runs off into three places: the city's sewers, the Chicago River and Lake Michigan. Chicago sewers are outdated and were designed not only to manage storm water runoff but also to deal with waste from factories and homes as well. With heavy precipitation, sewers are overwhelmed to their capacity leading to not only water flooding basements, release of sewage to the natural environment. The goal of this unit is to use math concepts such as geometry to measure areas of surfaces while identifying pervious and impervious surfaces in a city. The area my students will be measuring will be the surrounding surface areas of Edwards Elementary including pavements, sidewalks, parking lots, buildings, playgrounds, and soccer fields. This area will be the city block the school is located on. My students will learn how areas of pervious and impervious surfaces can be measured using the lengths and widths of rectangular surface areas. My students will use proportions and rates to measure rainfall and water runoff by organizing data on tables.

Student Demographics:

My school Richard Edwards IB Dual Language Elementary is a part of Chicago School District #299. Edwards has one of the largest elementary student populations in Chicago with an enrollment of approximately 1,500 students. The demographics of the school are: Hispanic 95.8%, White 1.6% and Black 1.2% with an approximate amount of 90% of the student enrollment are low income, 51.6% are limited English proficient, and 15% are diverse learners. There will be approximately 75 seventh grade students I will be teaching bilingual math in the upcoming school year.

Rationale:

The urban area has become dominant in today's landscape. "In 2009, the number of people living in urban areas (3.42 billion) surpassed the number living in rural areas (3.41 billion), and since then the world has become more urban than rural.[3] This is the first time that the majority of the world's population lived in a city".[2] As cities grow in size their impact on the environment has become a major issue. Urban development affects the landscape. Open plains and fields of grass and soil are covered with impervious surfaces such as pavement, buildings and asphalt. This change in landscape impacts the environment through water runoff in which storm water is directed away from the soil and its role in replenishing the local water table. Understanding urban runoff requires a strong knowledge of geometry. Generally, area is taught with surface area and volume. Students connect their understanding from area to surface area to volume, scaffolding from two dimensional measurement of flat surfaces (the area of the classroom floor) to three dimensional measurement (surface area and volume of a box of cereal). In this unit, students will calculate the surface area of the space encompassing their school surroundings. Students will distinguish between different types of surfaces found within this vicinity: grass, gravel, concrete asphalt. Students will categorize between by measuring the surface area of the surrounding ground, students will determine the area of a two-dimensional space and not a geometrical solid encompassing the total area of faces. Students will compare differences of surfaces (permeable and impermeable) to distinguish between them. This unit will focus on permeable and impermeable surfaces of area and its role in surface storm runoff and flooding, the measuring of these surface areas using formulas for area, the proportion and rates of absorption and water runoff on both pervious and impervious surfaces. The activities of the unit will be related to the learning standards involving proportions and rates as well as measurement. One of the greatest successes of my previous unit was my student's investment in the activities involving area, surface area and volume.

Background:

Urbanization:

As the world's population grows the increase of people moving from the country to urban areas also increases. Urban areas are dense spaces with tall building being erected to utilize the limited amount of space to work with. Presently half the world's populations live in these urban areas, cities of millions of residents compacted and compressed. Urbanization and surface runoff become a potent combination in the decrease of water reaching soil. The majority of urban areas consist of concrete found in buildings and infrastructure such as sidewalks and highways. Concrete is an impervious surface which does not allow percolation of the water runoff back into the soil. Water runoff is then redirected into the grates of sewers which move the runoff inevitably to a stream or river which contributes to the erosion of these channels. Urban development also causes soil to be compacted to the point where it can become impervious to water.

Challenges of Urbanization:

Impervious surfaces are created in the majority of urban areas. Because of this increase of impervious materials, surface runoff is prevalent. Urbanization includes the laying down of various forms of pavement and the construction of buildings which are impervious to water and contribute to the slowing down of absorption into the soil. Because of impervious surfaces the increase of water runoff into channels, streams or rivers lead to soil erosion. With a lack of water being absorbed into the soil, the impacts of droughts may be intensified by the lowering of the water table. Flooding also occurs when runoff systems are overwhelmed. Runoff patterns on surfaces have been strongly impacted by urbanization across the globe. "With urban growth and development there is an increasing need for flood information and techniques to evaluate effects of urbanization on flooding in areas where few or no data exist.".[2]

Permeable Surfaces:

Permeable surfaces include surfaces which absorb water and impact the amount of run off by reducing it. Permeable surfaces include ones which are connected to nature like plants, grass, flower beds, gravel and landscape. These surfaces allow water to seep into soil which contributes to the removal of pollutants. Figure 1 is of Edwards Elementary soccer field adjacent to the school as an example of a pervious surface which supports runoff and promoting absorption into the ground via the permeable artificial turf.

Figure 1: Edwards's soccer field an example of a pervious surface

Impermeable surfaces:

Impermeable surfaces do not water to absorb into solid surfaces, which leads to water runoff. These surfaces are known as impervious and include pavements, concrete and asphalt. Examples of pavement can be found everywhere right outside our front door and include driveways, sidewalks, roads, and parking lots. Impermeable surfaces are also materials which are made to be water-resistant such as brick, stone and materials used for rooftops.

The impact of Impermeable surfaces:

A critical factor involving urban areas is its reliance on impermeable surfaces. Concrete and pavement are impermeable and everywhere in the city the landscape is dominated by these surfaces. A great number of problems arise from this including water runoff being polluted as it flows into sewer drains. Some of these pollutants inevitably reach into and carried by streams, rivers, lakes and oceans. This heavy runoff can contribute towards erosion within these bodies of water. During heavy rainfall the water runoff that is produced while flowing over impermeable surfaces can overwhelm storm water collection systems and cause major flooding. Another impact of impermeable surfaces is that it doesn't allow the water table to recharge itself. With the majority of storm runoff being directed into the grates of sewers, this runoff is directed away from the ground impacting the amount of water reaching the aquifers. A common concern in the city and a source of great irritation are the formations of water puddles which congregate and flood streets and street corners. In the summer these puddles add to an increase of insects including mosquitos that are vectors for disease. Impermeable surfaces affect the environment because it changes the makeup of the surface landscape. From swaths of nature and greenery being replaced by lots of concrete and pavement the resources of water and air are changed. The materials used in the making of impermeable surfaces such as pavement seal soil surface, like a lid over a pot. This impact is felt throughout the entire country. In areas in the Northwest part this from the *Seattle Times:* "While urban areas cover only three percent of the United States, it is estimated that their runoff is the primary source of pollution in 13% of rivers, 18% of lakes and 32% of estuaries." Impermeable surfaces act as a carrier of a wide assortment of pollutants including fertilizers and their excess nutrients; pet waste and their pathogens; fossil fuel products such as oil, gasoline from automobiles. In some municipalities the excess of water runoff compromises sewer systems leading to overflow and discharge into other forms of water ways such as streams and rivers carrying pollutants along with the runoff. Ultimately, the runoff of excess storm water impacts the environment in the form of how it effects plants, animals, fish and the human community overall. In Chicago's developed land, a variety of issues occur from the problem of storm water runoff. Extra runoff can contribute towards the basements of homes and streets getting flooded. The quality of water in the Chicago River can be impacted by the release of runoff from storms. With the construction of man-made structures like roads and buildings adds to the impact humans are making on the planet. These structures have impervious surfaces which shift water runoff away from the water table and into sewer systems which carry pollutants into other sources of moving water. "Urban storm runoff is becoming a substantial source of surface-water pollution in the United States. Because collection and analysis of urban-storm-runoff data are expensive and time consuming, city planners and engineers need techniques to make estimates where minimal or no data exist".[4] Overland flow is the buildup and collection of runoff water over surfaces. Watersheds involve the flow of water runoff directly into a specific point over land area.

Peak Runoff Rate:

A Unit Hydrograph can be used to measure the peak runoff rate *Q*, the amount of runoff over a period of time where it collects in certain point to the amount of rainfall. Each storm in itself determines the information found within the graph with the measurements of total rain being used as data. By using probability and statistics this information can be used to help the possibility of rainfall in future events and where these events may occur as data continues to be collected from storms, these aids in the prediction and forecasting of storms.

Direct Runoff Formula:

Students can determine the amount of water from rainfall using basic calculating methods. By using a direct runoff formula (in in^3) students can determine runoff by using the operation of multiplication and multiplying the inches of rainfall by the area of a roof. Run off rate (Q) is equal to the precipitation of an area, minus losses, which are mostly infiltration into soil.

Water Management and Treatment:

In Chicago the city's water management system links residents across the entire city and outlying municipalities. On a daily basis this system directs approximately one billion gallons of water. In addition, Chicago's elaborate and complex sewer system is used to handle runoff from storms and waste water, i.e. combined sewers. The city's aim is to protect the priceless resource of drinking fresh water found in the Great Lakes which Lake Michigan representing the second largest by volume of all the Great Lakes and the only one which is completely located within the boundaries of the United States.

Solutions in Natural Landscaping:

As the class investigates the physical landscape of outside the school we begin to discover the natural landscaping which is present. The students begin to identify and categorize between pervious and impervious surfaces in relation to the various examples of vegetation surrounding the school's perimeter. The use of vegetation within a surface is referred to as natural vegetation. Landscape area with vegetation will produce less water runoff than a traditional landscape. This vegetation helps in absorption into the soil and the evaporation of runoff from moist soil. Natural landscaping can make runoff improve when on surfaces which are impervious while this specific type of landscaping assists in the removal of pollutants from runoff. The following are a number of examples of natural landscaping.

Permeable Alleys:

This alley in the city is composed primarily of gravel and helps in the use of permeable surfaces rather than impermeable surfaces. Runoff would absorb into the ground through the gravel limiting water runoff into the sewer systems and help in limiting local flooding, see Figure 2.

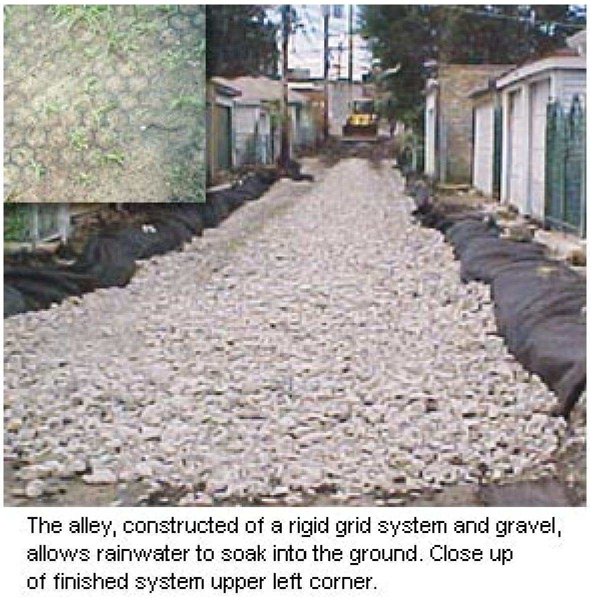

Figure 2: Permeable alleys

***Permeable Paving*:**

There are materials generally associated with impermeable surfaces such as concrete, plastic and stone that can help in the absorption of runoff. This surface is known as permeable pavement which has openings which have soil and sand. With storm runoff the openings trap water and allow absorption into the soil underneath.

“Green” roofs:

Engineers and architects are including “green” roof design into building to help with water runoff. From schools to office buildings green roofs are becoming popular while addressing some of today’s environmental issues involving water runoff over surfaces which are impermeable. A green roof uses a layer of natural vegetation as a way of storing and filtering out via the roofs soil and plants. Passing through this layer of vegetation, the movement of water runoff is slowed helping in the process of cleaning the water while keeping it cooler. The vegetation of these roofs can help with keeping buildings cooler in the summer and reducing the cost of heat.

Drainage swales:

One way of moving and temporary storing rain runoff is by using a natural channel of vegetation called a swale. Swales also can promote the filtering of pollutants. Swales can be another option besides the use of storm sewers to move runoff quickly from impermeable surfaces.

Downspouts Rain Barrels and Cisterns:

In urban areas run off from roofs can be directed by downspouts into sewer systems. But a better option is to redirect run off from roofs directly into areas of grass and soil. Downspouts from roof tops can direct rainfall into rain barrels and cisterns to be stored temporarily. During small storms rain barrels can hold and store rain runoff. Rain barrels can be effective in storage volume in comparison to the size of the roof. An example of this, a 1,200 square foot roof could utilize 55-gallon cisterns to hold runoff from the roof of the house. The resultant storage is equivalent to about 0.3 inches of runoff. See Figure 3 for an image.

Filter strips:

Filter strips help in the runoff from surfaces which are impervious. The function of these strips is to slow down the movement of runoff and help in water absorption into the soil. See Figure 3 for an image.

Naturalized Detention Basins:

In a conventional detention basin design flooding is prevented by temporarily storing run off from storm water and discharging it slowly into drainage systems. Naturalized detention serves many things including the removal of pollutants, the prevention of floods, and the support of wildlife. At the edges of the water flat slopes are incorporated. See Figure 3 for an image.

Figure 3: the following are different projects of water conservation which can be used to manage storm water runoff. Top left is a bio-infiltration system called a swale. Top right is an example of a downspouts being used with rain barrels and cisterns. Bottom left is an example of vegetated areas known as filter strips. Bottom right is an example of a naturalized detention basin.

Teaching Strategies:

The unit will focus on the students working in small independent groups and be prepared to complete both informal and summative assessments. Students will participate in blended learning so as to utilize online resources and materials in an effort to promote online discourse with the traditional classroom method. Students will have a set of high expectations in place, to promote a challenge to succeed. They will investigate environmental and engineering challenges to spur creative design and solutions. The gradual release of responsibility to the students as the teacher becomes facilitator while at the same time spurring discussion and critical thinking through the use of open ended questions. Use events to hook students into engagement of problem solving. The class will follow a set of roles to maintain their purpose and direction focused. It is critical that students participate in hands on learning through observation, data collecting, analysis and experimentation. Offering students opportunities to reflect on the activities and the class discussion offers them opportunities in collaborative team building. While promoting the use of digital tools and resources while engaging in inquiry-oriented methods of discourse. The unit will concentrate heavily on a blended learning and project-based approach that incorporates station rotation with maker-space, mini labs, reading comprehension and critical skill development in independent groups. Students will be expected to take Cornell Notes during the lecture portion of class with periodic informal assessments. During the subsequent class period, students will apply and practice concepts introduced in the lecture series through station rotation. The number of stations may vary based on student population and dynamics. The idea of station rotations is for students to maximize their learning and to develop skills of independent problem solving. The system is designed to incorporate different modes of learning. Groups will be organized based on student strengths and weaknesses.

Activities:

Objective for Activity One

Students will answer the question: what is area? All shapes have space inside their figures which is called area. This space can be measured in squares to find the amount of area. The objective for students is to know how to calculate and finding the area of a rectangle we can multiply its length with its width, which will be equal to the total area of the shape. Students will use plain figure manipulative such as colored tiles to reconnect with concepts of area, surface area and perimeter. Students will use geo-boards to practice length and width in determining area of quadrilaterals. The goal is for students to understand how to calculate length and width to find the area

Mini-Lesson for Activity One

Students will work with flat manipulative quadrilaterals to find the area of various shapes.

Objective for Activity Two

One activity will be determining the length of a mile. The students will understand that eight city blocks in Chicago in the direction of north/south will be approximately one mile. There are 5280 feet in a mile so if we multiply 660 feet by eight blocks we have a total of 5280 feet. If we multiply 16 blocks east/west by its length of 330 feet we find that the total of the blocks is 5280 feet. Students will utilize anchor charts which are completed with teacher and students during lesson. Students will participate in group discussion to visualize student's ideas and strategies.

Mini-Lesson for Activity Two

Students will understand that eight city blocks in length is equal to one mile. Students will draw and label the total of eight city blocks from their community in the direction of north/south. The students will label each street of the eight blocks. Each block's length is approximately 660 feet. The students will calculate the length of the eight blocks by 660 feet x 8 blocks= 5,280 feet (one mile).

Objective for Activity Three

Students will understand how the city of Chicago uses a grid system model for streets. A big advantage of Chicago was its geography with no mountains or other features which would impact the remaking of the layout of the city. An orderly street grid system was designed and implemented. I want my students to see how this one single city block is connecting to a wide network of dozens of other blocks. Figure 4 shows an early grid map of the city.

Figure 4: Early grid map of Chicago.

Mini-Lesson for Activity Three

Students will be use a copy of an image of Chicago’s street grid model. Students will calculate and approximate the number of miles the city has in the direction of north/south.

Objective for Activity Four

Students will work cooperatively with peers to distinguish between permeable surfaces which permit water runoff to be absorbed and impermeable surfaces such as pavement which do not allow absorption into the soil but channel to water runoff into sewers.

Mini-Lesson for Activity Four

Students will brainstorm in small groups by using a table to list different examples of permeable and impermeable surfaces.

Objective for Activity Five

The surface of an area has different parts. It can contain soil, rock and grass. Students will use the area of the city block their school campus measuring and approximating the percent of total areas of permeable and impermeable surfaces.

Mini-Lesson for Activity Five

Students will categorize surface area between permeable and impermeable surfaces from a Google Map image. Using this image students will approximate the amount of area of field and other permeable surfaces. Figure 5 shows a view of Richard Edwards Elementary in Chicago from Google Maps. Students will be able to identify permeable surfaces like green spaces and the soccer field to impermeable surfaces like buildings, pavements, and parking lots.

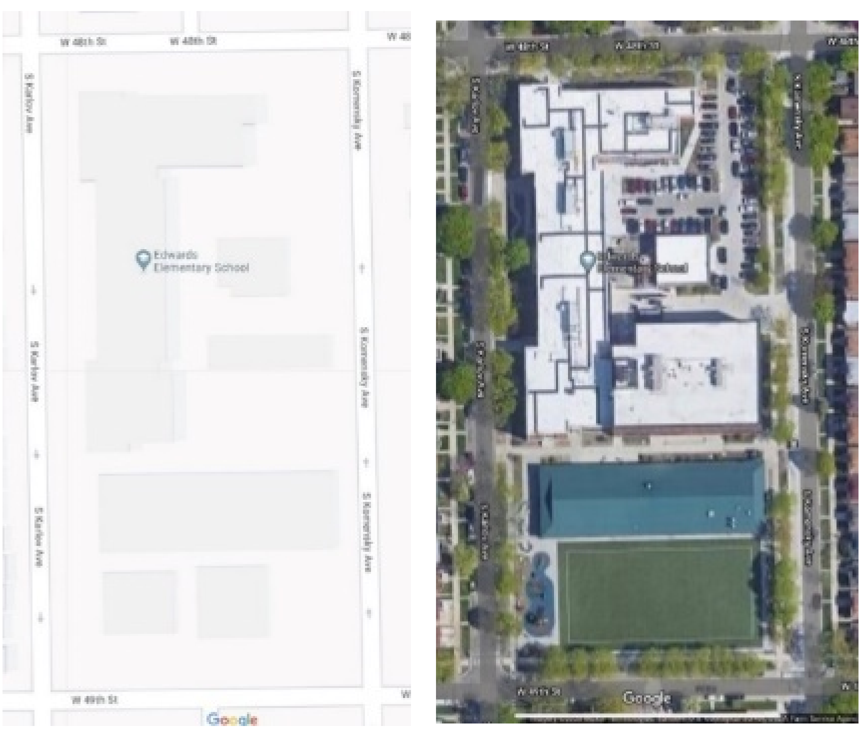

Figure 5: View of Richard Edwards Elementary using Google maps.

Students will investigate the perimeter of the area including structures, pavements, parking lots, sidewalks, grass/lawn and other various surface area landscapes. Groups of students will identify both permeable and impermeable surfaces. Students will measure the length and width of a permeable or impermeable area then multiplying its total area. Students will sketch the block determine the total percent of the area into two groups of permeable and impermeable surfaces. Students will be able to distinguish the perimeter of the block so that the total area of the surface can be determined.

Objective for Activity Six

Students will work with a peer and use Google map images to compare different school campuses to distinguish between the amount of pervious and impervious areas found.

Mini-Lesson for Activity Six

The students will compare their school to different schools in the city to measure and determine the percent of pervious and impervious surfaces found in these locations. Figure 6 is Richardson Middle School which was built in 2016. Students will use examples of these schools and others to visually understand how architects and engineers are considering landscape as an important part of design while addressing environmental concerns of storm water runoff.

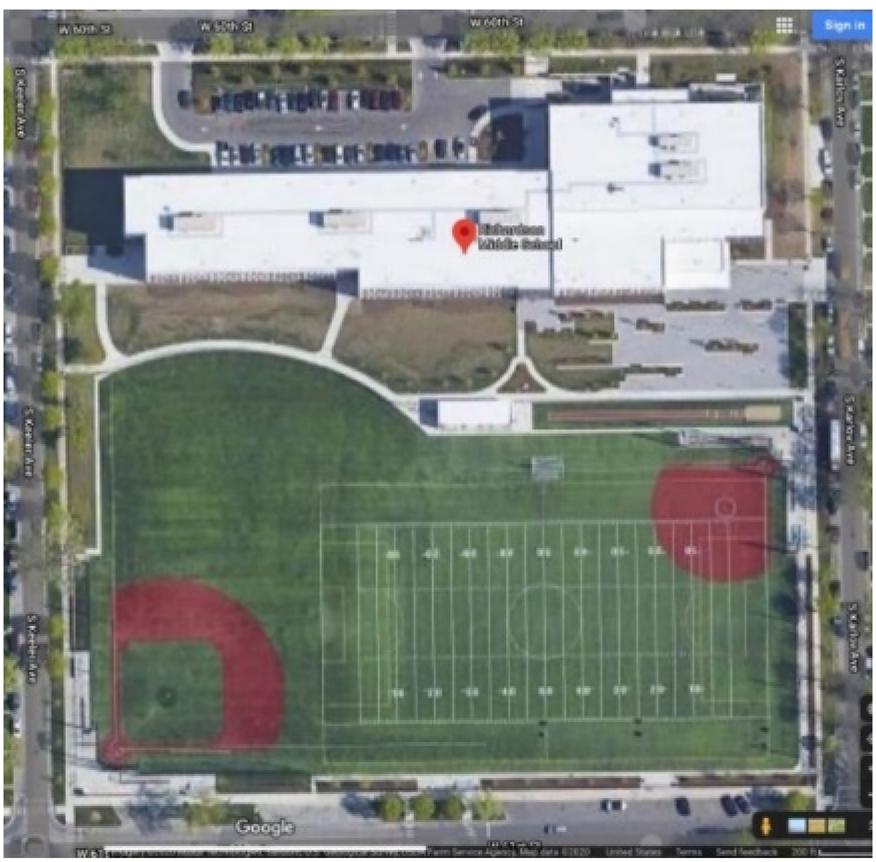

Figure 6: Richardson Elementary

Appendix on Implementing District Standards:

Common Core Standards:

CCSS.MATH.CONTENT.7.SP.C.7.A Develop a uniform probability model by assigning equal probability to all outcomes, and use the model to determine probabilities of events. *For example, if a student is selected at random from a class, find the probability that Jane will be selected and the probability that a girl will be selected*.

NGSS Standards:

MS-ESS3-3.	Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.* [Clarification Statement: Examples of the design process include examining human environmental impacts, assessing the kinds of solutions that are feasible, and designing and evaluating solutions that could reduce that impact. Examples of human impacts can include water usage (such as the withdrawal of water from streams and aquifers or the construction of dams and levees), land usage (such as urban development, agriculture, or the removal of wetlands), and pollution (such as of the air, water, or land).]
MS-ESS3-5.	Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century. [Clarification Statement: Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Examples of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities. Emphasis is on the major role that human activities play in causing the rise in global temperatures.]
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.

Bibliography:

"Urban Storm Runoff in the Roseburg Area, Oregon, as Related to Urban Flood Characteristics of the Willamette Valley." 1992. doi:10.3133/wri914063.

Green Urban Infrastructure: Assessing Potential Ecosystem Services in Urban Cities. (n.d.). *Climate Change and Law Collection*.doi:10.1163/9789004322714_cclc_2016-0002-003

Maksimović, Čedo, Ana Tomanović, and Dubravka Pokrajac. "Pollution Potentials of Storm Runoff from Urban and Industrial Areas." *Environmentally Devastated Areas in River Basins in Eastern Europe*, 1998, 105-15. doi:10.1007/978-3-642-72266-0_8.

"Techniques for Estimation of Storm-runoff Loads, Volumes, and Selected Constituent Concentrations in Urban

Watersheds in the United States." 1990. doi:10.3133/wsp2363.

"Analysis of Urban Storm-runoff Data and the Effects on the South Platte River, Denver Metropolitan Area, Colorado." 1984. doi:10.3133/wri844159.

Endnotes:

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[1] https://www.epa.gov/students/lesson-plans-teacher-guides-and-online-environmental-resources-educators

[2] https://www.cocorahs.org/

[3] https://ideagalaxyteacher.com/surface-area-activities/

[4] https://www.chicago.gov/city/en/depts/water.html

[5] https://www.chicago.gov/city/en/depts/water/supp_info/conservation/whatcanido.html

[6] https://www.chicago.gov/city/en/depts/water/supp_info/conservation/green_design.html

[7] https://www.chicago.gov/city/en/depts/water/supp_info/conservation/permeable_alleys.html

[8] https://www.chicago.gov/city/en/depts/water/supp_info/conservation/downspout_disconnection.html

[9] https://www3.epa.gov/npdes/pubs/nps_urban-facts_final.pdf

[10] https://www.rivernetwork.org/our-work/clean-water/best-practices/managing-urban-runoff/

[11] https://sites.google.com/a/owu.edu/water-runoff-in-urban-areas/water-cycle/harmful-effects

[12] https://www.un.org/en/development/desa/population/publications/urbanization/urban-rural.shtml

[13] https://www.chicagotribune.com/news/breaking/ct-met-chicago-flooding-basement-sewage-20190506-story.html

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