Geodesign to Support Green Stormwater Infrastructure

Gabriel Wilkins, Kayla Wandsnider, Celeste Gunderson, Christina Dennis, Scott McComb, and David A. Hart

University of Wisconsin Sea Grant Institute
May 11, 2023

The University of Wisconsin Sea Grant Institute has developed a green stormwater infrastructure geodesign tool to assist water resource managers and others interested in incorporating green infrastructure into existing stormwater systems. The tool uses ArcGIS GeoPlanner to design alternatives and measure the cost and impact of green stormwater infrastructure (GSI) practices across different landscape scales.

Background

Urban development, with its associated construction of buildings and transportation systems, has a profound impact on water resources. When rain falls on these hardened urban surfaces, water is not absorbed into the ground where it falls and quickly flows away. Cities have engineered stormwater drainage systems to capture this runoff and move it downstream as quickly as possible through a series of pipes and channels. Collectively, these engineered systems are known as gray infrastructure and many such systems around the world are undersized and aging. The result has been increased flooding and water pollution affecting urban areas.

Broadly defined, green infrastructure is any landscape feature that can support or mimic natural functions, such as wildlife habitat, water absorption or food production. At a regional scale this can take the form of a floodplain, wetland, forest or prairie. At the scale of a building site, green infrastructure can include individual trees, pockets of landscaped plants or permeable pavement. Preserving and restoring natural features – especially in urban environments with high concentrations of hardened surfaces – can help mitigate urban heat islands and high air pollution levels, as well as provide habitat for wildlife and pollinators.

Integrating green stormwater infrastructure practices into gray stormwater infrastructure systems can help reduce runoff volumes by slowing, capturing, and infiltrating rainwater. Green stormwater infrastructure includes practices as varied as trees with large canopies, rain barrels, rain gardens, bioswales, permeable pavement and vegetated rooftops. While any individual green stormwater infrastructure practice may not make a large contribution to reducing flooding, a concentration of practices in an urban drainage catchment area can capture and infiltrate the first flush of rainfall events and help reduce the burden on gray infrastructure systems. There is a need for software solutions that can measure and visualize the cumulative cost and benefits of green stormwater infrastructure across different scales of the landscape and support the design of alternative scenarios for reducing flooding and improving water quality.

Lesson Overview

This lesson will allow users to follow a series of steps to build a green stormwater infrastructure geodesign application using ArcGIS GeoPlanner. The resulting tool will allow users to design and compare different green stormwater infrastructure practices based on water capture and construction cost metrics. The lesson location is Green Bay, Wisconsin, but it will have broad applicability to other locations. Where metrics or values are specific to Green Bay, this lesson will explain how to modify them for other locations.

Software Requirements

An ArcGIS Online account and the ArcGIS GeoPlanner premium application are required to complete this lesson. If you are affiliated with an organization that has an enterprise ArcGIS account, check with your account administrator about access to the required software.

A 21-day "ArcGIS Online Trial Account" (https://www.esri.com/en-us/arcgis/products/arcgis-online/trial) and a 21-day "Learn ArcGIS Educational Trial" (https://www.esri.com/en-us/lg/training-and-services/learn-arcgis-education-trial) both include ArcGIS GeoPlanner for non-commercial use. These trial accounts are designed for learning and practicing with ArcGIS. It is important to note that there is no way to convert temporary trial accounts into a permanent one and you cannot keep the content created there after the 21-day trial ends. Use of the trial accounts for courses, workshops, or commercial activities are grounds for early termination.

To purchase ArcGIS Online as a business, you would require a Creator user type account. As an individual, both "ArcGIS for Personal Use" and "ArcGIS for Student Use" include the ArcGIS GeoPlanner premium app (https://www.esri.com/en-us/arcgis/products/arcgis-online/buy). ArcGIS GeoPlanner may be purchased individually (https://www.esri.com/en-us/arcgis/products/arcgis-geoplanner/buy). Users must have a subscription to ArcGIS GeoPlanner and an ArcGIS Creator user type.

Finally, for advanced business users, joining the Esri Partner Network (https://www.esri.com/en-us/about/partners/become-partner) provides access to many Esri products and services.

Learning objectives

This lesson is divided into three parts. The objectives of the first part are to create a customized GeoPlanner project for assessing green stormwater infrastructure; and develop dashboards to assess scenarios in real-time to help meet water capture and construction cost goals. The objective of the second part is to design, compare and evaluate alternative scenarios to meet stormwater capture goals at the site scale. The objective of the third part is to demonstrate how scenarios developed at the site scale can be evaluated at broader scales, such as urban drainage catchment areas to show the urban hydrology benefits of green stormwater infrastructure.

Lesson plan

- Part 1- Setting Up a GeoPlanner Project for Green Stormwater Infrastructure (60 minutes)

- Part 2 - Designing Scenarios to Meet a Site-specific Water Capture Goal (45 minutes)
- Part 3 - Compare Scenarios Across Spatial Scales (15 minutes)

Total time: 2 hours

Part 1: Setting Up a GeoPlanner Project for Green Stormwater Infrastructure

Set Up the Project

To begin, you will create a new project for Green Bay, Wisconsin and a bookmark to easily reference the project area.

- Navigate to ArcGIS GeoPlanner (https://geoplanner.arcgis.com/)

- Click "Sign In" to log into ArcGIS GeoPlanner. You will have a choice to use an ArcGIS login or your ArcGIS organization's URL.

After you sign in, a gallery of your recent projects will appear. If this is your first time using GeoPlanner, the space will be empty.

- Click **Create New**.
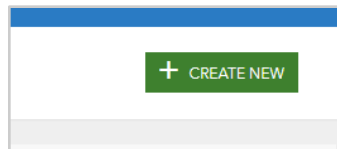
The **Create Project – Select a Template** window will appear with many Esri and user created templates. Click the **Curated** tab and scroll down or search for the **GeoPlanner Basic Template**. Click **Select**. At the end of this lesson, you will be able to create your own template to use when creating a new project, so you don't have to do all this work each time.
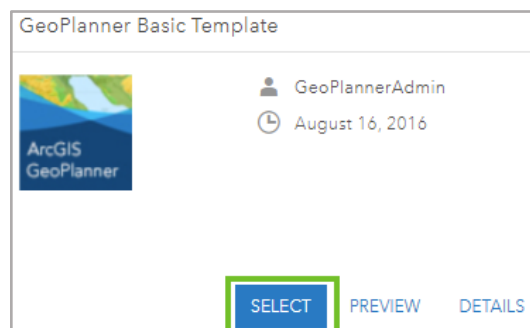
- The **Create Project** window will appear. Review and type the following information under each category to customize the template information:

  - For **Title**, type "Green Stormwater Infrastructure Tutorial – <Your Initials>".
  - For **Summary**, type "This project serves as an example of how to construct a GeoPlanner project for planning and assessing green infrastructure sites."
  - For **Description**, type "This project includes symbols, dashboards and geospatial data layers to help locate sites for green infrastructure practices and assess scenarios to reduce urban stormwater runoff to meet community goals. It includes one point and three polygon design feature layers that represent different green infrastructure practices. It also contains geospatial data layers to help delineate focus areas. Symbols and attribute default values can be customized using the Design Types editor."
  - For **Tags**, type "Green Infrastructure, Stormwater Management, Urban runoff, Flooding"

- Click **Create**. After a few moments, a new window will display a world map. Navigate to the study area by selecting the **Place Finder** tool and typing Green Bay, Wisconsin.
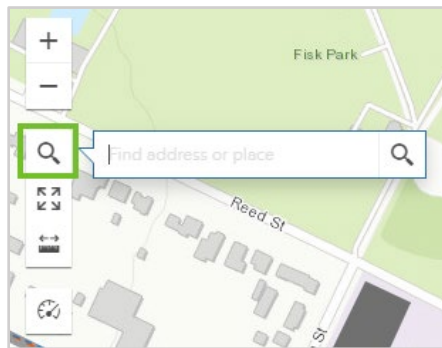
  Different locations will begin to appear below it. Select **Green Bay, WI, USA (Brown County)**. The map will then zoom into that extent.

- Bookmark the City of Green Bay extent to easily reference the area for future steps. Click the **Extent** tool and choose **+ Add Bookmark**.
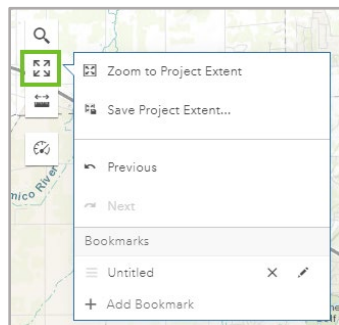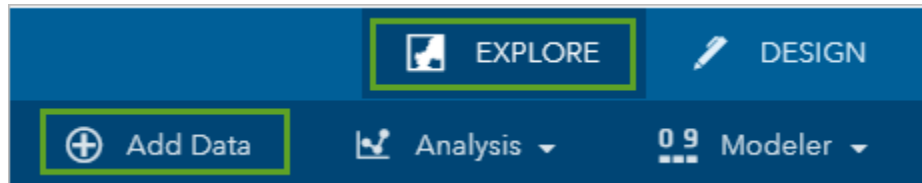
Type Green Bay, WI. Press Enter to add the bookmark and then click on the map to dismiss the display.

Add Data

Next you will add boundary data for three different sites in Green Bay. These data layers will help you create Study Areas and, in future lessons, compare the impact of practices.

1. On the ribbon, click the **Explore** tab and click **Add Data.**

The **Search for Data** window will appear. To filter all available data within Green Bay, toggle on **Consider your map extent** so it turns green and click the **All** tab to make sure it includes all data that can be found on ArcGIS Online.
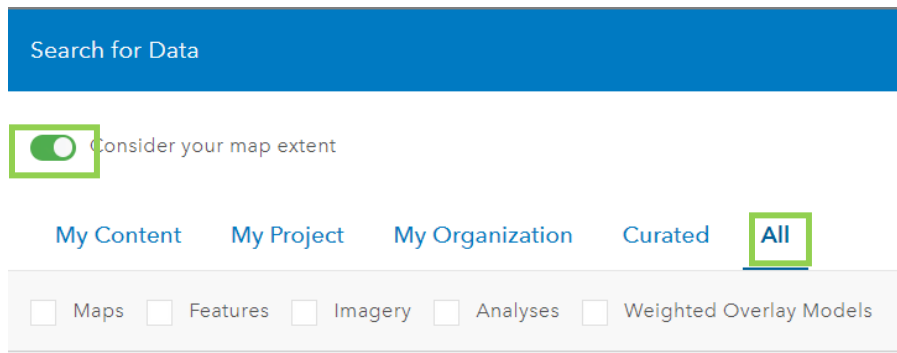
2. In the search bar, type "Green Bay West High School Site" and press enter.

If multiple features appear, navigate to one owned by "**dahart@wisc.edu_UW_Mad**". Click **Add**, to bring this feature into the map. Continue to search until you have added all of the features listed below:

- Green Bay West High School Site (owner: dahart@wisc.edu_UW_Mad)
- Fisk Addition Neighborhood Boundary (owner: dahart@wisc.edu_UW_Mad)
- Green Bay Storm Basins (owner: wandsnider@wisc.edu_UW_Mad)

Close the **Search for Data** window by clicking the "X" in the upper right corner.

The **Contents** pane is updated to list the added layers. If you don't see a list of layers, click the stack icon in the top left of your screen.

Turn the data layers on and off and zoom in and out to explore the geographic layout and connectivity of the area and between the different project sites.

Bookmark project sites

1. Next to the Green Bay West High School layer click **Option** and **Zoom to**. This will adjust the map display to the Fisk Addition neighborhood extent.
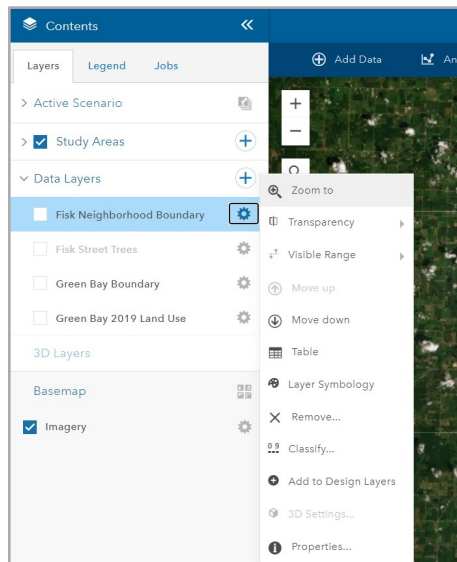
2. Click **Extent** and then **+Add Bookmark**. Type "Green Bay West High School".
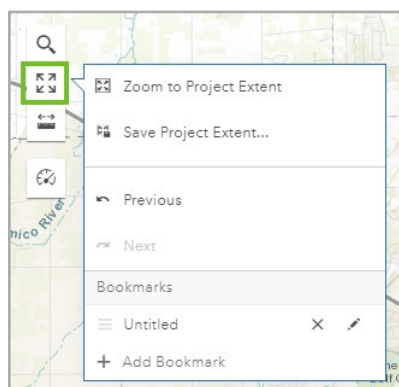
Press **Enter** to add the bookmark and then click on the map to dismiss the display.

Create bookmarks for each of the three boundaries to easily move from one site to another when designing and comparing scenarios. The map will also move whenever you change which study area is activated.
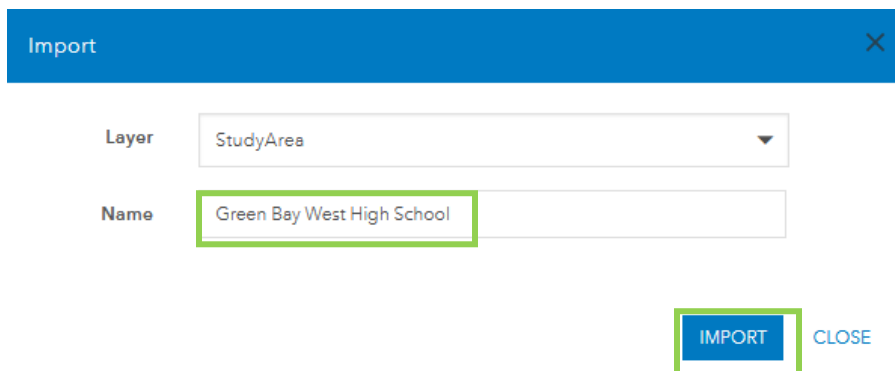
Define study areas

Define the study areas where you will design green stormwater infrastructure scenarios.

1. In the **Contents** pane, turn off all data layers except **Green Bay West High School Site**.

2. On the map, click anywhere within the Green Bay West High School boundary to bring up its attribute box. Then, click **Import**.
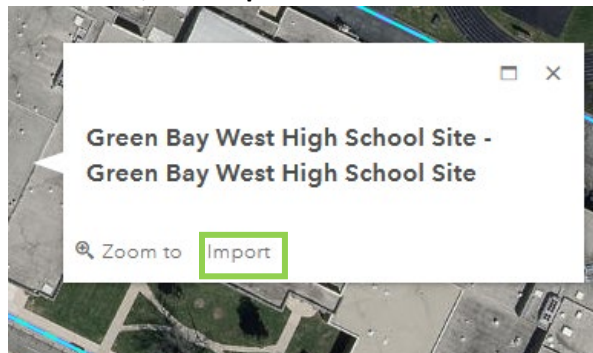
Next to **Layer** select the dropdown **Study Area** and for the name type "Green Bay West High School". Click **Import** and close out of the attribute box.


3. If you wish to change the basemap, you can do so by selecting the symbol to the right of **Basemap**. In the **Contents** pane click **Change Basemap** and choose **Imagery**.
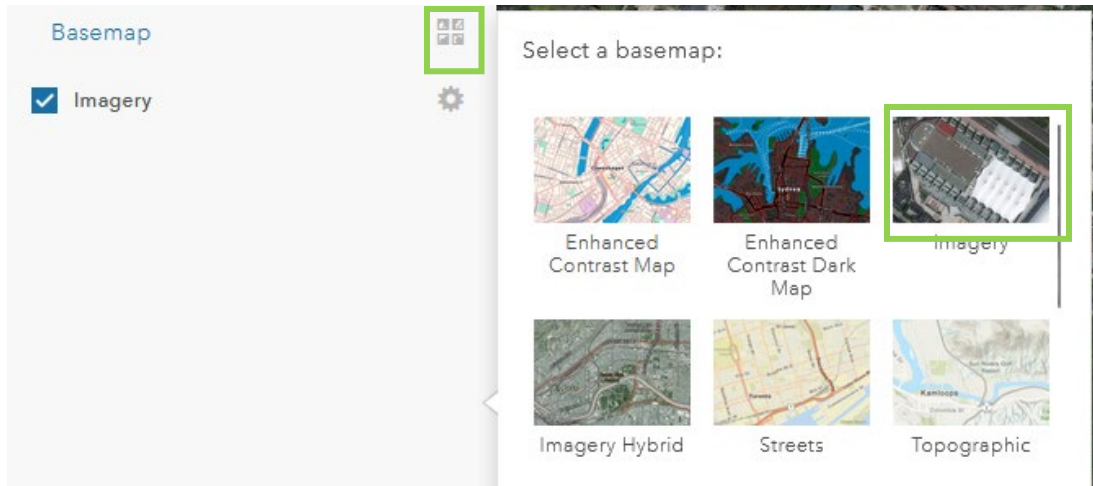
Create green infrastructure types

Next you will customize point and polygon design types to represent the green stormwater infrastructure practices you will plan with later. For this tutorial, we will use four types of green stormwater infrastructure practices: trees, green roofs, permeable pavement, and rain gardens. For each practice, we will estimate its rainfall capture rate and installation cost.

1. Before customizing the design types, delete the design type **LINE** as this tutorial will not include linear green stormwater infrastructure practices. In the **Contents** pane under **Active Scenario** click **Options** next to the design type **LINE** and click **Delete Design Layer**.
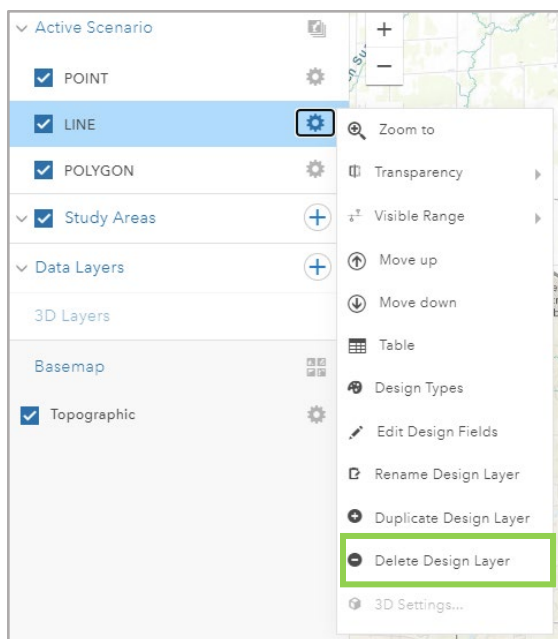

A warning display will appear. Click **Delete Layer**.

Point Design Layers

Customize the point design layer to include a tree by editing the design fields and design types.

1. To begin, change the default design fields to include the metrics you will use to measure and compare green infrastructure practices. For **POINT**, click the **Options** button and choose **Edit Design Fields**.
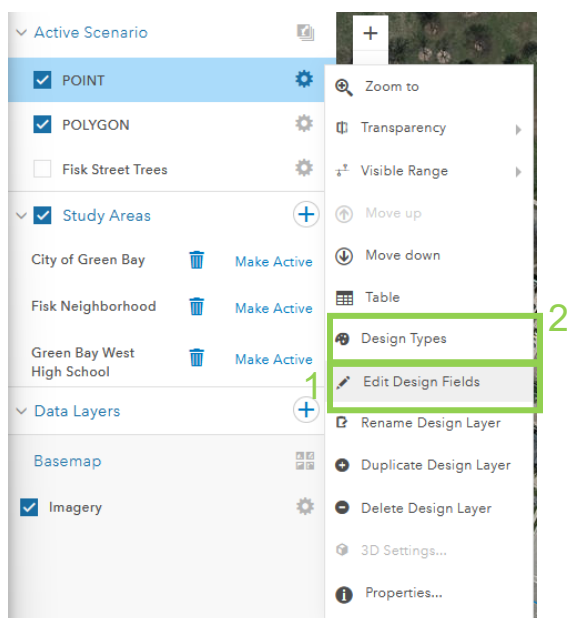
The **Design Fields: POINT** window appears. Change the **Display Name** text for **DESIGN_FIELD_1** to *Water capture rate (gal/tree)*. Next change the **Display Name** text for **DESIGN_FIELD_2** to *Installation cost ($US/tree).* After modifying these design field names, click **Save**.

2. Click **Options** next to the design type **POINT** once again, but this time click **Design Types**.

3. The **Point** window will appear with five point features displayed. Delete points 2 through 5 by clicking **Delete** and confirming the deletion when the **Delete Type** warning appears by selecting **Delete**. POINT 1 should be the only point remaining (you can always add a new point by clicking **+ ADD**).

4. Design the symbology and default values for POINT 1. In the **POINT** display window, select the **Symbol** tab. Under the tab select **Fill** and choose a dark green color.
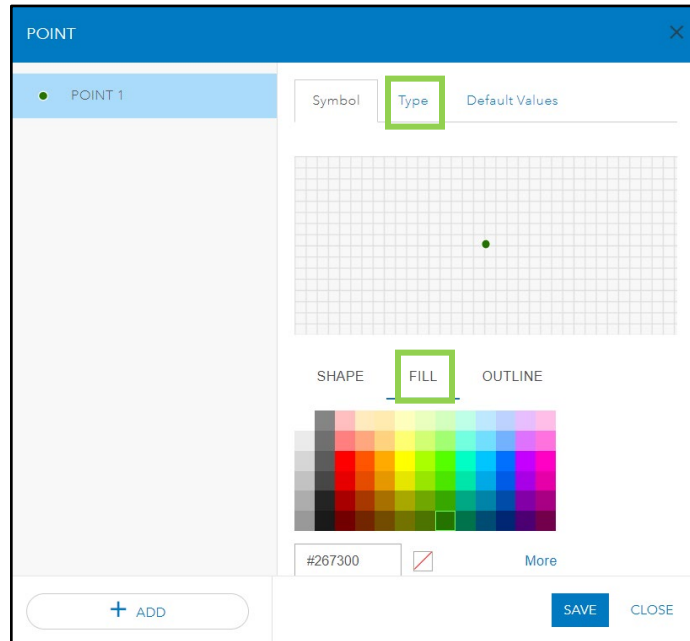
Next click the tab, **Type**. For the label type *Tree.*

Last, you will add the design values for a tree. Click the **Default Values** tab and type the following text and figures to describe its capabilities:

- For Name, type *Tree.*
- For Description, type *An urban street tree of average size.*
- For Max water capture rate (gal/tree), type: *311.2.*
- For 25 Year Cost ($US/tree), type: *3,850.*

Click **Save** to update the design layer.

Polygon Design Layers

Now you will design the symbology for the three polygon green infrastructure practices. Most of the steps are the same, but because the capture and cost metrics are measured as a per square foot rate, they have to be inputted a little differently. We will do this in the next section.

1. First, under the "Active Scenario" section of the "Layers" tab, select **Options** for the POLYGON layer (gear icon). Select **Design Type** from the dropdown options. Delete polygons 4 and 5.
2. After deleting polygons 4 and 5, modify the 3 types based on the table below.

Feature	Color	Label/Name	Description
POLYGON 1	Green (#4ce600)	Green Roof	Rooftop vegetation system designed to store water in soil
POLYGON 2	Yellow (#ffff73)	Permeable Pavement	Gravel topped with porous concrete/asphalt or pavers that holds water and allows it to infiltrate into soil
POLYGON 3	Blue (#0070ff)	Rain Garden	Depressions filled with engineered soil and native, water-tolerant plants to capture, hold, and infiltrate runoff

3. Select **Save** after adding the information for the remaining polygons.

Creating dashboards to measure impacts

Build a series of dashboards to measure and visualize the cumulative impacts of green infrastructure practices placed within the study area. The dashboards will help track progress towards meeting runoff capture goals and the total project cost.

Define Constants

While default values and design types are useful, once an individual point or polygon is made, that value can only be changed by manually editing the design layer's table. Therefore, it is best to use those fields for attributes specific to an individual green stormwater infrastructure practice, not values that are averages or that may change depending on certain design assumptions.

Within GeoPlanner, however, we can also define variables by using "constants" within the dashboard

1. Click **Dashboard** on the left hand side of the map, and then select **Maximize**.
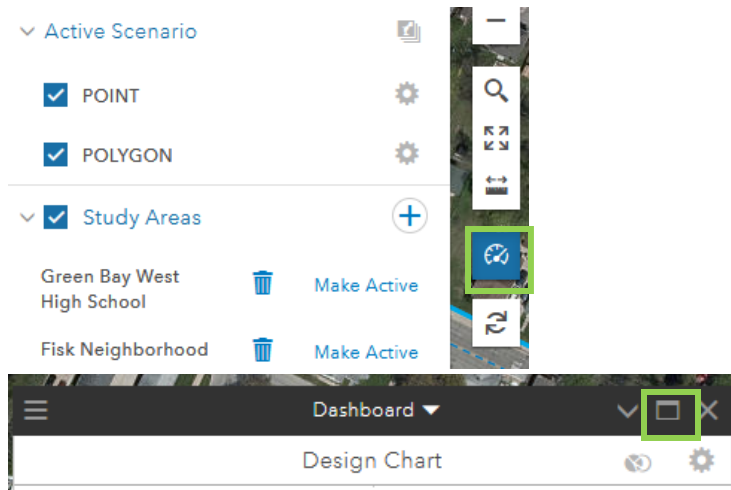
2. Next, select **Dashboard Options** and click **Constants**
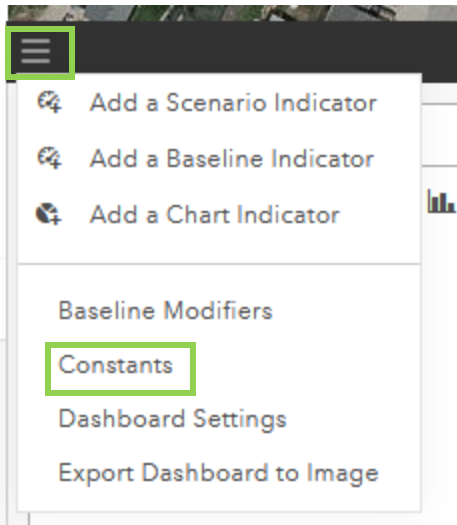
3. Click **ADD** to create a new constant. Name it *Rainfall* and set the value to *0.5*. This will represent the amount of rain, in inches, around which we will model green stormwater infrastructure volume capture.
4. Continue adding constants until you have added all of the below variables. (You may notice there is no Green Roof capture rate, and that is intentional. We will cover green roofs in the next section.)

Name	Value	Source/Explanation/rationale
Rainfall (in.)	**0.5**	Capturing the first ½ inch of rainfall is a common goal
Rainfall Conversion Factor (in. to gal/sqft)	**0.623**	This allows users to modify rainfall in inches, instead of converting to gal/sqft manually
Impermeable Area Ratio	**0.83**	Percentage of land area that is impermeable, **specific to each individual Study Area**
Permeable Pavement capture rate (gal/sqft)	**1.46**	
Rain Garden capture rate (gal/sqft)	**6.32**	
Green Roof 25 year cost ($/sqft)	**24.00**	Average lifespan: 40 years
Permeable Pavement 25 year cost ($/sqft)	**9.08**	Average lifespan: 30 years
Rain Garden 25 year cost ($/sqft)	**14.27**	Average lifespan: 22.5 years

5. Click **Save** once you have added all the constants.
   a. Capture rate and cost values come from the Center for Neighborhood Technologies' [Green Values Stormwater Management Calculator](). This tool, produced by the Center for Neighborhood Technology pairs peer-reviewed research with a large amount of sample data to produce reliable estimates for a number of green stormwater infrastructure practices. It also provides a detailed framework for modifying various parameters so that users can tailor the tool to any particular site.

Create Numeric Dashboards

1. We will now build a series of dashboards to show the different water capture and cost metrics that will be used to assess planned green stormwater infrastructure practices. If needed, open and expand the **Dashboard**.
2. Build an indicator for the rainfall capture goal, which will calculate the total volume of water falling on impervious surfaces based on some of the constants we defined earlier.

   Find the "Key Performance Indicator – Polygon" dashboard and select **Options** (gear icon). This will open the "Scenario Indicator" dialogue box.
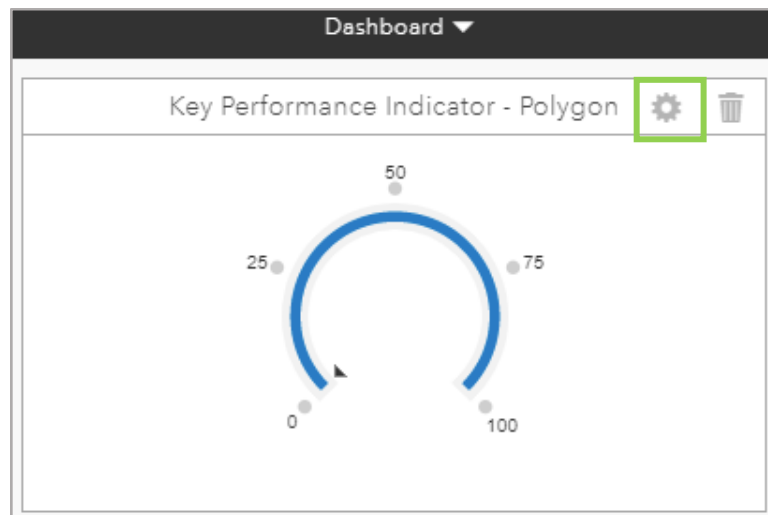
   In the dialogue box, enter or select the following information for each field:
   - Caption: *Rainfall Capture Goal (gal)*
   - Type: select **Numeric** (make sure the composite box is <u>not</u> checked)
   - Rounding Style: select **Default** from the dropdown menu
   - Scenario Layer: select **StudyArea** from the dropdown menu.
   - Equation: select **Equation Builder** below the text box. This will open the "Polygon'' dialogue box. Select and delete any text in the large text box before building the equation. Enter the equation: *[Rainfall (in.)]*[Rainfall conversion factor (in. to gal/sqft)]*[Impermeable Area Ratio]*[squareFeet]*. To build this equation select **[Rainfall (in)]** under "Constants." This will add it to the large text box. Next, select ***** (multiply icon), and then select **[Rainfall conversion factor (in to gal/sqft)]** under "Constants." Multiply a third time by **[Impermeable Area Ratio]**, and finally, select

by **[squareFeet]** under "Measures." Select **OK** to return to the "Scenario Indicator" dialogue box, then select **Sum** from the dropdown menu.

● Save the equation by selecting **UPDATE**.

The water capture goal is a special case, with its equation and use within the GeoPlanner project different from most of the other dashboard indicators due to its reliance on the impermeable area ratio, which varies wildly across different spaces. The number you inputted earlier for that ratio (0.83, meaning that 83% of the surface is impermeable) reflects an analysis by the authors of the Green Bay West High School site using iTree Canopy. When analyzing a different site, this analysis will have to be redone for that specific area.

3. The indicator calculating the green roof capture total is also somewhat different, but it still serves as a helpful exercise for getting to know how dashboard indicators work.
   ○ Green roofs only capture water which falls directly on them, whereas other practices can store water draining into them from adjacent impermeable surfaces. Thus, while other practices will "fill up" to their maximum even in light rain events, green roofs will rarely ever hit their maximum possible retention volume (most would require 4-5 inches of rain in a short period, which is an extremely rare occurrence in most places).
   ○ To create the green roof water capture indicator, then, we simply need to calculate the volume of water falling directly on the green roof, since it is likely able to capture all of it.
      ■ Edit "Key Performance Indicator - Line" or create a new scenario indicator, and enter information below
         ● Name: *Water Capture - Green Roofs Rain (gal)*
         ● Type: **Numeric** (composite unchecked).

- Rounding Style: **Default**
- Scenario Layer: **POLYGON** (Filter: **Green Roof**)
- Equation Builder: [Rainfall (in.)] * [Rainfall conversion factor (in. to gal/sqft)] * [squareFeet]
- Equation type: **Sum**
   ○ You may see the following warning: "No data available in this area." The message appears because no Green Roof polygons have been placed on the map yet, so the total square footage is zero.
      ■ If you still see this warning despite having added polygons, make sure that no design field or constant names have been changed. If they have, you will have to update the name within the equation builder.
4. Build the remaining water capture and cost indicators. As primary indicators, these are calculated directly from the data. After they are added, we'll look at different kinds of indicators.
   ○ Modify the existing indicators or, to add a new indicator, select **Dashboard Options** (three bars in top left) and then **Add a Scenario Indicator.**
      ■ Note: It is easy to accidentally drag the dashboard window around when trying to select a button. If that happens, just close and maximize the window again
   ○ Create the indicators in the following table

Water Capture Indicators

Caption	Type	Rounding Style	Scenario Layer	Filter	Equation	Sum or Average
Rainfall Capture Goal (gal)	Numeric	Default	StudyArea	None	[Rainfall (in.)] *[Rainfall conversion factor (in. to gal/sqft)] *[Impermeable Area Ratio] *[squareFeet]	Sum
Water Capture - Green Roofs (gal)	Numeric	Default	POLYGON	Green Roof	[Rainfall (in.)] *[Rainfall conversion factor (in. to gal/sqft)] *[squareFeet]	Sum
Water Capture - Permeable Pavement (gal)	Numeric	Default	POLYGON	Permeable Pavement	[Permeable Pavement capture rate (gal/sqft)]*[squareFeet]	Sum
Water Capture - Rain Gardens	Numeric	Default	POLYGON	Rain Garden	[Rain garden capture rate	Sum

| Caption	Type	Rounding Style	Scenario Layer	Filter	Equation	Sum or Average
(gal)					(gal/sqft)]*[squareFeet]	
Water Capture - Trees (gal)	Numeric	Default	POINT	Tree	[DESIGN_FIELD_1]	Sum
Cost - Green Roofs ($US)	Numeric	Default	POLYGON	Green Roof	[Green Roof 25 year cost ($/sqft)]*[squareFeet]	Sum
Cost - Permeable Pavement ($US)	Numeric	Default	POLYGON	Permeable Pavement	[Permeable Pavement 25 year cost ($/sqft)]*[squareFeet]	Sum
Cost - Rain Gardens ($US)	Numeric	Default	POLYGON	Rain Garden	[Rain Garden 25 year cost ($/sqft)]*[squareFeet]	Sum
Cost - Trees ($US)	Numeric	Default	POINT	Tree	[DESIGN_FIELD_2]	Sum
Total Rain Capture (gal)	Numeric (composite)	Default	n/a	n/a	[Water Capture - Green Roofs Rain (gal)]+[Water Capture - Permeable Pavement (gal)]+[Water Capture - Rain Gardens (gal)]+[Water Capture - Trees (gal)]	n/a
Total Cost ($US)	Numeric (composite)	Default	n/a	n/a	[Cost - Green Roofs ($US)]+[Cost - Permeable Pavement ($US)]+[Cost - Rain Gardens ($US)]+[Cost - Trees ($US)]	n/a

Final Dashboard Settings

1. Rearrange the dashboards by selecting on the dashboard name and dragging it to a new location. Note the "Design Chart" dashboard cannot be moved and will always appear first. Order the dashboard as follows:
   1. Design Chart
    2. Rainfall Capture Goal (gal)
    3. Rain Captured by Practices (gal)

4. Total Cost ($US)
5. The individual practice type capture totals
6. The individual practice type cost totals

2. In order to make sure the dashboards are including all placed green infrastructure practices, select **Dashboard Options** (icon of 3 stacked lines in top left corner of the "Dashboard" display). From the dropdown menu choose **Dashboard Settings**. For "Scenario and Baseline Indicators" select **All Features**. For "Charts" select **All Features**. Select **OK** to exit. Close the dashboard window to return to the map.
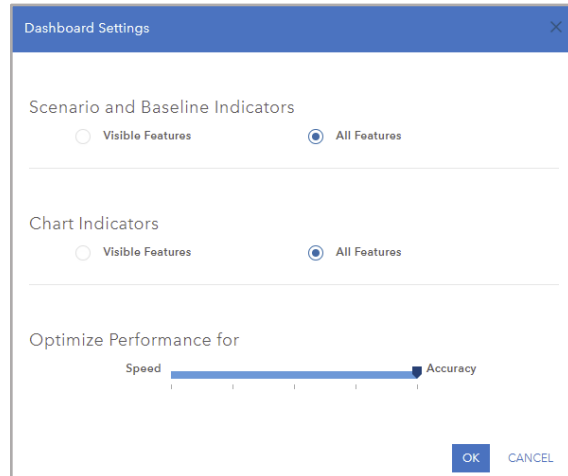
Even with this setting, indicators still occasionally "complete" their calculations prematurely in order to decrease computational usage. If you ever see the below icon on an indicator, try activating a different study area or going to its settings and updating it (you may not even have to actually change anything in the settings). Either of these methods essentially "forces" the indicator to complete a full calculation, which may take longer but will include all included design layers.
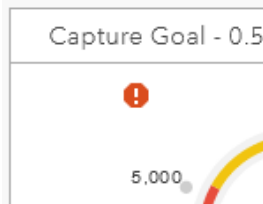

Recap: In Part 1 we set up a GeoPlanner project, added data and view bookmarks, designated study areas, created design types, specified constants, and created dashboard indicators.

Part 2: Meeting a Site-Specific Water Capture Goal

We will now use the various green stormwater infrastructure (GSI) practices and dashboard indicators to develop a rainwater capture plan for Green Bay West High School. This will involve placing various GSI practices until their combined rainfall capture estimate exceeds the high school's rainfall capture goal. We will begin by looking at only one kind of practice at a time so that we can learn its pros and cons, but will end by applying all types. This staggered approach will also allow us to introduce different design features one by one.

When designing stormwater capture plans, keep in mind the overall capture goal as well as any budgetary constraints. You'll also find it helpful to consider how different practices fit into what already exists on site, whether aesthetically or functionally.

1. To begin, first open the **Dashboard** and press "Dock". This will expand the number of dashboards that you can view at once, while also letting you manipulate the map. You can also scroll through the dashboard while it is docked to see the other indicators.
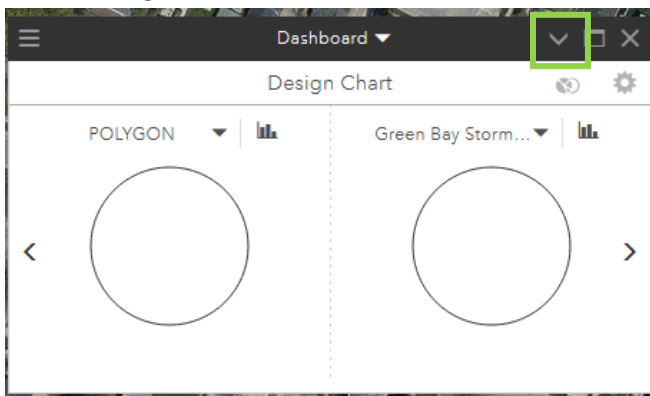
2. You may see a very large number for "Rainfall Capture Goal (gal)". That is because it is currently basing its calculation on the total number of square feet of all Study Areas. This could be useful as a way to quickly estimate a capture goal for a combination of multiple areas, but be careful, as it will count the same area twice if two different study areas both contain it. In either case, we will not be using this feature, and so you can go ahead and activate **Green Bay West High School**.
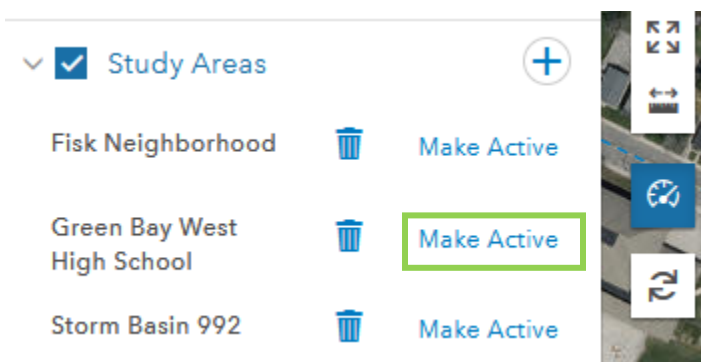
3. This will focus the map on that Study Area, as well as modify the dashboard indicators so that they only calculate features within that boundary. As such, the capture goal is much smaller, around 117,000 gallons. We will now meet this goal by adding green infrastructure practices.
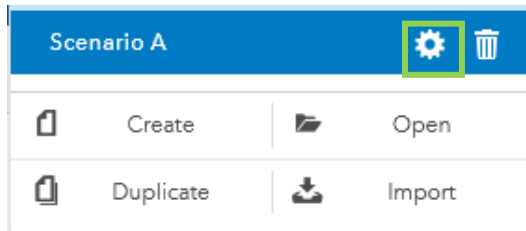
Scenarios

Any design layers (points and polygons) that you add within GeoPlanner are only added to the active scenario, each of which acts within ArcGIS Online as a feature layer (i.e., shapefile). This allows you to swap between multiple scenarios to test different spatial configurations of design layers while having the same study areas and dashboards present to use for analysis. We will start with a scenario focused on trees, then move through progressively more impactful green stormwater infrastructure practices.
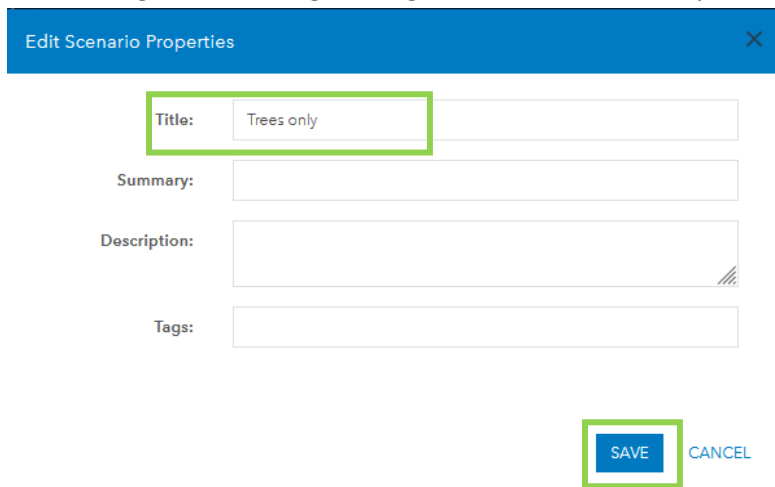
Trees

1. To start off, we'll edit the current scenario to show that it only includes trees. On the top left of your screen, click on "Scenario A".
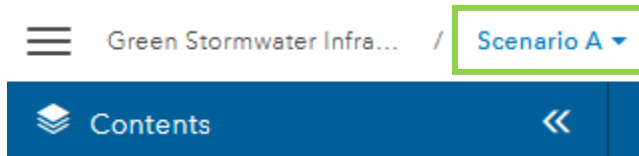
2. Inside this menu, you will see various options for manipulating scenarios. Select **Scenario Properties**, then **Edit**.

3. Here you can change the title, as well as add a summary, description, and even tags (to help with sorting and searching). Change the title to "Trees only", then click **save**.
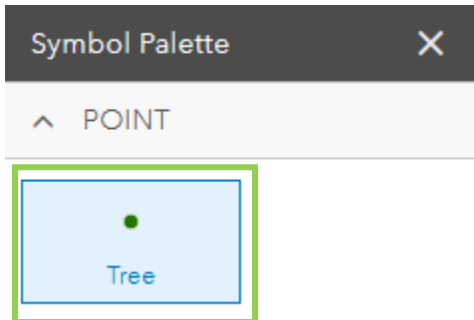
4. Select **DESIGN** at the top of your screen, then select **Drawing Tools**.
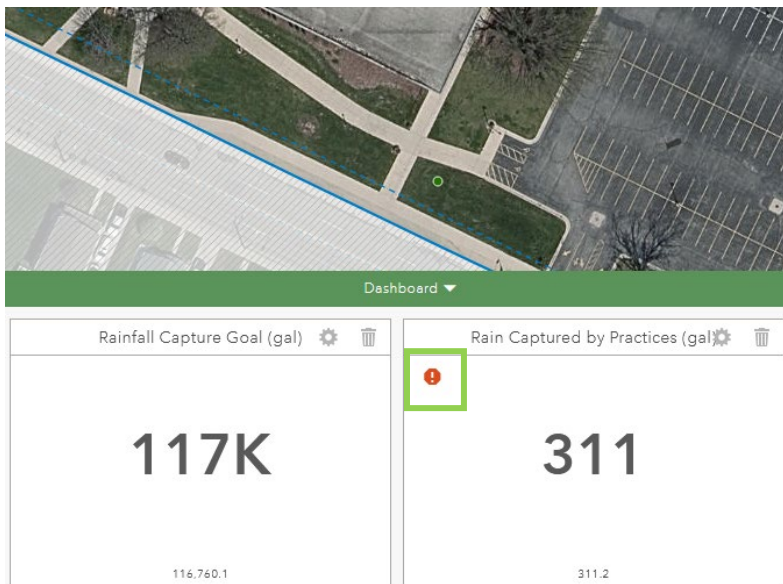

5. By default, you should have **Draw point** selected. If not, select its icon.

Also make sure that **Trees** is selected under **POINT** in the symbol palette.

6. Back to the map, zoom in and find a spot on the school's lawn where a tree or two could fit. Place them by clicking on the map. You will see that the dashboard updates, but that a warning symbol appears.


7. This happens because GeoPlanner only calculates totals based on the kind of design layer being added (in this case, points). To make it calculate all types, click **Settings** and then **Update**. Since we haven't added any polygons yet, the totals will be the same. But once we add both points and polygons, you may have to update the indicator frequently to get the most complete information.

8. Continue to add more trees, but be careful about spacing. Putting too many trees too close together risks having some outcompete the others, leading down the road to fewer total trees

surviving. With little green space and some trees already present, there may not be many you can comfortably place, and that is okay.

9. If you do run into a situation where you need to delete features, it's rather easy to do. Within the Design tab, switch from **Draw** to **Select Feature**.

By default, you will now be able to select any single feature. To select multiple features, swap the tool to **Multi-select**.
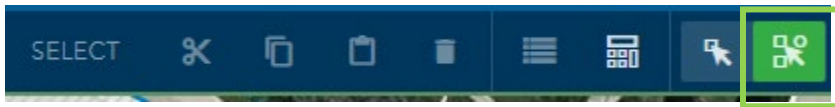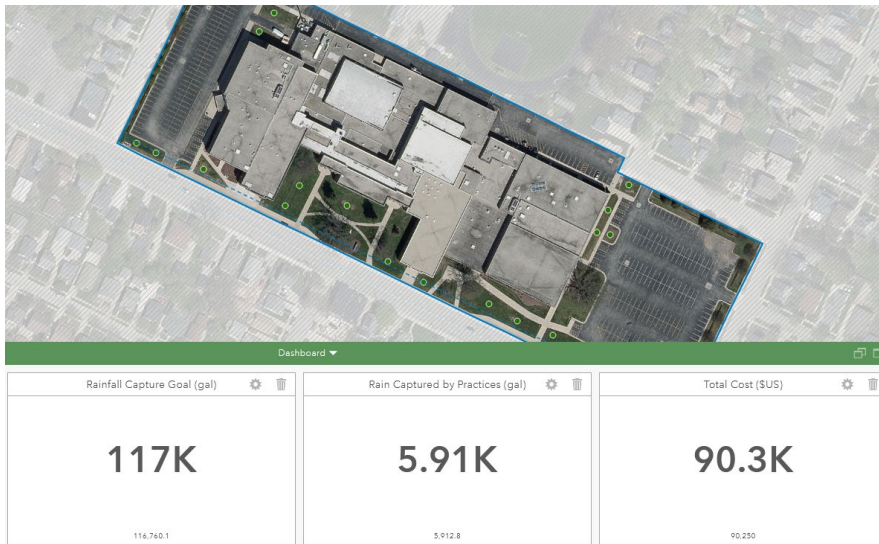

This will bring up another window, where you can choose which design layer to select from as well as what shape to draw when making a selection.
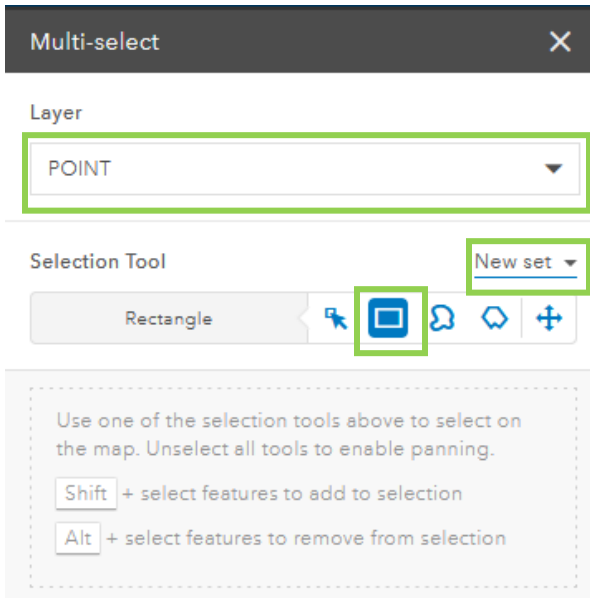
Selecting a feature also allows you to move it around, and with polygons it allows you to stretch and rotate them.

10. Return to **Drawing Tools** and keep adding trees, moving or deleting them as needed, until you are comfortable with the number and placement. You may quickly run out of space to reasonably place any trees without getting very close to meeting the capture goal, and that is okay. Trees can be placed in many areas and are relatively inexpensive to install and maintain, but their density is significantly constrained by other types of urban land cover and they do not capture as much water as other green stormwater infrastructure practices.

Rainfall Capture Goal (gal) ⚙ 🗑 | Rain Captured by Practices (gal) ⚙ 🗑 | Total Cost ($US) ⚙ 🗑

117K | **5.91K** | **90.3K**

116,760.1 | 5,912.8 | 90,250

Recap: In this section we covered editing scenarios; selecting, adding, moving, and deleting design features; and updating dashboard indicators.

Green Roofs

1. Now we will move onto green roofs, a unique practice that, at least on our site, has more options for placement than trees. First, we will have to create a new scenario named **Green Roof only**.
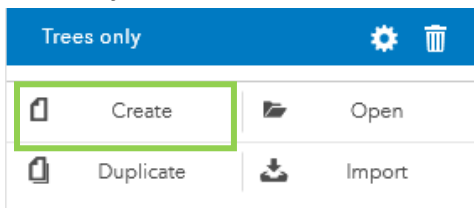
2. Open up the design tab, changing the Symbol Palette to **Polygon**.
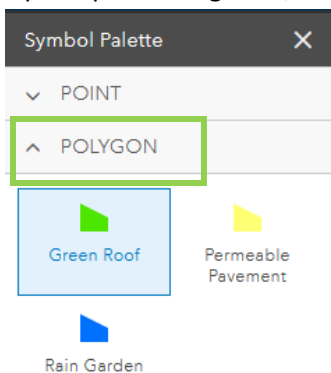
3. For best performance, make sure **Draw Polygon** is selected.

4. Add a green roof to a small portion of the high school's roof by clicking on the map where you want the vertices to be. When placing the last vertex, double-click to finish drawing. You will

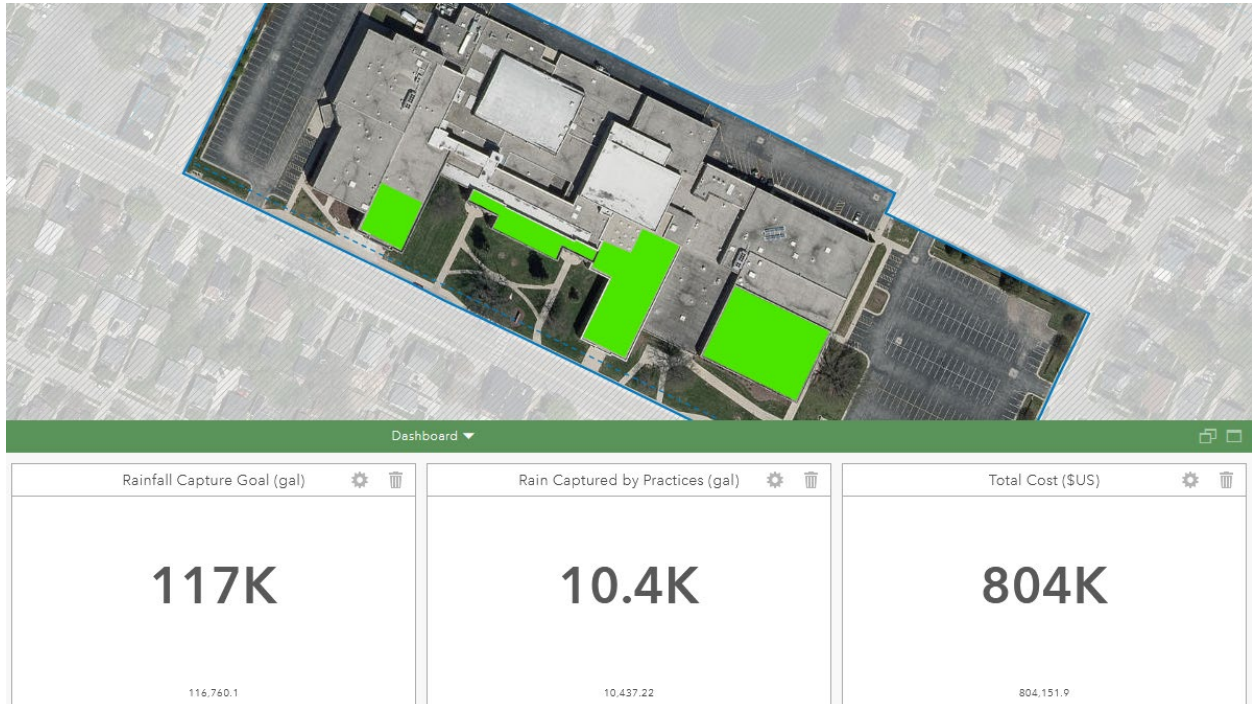notice the dashboard update, likely with the same warning icon as earlier. Since we are only using one kind of practice, it does not matter much yet, but will eventually come into play.
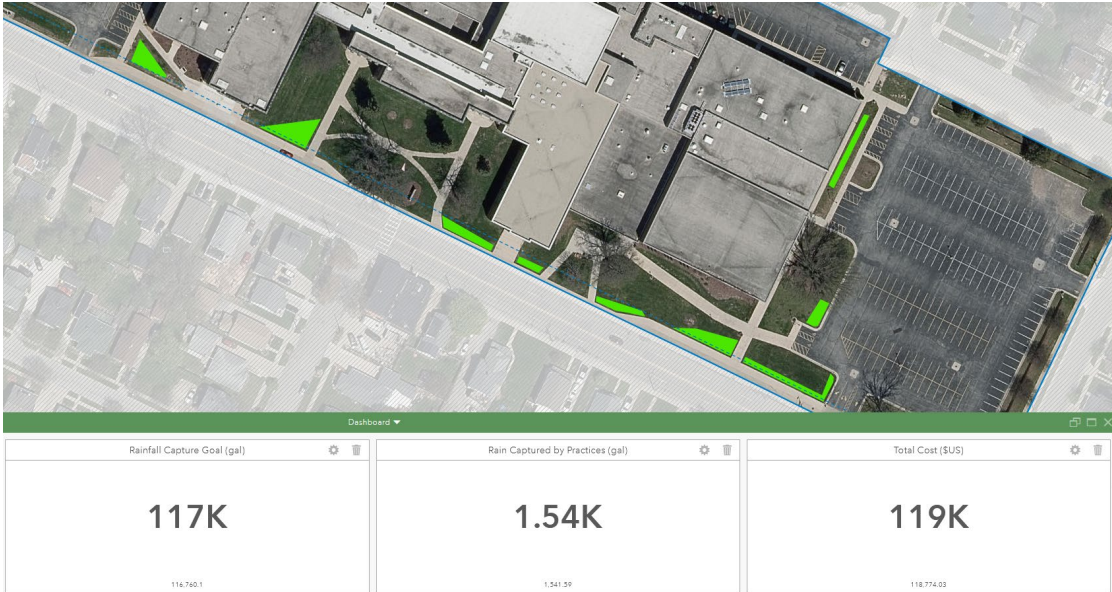
5. Place a few more green roof polygons, obviously sticking to the roof of the building. You'll quickly notice how expensive green roofs are, even though they don't capture very much rain. This is because their location on rooftops precludes any water from being drained into them – they can only capture what water falls on them directly. Even so, the materials required to prevent water seeping onto the roof – and to support the weight of necessary soil – are quite expensive. Thus, while this scenario captures almost twice as much water as our previous scenario (trees only), it costs almost nine times as much.

Rainfall Capture Goal (gal)	Rain Captured by Practices (gal)	Total Cost ($US)
117K	10.4K	804K
116,760.1	10,437.22	804,151.9

Recap: In this section we created a new scenario, introduced polygon design features, and cursorily compared two different scenarios.

Rain Gardens
1. Next, we will move on to rain gardens, which offer the largest amount of water captured per square foot, but do so by draining a large area around them, and thus cannot be placed too near to each other. Even so, they will be a useful part of any rainwater-capturing landscaping.
2. Create a new scenario named "Rain Gardens only" and make sure you are drawing a polygon (not freehand).
3. Find a few spots on the school's grounds to add a rain garden. Rain gardens are designed to capture the runoff of nearby impervious surfaces, so look for areas in between the school's roof and the sidewalk/road. After adding a few, you might have an image like the one below.

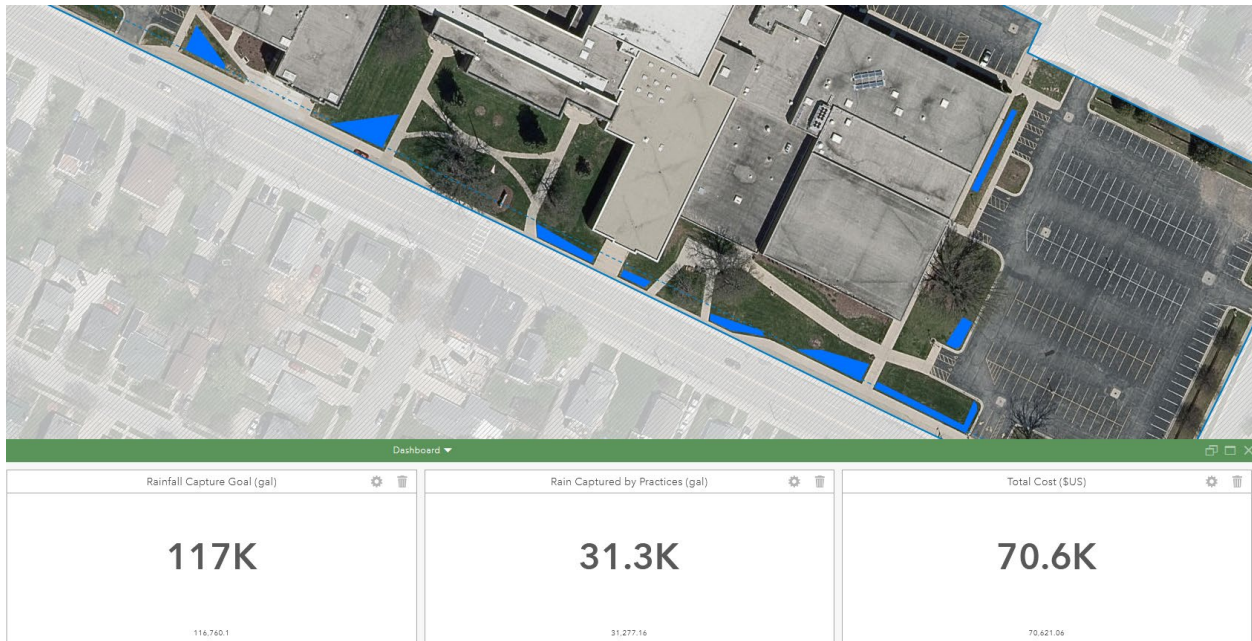| Rainfall Capture Goal (gal)	Rain Captured by Practices (gal)	Total Cost ($US)
117K	**1.54K**	**119K**
116,760.1	1,541.59	118,774.03

4. Whoops! It looks like I forgot to swap from **Green Roof** to **Rain Garden** in the symbol palette. That's okay, we don't have to start over, we can just 'paint' the polygons a different color/practice.

5. Select "Paint" under the Design tab, and make sure you have selected **Rain Garden** in the symbol palette.

6. Then, either select polygons individually or by drawing a selection rectangle around them and turn them into rain gardens.

Rainfall Capture Goal (gal)	Rain Captured by Practices (gal)	Total Cost ($US)
1.38M	**1.54K**	**119K**
1,378,449.57	1,541.59	118,774.03
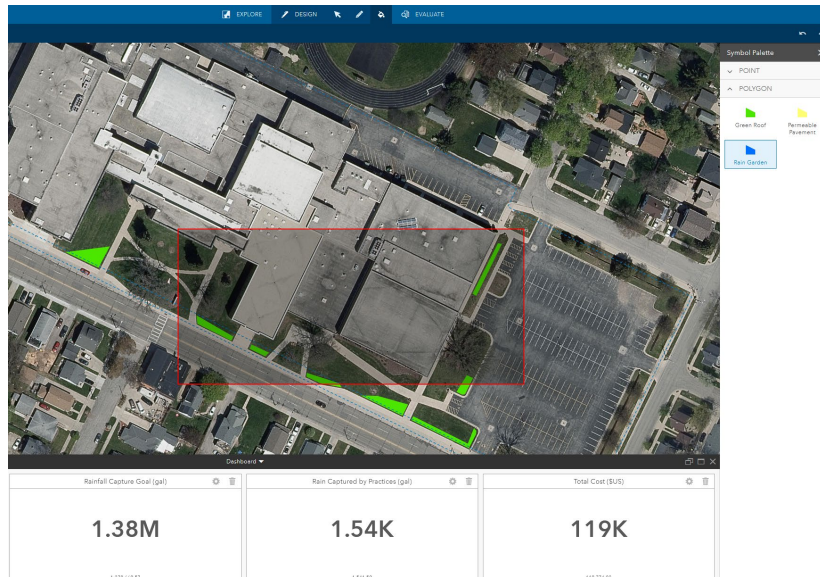
7. After changing them all over to rain gardens, you should have an image like that below.

| Rainfall Capture Goal (gal) ⚙ 🗑	Rain Captured by Practices (gal) ⚙ 🗑	Total Cost ($US) ⚙ 🗑
117K	**31.3K**	**70.6K**
116,760.1	31,277.16	70,621.06

8. You'll notice that you quickly run out of places where rain gardens make sense, but that they have made significant progress towards the site capture goal. In addition, this comes at a relatively low cost (compared to green roofs).

Recap: In this section we created a new scenario, introduced an additional polygon design feature, and covered how to change design type using the "paint" feature.

Permeable Pavement

1. A good portion of this site's impermeable surfaces comes from its parking lots and access road. Because they are lower than surrounding vegetated areas, it is difficult to drain the water that falls on them to adjacent rain gardens. Thus, we will investigate how making the pavement itself more permeable will allow the rainfall to infiltrate right then and there instead of running off into storm drains.

2. Create a third scenario named "Permeable Pavement only"

3. Then, in the **design** tab swap back to **Polygon** and select **Permeable Pavement**. Make sure you are drawing a polygon (not freehand) and turn on **Snapping**. This ensures that any vertex you draw doesn't overlap with another polygon or layer, but perfectly intersects with it, instead. This will help us when drawing along the edge of the study area.

4. Pan up to the northern edge of the high school and draw a polygon covering the back access road behind the school. Snapping is helpful here to line up the polygon with the
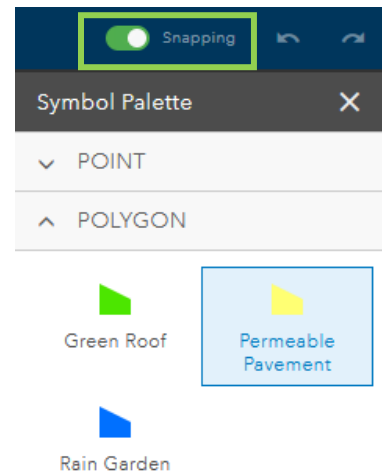
study area boundary. After finishing the access road, cover one of the parking lots with another polygon.

Rainfall Capture Goal (gal)	Rain Captured by Practices (gal)	Total Cost ($US)
117K	94.6K	588K
116,760.1	94,588.6	588,265.38

5. Permeable pavement is a powerful tool for turning previously impermeable surfaces into permeable ones. However, it is not without its downsides, such as rougher rides for vehicles and an increased maintenance cost (predominantly from regularly cleaning the gaps between pavers). For these reasons, it may be advantageous to design a scenario using multiple different practices.

Recap: In this section we created a new scenario, introduced our final polygon design feature, and used "snapping" to aid in the placement of practices.

Creating a multi-practice scenario

Each of these four practices - trees, green roofs, permeable pavement, and rain gardens - are tailored to different spaces. Where permeable pavement may be appropriate for a parking lot or sidewalk, a rain garden is better suited to areas down slope from such areas, so that water can be channeled towards it. This is partly why, when restricting scenarios to only one type of green stormwater infrastructure, it is either impossible or impractical to meet Green Bay High School's water capture goal.

As such, let's now move towards a scenario that incorporates all four of these GSI practices to meet the capture goal.

1. Create a new scenario, naming it "All Practices Allowed"
2. Beginning with any of the practices, place points and polygons until their total water capture meets (and hopefully exceeds) the water capture goal that we've set. Below is one example of such a site plan, if you are in need of inspiration.
3. Remember to update the dashboard indicators periodically to ensure you have the fullest count of water capture.

Once you've met or exceeded the goal, you are done with part 2! Feel free to move onto part 3 now or wait until later. ArcGIS GeoPlanner will automatically save your progress.

Recap: In Part 2 we learned about scenarios, the various designing tools, and the benefits/drawbacks of each of the four green stormwater infrastructure practices.

Part 3: Compare Design Scenarios Across Spatial Scales

While designing a stormwater capture plan for a given site is great, there is a lot more work to be done in order for cities *as a whole* to reduce their stormwater runoff. In order to accomplish this, individual site plans will have to be assessed in the context of wider geographic needs. In other words, how one site is designed may be determined – in part – by how other nearby areas are designed. Places where lots of practices can be placed may need to overshoot their site's individual goal to make up for nearby areas which cannot meet their own site goals.

To aid in this multi-scale assessment, GeoPlanner provides users with the ability to quickly change the area of focus on the map, and thus the dashboard indicators based off of that area. This will allow us to compare how far practices on one site go towards meeting a larger area's capture goal.

1. To see this in action, first we will need to create a second study area. Turn on **Green Bay Storm Basins**, and turn off all other data layers and study areas. Click somewhere around the high school. You should be met with a pop-up that includes "**BASIN: 992**".
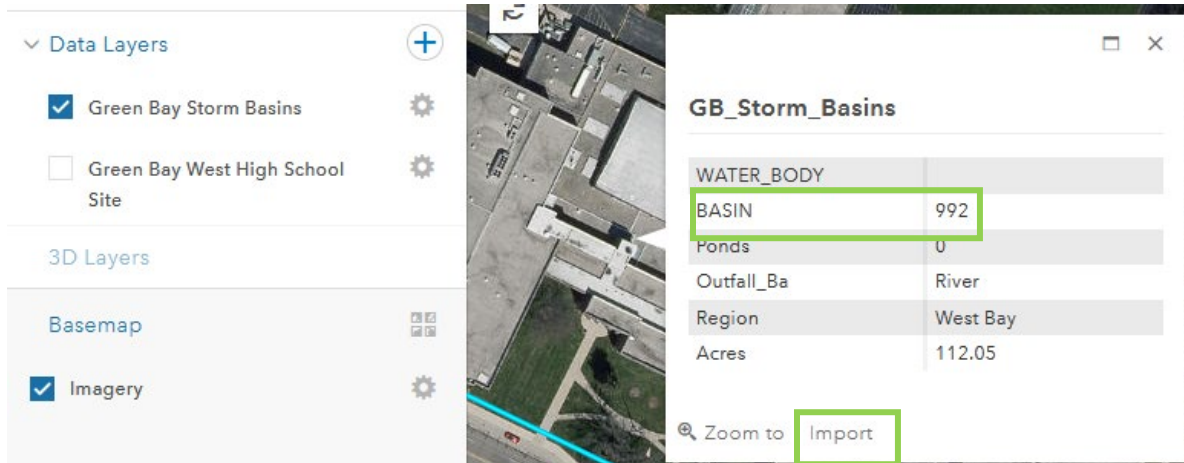

a. Select **Import** and add this polygon as a Study Area. This will add only Storm Basin 992 as a Study Area, allowing us to use this boundary without the map getting visually confusing with the other storm basins present.

Moving Between Study Areas

1. Now that we have a second study area, you can switch between them by selecting "Make Active" on a different Study Area.
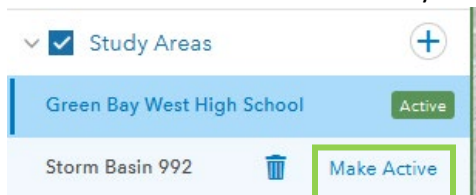
2. Doing this will immediately change two things: the focus of the map and the value of the [squareFeet] variable used in any dashboard indicators based on Study Areas (square feet for Polygons and Points is not changed). Note how these two items change (images below) when swapping the activation from the high school to the storm basin.
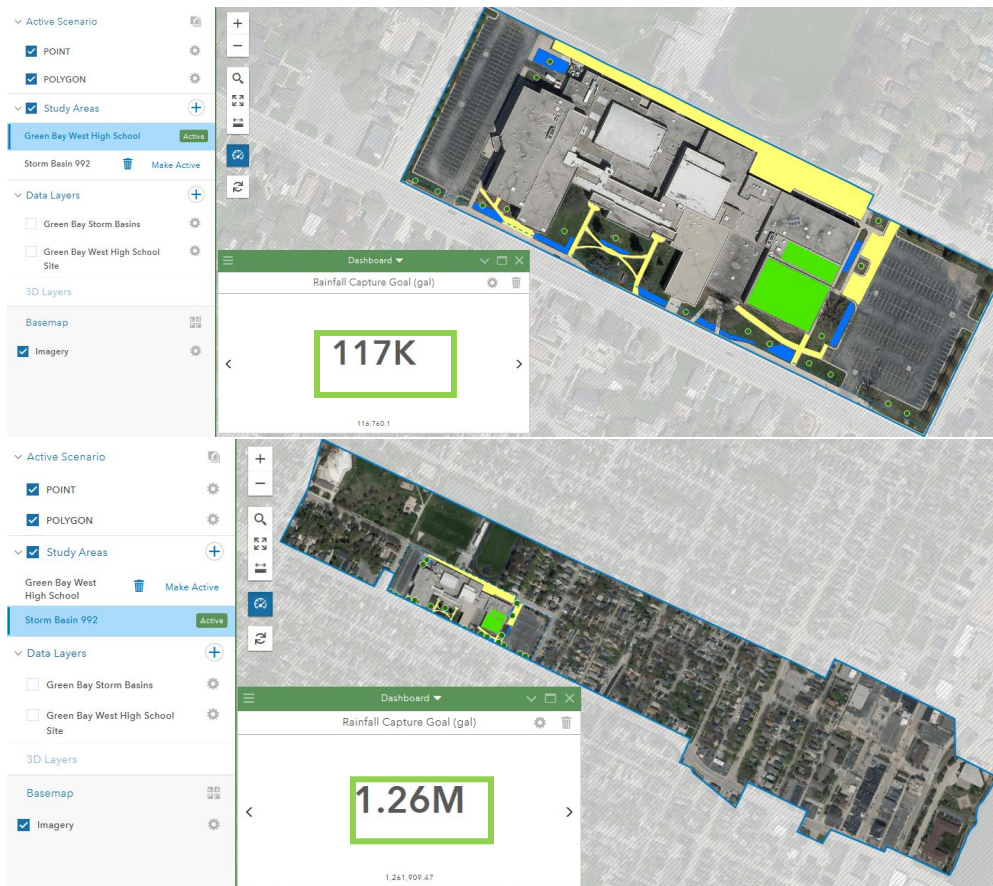
3. This will be a crucial tool for assessing how the practices we added in Part 2 impact capture goals for other geographic areas. We placed those practices in order to meet a capture goal for a high school, but this process lets us see how actions like that help add up to meeting a capture goal for a much larger area.

4. However, caution is advised when it comes to how swapping the active study area impacts certain dashboards. The swap is useful because it automatically changes the area (squareFeet) value, but many indicators use other variables in their calculation that *aren't* updated automatically. For instance, the "Rainfall Capture Goal (gal)" indicator – one of the two main indicators we are using to assess green stormwater infrastructure implementation – includes in its equation 3 other elements: rainfall in inches, a constant used to convert that number to one with more useful units, and the percentage of an area's surface that is impermeable.

5. The first two aren't much of an issue: the amount of rainfall we are modeling off of (0.5 inches) is not dependent on the area we are studying, and the conversion factor is a mathematical constant inherent to how the various units involved relate to one another. The third, however – the ratio of impermeable to permeable area – is of vital importance to our topic as well as being very site-specific. As such, we must address it when changing study areas in order to maintain an accurate capture goal calculation.

Modifying the Capture Goal

1. Changing the capture goal – the second step necessary to compare scenarios across scales – is relatively simple, as one merely needs to change the value of "Impermeable Area Ratio" in the "Constants" section of the dashboard settings. This change will propagate to the "Rainfall Capture Goal (gal)" indicator, which will then have a capture target accurate for the updated study area.
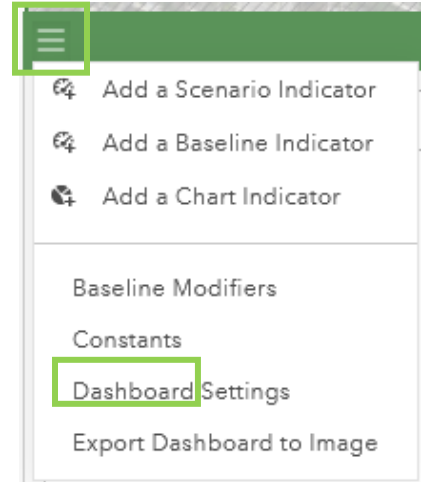
2. However, now that we know *how* to change the impermeable area ratio, what do we change it *to*? We could ask the same question of the value already here: where did "0.83" come from? Well, GeoPlanner was not actually used to calculate this. The value of "0.83" – which means that 83% of the area is covered by an impermeable surface – was calculated using a tool called iTree Canopy. Hosted by the United States Forest Service, iTree Canopy allows users to perform a land classification analysis using random points on top of satellite imagery. While diving into the tool is out of the scope of this tutorial, you can view our workflow documentation here.

3. Suffice it to say, this tool was used to generate a number reflecting how much of the surface area in the two sites – Green Bay West High School and Storm Basin 992 – is impermeable. The numbers for both of these areas are included in the table below, along with statistics about how much water the combined practice scenario captured relative to each area's goal.

Geography	Impermeable Area	Rainfall Capture Goal	Percent captured by

	Ratio	(gal)	final scenario
Green Bay West High School	0.83	116,684.978	107.38%
Storm Basin 992	0.55	836,883.220	14.86%

4. You may be wondering why these particular kinds of boundaries were used. One main reason, as you have now explored, is that while it may make sense to plan for the construction of green stormwater infrastructure at a site scale (i.e., on property such as a high school), there is also great value in connecting such developments to various other geographies at a broader scale, such as a storm basin.

5. The two study areas also highlight the many different ways that space in a city can be categorized. The high school property makes sense when thinking about Green Bay in terms of social and political boundaries. But since water often flows in ways that don't match up to such human-made boundaries, a different geographic methodology is called for. Thus, stormwater engineers use geographies like storm basins and sewersheds to describe how water flows across landscapes. These different geographies can be nested – where an overarching boundary breaks down into smaller parts, which in turn break down again (and again) – or overlap in non-contiguous ways. Therefore, it is important, when designing any stormwater capture plan, to consider the multiple different boundaries that all crisscross the area in question.

This tutorial was largely focused on the site-scale because that is the scale at which green stormwater infrastructure is often designed and implemented. However, much of the value of GeoPlanner stems from its ability to act as a repository for many different proposals, plans, and scenarios, with the added benefit of comparing them across different spatial areas. Having worked through this tutorial, I hope it is clear how valuable such a tool can be when showing how GSI practices, though designed at a narrow, site-specific scale, can quickly combine their impacts when implemented across wide areas. Tracing a line from a single site, up to a block with a couple sites, then up the sociopolitical (neighborhoods, municipalities) and/or hydrological (storm basins, watersheds) track can be very valuable for designing, tracking, and advocating for green stormwater infrastructure. GeoPlanner makes this process simpler and more accessible for GIS novices to both use and understand.