National Park Service
U.S. Department of the Interior

Urban Ecology Research Learning Alliance

# Understanding the Effects of Tree Removal in Soapstone Valley Using i-Tree Software

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## Abstract

i-Tree Hydro modelling is used to predict the effects of tree removal, one element of a planned sewer rehabilitation project, on the total flow, pervious runoff, and total suspended solids in the Soapstone Valley satellite park of Rock Creek Park and in the Soapstone Valley watershed. These factors are important to understand given the specific concerns of flooding and erosion in Rock Creek Park. i-Tree Canopy is used to calculate the land cover percentages for the i-Tree Hydro cover classes, while literature searches, a site visit to Soapstone Valley, and consultation with i-Tree experts also informed model inputs. The different land cover cases modelled include the current land cover prior to tree removal, predicted land cover after tree removal, and a possible revegetation scenario. Each of these cases are modelled during 3 representative years (average precipitation, a wet year, and a dry year) from the last 10 years. Additionally, a short-term, high intensity storm event and a long duration, low intensity storm event are modelled to understand the impacts of these two extremes. It appears that this project will have very little effect on both the Soapstone Valley watershed and Soapstone Valley Park scales. Further alterations to the inputs, including design, artificially created to have a specific intensity, duration, and frequency, storm events and consideration of erosion and sediment control measures, would be useful directions for future research.

## Acknowledgements

I would like to express my very great appreciation to Ann Gallagher, Science Education Coordinator for the Urban Ecology Research Learning Alliance at Natural Resources & Science, Region 1 - National Capital Area of the National Park Service, and Ana Chuquin, Natural Resource Botanist for the National Park Service, for their mentorship during this project, and for extending to me the opportunity to participate in this Quantifying Ecological Benefits of Trees in a National Park internship. They so generously gave their time to supervising me over the past four months and provided me with invaluable insight and guidance as I navigated this project. I would also like to thank Robert Coville, Natural Resource Specialist at The Davey Tree Expert Company and the Davey Institute, and James Kruegler, Urban Forest Hydrology Specialist at the Davey Tree Expert Company, whose expertise and i-Tree technical support I greatly benefitted from at all steps of this project. Further thanks is due to Cynthia Wanschura, Regional GIS Coordinator, Region 1 – National Capital Area of the National Park Service, for her guidance in sourcing and creating the digital elevation models. Finally, I would like to thank Matt Schley, Hydrologist at the National Park Service, for providing me with suggestions for my report from a hydrology perspective.

## Introduction

Soapstone Valley Park is a satellite park unit of Rock Creek, in the National Capital Area: Region 1. District of Columbia forest land connects Soapstone Valley to the southwestern part of the main body of Rock Creek Park. A tributary of Rock Creek, Soapstone Creek, runs through the valley and is flanked by banks with 15-40% slope (United States Department of Agriculture n.d.). While the parkland is forested with about 80-100% canopy cover (Ana Chuquin, personal communication, 2020), its watershed is encompassed by a mixture of residential, commercial, and institutional land. The park also contains dirt trails and creek crossings for visitor use.

DC Water, the District of Columbia's water treatment utility, is preparing to perform sewer rehabilitation on the outdated pipes within Soapstone Valley Park. Though using trenchless methods designed to minimize disturbance, the project requires removal of approximately 300 trees in Soapstone Valley, across both National Park Service (NPS) and DC land, to make paths for equipment to access existing manholes (National Park Service 2019a). Once trees are removed, geotextile, mulch, and wooden mats will be installed on the access paths and will remain in place throughout the construction process. At the conclusion of the project, the cleared areas will be revegetated using NPS-approved seed mixes with consideration to contiguous habitat and invasive species suppression (National Park Service 2019c).

The possible effects of tree removal at this site are wide ranging including impacting forest resilience to climate change, increasing edge habitat, enhancing opportunity for invasive species to flourish, reducing refugia habitat for urban wildlife, and impacting visitor access. Of specific concern in Soapstone Valley Park, and Rock Creek Park as a whole, is the effect that tree removal may have on the hydrology of the area, as it experiences risk of flooding and erosion.

I am exploring the use of the i-Tree modelling software as a tool for understanding the effects of the planned land cover change in Soapstone Valley on hydrology of the park. i-Tree is a peer-reviewed software suite offered by the USDA Forest Service that “provides urban and community forest analysis and benefit assessment tools” (i-Tree 2020). One analysis tool in the suite is i-Tree Hydro, a desktop application specifically designed to model the effect of urban land cover and vegetation change on hydrology and water quality (i-Tree 2020). i-Tree Hydro may be used for both watershed or non-watershed simulations based on a user-input digital elevation model. It allows comparison of a base case and alternative cases between which land cover, directly connected impervious area, and canopy parameters may be adjusted. Other specific hydrological and advanced vegetation parameters may also be specified, or the model can be run with default values. Model outputs are presented in an executive summary, bar graphs, or time series line graphs or tables.

In addition to addressing questions about the effect of this sewer rehabilitation project on Soapstone Valley Park and its watershed, further implications of this study include broadening the use of i-Tree tools to support science-informed management decisions within the National Park Service.

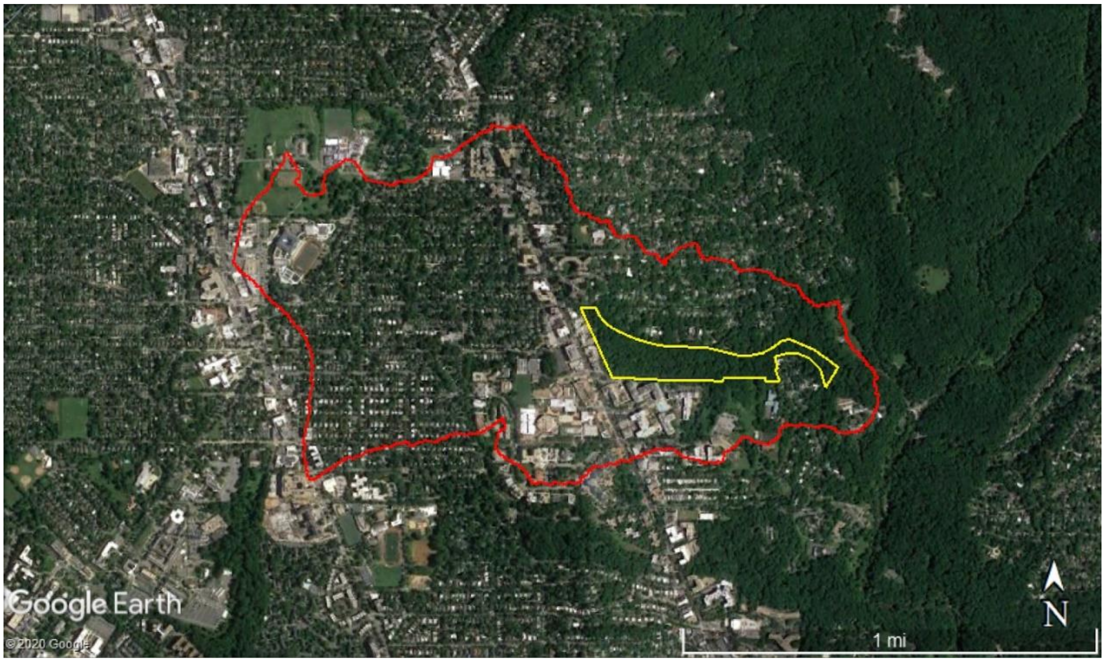


**FIGURE 1**: Red outline: Soapstone Valley Watershed; Yellow outline: Soapstone Valley NPS Land (Google Earth Pro 2020)

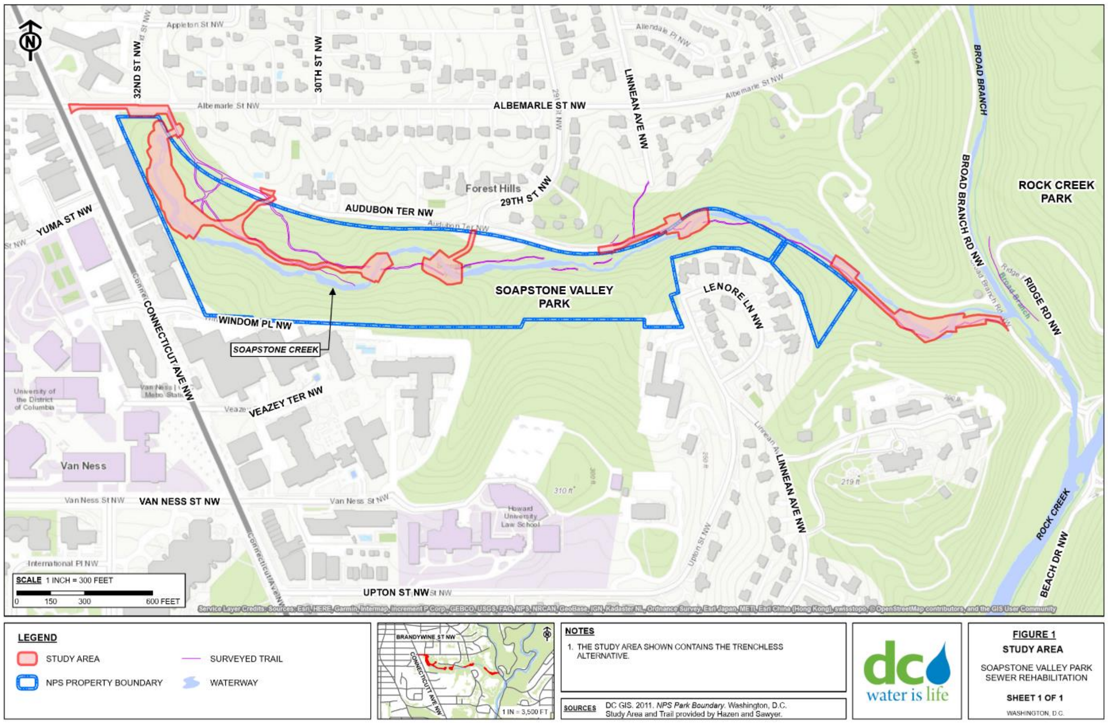


**FIGURE 2:** Tree removal and access path installation within red polygons (National Park Service 2019b)

## Methods

I modelled 3 land cover scenarios for both the Soapstone Valley watershed and the Soapstone Valley NPS Land: the Base Case with land use as it is today, Alternate Case 1 with land use following tree removal, and Alternate Case 2 with land use representing a possibility of the preliminary rehabilitation stages. I also modelled 5 different weather scenarios for the study areas and each of the land cover scenarios, focusing on extremes to better understand the possible effects of different levels and durations of precipitation.

i-Tree Hydro v6.3 beta is used as the primary modelling tool, with i-Tree Canopy used to find supporting information. The main task involved in modelling with i-Tree Hydro is collecting data for input into the modelling parameters. My process of data collection for this project includes a site visit to Soapstone Valley, literature searches, and consultation with i-Tree developers.

### Project Area Information

### *Topographic Data*

The i-Tree Hydro User's Manual (i-Tree 2020) outlines directions for making a suitable digital elevation model. I used the USGS StreamStats tool (U.S. Geological Survey 2016) to delineate a watershed for Soapstone Valley (Fig. 3) and to obtain a shapefile polygon of the watershed. Using an image (Fig. 2) from the Soapstone Valley Park Sewer Rehabilitation Environmental Assessment (2019a), I georeferenced the study area to obtain a polygon of National Park Service land within Soapstone Valley. As recommended by the i-Tree Hydro experts (personal communication, 2020), a 1/3 arc-second 10m resolution 3DEP image of the study area (U.S. Geological Survey 2020) was used to develop digital elevation models (DEM) for the Soapstone Valley watershed and the NPS land in Soapstone Valley. These DEMs were used as the topography data for i-Tree Hydro to model.

Within i-Tree Hydro, catchment areas can be associated with a stream gage, which is selected using the internal Stream Gage Selector to utilize USGS hourly stream gage data (i-Tree 2020). In the context of i-Tree Hydro, non-catchment areas are not treated as watersheds, and therefore are not auto calibrated using stream gage data. Soapstone Valley Park and its watershed do not contain a stream gage. While the Soapstone Valley watershed may be considered a catchment area, Soapstone Valley Park may be more usefully characterized by park managers as a non-catchment area because of its park-defined boundaries. So, both study regions are treated as non-catchment areas for the purpose of i-Tree Hydro modelling.

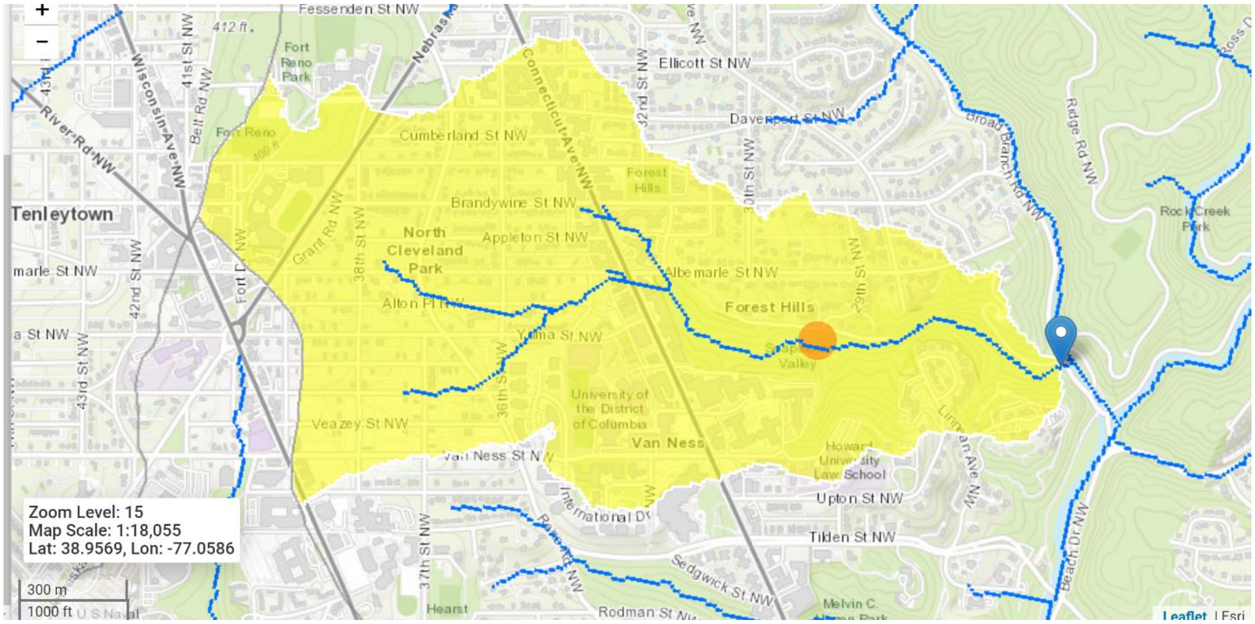


**FIGURE 3:** Soapstone Valley watershed (U.S. Geological Survey 2016)

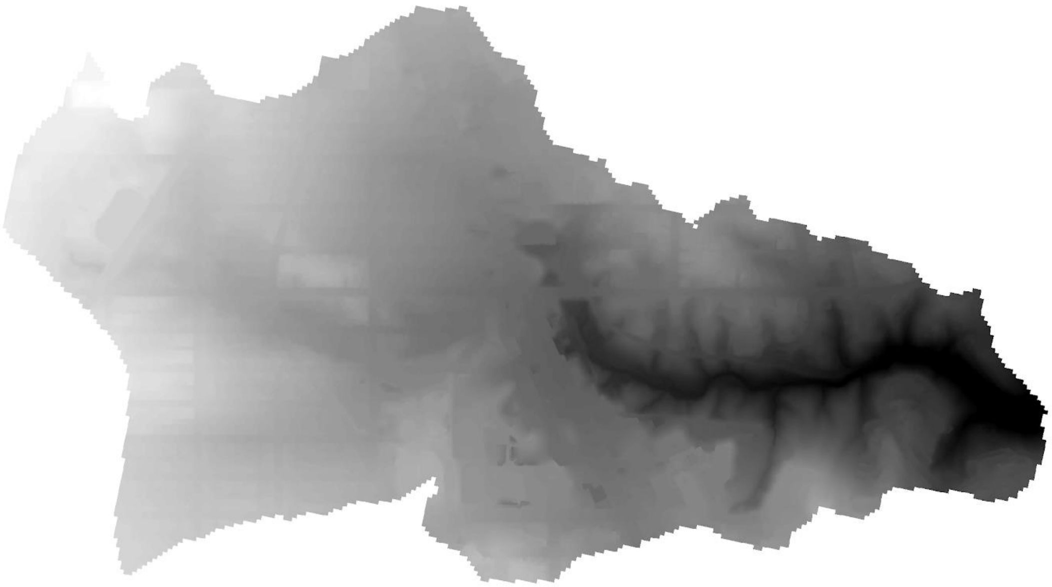


**Figure 4:** Soapstone Valley Watershed digital elevation model (USGS

*Weather Station Data*

Using the weather station locator in i-Tree Hydro, I identified the closest weather station as Ronald Reagan Washington International Airport, station number 724050-13743. I averaged the amount of precipitation over the last full, recorded 10 years (2010-2019) and found the year with closest to the average precipitation, the year with the most precipitation, and the year with the least precipitation (Table 1). From the average precipitation year, I selected the short duration, high intensity storm event by identifying the event that contained the single hour in which the greatest amount of precipitation was recorded. I chose a long duration rain event by identifying the 48-hour period with the greatest number of hours in which precipitation was recorded within the average year (Tables 1 and 2). Based on instruction from Robert Coville (personal communication, 2020), I downloaded and formatted the hourly weather data from the 3 reference years (average, wet, and dry years) for input into Hydro.

The standard operating procedure for using this raw weather data in Hydro is still being drafted, so I relied on Robert's instructions. In short, I downloaded raw weather data by year and station ID from NOAA FTP (National Centers for Environmental Information n.d.), unzipped the NOAA FTP raw data archive using 7-Zip, downloaded and unzipped the i-Tree Research Suite weather preprocessor (i-Tree n.d.), used the command line to navigate to the directory containing ishapp2.exe and finally generated the desired output file by entering "ishappe2.exe<raw-input-file-path> <output-name-for-raw-formatted-output.txt>" (Robert Coville, personal communication, 2020). This output file is correctly formatted for use in i-Tree Hydro.

When modelling a rain event in i-Tree Hydro, it is best practice to expand the simulation period to include at least one rain event preceding the event of interest so that the variables have a chance to overcome any initial extremes and reach a stable state (Robert Coville, personal communication, 2020). In addition to including the preceding rain event, I observe 60 hours after the last instance of precipitation in the event, during which time no additional rain fell. So, the period used for calculation of total flow, pervious runoff, and sum of mean TSS for the high intensity and low intensity storm events are between the hour of the event's first rainfall to 60 hours after the end of the event's rainfall, and do not include the preceding storm event (Table 2). The amount of time modelled by Hydro reflects the inclusion of the preceding rain event and remaining hours of the last observed day to 23:00:00, which is advised for running the v6.3 beta model.

For the short and long duration scenarios, I selected rainfall events based on their high magnitude and long duration characteristics with the understanding that results of these events are not necessarily representative of broader trends (Robert Coville, personal communication, 2020). Stormwater engineers or other management professionals may prefer to use a design rain event with artificially distributed rainfall. Currently, i-Tree does not have guidance for customization of these rainfall inputs, however Robert Coville provided some resources to inform accomplishing this (personal communication, 2020).

Total rainfall for a design storm is available for DC from the NOAA Atlas 14 Point Precipitation Frequency Estimates (National Oceanic and Atmospheric Administration 2005). Also available on the NOAA Atlas page's Supplementary Information is a Temporal Distribution table for a 24-hr period, which outlines how precipitation is likely distributed by hour during the event. The USDA Natural Resources Conservation Service offers information on rainfall frequency, and distributions (n.d.a.) and offers an overview on design rainfall distributions using NOAA Atlas (Merkel, Moody, and Quan 2015). Methods for inputting the precipitation timeseries into the weather format for Hydro can be found on the i-Tree Hydro Forum (Coville 2018).

Table 1. Reference Precipitation Ranges

| Weather Condition | Dates | Precipitation (mm) | Soapstone Watershed # Flow Events Above 1 SD | Soapstone NPS # Flow Events Above 1 SD |
|---|---|---|---|---|
| Average Year | 01/01/2019 at 00:00:00 - 12/30/2019 at 23:00:00 | 1114.81 | 21 | 14 |
| Wet Year | 01/01/2018 at 00:00:00 - 12/30/2018 at 23:00:00 | 1739.65 | 26 | 22 |
| Dry Year | 01/01/2016 at 00:00:00 - 12/30/2016 23:00:00 | 849.38 | 19 | 14 |

Table 1 displays the dates and associated information for the weather of the 3 modelled years.

Table 2. Reference Precipitation Durantions

| Weather Event | Dates | Period of Observation | Duration of Storm Event | Precipitation (mm) | Selection Criteria |
|---|---|---|---|---|---|
| Short Duration | 07/06/2019 at 00:00:00 - 07/11/2019 at 23:00:00 | 07/08/2019 at 8:00:00 – 07/11/2019 at 13:00:00 | 07/08/2019 at 08:00:00 – 07/08/2019 at 13:00:00 | 90.68 | 82.8 mm in 1 hour |
| Long Duration | 01/29/2019 at 00:00:00 - 02/15/2019 at 23:00:00 | 02/10/2019 at 22:00:00 – 02/15/2019 at 12:00:00 | 02/10/2019 at 22:00:00 – 02/13/2019 at 00:00:00 | 29.46 | 39 hours with precipitation recorded in 48- hour period |

Table 2 shows the dates modelled in i-Tree Hydro, period of observation used to calculate results, duration of the storm event, and other associated information for the 2 modelled storm events.

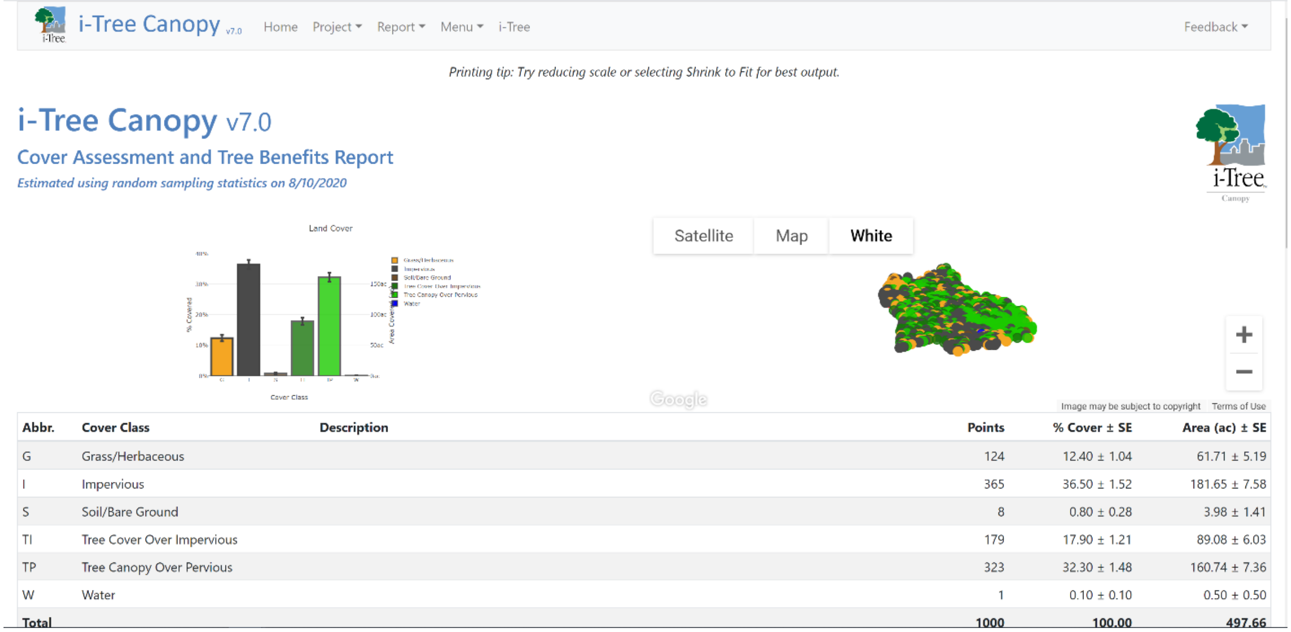
## Land Cover Inputs

### *Project Area*

The StreamStats application provided the area for the Soapstone watershed. The area of Soapstone Valley Park was determined by calculating geometry in ArcGIS 10.4.1. The Soapstone Watershed is 499.20 acres, and the NPS land within the Soapstone watershed is 26.09 acres, representing 5.23% of the watershed. The total area of tree canopy loss due to removal, calculated using ArcGIS, is 4.23 acres, 2.89 acres of that within Soapstone Valley Park NPS boundaries. The tree removal represents 0.85% of the Soapstone Valley Watershed, and 11.08% of Soapstone Valley Park.

### *Bulk Land Cover Area*

I used i-Tree Canopy to review Google Maps aerial photography and classify the land cover of 1000 random points in the Soapstone Valley watershed. The six categories needed for Hydro are: Pervious Under Tree Canopy, Impervious Under Tree Canopy, Herbaceous, Water, Impervious, and Bare Soil. While Hydro also considers Shrub Canopy area, this was difficult to distinguish from other vegetation classes in aerial photographs, so I did not estimate shrub cover using i-Tree Canopy. To find percentage values for Pervious Under Tree Canopy and Impervious Under Tree Canopy, I inferred land cover under the canopy based on visual interpretation of i-Tree Canopy imagery.



*Printing tip: Try reducing scale or selecting Shrink to Fit for best output.*

i-Tree Canopy v7.0

Cover Assessment and Tree Benefits Report

*Estimated using random sampling statistics on 8/10/2020*

| Abbr. | Cover Class | Description | Points | % Cover ± SE | Area (ac) ± SE |
|---|---|---|---|---|---|
| G | Grass/Herbaceous | | 124 | 12.40 ± 1.04 | 61.71 ± 5.19 |
| I | Impervious | | 365 | 36.50 ± 1.52 | 181.65 ± 7.58 |
| S | Soil/Bare Ground | | 8 | 0.80 ± 0.28 | 3.98 ± 1.41 |
| TI | Tree Cover Over Impervious | | 179 | 17.90 ± 1.21 | 89.08 ± 6.03 |
| TP | Tree Canopy Over Pervious | | 323 | 32.30 ± 1.48 | 160.74 ± 7.36 |
| W | Water | | 1 | 0.10 ± 0.10 | 0.50 ± 0.50 |
| Total | | | 1000 | 100.00 | 497.66 |

**Figure 5:** i-Tree Canopy Cover Assessment of Soapstone Valley Watershed

For the Soapstone Valley NPS land, the land cover results using i-Tree Canopy returned 100% Tree Canopy. I knew this was not accurate based on my observations during my site visit and based on the estimation of 80-100% tree cover made by Ana Chuquin, the natural resource botanist at Rock Creek Park. Given these considerations, I estimated the tree cover to be 90%, and split the remaining 10% evenly amongst the remaining pervious surface classes. There is negligible impervious surface within Soapstone Valley Park, consisting mainly of manhole covers and exposed concrete supports, so I treated impervious area as 0%. Only tree removal occurring within the park boundaries is considered in the models for Soapstone Valley Park.

The i-Tree experts, Robert Coville and James Kruegler, indicated that directly connected impervious area (DCIA), the portion of impervious cover that conveys water directly to the stream (i-Tree 2020), is a sensitive parameter for the i-Tree Hydro model (personal communication 2020). The DCIA calculator included in i-Tree Hydro inputs total impervious cover (Impervious + Impervious Under Tree Canopy) into the Sutherland equations, which are commonly used to relate the total impervious area to the area's level of development (Sutherland 2000; United States Environmental Protection Agency 2010). The Soapstone Valley watershed most closely corresponds to the "Average" Sutherland equation, or "Medium Density" as found in the i-Tree Hydro DCIA calculator (James Kruegler, personal communication 2020). So, I estimated DCIA using this calculator and the "Medium Density" equation.

### *Canopy Leaf Parameters*

I did not find values for Tree, Shrub, and Herbaceous leaf areas specific to this study area, so I kept the default values. The i-Tree experts explained that the model is not very sensitive to these inputs and stated that the default values would be acceptable (personal communication 2020).

According to the National Land Cover Database (United States Geological Survey et al. 2010), forest type in this area is largely broadleaf deciduous, with 1.07% classified as "Mixed Forest" including both deciduous and evergreen trees. Because more detailed information about evergreen proportion for this section of Rock Creek Park was not available, I input 0% for the Evergreen Tree Canopy and Evergreen Shrub Canopy categories which was estimated during my site visit.

### *Soil Type*

According to the Natural Resources Conservation Service Web Soil Survey (United States Department of Agriculture n.d.b), the soil type in Soapstone Valley is "gravelly loam." The option within Hydro that most closely matches this soil type is "Sandy Loam" (Robert Coville and James Kruegler, personal communication, 2020), so this was used as the input for soil-type.

Land Cover Scenarios

### Base Case

The Base Case uses current, pre-rehabilitation estimates of land cover percentages for the Soapstone Valley Watershed (Table 3) and Soapstone Valley Park (Table 4) confirmed during the site visit.

### Alternate Case 1

Alternate Case 1 accounts for the short-term effects of the rehabilitation project by considering areas of tree removal as Bare Soil rather than Tree Canopy. Geotextile, mulch, and wooden mats will be installed on the ground and removed at the conclusion of the project, so are considered Bare Soil for modelling purposes. All other inputs remain the same as the Base Case. See Tables 3 and 4 for specific values.

### Alternate Case 2

Alternate Case 2 considers a possible future prediction in which the tree removal area is divided evenly between Shrub Canopy and Bare Soil. While the specific rehabilitation plan is speculative at this time, this case provides a broad, intermediary case for land cover after “planting a combination of 2.5-3-inch caliper trees, bushes, livestakes, and permanent seeding” (National Park Service 2019a). All other inputs are the same as the Base Case, and specific values can be found in Tables 3 and 4.

Table 3. Full Soapstone Watershed Land Cover i-Tree Inputs

| (%) | Base Case | Alternate Case 1 | Alternate Case 2 |
|---|---|---|---|
| Tree Canopy | 50.2 | 49.35 | 49.35 |
| Pervious Under TC | 32.3 | 31.45 | 31.45 |
| Impervious Under TC | 17.9 | 17.9 | 17.9 |
| Shrub Canopy | 0 | 0 | 0.42 |
| Herbaceous | 12.4 | 12.4 | 12.4 |
| Water | 0.1 | 0.1 | 0.1 |
| Impervious | 36.5 | 36.5 | 36.5 |
| Bare Soil | 0.8 | 1.65 | 1.23 |

Land cover percentages were obtained using i-Tree Canopy. Change in Tree Canopy and Bare Soil is based on ArcGIS calculation of tree removal area. These values were inputted into i-Tree Hydro during modelling.

Table 4. Soapstone Rock Creek Park NPS Unit Land Cover Inputs

| (%) | Base Case | Alternate 1 | Alternate 2 |
|---|---|---|---|
| Tree Canopy | 90 | 78.96 | 78.96 |
| Pervious Under TC | 90 | 78.96 | 78.96 |
| Impervious Under TC | 0 | 0 | 0 |
| Shrub Canopy | 2.5 | 2.5 | 8.02 |
| Herbaceous | 2.5 | 2.5 | 2.5 |
| Water | 2.5 | 2.5 | 2.5 |
| Impervious | 0 | 0 | 0 |
| Bare Soil | 2.5 | 13.54 | 8.02 |

Land cover percentages were obtained using i-Tree Canopy. Change in Tree Canopy and Bare Soil is based on ArcGIS calculation of tree removal area. These values were inputted into i-Tree Hydro during modelling.

*Comparisons*

For each case and precipitation scenario, I compared the model outputs of Total Flow ($m^3$), Pervious Runoff ($m^3$), and Sum of Mean Total Suspended Solids (TSS) (measured in kg/hour) over each modelled time period (identified in Table 1). As defined in the Executive Summary of the models produced by i-Tree, Total Flow is the amount of streamflow including pervious runoff, impervious runoff, and streamflow from groundwater with no recent storm runoff over the course of the model time period. i-Tree calculates total flow by multiplying the total stream flow rate for each hour by the watershed area for each land cover type and the total number of timesteps.

## Results

### Soapstone Watershed

Within the Soapstone Watershed, the greatest total flow, pervious runoff, and sum of mean hourly TSS occurs during the wet year, followed by the average year and dry year. Each of these values is higher for the Alternate Case 1, and the values for Alternate Case 2 fall between the other two cases. Similarly, the short duration rain event with high intensity has higher values than the long duration event. Total flow, pervious runoff, and sum of the mean TSS vary with the same pattern as total precipitation in the year.

Table 5. Soapstone Watershed Base Case

| | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Total Precipitation (mm) | 1114.81 | 1739.65 | 849.38 | 90.68 | 29.46 |
| Total Flow ($m^3$) | 1,567,553.7 | 2,859,718.4 | 1,041,552.4 | 176,004.8 | 34,120.4 |
| Pervious Runoff ($m^3$) | 1,141,463.7 | 2,156,147.4 | 730,993.0 | 136,573.8 | 21,577.0 |
| Sum of Hourly Mean TSS (kg/modelled time period) | 122,183.6 | 223,489.3 | 80,944.9 | 13,775.9 | 2,628.4 |

This table displays the measurements of total rainfall and model results of the Soapstone Watershed Base Case for each modelled weather condition.

Table 6. Soapstone Watershed Alternate Case 1

| | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Total Flow ($m^3$) | 1,568,616.3 | 2,860,961.4 | 1,042,688.5 | 176,034.8 | 34,135.27 |
| Pervious Runoff ($m^3$) | 1,142,526.3 | 2,157,390.6 | 732,129.3 | 136,603.9 | 21,591.9 |
| Sum of Hourly Mean TSS (kg/modelled time period) | 122,266.9 | 223,586.8 | 81,034.0 | 13,778.2 | 2,629.6 |

This table displays the model results of Alternate Case 1 for each modelled weather condition within the Soapstone Watershed.

Table 7. Soapstone Watershed Alternate Case 2

| | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Total Flow ($m^3$) | 1,568,384.7 | 2,860,625.3 | 1,042,435.5 | 176,028.1 | 34,130.7 |
| Pervious Runoff ($m^3$) | 1,142,294.5 | 2,157,054.5 | 731,876.2 | 136.597.2 | 21,587.3 |
| Sum of Hourly Mean TSS (kg/modelled time period) | 122,248.8 | 223,560.4 | 81,014.2 | 13,777.7 | 2,629.2 |

This table displays the model results of Alternate Case 2 for each modelled weather condition within the Soapstone Watershed.

Between the Base Case and Alternate Case 1, the i-Tree Hydro model found a projected increase in total flow of 0.07% in the average year, 0.04% in the wet year, 0.11% in the dry year, 0.02% in the high intensity rain event, and 0.04% in the long duration rain event (Table 5). The increase in pervious runoff in the modelled average, wet, dry, high intensity, and long duration weather is 0.09%, 0.06%, 0.16%, 0.02%, and 0.07% respectively (Table 6). Mean total suspended solids increase by 0.07% in the average year, 0.04% in the wet year, 0.11% in the dry year, 0.02% in the high intensity rain event, and 0.04% in the long duration event (Table 7).

Following revegetation efforts represented by Alternate Case 2, the model estimated an increase of 0.05%, 0.03%, 0.09%, 0.01%, and 0.03% in total flow from the Base Case for average, wet, dry, high intensity event, and long duration event (Table 5). Pervious runoff increased 0.07%, 0.04%, 0.12%, 0.02%, and 0.05% (Table 6), and mean total suspended solids increased 0.05%, 0.03%, 0.09%, 0.01%, and 0.03% for the average year, wet year, dry year, high intensity event, and long duration event respectively (Table 7).

Table 5. Soapstone Watershed Total Flow

| $m^3$ | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Alt 1 – Base | 1,062.6 | 1,243.0 | 1,136.1 | 30.0 | 14.9 |
| Alt 2 – Base | 831.0 | 906.9 | 883.1 | 23.3 | 10.3 |
| Alt 1 – Alt 2 | 231.6 | 336.1 | 253.0 | 6.7 | 4.6 |

This table displays the differences in total flow between the cases and for each weather condition in Soapstone Valley Park.

Table 6. Soapstone Watershed Pervious Runoff

| $m^3$ | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Alt 1 – Base | 1,062.6 | 1,243.2 | 1,136.3 | 30.1 | 14.9 |
| Alt 2 – Base | 830.8 | 907.1 | 883.2 | 23.4 | 10.3 |
| Alt 1 – Alt 2 | 231.8 | 336.1 | 253.1 | 6.7 | 4.6 |

This table displays the pervious runoff differences between the cases and for each weather condition in Soapstone Valley Park.

Table 7. Soapstone Watershed Sum of Hourly Mean TSS

| kg/modelled time period | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Alt 1 – Base | 83.3 | 97.5 | 89.1 | 2.4 | 1.2 |
| Alt 2 – Base | 65.2 | 71.1 | 69.2 | 1.8 | 0.8 |
| Alt 1 – Alt 2 | 18.2 | 26.4 | 19.8 | 0.5 | 0.4 |

This table displays the difference between each case in the sum of hourly mean TSS over the course of the study time period for the Soapstone watershed.

### Soapstone Valley Park NPS Unit

Within Soapstone Valley Park, the greatest total flow, pervious runoff, and sum of mean hourly TSS occurs during the wet year, followed by the average year and the dry year. Additionally, the high intensity storm has higher values than the long duration event. Precipitation is also greatest in the wet year, then the average year, dry year, high intensity event, and the long duration event. Overall, Alternate Case 1 has the greatest total flow, pervious runoff, and sum of mean TSS values, followed by Alternate Case 2 then the Base Case.

Table 8. Soapstone NPS Unit Base Case

| | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Total Precipitation (mm) | 1114.81 | 1739.65 | 849.38 | 90.68 | 29.46 |
| Total Flow ($m^3$) | 63,003.3 | 130,150.6 | 37,702.9 | 8,595.4 | 531.8 |
| Pervious Runoff ($m^3$) | 62,541.6 | 129,688.8 | 37,241.1 | 8,566.8 | 491.70 |
| Sum of Mean Hourly TSS (kg/modelled time period) | 4,903.3 | 10,167.6 | 2,919.7 | 671.6 | 38.6 |

This table displays the measurements of total rainfall and model results of the Soapstone NPS Unit Base Case for each modelled weather condition.

Table 9. Soapstone NPS Unit Alternate Case 1

| | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Total Flow ($m^3$) | 63,580.3 | 130,944.0 | 38,387.6 | 8,622.9 | 541.9 |
| Pervious Runoff ($m^3$) | 63,118.4 | 130,482.2 | 37,925.8 | 8,594.4 | 501.78 |
| Sum of Hourly Mean TSS (kg/modelled time period) | 4,948.5 | 10,229.8 | 2,973.4 | 673.8 | 39.3 |

This table displays the model results of Alternate Case 1 for each modelled weather condition within the Soapstone NPS Unit.

Table 10. Soapstone NPS Unit Alternate Case 2

| | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Total Flow ($m^3$) | 63,446.2 | 130,750.7 | 38,229.3 | 8,617.2 | 538.8 |
| Pervious Runoff ($m^3$) | 62,984.5 | 130,288.9 | 37,767.5 | 8,588.6 | 498.7 |
| Sum of Hourly Mean TSS (kg/modelled time period) | 4,938.0 | 10,214.7 | 2,961.0 | 673.4 | 39.1 |

This table displays the model results of Alternate Case 2 for each modelled weather condition within the Soapstone NPS Unit.

The modelled increase in total flow between the Base Case and Alternate Case 1 is 0.92% during the average year, 0.61% during the wet year, 1.81% during the dry year, 0.32% during the high intensity event, and 1.90% during the long duration event (Table 11). The increase in pervious runoff as a result of tree removal is 0.93%, 0.61%, 1.85%, 0.32%, and 2.05%, for an average year, wet year, dry year, high intensity event, and long duration event, respectively (Table 12). The positive change in mean TSS for each of the modelled weather conditions is 0.92%, 0.61%, 1.84%, 0.32%, and 1.90% (Table 13).

Between the Base Case and Alternate Case 2, the difference in total flow is a 0.70%, 0.46%, 1.40%, 0.25%, and 1.40% increase for the average year, wet year, dry year, high intensity event, and long duration event (Table 11). Pervious runoff increases by 0.71% in the average year, 0.46% in the wet year, 1.42% in the dry year, 0.25% in the high intensity event, and 1.42% in the long duration event (Table 12). Total suspended solids are expected to be 0.71%, 0.46%, 1.41%, 0.25%, and 1.42% greater than the Base Case depending on the modelled weather condition (Table 13).

Table 11. Soapstone NPS Unit Total Flow

| $m^3$ | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Alt 1 – Base | 576.9 | 793.4 | 684.7 | 27.5 | 10.1 |
| Alt 2 – Base | 442.9 | 600.1 | 526.4 | 21.8 | 7.0 |
| Alt 1 – Alt 2 | 134.0 | 193.3 | 158.3 | 5.7 | 3.1 |

This table displays the differences in total flow between the cases and for each weather condition in Soapstone Valley Park.

Table 12. Soapstone NPS Boundary Pervious Runoff

| $m^3$ | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Alt 1 – Base | 578.9 | 796.2 | 687.2 | 27.6 | 10.1 |
| Alt 2 – Base | 442.9 | 602.3 | 528.3 | 21.8 | 7.0 |
| Alt 1 – Alt 2 | 134.0 | 193.9 | 158.9 | 5.8 | 3.1 |

This table displays the pervious runoff differences between the cases and for each weather condition in Soapstone Valley Park.

Table 13. Soapstone NPS Boundary Sum of Hourly Mean TSS

| Kg/modelled time period | Avg Year | Wet Year | Dry Year | High Intensity | Long Duration |
|---|---|---|---|---|---|
| Alt 1 – Base | 45.3 | 62.2 | 53.7 | 2.2 | 0.7 |
| Alt 2 – Base | 34.7 | 47.1 | 41.3 | 1.7 | 0.6 |
| Alt 1 – Alt 2 | 10.6 | 15.1 | 12.4 | 0.5 | 0.1 |

This table displays the difference between each case in the sum of hourly mean TSS over the course of the study time period for Soapstone Valley Park.

## Conclusions

Even at the initial tree stage with maximum bare soil (Alternate Case 1), it seems as though this sewer rehabilitation project will have very little effect on the Soapstone Valley watershed. During the year-long weather condition models (average, wet, and dry), the increase in total flow ranges from 0.04% in the wet year to 0.11% in the dry year. Overall, the greatest change one could expect to see as a result of this work during the year-long weather models is a 0.16% increase in pervious runoff during dry conditions, with the least change of 0.06% in the wet year. The range in TSS is 0.04% to 0.11% from the wet and dry year, respectively. For the two event-based models, change from the base conditions in total flow, pervious runoff, and sum of TSS is greater in the long duration (0.04%, 0.69%, and 0.04%) than in the high intensity event (0.02%, 0.02%, 0.02%).

In hypothetical initial revegetation stages of the Soapstone watershed as modelled by Alternate Case 2, the greatest difference in total flow from the Base Case, 0.09%, is during the dry year, and the least change from the Base Case, 0.03%, is seen during the wet year. The high intensity rain event is also more similar to the Base Case, with a difference of 0.01%, while there is more difference, 0.03%, during the long duration event. With regards to pervious runoff, the dry year has the greatest increase of 0.07%, and the wet year has the smallest difference, 0.04%, from the Base Case. The high intensity rain event has a closer value to the Base Case than the long duration event, with a change of 0.02%

compared to 0.05% in the long duration event. Similarly, the difference in total suspended solids is greatest for the dry year, 0.09%, and smallest for the wet year, 0.03%. The high intensity rain event also has a smaller change in sum of mean TSS than the long duration event, with a comparison of 0.01% to 0.03%.

For the NPS unit, the effects of this sewer rehabilitation project are slightly higher than for the watershed as a whole, but remain relatively minimal. The difference in total flow between Alternate Case 1 and the Base Case is greatest during the dry year (1.81%) and the long duration event (1.90%), and smallest in the wet year (0.61%) and short duration event (0.32%). Pervious runoff also has greatest differences in the dry year and the long duration storm, 1.85% and 2.05%, and the smallest differences in the wet year and short duration event, 0.61% and 0.32%. Similarly, the largest differences in sum of hourly mean TSS are 1.84% and 1.90% in the dry year and long duration rain event respectively, while the wet year and high intensity event are more similar to the base case with 0.61% and 0.32%.

The revegetation alternative in Soapstone Valley Park, as modelled by Alternate Case 2, generally has comparable results to Alternate Case 1. The dry year and long duration event have the greatest increase from the Base Case, both with a value of 1.40%. The wet year and the short event are closest to the Base Case, with an increase of 0.46% and 0.25% respectively. This pattern is also exhibited in the pervious runoff and sum of the mean TSS differences from the Base Case. The dry and long rain event increases in pervious runoff are both 1.40%, while 0.46% and 0.25% are the smallest differences for the wet year and high intensity storm. With values of 1.41% and 1.42%, the dry year and long duration event show the greatest sum of mean TSS increase from the Base Case, and wet year and short duration event have the least increases of 0.46% and 0.25%.

One reason why the smallest changes are seen during the wet year is that it is possible this year had more high intensity storms. Trees do not make as much of a difference in mitigating runoff during high-intensity storm events, so the effects of tree removal would not be as evident in a year with these types of storms (Robert Coville, personal communication, 2020). This is also reflected by the models of the storm events. The long duration rain event always had greater change between the cases than the short duration, high intensity rain event. However, given that there is not statistical confidence in how these storm events represent broader trends, further research is needed to make a conclusion about this case.

Following the rehabilitation project, the revegetation in Alternate Case 2 could model what temporary longer-term impacts of the project might be for Soapstone Valley. The differences between this case and the Base Case are smaller than those of Alternate Case 1 for both the Soapstone Valley watershed and Soapstone Valley Park. This impact of reduced total flow, pervious flow, and mean TSS is expected given that vegetation helps to reduce these values. The modelled revegetation provides the greatest benefit mitigating total flow during the dry year and the long duration rain event, and the least change is seen during the wet year and the high intensity rain event.

Total suspended solids serve as an imperfect proxy indicator for erosion. While the sum of the mean TSS is greatest during the wet year and the high-intensity rain event, the greatest increase in total mean TSS due to tree removal occurs during the dry year and the long-duration event. Accurate estimates of erosion are dependent on specific hydrological factors, however i-Tree Hydro outputs may provide park managers with a supplemental and preliminary tool for considering erosion.

The overwhelming pattern is that the greatest effects of this change are seen during the dry year conditions. Out of the last 10 years of monthly precipitation averages for the District of Columbia (National Oceanic and Atmospheric Administration and National Weather Service n.d.), the month with the lowest average rainfall is November, followed by January. i-Tree models suggest that the effects of tree removal on total flow, pervious runoff, and the sum of the mean TSS are greatest during dry conditions. Given this information, park management might choose to ensure that revegetation efforts occur before the driest months in order to maximize mitigation of the more profound effects of the tree removal.

One consideration about this model is that it is a statistically distributed hydrology model (Robert Coville, personal communication, 2020), so it doesn't take into account information about the area where land cover change occurs. It is possible that this may impact the accuracy of results, depending on the characteristics of the land and land cover change, or that this tool may be less useful for certain questions in which location is particularly influential.

The Soapstone Valley Park Sewer Rehabilitation Environmental Assessment Appendix C (National Park Service 2019c) outlines some of the sediment mitigation measures in place throughout the project. The mitigation includes implementation of an approved Soil Erosion and Sediment Control Plan, such as installation of tree protection fencing and super silt fence along the boundaries of access paths (National Park Service 2019c). In the context of this project, these measures raise questions about how reasonably applicable i-Tree Hydro results are to management projects in situations where efforts to reduce runoff and sedimentation are installed.

Further research could use a design storm event to predict what the effects of specific storm events are. The results using a design storm could be representative of broader trends with statistical confidence, providing more applicable data for land management. Another possible direction for further research is learning how sediment and runoff control measures can be included within the i-Tree Hydro parameters to create a more accurate model of specific projects. Further consideration should be given to the interpretation of i-Tree Hydro model results with respect to other components of ecosystem dynamics such as fragmentation, forest edge, biodiversity of species, age categories, and tipping points.

Finally, these methods should be applied to additional areas and projects for fine-tuning, and to broaden the use of i-Tree tools in informing National Park Service management decisions.

**Appendix: Terms**

Alternative Case: The modeled scenario contrasted with the base case, with land cover and canopy parameter values changed.

Base Case: The original modeled scenario defined by the initial land cover values.

Catchment: For the purposes of i-Tree Hydro modelling, a catchment area is considered to be a watershed, such as the watershed for a USGS stream gage.

Design Rain Event: Artificial rain event created to have certain intensity, duration, and frequency.

Digital Elevation Model (DEM): According to the USGS, DEMs are “arrays of elevation values referenced to either a Universal Transverse Mercator (UTM) projection or to a geographic coordinate system.”

Directly Connected Impervious Area (DCIA): The portion of impervious are that conveys water directly to the stream only over impervious cover.

Hydrologic Unit Code (HUC): The identifying number for USGS-designated hydrologic regions within the United States.

Non-Catchment: For the purposes of i-Tree Hydro modelling, a non-catchment area is considered as an area that does not follow watershed boundaries, such as a park, city, or town’s municipal area.

Streamgage: Station that is used to monitor stream characteristics, such as velocity and water level.

Sutherland Equations: Equations are commonly used by hydrologists to relate total impervious area to the area’s level of development

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