Understanding the Effects of Tree Removal in Glover-Archbold 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 Glover-Archbold satellite park of Rock Creek Park and in the Glover-Archbold 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 and consultation with i-Tree experts 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 Glover-Archbold watershed and Glover-Archbold 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.

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Introduction

Glover-Archbold Park is a satellite park unit of Rock Creek, in the National Capital Area: Region 1. It is located southwest of the main body of Rock Creek Park, in western DC. Foundry Branch runs partially through Glover-Archbold Park, and runoff from the park outputs into the C & O Canal and the Potomac River. While the parkland is forested, it is intersected by four streets and its watershed is encompassed by a mixture of residential, commercial, and institutional land. The park contains dirt trails for visitor use.

DC Water, the District of Columbia's water treatment utility, is preparing to perform sewer rehabilitation on the outdated pipes within Glover-Archbold Park. Though using trenchless methods designed to minimize disturbance, the project requires removal of approximately 500 trees in Glover-Archbold. 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.

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 Glover-Archbold 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 Glover-Archbold 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 Glover-Archbold 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.

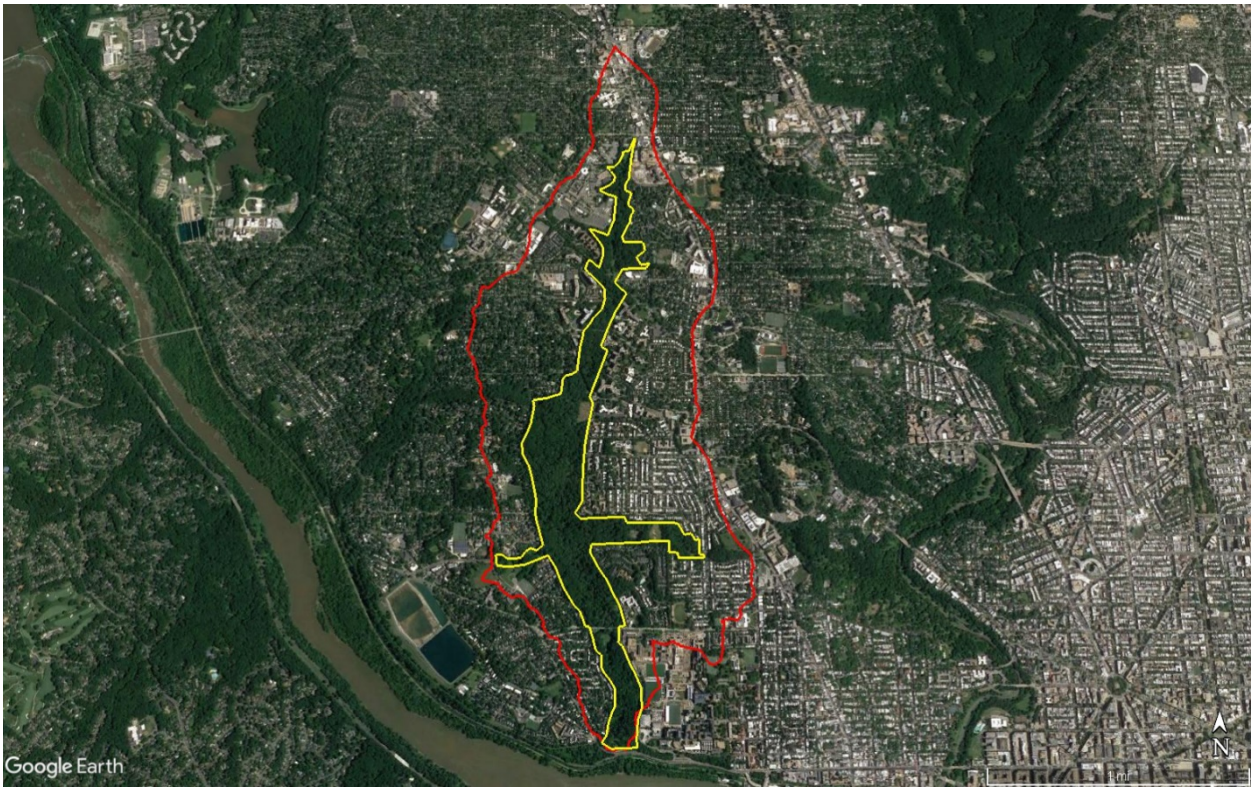

FIGURE 1: Red outline: Glover-Archbold Watershed; Yellow outline: Glover-Archbold NPS Land (Google Earth Pro 2020)

Methods

I modelled 3 land cover scenarios for both the Glover-Archbold watershed and the Glover-Archbold 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 literature searches, use of i-Tree Canopy, 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 Glover-Archbold (Fig. 3) and to obtain a shapefile polygon of the watershed. The Glover-Archbold park boundaries were outlined using a reference map image. 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 Glover-Archbold watershed and the NPS land in Glover-Archbold. 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. Glover-Archbold Park and its watershed do not contain a stream gage. While the Glover-Archbold watershed may be considered a catchment area, Glover-Archbold 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.

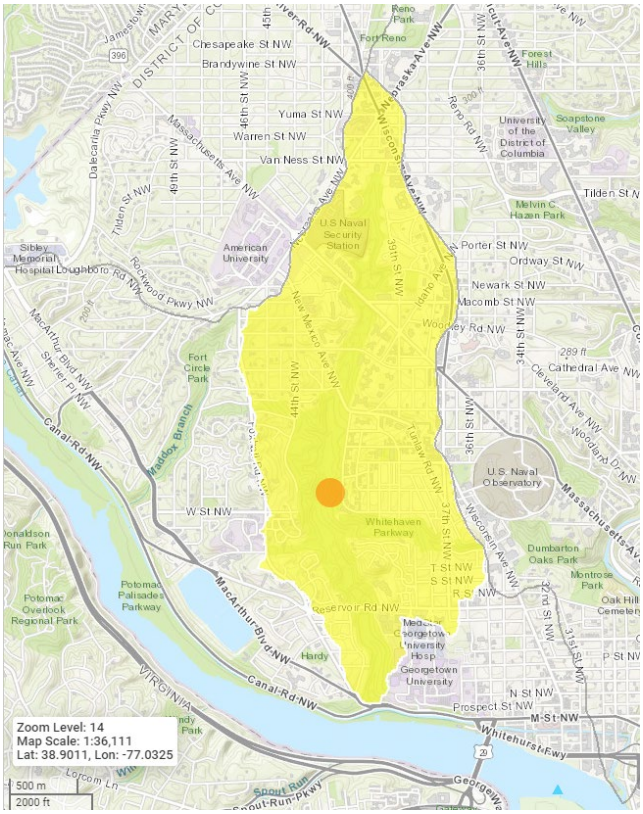

FIGURE 2: Glover-Archbold watershed (U.S. Geological Survey 2016)

Figure 3: Glover-Archbold Watershed digital elevation model

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. Details on how to format weather data for use in i-Tree Hydro can be found in the UERLA Report "Understanding the effects of Tree Removal in Soapstone Valley Using i-Tree Software" (Oliver 2020).

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 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, which are summarized in the 2020 UERLA Report on Soapstone Valley (Oliver 2020).

Table 1.

Weather Condition	Dates	Precipitation (mm)	Glover-Archbold Watershed # Flow Events Above 1 SD	Glover-Archbold 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.

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 Glover-Archbold watershed. The area of Glover-Archbold park was determined by calculating geometry in ArcGIS 10.4.1. The Glover-Archbold Watershed is 1,250.6 acres, and Glover-Archbold Park is 252.1 acres, representing 20.16% of the watershed. The total area of tree canopy loss due to removal, calculated using ArcGIS, is 13.5 acres. The tree removal represents 1.08% of the Glover-Archbold Watershed, and 5.36% of Glover-Archbold 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 Glover-Archbold 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. This process was repeated to estimate Glover-Archbold Park land cover.

Abbr.	Cover Class	Description	Points	% Cover ± SE	Area (mi²) ± SE
H	Grass/Herbaceous		131	13.10 ± 1.07	0.26 ± 0.02
I	Impervious		316	31.60 ± 1.47	0.62 ± 0.03
IUC	Impervious Under Canopy		116	11.60 ± 1.01	0.23 ± 0.02
PUC	Pervious Under Canopy		413	41.30 ± 1.56	0.81 ± 0.03
S	Soil/Bare Ground		21	2.10 ± 0.45	0.04 ± 0.01
W	Water		1	0.10 ± 0.10	0.00 ± 0.00
Total			**1000**	**100.00**	**1.96**

Figure 4: i-Tree Canopy Cover Assessment of Glover-Archbold Watershed

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 "Medium Density" equation, as found in the i-Tree Hydro DCIA Calculator, was used to estimate the DCIA for Glover-Archbold watershed. The park contains very little impervious area, so

the "Low Density" development pattern equation was used for the Glover-Archbold Park DCIA estimation. The DCIA used for the watershed was 28.59 and the DCIA for the park was 0.22.

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 no evergreen or mixed forest area. So, I input 0% for the Evergreen Tree Canopy and Evergreen Shrub Canopy categories.

Soil Type

According to the Natural Resources Conservation Service Web Soil Survey (United States Department of Agriculture n.d.b), the soil type in Glover-Archbold 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.

<u>Land Cover Scenarios</u>

Base Case

The Base Case uses current, pre-rehabilitation estimates of land cover percentages for the Glover-Archbold Watershed (Table 3) and Glover-Archbold Park (Table 4).

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. 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 revegetation. All other inputs are the same as the Base Case, and specific values can be found in Tables 3 and 4.

Table 3. Glover-Archbold Watershed Land Cover i-Tree Inputs

(%)	Base Case	Alternate Case 1	Alternate Case 2
Tree Canopy	52.9	51.82	49.35
Pervious Under TC	41.3	40.22	31.45
Impervious Under TC	11.6	11.6	11.6
Shrub Canopy	0	0	0.54
Herbaceous	13.1	13.1	13.1
Water	0.1	0.1	0.1
Impervious	31.8	31.8	31.8
Bare Soil	2.1	3.18	2.64

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. Glover-Archbold Park Land Cover Inputs

(%)	Base Case	Alternate 1	Alternate 2
Tree Canopy	92.2	86.87	86.87

Pervious Under TC	90.9	85.57	85.57
Impervious Under TC	1.3	1.3	1.3
Shrub Canopy	0	0	2.665
Herbaceous	5.2	5.2	5.2
Water	0.7	2.5	2.5
Impervious	0.4	0.4	0.4
Bare Soil	1.5	6.83	4.165

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

Glover-Archbold Watershed

Within the Glover-Archbold 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. Glover-Archbold 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)	37,009,705.8	40,261,571.2	35,790,756.2	641,128.9	992,584.0
Pervious Runoff (m^3)	3,111,178.8	5,967,252.9	1,959,379.7	407,385.5	54,364.0
Sum of Hourly Mean TSS (kg/modelled time period)	290,717.3	545,663.5	187,520.3	34,347.0	5,597.3

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

Table 6. Glover-Archbold Watershed Alternate Case 1

	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Total Flow (m^3)	37,013,016.8	40,265,384.0	35,794,622.5	641,308.3	992,631.3
Pervious Runoff (m^3)	3,114,489.3	5,971,066.7	1,963,245.4	407,564.9	54,411.3
Sum of Hourly Mean TSS (kg/modelled time period)	290,976.8	545,962.5	187,823.4	34,354.6	5,601.0

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

Table 7. Glover-Archbold Watershed Alternate Case 2

	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Total Flow (m^3)	37,012,291.1	40,264,439.7	35,793,810.6	641,266.0	992,616.7
Pervious Runoff (m^3)	3,113,763.6	5,970,122.5	1,962,433.9	407,522.8	54,396.6
Sum of Hourly Mean TSS (kg/modelled time period)	290,920.0	545,888.4	187,759.8	34,352.9	5,599.9

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

Between the Base Case and Alternate Case 1, the i-Tree Hydro model found a projected increase in total flow of 0.01% in the average year, 0.01% in the wet year, 0.01% in the dry year, 0.03% in the

high intensity rain event, and 0.01% in the long duration rain event (Table 8). The increase in pervious runoff in the modelled average, wet, dry, high intensity, and long duration weather is 0.11%, 0.06%, 0.20%, 0.04%, and 0.09% respectively (Table 9). Mean total suspended solids increase by 0.09% in the average year, 0.06% in the wet year, 0.16% in the dry year, 0.02% in the high intensity rain event, and 0.07% in the long duration event (Table 10).

Following revegetation efforts represented by Alternate Case 2, the model estimated an increase of 0.01%, 0.01%, 0.01%, 0.02%, and 0.00% in total flow from the Base Case for average, wet, dry, high intensity event, and long duration event (Table 8). Pervious runoff increased 0.08%, 0.05%, 0.16%, 0.03%, and 0.06% (Table 9), and mean total suspended solids increased 0.07%, 0.04%, 0.13%, 0.02%, and 0.05% for the average year, wet year, dry year, high intensity event, and long duration event respectively (Table 10).

Table 8. Glover-Archbold Watershed Total Flow

Difference from Base	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Alt 1	0.01%	0.01%	0.01%	0.03%	0.01%
Alt 2	0.01%	0.01%	0.01%	0.02%	0.00%

This table displays the percent difference in total flow between the cases for each weather condition in Glover-Archbold Park.

Table 9. Glover-Archbold Watershed Pervious Runoff

Difference from Base	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Alt 1	0.11%	0.06%	0.20%	0.04%	0.09%
Alt 2	0.08%	0.05%	0.16%	0.03%	0.06%

This table displays the percent difference in pervious runoff between the cases for each weather condition in Glover-Archbold Park.

Table 10. Glover-Archbold Watershed Sum of Hourly Mean TSS

Difference from Base	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Alt 1	0.09%	0.06%	0.16%	0.02%	0.07%

Alt 2	0.07%	0.04%	0.13%	0.02%	0.05%

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

Glover-Archbold Park NPS Unit

Within Glover-Archbold 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 11. Glover-Archbold 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)	21,865,602.0	22,514,161.0	21,660,233.6	190,628.6	591,713.3
Pervious Runoff (m^3)	603,107.9	1,251,651.4	335,596.8	85,127.3	4,710.9
Sum of Mean Hourly TSS (kg/modelled time period)	47,285.4	98,132.5	26,312.1	6,494.9	369.0

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

Table 12. Glover-Archbold NPS Unit Alternate Case 1

	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Total Flow (m^3)	21,868,268.7	22,517,813.5	21,663,383.8	190,777.8	591,760.3
Pervious Runoff (m^3)	605,774.5	1,255,304.4	338,747.4	85,276.5	4,758.0
Sum of Hourly Mean TSS (kg/modelled time period)	47,494.5	98,418.9	26,559.1	6,504.9	372.7

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

Table 13. Glover-Archbold NPS Unit Alternate Case 2

	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Total Flow (m^3)	21,867,655.5	22,516,852.3	21,662,520.9	190,745.2	591,745.8
Pervious Runoff (m^3)	605,161.3	1,254,342.9	337,884.2	85,243.9	4,743.4
Sum of Hourly Mean TSS (kg/modelled time period)	47,446.4	98,343.5	26,491.4	6,502.8	371.6

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

The modelled increase in total flow between the Base Case and Alternate Case 1 is 0.01% during the average year, 0.02% during the wet year, 0.02% during the dry year, 0.08% during the high intensity event, and 0.01% during the long duration event (Table 11). The increase in pervious runoff as a result of tree removal is 0.44%, 0.29%, 0.94%, 0.18%, and 1.00%, 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 0.44%, 0.29%, 0.94%, 0.16%, and 1.00% (Table 13).

Between the Base Case and Alternate Case 2, the difference in total flow is a 0.01%, 0.01%, 0.01%, 0.06%, and 0.01% increase for the average year, wet year, dry year, high intensity event, and long duration event (Table 11). Pervious runoff increases by 0.34% in the average year, 0.22% in the wet year, 0.68% in the dry year, 0.14% in the high intensity event, and 0.69% in the long duration event (Table 12). Total suspended solids are expected to be 0.34%, 0.22%, 0.68%, 0.12%, and 0.69% greater than the Base Case depending on the modelled weather condition (Table 13).

Table 11. Glover-Archbold NPS Unit Total Flow

Difference from Base	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Alt 1	0.01%	0.02%	0.02%	0.08%	0.01%
Alt 2	0.01%	0.01%	0.01%	0.06%	0.01%

This table displays the differences in total flow between the cases and for each weather condition in Glover-Archbold Park.

Table 12. Glover-Archbold NPS Boundary Pervious Runoff

Difference from Base	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Alt 1	0.44%	0.29%	0.94%	0.18%	1.00%
Alt 2	0.34%	0.22%	0.68%	0.14%	0.69%

This table displays the pervious runoff differences between the cases and for each weather condition in Glover-Archbold Park.

Table 13. Glover-Archbold NPS Boundary Sum of Hourly Mean TSS

Difference from Base	Avg Year	Wet Year	Dry Year	High Intensity	Long Duration
Alt 1	0.44%	0.29%	0.94%	0.16%	1.00%
Alt 2	0.34%	0.22%	0.68%	0.12%	0.69%

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

Conclusions

Even at the initial tree removal stage with maximum bare soil (Alternate Case 1), it seems as though this sewer rehabilitation project will have very little effect on the Glover-Archbold watershed. During the year-long weather condition models (average, wet, and dry), the increase in total flow is 0.01% in all yearly conditions. Overall, the greatest change one could expect to see as a result of this work during the year-long weather models is a 0.20% increase in pervious runoff during dry conditions, with the smallest pervious runoff increase of 0.06% in the wet year. The range in TSS is 0.06% to 0.16% from the wet and dry year, respectively. For the two event-based models, change from the base conditions in total flow is greatest in the high intensity storm event with an increase of 0.03%, with the smallest increase of 0.01% in the long duration storm event. Pervious runoff and sum of TSS is greater in the long duration (0.09% and 0.07%) than in the high intensity event (0.04% and 0.02%).

In hypothetical initial revegetation stages of the Glover-Archbold watershed as modelled by Alternate Case 2, the difference in total flow from the Base Case is 0.01% during the average, wet, and

dry years. For the long duration storm event, Alternate Case 2 is no different from the Base Case, while the high intensity storm event has a 0.02% increase in total flow from the Base Case. With regards to pervious runoff, the dry year has the greatest increase of 0.16%, and the wet year has the smallest difference, 0.05%, 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 0.03% compared to 0.06% in the long duration event. Similarly, the difference in total suspended solids is greatest for the dry year, 0.13%, and smallest for the wet year, 0.04%. The high intensity rain event also has a smaller change in sum of mean TSS than the long duration event, with a comparison of 0.02% to 0.05%.

For the NPS unit, Glover-Archbold Park, 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 in the wet and the dry year (both 0.02%) and the long duration event (0.08%). The increase of total flow is smallest in the average year (0.01%) and high intensity event (0.01%). Pervious runoff has greatest differences in the dry year and the long duration storm, 0.94% and 1.00%, and the smallest differences in the wet year and short duration event, 0.29% and 0.18%. Similarly, the largest differences in sum of hourly mean TSS are 0.94% and 1.00% in the dry year and long duration rain event respectively, while the wet year and high intensity event are more closer to the base case with 0.29% and 0.16% increases.

The revegetation alternative in Glover-Archbold Park, as modelled by Alternate Case 2, generally has comparable results to Alternate Case 1. Total flow increases by 0.01% in the average, wet, and dry years. The high intensity storm event has the greatest increase in total flow from the Base Case, with a value of 0.06%, while the long duration storm event increases by 0.01%. The dry year and long rain event have the greatest pervious runoff increases from the Base Case with 0.68% and 0.69%, while 0.22% and 0.14% are the smallest differences for the wet year and high intensity storm event. With

values of 0.68% and 0.69%, the dry year and long duration event also show the greatest sum of mean TSS increase from the Base Case, and wet year and short duration event have the least increases of 0.22% and 0.12%.

For both the watershed and the park, the change in total flow differs from the change in pervious runoff and sum of mean TSS values, which are generally similar to each other for each land cover scenario. The increases in total flow are smaller than increases in pervious runoff and sum of mean TSS. Additionally, the average, wet, and dry years have the same total flow percent increases for the watershed, and the wet and dry years have equivalent values greater than the average year for the park. The percent increase in total flow of the high intensity event is greater than the low intensity event for both the watershed and the park. These patterns differ from those displayed by pervious runoff and sum of mean TSS, in which the dry year and the long duration storm event have the greatest change from the Base Case while the wet year and high intensity storm event have the least change.

One reason why smallest changes in pervious runoff and TSS are seen during the wet year is that this year may have 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 in which the long duration rain event 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 application.

The Glover-Archbold Park and watershed total flow results differ from the expected pattern displayed in both the pervious runoff and sum of mean TSS values. Robert Coville explained that one would primarily expect to see flow differences as a result of land cover change in the runoff component

of flow, so these model results are reasonable (personal communication, 2021). The greatest total flow increase during the high intensity storm event initially appears irregular with the expected pattern of results. This result may occur during the high intensity event because during this event at this site, runoff makes up a large proportion of total flow, thereby causing a relatively greater increase in total flow even though the increase in pervious runoff is smaller when compared to the other weather conditions (Rovert Coville, personal communication, 2021).

Following the rehabilitation project, the revegetation in Alternate Case 2 could model what temporary longer-term impacts of the project might be for Glover-Archbold. The differences between the total flow of this case and the Base Case are smaller than those of Alternate Case 1 for both storm events at the Glover-Archbold watershed scale, and for the wet, dry, and high intensity conditions for the Glover-Archbold Park. For all other weather conditions, the same total flow increase is seen in both Alternative 1 and Alternative 2. However, the changes in pervious runoff and sum of mean TSS are smaller over all weather conditions for Alternate Case 2 than Alternate Case 1. This impact of reduced pervious flow and mean TSS is expected given that vegetation helps to reduce these values.

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 in pervious runoff and sum of mean TSS during the dry year and long duration storm event 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 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. Furthermore, mitigation of pervious runoff and TSS sources could be of particular focus since these carry the greatest impacts of the sewer rehabilitation project.

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.

Sediment mitigation measures such as Soil Erosion and Sediment Control Plans are common practice for projects. However, they are not taken into account for i-Tree Hydro modelling and may impact the accuracy of TSS outputs. In the context of specific projects, the exclusion of these measures from modelling raises 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 the effects of specific storm events. 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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