**Green Infrastructure and Green Roofs**

**Objectives**

In this module, you will explore green roofs as a potential solution to the environmental impacts of increased precipitation brought on by climate change. You will evaluate data collected from studies on 15 green roofs from different areas of the US and other countries, as well as historical precipitation data from Central Park in NY to illustrate how precipitation patterns are changing and to determine if we need to use green infrastructure, such as green roofs, to combat the symptoms of climate change. You will also use Model My Watershed[[1]](#footnote-1), a watershed-modeling web app, to analyze real land use data, model stormwater runoff and water-quality impacts using professional-grade models, and compare how different conservation or development scenarios could modify runoff and water quality.

**Introduction & Background**

Runoff in urban areas is an increasingly important issue when it comes to water quality.  It is a major hydrologic issue in New York City, as urban infrastructure creates excess runoff and impervious surfaces decrease the infiltration rate of land surfaces.  This excess runoff, which often times carries with it pollutants and contaminants, has proven to create water quality issues. It has become ever more critical to try to mitigate the influx of runoff into our waterways.  Urbanization increases runoff, and in NYC 64% of the area is impervious.

One way of addressing this issue of water quality is to invest in green infrastructure in order to offset the impact of urban runoff.  In NYC there are ten wastewater treatment plants which can effectively handle dry weather sewage. A problem ensues when surface water runoff during heavy rain events degrades water quality in creeks and bays, which is a direct violation of the Clean Water Act of 1972.  Hundreds of combined sewer outfalls (CSO) discharge excess combined storm water and sewage in local waterways and it is currently the most important water quality issue in the NY-NJ harbor.

The combined sewage contains fecal pathogens, nutrients and heavy metals and there are potential human and ecosystem impacts when combined sewage overflow events occur.  Standards are likely to become stricter in the near future in order to try and reduce the negative impact on water quality. There have been various Department of Environmental Protection (DEP) pilot projects ranging from blue and green roofs, porous pavement for parking lots, greenstreets, tree pits, streetside swales, constructed wetlands and swales for parks, rain barrels for low density single family housing.  Exploring options for green infrastructure which can address these issues is extremely critical for not only city planning, but protecting and conserving our water resources.

The US Environmental Protection Agency (US EPA) did a study[[2]](#footnote-2) in 2009 to evaluate the effectiveness of Green Roofs for stormwater runoff control. This project evaluated green roofs as a stormwater management tool. Specifically, runoff quantity and quality from green roofs and flat asphalt roofs were compared.

Results indicate that the green roofs are capable of removing 50% of the annual rainfall volume from a roof through retention and evapotranspiration. Rainfall not retained, or absorbed, by green roofs is detained, or collected, which reduces peak flows of runoff for a watershed. Due to the reduction in volume, the amount of nutrients and pollutants (such as Nitrogen and Phosphorous) in runoff from green roofs are lower than in runoff from asphalt roofing.

Green roofs can provide many services, including reducing runoff, increasing habitats, reducing heating and cooling costs for homes and buildings, and reducing urban heat island effects. Watch the NPR video “Do Cities Need More Green Roofs?” at <https://www.youtube.com/watch?v=FlJoBhLnqko>. Take note of the practical benefits of installing a green roof on the Javits Center in NYC and write down three issues green roofs can solve.

Nations around the world have been brainstorming ways to address climate change and the impending consequences of warmer average global temperatures. China has embarked upon very forward-thinking efforts to minimize carbon emissions, and among them is the current construction of a forest city in Liuzhou. The world’s first “Forest City,” created to fight pollution, is now under construction. The futuristic Forest City will be home to a community of about 30,000 people. It will be covered in greenery, including nearly 1 million plants of more than 100 species and 40,000 trees that together absorb almost 10,000 tons of carbon dioxide and 57 tons of pollutants, and produce approximately 900 tons of oxygen annually. As a result, Forest City will help to decrease the average air temperature, improve local air quality, create noise barriers, generate habitats, and improve local biodiversity in the region[[3]](#footnote-3). Watch the GeoBeats News video “China’s First ‘Forest City’ Is Now Under Construction“ at <https://youtu.be/TqAvOuHRVWA>.

In NYC’s latest plan, an increased effort is being made to implement decentralized, low-impact development techniques, also called ‘green’ stormwater infrastructure, as an alternative to traditional methods such as underground detention basins. A major goal of NYC’s plan is to capture 10% of the first 2.5 cm of runoff from the impervious surfaces in every NYC sewer shed using green strategies, which includes the use of vegetated rooftops (NYC DEP 2010). The strategies to achieve the 10% goal vary by land use (see **Table 1** on following page). These strategies include not only green roofs but also include solutions such as rain barrels rain gardens, swales, permeable pavement, engineered wetlands and more.[[4]](#footnote-4)

Some Types of Green Infrastructure[[5]](#footnote-5):

Green roofs can effectively:

* reduce runoff volumes,
* regulate building temperatures,
* reduce urban heat island effects, and
* provide urban wildlife habitat.

Rain gardens and planter boxes—both forms of bioretention—can support:

* ground water recharge,
* pollutant removal, and
* runoff detention.

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**Table 1: NYC Strategies by Land Use for stormwater management**[[6]](#footnote-6)

Various types of Low impact Development (LID), or green infrastructure (such as porous pavement, green roof, bio-retention raingardens and conserving natural resources like forests), can reduce the impacts of stormwater and pollutants from land development. The EPA has a lot of information about different types of green infrastructure here:

<https://www.epa.gov/green-infrastructure/what-green-infrastructure>.

As water supplies dwindle due to increased temperatures from climate change and increases in population, it is critical that society and the government properly manage our water resources. Water is a basic necessity for life and if steps are not taken to mitigate pollution and contamination that results from excess urban runoff, we will be paying the consequences for years to come.

**Procedure**

Activity A

Start by downloading precipitation data for Central Park, NY from 1869-2019. This data can be found at: <https://www.weather.gov/okx/CentralParkHistorical> by scrolling down to Climatological Data, and hovering over precipitation, then click on "Monthly and Annual". An excel file with this data has been provided for this module.

Next, create a graph to show how precipitation has changed over time.  Annual rainfall should be on the y-axis and the year should be on the x-axis. Add a trendline to determine the overall rate of change by using linear regression.

Recall that for the equation of a line: y=mx+b, and m is the slope (or rate of change). By adding an equation to your trendline, you can determine the rate of change.

Activity B

Download the highest precipitation events data for Central Park, NY from 1869-2019. This data can be found at: <https://www.weather.gov/okx/CentralParkHistorical> by scrolling down to Climatological Data, and hovering over precipitation, then click on "Greatest Daily". An excel file with this data has been provided for this module.

Evaluate what the temporal distribution of intense rain events has been. In order to do this, we must first format the data in Excel. Since Excel cannot display dates before 1900 as a number and instead only recognizes them as text, we must first convert the date into three columns: month, day and year. To do this, highlight the dates and click on the Data tab, then click on “Text to Columns”. Next, select “Delimited”, click “Next”, uncheck the delimiter “Tab”, and check “Space”. Finally, click “Next” and then “Finish”. This will leave the month in your date column and you will see the day and year in the adjacent columns.

You can use a formula to calculate how many occurred between 1869 and 1944 (first 75 years) and how many have occurred between 1945 and 2019 (most recent 74 years). You will see headers in the Excel file already created for you.

Beneath the header “High Rainfall Events Between 1869-1944”, type in the following function:

=COUNTIFS(E3:E17,">1868",E3:E17,"<1945").

Beneath the header “High Rainfall Events Between 1945-2019”, type in the following function:

=COUNTIFS(E3:E17,">1945",E3:E17,"<2019").

Of the top 15 highest rainfall events since 1869, how many occurred between 1869 and 1944 (first 75 years)? How many have occurred between 1945 and 2019 (most recent 74 years)?

Download the wettest years data for Central Park, NY from 1869-2019. This data can be found at: <https://www.weather.gov/okx/CentralParkHistorical> by scrolling down to Climatological Data, and hovering over precipitation, then click on "Wettest & Driest Years/Months". An excel file with this data has been provided for this module.

Evaluate what the temporal distribution of wettest years has been. You can use a formula to calculate how many occurred between 1869 and 1944 (first 75 years) and how many have occurred between 1945 and 2019 (most recent 74 years). You will see headers in the Excel file already created for you.

Beneath the header “Wettest Years Between 1869-1944”, type in the following function:

=COUNTIFS(C3:C12,">1868", C3:C12,"<1945").

Beneath the header “Wettest Years Between 1945-2019”, type in the following function:

=COUNTIFS(C3:C12,">1945", C3:C12,"<2019").

Of the top 10 wettest years since 1869, how many occurred between 1869 and 1944 (first 75 years)? How many have occurred between 1945 and 2019 (most recent 74 years)?

Use this information to decide where you want to clip your graph from Activity A. Decide when you believe intense rainfall event frequency has increased and graph the annual precipitation vs time from that year through 2019. Add a trendline to determine the overall rate of change by using linear regression.

**After you complete your new graph, share and compare your rate of change with other classmates.**

**Does the rate of change differ from the initial graph you made? How did the rate of change fluctuate for the majority of your classmates?**

Activity C

Now let’s take a look at how well green roofs have worked to reduce runoff. In a summary of studies on the hydrologic performance of full-scale green roofs[[7]](#footnote-7), the findings for 15 green roofs that were evaluated for the overall percent retention was reported. This data has been provided for this module.

What is the range of rainfall is retained by using a green roof? You can use formulas in Excel to determine the minimum (=MIN()) and maximum (=MAX()) values for the “Overall Retention (%)” column. You should also determine the standard deviation (=STDEVA()) to see how the data varies from one study location to another.

**Based on your calculations, are all green roofs created equally? Are they the only solution to reducing runoff?**

Model My Watershed[[8]](#footnote-8) was used to calculate land use using the National Land Cover Database (NLCD 2011) for the East River-Hudson River, HUC-12 subwatershed, which is the subwatershed for Central Park. This data has been provided for this module.

Impervious surfaces are the leading cause of excess runoff. When implementing green infrastructure, it’s a good idea to focus on areas with a high percentage of land use that is “Developed”, since these are areas that have the highest percentage impervious surfaces.

**Given the different types of land use in East River-Hudson River Subwatershed – what land use categories do you think should be targeted for green infrastructure implementation?**

We can use Model My Watershed to evaluate whether or not green infrastructure can be a viable solution to water quality issues and CSO events that are caused by excess runoff.

Go to <https://modelmywatershed.org/>, and click on “Get started”.

Next, type Central Park in the box on the upper right hand corner (where it says “Jump to location”). Click on “Select boundary” and click on USGS Subwatershed unit (HUC-12), then click anywhere near the dropped pin near Central Park.

Here we can analyze the land use and download a variety of different datasets. Land use data has been provided for this activity, so we will proceed to modeling a few different scenarios. Click on “Model” in the upper left, and then select “Site Storm Model.” This will allow us to simulate a hypothetical 24-hour storm using a variety of model algorithms.

You can change the amount of precipitation using the “Precipitation” setting. Begin with 1cm of rain. Given the current conditions of this watershed, what percentage of the rainfall becomes runoff (below the graph, a table with water depth in cm provides the data you will need to complete this calculation)? Change the settings to model 2.5 cm of rain. Now what percentage of the rainfall becomes runoff? Change the settings to model 4 cm of rain. Again, calculate the percentage of rainfall that becomes runoff.

Let’s re-visit some of the data from Activity B: convert the top 15 rainfall events from inches to cm using a formula in Excel (eg: =2.54\*B3). Pick one or more of the top 15 rainfall events and run the Site Storm Model with this level of precipitation to see what percentage of rainfall becomes runoff.

**What kind of impact does rainfall intensity have on the percentage of water that becomes runoff?**

Next, we will explore how different forms of green infrastructure can influence the quantity of runoff and the water quality. We will use total suspended solids (TSS) as an indicator for water quality. Higher concentrations of suspended solids can serve as carriers of toxics, which readily cling to suspended particles[[9]](#footnote-9). Total solids measurements can be useful as an indicator of the effects of runoff from construction, agricultural practices, logging activities, sewage treatment plant discharges, and other sources, and concentrations often increase sharply during rainfall, especially in developed watersheds. Sources of total solids include industrial discharges, sewage, fertilizers, road runoff, and soil erosion.

Click on “+ Add changes to this area”, then click on “+ Conservation Practice” and add different types of green infrastructure to the watershed. You can quantify the modifications you add by clicking on Modifications at the upper right hand side of the screen and adding up the total effective area for each conservation practice you add to your scenario in the Excel table provided. See example of where to find the Modifications button in **Figure 1**. It is recommended that you explore various combinations of green infrastructure conservation practices and try adding them to your scenario/plan for improving water quality and reducing runoff.

You create different scenarios by clicking on “+ New scenario” and exploring different combinations of green infrastructure to compare their effectiveness for reducing runoff and TSS load rates. Create at least 2 plans (scenarios) for green infrastructure.

Create one final scenario in which you have close to 100% green infrastructure coverage as “best case scenario” to compare current conditions and your designs to. Keep in mind, 17% of land cover is open water, so you will likely not have 100% coverage.

Take a screenshot of each plan and be sure to quantify the modifications you add by clicking on Modifications at the upper right hand side of the screen and adding up the total effective area for each conservation practice you add to your scenario in the table provided in Excel.

Map

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Compare

Modifications

**Figure 1:** Sample screenshot of green infrastructure scenario

Next, click on “Compare” to see how current conditions (no green infrastructure) compare to the different scenarios you created in terms of both the impact on the percent runoff and the loading rate of TSS for 1cm, 2.5cm, 4cm and a “top 15” rainfall event respectively (see **Figure 1**). If you click on the table icon in the upper right, the site will summarize this data, and you can change the rainfall intensity as you did before to record the runoff, evapotranspiration (ET), and infiltration quantities. See **Figure 2** for an example. Click on Water Quality and record the loading rate of TSS (kg/ha) at 1cm, 2.5cm, 4cm and a “top 15” rainfall event (from Activity B) for each scenario.

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Water Quality

Rainfall Intensity

Table Icon

**Figure 2:** Screenshot of “Compare” tool for evaluating effectiveness of scenarios

Calculate and compare the percent runoff and loading rate (kg/ha) of TSS without any green infrastructure (current conditions) for each precipitation level to the percent runoff and loading rate of TSS (kg/ha) for each of the scenarios you created, as well as the best case scenario green infrastructure scenario. You should also calculate total coverage for each conservation practice, as well as percent effective area. Compare the three (total) scenarios you created using the tables provided in excel. Below are formulas you should find helpful for completing the tables.

Begin by recording the total effective area for each conservation practice in each scenario. You can use Excel to sum the total area if you have more than one practice in your scenario (eg: 59 km2 and 20 km2 of green roof) by typing in the quantities (eg: =59+20).

Next, sum the total green infrastructure area for scenario 1 using a formula (eg: =SUM(B9:B14) based on **Template 1**). You can copy and paste these formulas for scenario 2 and best case scenario.

Graphical user interface, application, table

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Calculate as =SUM(C9:C14)

Calculate as =B9/209.5

Calculate as =SUM(B9:B14)

**Template 1**: Table 1, Activity C: Model My Watershed

Then, calculate the % effective area for each conservation practice in all three scenarios. There are 209.5 km2 in the watershed. To calculate percentage for rain garden in scenario 1, use a formula (eg: =B9/209.5 based on **Template 1**). Change the format of the cell to %. You can copy and paste this formula for the remaining conservation practices in scenario 1. Sum the total green infrastructure % effective area for scenario 1 using a formula (eg: =SUM(C9:C14) based on **Template 1**). You can copy and paste these formulas for scenario 2 and best case scenario.

Graphical user interface, application, table

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**Figure 2:** Table 1, Activity C: Model My Watershed

Use your calculations of the Total GI Coverage % Effective Area to complete the second table (shown in **Figure 2**). For Current Conditions, the % Effective Area will be zero. Fill in the storm size you selected from the top 15 rainfall event in the empty storm size cells in table 2 of the provided excel sheet. You should have already filled in the runoff depth, ET depth, infiltration depth and TSS loading rate.

Now you will calculate the % runoff using a formula (eg: D15/C15 based on **Template 2**). Change the format of the cell to %. You can copy and paste this formula for the remaining storm sizes for all the scenarios.

Graphical user interface, application, table, Excel

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Calculate as =D15/C15

**Template 2**: Table 2, Activity C: Model My Watershed

Graphical user interface, application, table, Excel

Description automatically generatedLastly, you should summarize your results in table 3. Calculate the reduction in % runoff and TSS loading rate for your 3 created scenarios by comparing them to current conditions using the table provided using a formula (eg, for scenario 1, storm size of 1cm: =G19-G$15, storm size of 2.5cm: =G20-G$16 based on **Templates 2 & 3** etc). Once you complete the formulas for reduction in % runoff for all 4 storm sizes in scenario 1, you can copy and paste these formulas for scenario 2 and best case scenario.

Calculate as =(H19-H$15)/H15

Calculate as =(H20-H$16)/H16

Calculate as =G19/G$15

Calculate as =G20/G$16

**Template 3**: Table 3, Activity C: Model My Watershed

To calculate the percent reduction in TSS loading rate for your 3 created scenarios, compare them to current conditions using the table provided using a formula (eg, for scenario 1, storm size of 1cm: =(H19-H$15)/H15, storm size of 2.5cm: =(H20-H$16)/H$16 based on **Templates 2 & 3** etc). Then convert the format of these cells to %. Once you complete the formulas for reduction in % runoff for all 4 storm sizes in scenario 1, you can copy and paste these formulas for scenario 2 and best case scenario.

You can use this tool to view the land use data for the watershed where you live too!

**Questions**

1. Why is it important to preserve water quality? Do some research to explain how poor water quality impacts public health and recreational activities.
2. What are some of the environmental problems associated with stormwater runoff? What is a CSO?
3. Include your graphs of annual rainfall over time. How did the rate of change shift when you made your second graph? How does this compare to the overall class data?
4. As climate change causes more rainfall in some areas, why do we need to come up with adaptations in our infrastructure which address the negative impact that excess runoff has on water quality?
5. Explain how green roofs can increase and connect habitats.  What kind of impact do you think this would have on the biodiversity of an area which had buildings constructed with primarily green roofs?
6. How can green roofs reduce heating and cooling costs for homes and buildings?  What does this mean for energy usage?
7. What was the range of the percent retention of runoff per building from the different green roof studies? What was the standard deviation?
8. Based on the studies of the hydrologic performance of full-scale green roofs, how effective do you feel green roofs can be in reducing runoff? Are there other forms of green infrastructure that can be utilized to reduce runoff?
9. Evaluate the different types of land use in the East River-Hudson River Subwatershed – what land use category comprises the largest percentage of land cover? Does this make the East River-Hudson River Subwatershed a good candidate for the implementation of green infrastructure designed to reduce runoff? Explain.
10. Based on your calculations from Model My Watershed, in current conditions (without your green infrastructure scenario), what kind of impact does rainfall intensity have on the percentage of water that becomes runoff?
11. Include **Tables 2 and 3** you completed summarizing the data you collected and analyzed from Model My Watershed. Discuss changes in percent runoff and loading rate of TSS (kg/ha) of total suspended solids without any green infrastructure (current conditions) for each precipitation level to the percent runoff and loading rate (kg/ha) of TSS for each of the scenarios you created.
12. Share your scenario and inferences on a digital Gallery Walk as 1 or 2 slides of a Google Slide deck.
    1. Discuss your plans for implementation of green infrastructure to reduce runoff. Include **Table 1** which quantifies your conservation practices. Describe the conservation practices you added for both of your scenarios. Be specific and justify your choices. Include the screenshots of each scenario (see example from **Figure 1**).
    2. How did your most effective plan respond to a “top 15” event? Considering NYC’s goal to capture 10% of the first 2.5cm of runoff from impervious surfaces, does your plan meet that goal? How feasible is your plan? Some questions to consider:
       1. What might be some challenges to implementation of green infrastructure?
       2. How might a city get community buy-in and what challenges would need to be overcome to do so?
       3. How might cost be a factor?
       4. What about maintenance?
13. Discuss how you think city planners should consider the shifting magnitude and frequency of severe weather events when developing building guidelines and climate change mitigation strategies. What other actions might be needed to preserve water quality, aside from green infrastructure?

1. <https://wikiwatershed.org/model/> [↑](#footnote-ref-1)
2. Berghage, R., D. Beattie, A. Jarrett, C. Thurig, F. Razaei, AND T. OCONNOR. Green Roofs for Stormwater Runoff Control. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/026, 2009. [↑](#footnote-ref-2)
3. Lant, Karla. “China has officially started construction on the world’s first “Forest City”.” <https://futurism.com/china-has-officially-started-construction-on-the-worlds-first-forest-city/>. 2017. [↑](#footnote-ref-3)
4. NYC DEP 2010 NYC Green Insfrastructure Plan: a Sustainable Strategy for Clean Waterways <https://www1.nyc.gov/assets/dep/downloads/pdf/water/stormwater/green-infrastructure/nyc-green-infrastructure-plan-2010.pdf> [↑](#footnote-ref-4)
5. <https://www.epa.gov/green-infrastructure/what-green-infrastructure> [↑](#footnote-ref-5)
6. NYC DEP 2010 NYC Green Insfrastructure Plan: a Sustainable Strategy for Clean Waterways <https://www1.nyc.gov/assets/dep/downloads/pdf/water/stormwater/green-infrastructure/nyc-green-infrastructure-plan-2010.pdf> [↑](#footnote-ref-6)
7. Carson, T. B., et al. "Hydrological performance of extensive green roofs in New York City: observations and multi-year modeling of three full-scale systems." *Environmental Research Letters* 8.2 (2013): 024036. [↑](#footnote-ref-7)
8. <https://modelmywatershed.org/> [↑](#footnote-ref-8)
9. <https://archive.epa.gov/water/archive/web/html/vms58.html> [↑](#footnote-ref-9)