i-Tree

HydroPlus

Technical Manual

Updated: July 20, 2022

i-Tree is a cooperative initiative

About

Introduction

This document is intended to facilitate use and development of the HydroPlus environmental model suite – referred to as HydroPlus in reference to its source code – used as the backend for i-Tree Hydro, i-Tree Cool Air, i-Tree Cool River, i-Tree Green Infrastructure, and in the future potentially other models developed by the iTree-ESF collaborative. History is included to provide context and institutional knowledge.

Serving as an ad hoc FAQ for the researchers developing and using HydroPlus, this document is expected to evolve and expand over time to include basic information about code architecture and common development practices (e.g. how to add new functions and inputs); explanation and solutions to common problems that come up when working with these complex models; and different options or configurations possible for running this code.

As HydroPlus is part of the i-Tree Research Suite, i-Tree Tools' usual level of technical support and documentation is not available for HydroPlus. This document is intended for readers with a moderate level of expertise in environmental and computer science. Technical support is not available for free, but expert consultation can be arranged. If interested in consultation, reach out to the i-Tree Team at info@itreetools.org.

Disclaimer

The use of trade, firm, or corporation names in this publication is solely for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable. The software distributed under the label "i-Tree Suite" is provided without warranty of any kind. Its use is governed by the End User License Agreement (EULA) to which the user agrees before installation.

Feedback

The i-Tree Development Team actively seeks feedback on any component of the project: the software suite itself, the manuals, or the process of development, dissemination, support, and refinement. Please send comments through any of the means listed on the i-Tree support page: www.itreetools.org/support/.

Acknowledgements

Components of the i-Tree software suite have been developed over the last few decades by the U.S. Forest Service and numerous cooperators. Support for the development and release of the 2022 i-Tree software suite has come from USDA Forest Service Research, State and Private Forestry, and their cooperators through the i-Tree Cooperative Partnership of the Davey Tree Expert Company, Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, Casey Trees, and State University of New York College of Environmental Science and Forestry.

The i-Tree Cool Air model was originally developed by Drs. Yang Yang, SUNY College of Environmental Science and Forestry (SUNY-ESF), Ted Endreny (SUNY-ESF), and David J. Nowak, USDA Forest Service, Northern Research Station (USFS-NRS). The model code has been improved and integrated within i-Tree based on the work of Thomas Taggart (SUNY-ESF), Shannon Conley (Davey Institute), Robert Coville (Davey Institute), Vamsi Kodali (Syracuse University), Sneha Patil (Syracuse University), Arpit Shah (Syracuse University), and Reza Abdi (SUNY-ESF). i-Tree Cool Air uses i-Tree Hydro as its underlying hydrology model.

The i-Tree Hydro model was originally developed by Drs. Jun Wang SUNY College of Environmental Science and Forestry (SUNY-ESF), Ted Endreny (SUNY-ESF), and David J. Nowak, USDA Forest Service, Northern Research Station (USFS-NRS). The model code has been improved and integrated within i-Tree based on the work of Megan Kerr (Davey Institute), Yang Yang (SUNY-ESF), Sanyam Chaudhary (Syracuse University), Rahul Kumbhar (Syracuse University), Yu Chen (Syracuse University), Thomas Taggart (SUNY-ESF), Shannon Conley (SUNY-ESF), Pallavi Iyengar (Syracuse University), Jeevitha Royapathi (Syracuse University), Robert Coville (Davey Institute), Isira Samarasekera (Syracuse University), Vamsi Kodali (Syracuse University), Sunit Vijayvargiya (Syracuse University), Sneha Patil (Syracuse University), Arpit Shah (Syracuse University), Akshay (Syracuse University), and Reza Abdi (SUNY-ESF). Topographic Index calculations have been improved with algorithms developed for WhiteBox GAT (Lindsay, 2016) with permission by its creator John Lindsay, PhD (University of Guelph).

Many other individuals have contributed to the design, development, testing process, and help text including Scott Maco (Davey Institute), Mike Binkley (Davey Institute), David Ellingsworth (Davey Institute), Dr. Satoshi Hirayabashi (Davey Institute), Dr. Jim Fawcett (Syracuse University), Emily Stephan (SUNY-ESF), Evan Williams (SUNY-ESF), Ryan Morrison (SUNY-ESF), James Kruegler (SUNY-ESF), and Jeremy Hatfield (SUNY-ESF). This Technical Manual was written & designed by Robert Coville (Davey Institute) and merged with the i-Tree Hydro v6 User Manual by Jay Heppler (Davey Institute), with software development notes from Shannon Conley (Davey Institute), Ted Endreny (SUNY-ESF), and Reza Abdi (SUNY-ESF).

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Inputs & Running HydroPlus Models

Introduction to Using HydroPlus

To run any of the models within HydroPlus, the HydroPlus executable file must be run along with a command line argument giving the path to the input files without any trailing slash.

For example, the following could be run in a Windows command line interface:

C:\HydroPlus\x64\Release\HydroPlus.exe C:\HydroPlus\Projects\Inputs

The program will look in the inputs directory for a configuration file "HydroPlusConfig.xml". The config file determines what model is run and with what settings and parameters. Different input files are needed depending on which model is run. HydroPlus includes the following models:

- StatisticalHydro: the hydrology model used by i-Tree Hydro, operating in a semi-distributed aka statistically distributed framework.
- GI: a version of StatisticalHydro which includes green infrastructure features based on the EPA SWMM model and the work of Endreny & Abdi in 2019.
- SpatialTemperatureHydro: the air temperature model referred to as i-Tree Cool Air or originally PASATH, operating in a raster-based spatially distributed framework. This model uses StatisticalHydro's hydrology routines where possible.
- CoolRiver: one-dimensional river temperature model in steady and unsteady modes using temperature change driven by the advection, dispersion, energy flux, and mixing process.
- ECDynamic: Model for identifying non-point source runoff pollution loading hotspots, requiring extraction of event mean concentration (EMC) or export coefficient (EC) values from HUC watershed

More information about the Config File is available later in this section.

Required Input Files

StatisticalHydro

The following input files are expected in the input directory for the Hydro Model, including Green Infrastructure, to run:

- HydroPlusConfig.xml
- Dem.dat
    - OR powdecayTI.dat when config file includes <Infiltration>PowerDecay</Infiltration>

        - PowerDecay intended for use with a DEM or a powdecayTI file from HydroPlus; if a DEM is used, Hydro will subsequently produce a powdecayTI.dat file
    - OR expdecayTI.dat when config includes <Infiltration>ExponentialDecay</Infiltration>
        - ExponentialDecay intended for use with the TI files preloaded from Hydro GUI
- Weather.dat & Evaporation.dat (Pre-processed files from raw NOAA NCDC data using the WeatherPrep application. See Processing Weather Data for more information.)
- Pollutants.dat (Model can run without this, but no water quality results will be written)
- Qobs.dat (Only needed when config file does not include <CalibrationTimeStep>NoCalibration</CalibrationTimeStep>)

SpatialTemperatureHydro

The following input files are expected in the input directory for the Cool Air model to run:

- HydroPlusConfig.xml
- dem.dat
- Weather.dat
- Evaporation.dat (used only for snow evaporation potentials)
- SolarRadiation.dat
- Blockgroupmap.dat (optional)
- Treecover.dat
- Imperviouscover.dat
- Landcover.dat

See Processing Land Cover Data for more information on treecover.dat, imperviouscover.dat, and landcover.dat.

Config File (HydroPlusConfig.xml)

Config File settings applicable to all models

OutputDirectory is the full backslash path to the directory which output files will be written to, ending with \

Note that commenting out tags is ineffective: if a tag is written in the file that the code looks for, it will activate and grab values for that tag. Instead, to disable tags, the tags of interest must be wrapped in a <DISABLE></DISABLE> set of tags.

Config File Parameters

The HydroPlusConfig.xml files in the TestingFilesandScript/TestCases directory are commented to clarify XML configuration file options. An example of the HydroPlusConfig.xml file is attached. The following table explains the default values, source, and format of parameters in the XML file.

<SimulationStringParams>

```
   <OutputDirectory>PATH\</OutputDirectory> <!-- Output folder path ending with \,
C:\iTree\Projects\Hydro|syr_ny\output\ -->
    <OutputTimeStep>Hourly</OutputTimeStep> <!-- Options: NoCalibration, Hourly, Weekly, Daily -->
    <CalibrationTimeStep>NoCalibration</CalibrationTimeStep> <!-- Options: NoCalibration, Hourly,
Weekly, Daily -->
    <Model>SpatialTemperatureHydro</Model> <!-- Options: StatisticalHydro,
SpatialTemperatureHydro, ECDynamic, LCScalingTempSpatialPowerDecay-->
    <Infiltration>ExponentialDecay</Infiltration> <!-- Options: ExponentialDecay, PowerDecay -->
    <FlowPathAlgorithm>DInfinity</FlowPathAlgorithm> <!-- Options: DInfinity, MFD, D8; Describes
DEM flow routing method -->
    <Flag_ExtendedOutputs>0</Flag_ExtendedOutputs> <!-- Options: 0=None 1=Time series written -->
    <Flag_Recompute_TopographicIndex>0</Flag_Recompute_TopographicIndex><!--Options: 0 or 1; 0=Use
existing TI data 1=Recompute TI data -->
    <Flag_TI_PerviousOnly>0</Flag_TI_PerviousOnly><!--Options: 0 or 1; 0=No restriction on TI area
1=Restrict TI to pervious area as TopUrban by Valeo -->
    <Flag_CoolAir_AnthropogenicHeat>0</Flag_CoolAir_AnthropogenicHeat><!--Options: 0 or 1; 0=No
AH4GUC Map Inputs 1=AH4GUC Map Inputs -->
        <RefParamFolder>0,0</RefParamFolder> <!-- Options: 0,0; DataDrawer & DataFolder w/
Reference parameters; 0 = first -->
 </SimulationStringParams>
 <SimulationNumericalParams>
    <StartDay>YYYYMMDD</StartDay> <!-- Date format: YYYYMMDD; Must be date contained in
meteorological input files -->
    <EndDay>YYYYMMDD</EndDay> <!-- Date format: YYYYMMDD; Used to define TotalTimeSteps =
[(EndDay+1)- StartDay] * 24 -->
    <CatchmentArea_m2>AREA</CatchmentArea_m2> <!--Options: > 0; total simulated area within
DEM.dat, excluding -9999; units m^2-->
    <TopographicIndexBins>30</TopographicIndexBins> <!-- Options: 1 to 30; bins for topographic
index -->
    <TotalTimeSteps> </TotalTimeSteps> <!-- Options: empty or > 0; Use > 0 to redefine
TotalTimeSteps; units h -->
    <TimeStep_sec>3600</TimeStep_sec> <!-- Options: 0 or higher; time step between rows of
meteorological inputs; units s -->
 </SimulationNumericalParams>
 <DataOrganizer>
  <DataDrawer>
   <DataFolder>
        <Type>BulkArea</Type> <!-- Options: BulkArea; BulkArea required for 1st DataFolder in
DataDrawer -->
        <Area_m2>AREA</Area_m2> <!--Options: Hydro = CatchmentArea_m2 - all other Area; CoolAir =
cellsize^2; units m^2-->
        <TreeCanopyCover_overPervious_frac>0.0</TreeCanopyCover_overPervious_frac> <!-- Options:
>= 0; tree canopy over pervious; units fraction -->
        <TreeCanopyCover_overImpervious_frac>0.0</TreeCanopyCover_overImpervious_frac> <!--
Options: >= 0; tree canopy over impervious; units fraction -->
        <ShortVegCover_noTreeCanopy_frac>0.0</ShortVegCover_noTreeCanopy_frac> <!-- Options: >= 0;
short vegetation no tree canopy; units fraction -->
        <SoilCover_noTreeCanopy_frac>0.0</SoilCover_noTreeCanopy_frac> <!-- Options: >= 0; soil no
tree canopy; units fraction -->
        <WaterCover_noTreeCanopy_frac>0.0</WaterCover_noTreeCanopy_frac> <!-- Options: >= 0; water
no tree canopy; units fraction -->
        <ImperviousCover_noTreeCanopy_frac>0.0</ImperviousCover_noTreeCanopy_frac> <!-- Options:
>= 0; impervious no tree canopy; units fraction -->
        <DCIA_frac>0.65</DCIA_frac> <!-- Options: 0 to 1; directly connected impervious area
fraction -->
        <PerviousDepressionStorage_mm>1.0</PerviousDepressionStorage_mm> <!-- Options: >=0;
average ponding depth; units mm-->
        <ImperviousDepressionStorage_mm>2.5</ImperviousDepressionStorage_mm><!-- Options: >=0;
average storage depth; units mm -->
        <WaterDepressionStorage_mm>0.0</WaterDepressionStorage_mm><!-- Options: >=0; average
storage depth; units mm -->
```

```
        <Soil_Macropore_frac>0.1</Soil_Macropore_frac> <!-- Options: 0 to 1; soil macropore
fraction, units fraction -->
        <InfiltExcessGovernedArea_frac>1.0</InfiltExcessGovernedArea_frac> <!-- Options: 0 to 1;
area with Green-Ampt infiltration; units fraction -->
        <T0_m2ph>1.3E2</T0_m2ph> <!-- Defines soil transmissivity when entire soil depth is
saturated; units m^2/h -->
        <n>2</n> <!-- Options: > 0; scale parameter for PowerDecay of hydraulic conductivity;
unitless -->
        <m>0.023</m> <!-- Scale parameter of soil transmissivity -->
        <MSD_m>0.05</MSD_m> <!-- Options: > 0; maximum root zone storage deficit, e.g., capacity
to store water; units m -->
        <K0_mph>0.0127</K0_mph> <!-- Defines soil hydraulic conductivity at saturation; units m/h
-->
        <WFS_m>0.12</WFS_m> <!-- Options: > 0; soil wetting front suction for Green-Ampt
infiltration; units m -->
        <Soil_WiltingPoint_m3pm3>0.05</Soil_WiltingPoint_m3pm3> <!-- Options: 0 to 1; soil wilting
point; units m3/m3 -->
        <Soil_FieldCapacity_m3pm3>0.25</Soil_FieldCapacity_m3pm3> <!--  Options: 0 to 1; soil
field capacity; units m3/m3 -->
        <Soil_SaturationPoint_m3pm3>0.4</Soil_SaturationPoint_m3pm3><!-- Options: 0 to 1; soil
saturation point; units m3/m3 -->
        <Soil_Porosity_m3pm3>0.4</Soil_Porosity_m3pm3> <!-- Options: 0 to 1; soil porosity; units
m3/m3 -->
        <Soil_MoistureInitial_m3pm3>0.25</Soil_MoistureInitial_m3pm3> <!-- Options: 0 to 1;
initial moisture point; units m3/m3 -->
        <Evapotranspiration_Depth_m>1.0</Evapotranspiration_Depth_m><!--Options: >=0; depth
accessible to evapotranspiration demand; units m-->
        <Td_h>10</Td_h> <!-- Options: >0; time delay in draining unsaturated zone; units h -->
        <Q0_mph>1.6e-05</Q0_mph> <!-- Options: > 0; initial stream discharge and soil moisture
deficit; units m/h -->
        <PAQ_RT_A_h>40.0</PAQ_RT_A_h> <!-- Options: > 0; time constant a for pervious area flow;
units h -->
        <PAQ_RT_B_h>40.0</PAQ_RT_B_h> <!-- Options: > 0; time constant b for pervious area flow;
units h -->
        <DCIAQ_RT_A_h>40.0</DCIAQ_RT_A_h> <!-- Options: > 0; time constant a for impervious area
flow; units h -->
        <DCIAQ_RT_B_h>40.0</DCIAQ_RT_B_h> <!-- Options: > 0; time constant b for impervious area
flow; units h -->
        <SSQ_RT_h>120.0</SSQ_RT_h> <!-- Options: > 0; time constant for subsurface flow; units h -
->
        <TreeLAI>5.0</TreeLAI> <!-- Options: 0 or higher; Leaf area index, LAI, for canopy area w/
units m^2/m^2 -->
        <ShortVegLAI>2.2</ShortVegLAI> <!-- Options: 0 or higher; Leaf area index, LAI, for veg
area w/ units m^2/m^2 -->
        <LeafOnDay>1</LeafOnDay> <!-- Option: 1 to maximum Julian Day in Year; day when tree
reaches maximum LAI -->
        <LeafOffDay>365</LeafOffDay> <!-- Option: value > LeafOnDay; day when deciduous leaf has
LAI = 0 -->
        <LeafTransDays>28</LeafTransDays> <!-- Option: 0 or higher; days prior to LeafOnDay when
LAI transitions min to max-->
        <EvergreenTreeCover_frac>0.05</EvergreenTreeCover_frac> <!-- Options: 0 to 1; Portion of
tree cover that is evergreen -->
        <TreeBAI>1.7</TreeBAI> <!-- Options: 0 or higher; Bark area index, BAI, for canopy area w/
units m^2/m^2 -->
        <EverGreenShrubCover_frac>0.05</EverGreenShrubCover_frac> <!-- Options: 0 to 1; Portion of
veg cover that is evergreen -->
        <ShrubBAI>0.5</ShrubBAI> <!-- Options: 0 or higher; Bark area index, BAI, for canopy area
w/ units m^2/m^2 -->
        <TreeLeafStorage_mm>0.2</TreeLeafStorage_mm> <!-- Options: 0 or higher; Average depth of
water on LAI w/ units mm -->
    </DataFolder>
```

Table 1. SimulationStringParameters

Category	Source	Default Value	Format

Output Directory	N/A	N/A	C:/folder…/projectfolder/inputs
Output Time Step	N/A	N/A	Hourly, Weekly, or Daily
Calibration Time Step	N/A	N/A	Hourly, Weekly, or Daily
Flag Extended Outputs	N/A	1	0 = None, 1 = Time Series Outputs
Model	N/A	N/A	StatisticalHydro, SpatialTemperatureHydro, etc.
Infiltration	N/A	ExponentialDecay	Exponential or Power Decay
Flow Path Algorithm	N/A	Dinfinity	Dinfinity, MFD, D8
Flag Recompute Topographic Index	N/A	1	0 = Use existing, 1 = Recompute
Flag TI Pervious Only	N/A	1	0 = No restriction on TI Area, 1 = Restrict TI to pervious area
Reference Parameter Folder	N/A	0,0	0,0

Table 2. NumericalStringParameters

Category	Source	Default Value	Units
Start Day	N/A	N/A	YYYYMMDD(optional hh, otherwise default to 00:00)
End Day	NA	N/A	YYYYMMDD(optional hh, otherwise default to 23:00)
Catchment Area	DEM	N/A	m^2
Topographic Index Bins	DEM	30	Bins for topographic index
Total Time Steps	N/A	Empty	Time Steps
Time Steps Seconds	N/A	3600	Seconds

Table 3. DataOrganizer/DataDrawer/DataFolder Land Cover Parameters

Category	Source[a]	Default Value	Units
Tree Cover[b]	Eco, Canopy, UTC, GIS	N/A	%
Shrub Cover[b]	Eco, Canopy, UTC, GIS	N/A	%
Herbaceous Cover[b]	Eco, Canopy, UTC, GIS	N/A	%
Soil Cover[b]	Eco, Canopy, UTC, GIS	N/A	%
Water Cover[b]	Eco, Canopy, UTC, GIS	N/A	%
Impervious Cover[b]	Eco, Canopy, UTC, GIS	N/A	%
DCIA Fraction[d]	GIS, Literature	N/A	%
Tree LAI[c]	Eco, Literature	3.5	m2/m2
Short Veg LAI[c]	Eco, Literature	2	m2/m2
Leaf On Day	N/A	Region-Specific	Days

Leaf Off Day	N/A	Region-Specific	Days
Leaf Trans Days	N/A	Region-Specific	Days
Evergreen Tree Cover	Eco, GIS	0.1	%
Evergreen Shrub Cover	Eco, GIS	0.05	%
Tree Bark Area Index	N/A	1.7	N/A (m2/m2)
Shurb BAI	N/A	0.5	N/A (m2/m2)
Tree Leaf Storage	N/A	0.2	mm

[a] DEM = Digital Elevation Model data (see Appendix 1: Preparing a Digital Elevation Model). Eco = An existing i-Tree Eco study; although it is unlikely that the Eco study area and the Hydro study area will align exactly, your Eco results might offer some insight. Canopy = i-Tree Canopy. Visit www.itreetools.org for more information on i-Tree Eco and i-Tree Canopy. UTC = an existing urban tree canopy analysis. GIS = your local government or university GIS department. Literature = some data may be available for certain locations in the scientific literature or from the appropriate university department.
[b] Surface Cover Types (should total 100%)
[c] Leaf area indexes (LAI) can be calculated from Eco results for leaf area where Eco presents LAI in units of m^2/ha. Divide those results by 10,000 to get LAI.
[d] DCIA can be particularly difficult to find. One strategy is to adjust the value in the calibration process until the model streamflow resembles the observed streamflow.

Table 4. DataOrganizer/DataDrawer/DataFolder Hydrological Parameters (continued on next page)

Category	Range	Default Value	Units
Impervious Depression Storage	0 - 7.5	2.5	mm
Pervious Depression Storage	0 - 7.5	1	mm
Category	**Range**	**Default Value**	**Units**
Water Depression Storage	0-1	0	mm
Soil Wilting Point	0-1	0.05	m3/m3
Soil Field Capacity	0-1	0.2	m3/m3
Soil Saturation Point	0-1	0.35	m3/m3
Soil Porosity	0-1	0.4	m3/m3
Soil Initial Moisture	0-1	0.2	m3/m3
Evapotranspiration Depth	0-1	0.8	m3/m3
Soil Macropore fraction	0-1	0.1	m
Infiltrated Excess Governed Area	0 - 1	1	fraction
T0_m2ph	--	0.0161	m^2/h
WFS_m	--	0.0886	m
Td_h	--	10	hours
Q0_mph	--	0.0000047	m/h
n	--	2	N/A
m	--	0.25	N/A

PAQ_RT_A_h	--	1	hours
PAQ_RT_B_h	--	2	hours
DCIAQ_RT_A_h	--	1	hours
DCIAQ_RT_B_h	--	2	hours
SSQ_RT_h	--	120	hours

Green Infrastructure File Parameters

Green infrastructure features are available in the latest StatisticalHydro model mode, designed based on the EPA SWMM model's LID modules.

A Basic Workflow for Running GI

1. Open master config file(s) from Test Cases for GI of interest
2. Copy dataFolder(s) for GI of interest into your own project config file
3. Adjust parameters in each GI dataFolder. When unsure what value to give a parameter, you can refer to parameter values from your project's BulkArea dataFolder or from the GI's TestCase parameters. For more guidance on GI parameterization, see Config File settings for Hydro > Green Infrastructure.
4. Save config file & run HydroPlus.exe same as without GI (Inputs & Running HydroPlus Models).
5. Access outputs as you would without GI (Outputs).

GI model schematics

The following figures about GI modeling in HydroPlus are provided below, from HydroPlus GI developers at SUNY-ESF:

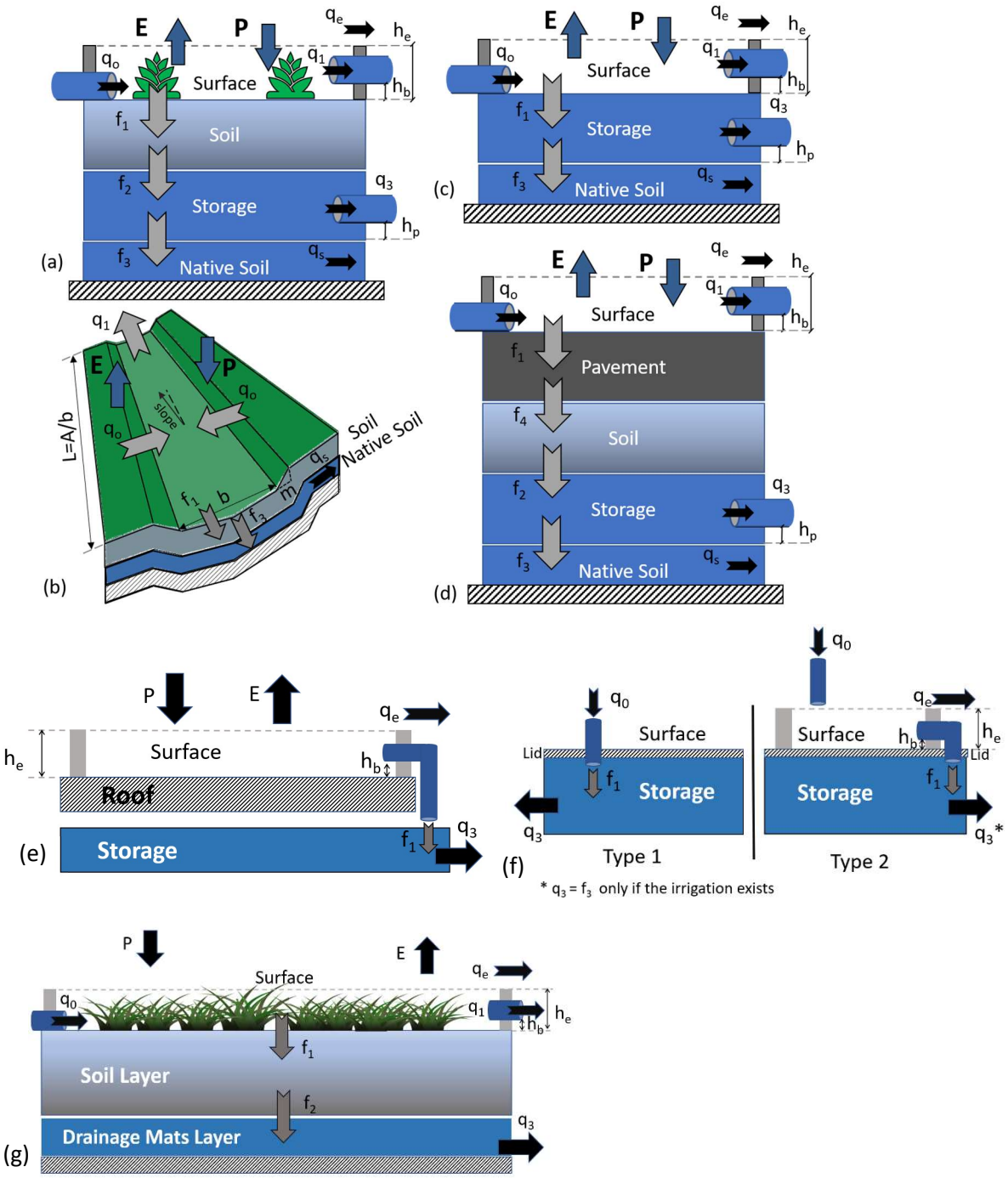


Fig. 1. The schematic design of the bioretention cell (a), vegetation swale (b), infiltration trench (c), permeable pavement (d), roof disconnection (e), rain barrel (f), and green roof (g). In the figure, the term *q* represents the water flow to and from the GI design with the substrates of $_0$ for the inflow, $_1$ for the surface outflow, $_3$ for the underdrain, $_e$ for the emergency spillway outflow, and $_s$ for the base flow. The term *f* represents the movement of water in the vertical direction with the substrates of $_1$ for the infiltration, $_2$ for the percolation, $_3$ for exfiltration, and $_4$ for percolation through the pavement. The h_b is the outflow pipe height from the surface, h_e is the emergency spillway outflow height, and h_p is the drain offset height. In panel (b), *L* is the length of the swale, *A* is the swale area, *b* is the bottom width, *P* is the rainfall, *E* is the evaporation, and *m* is the side slope.

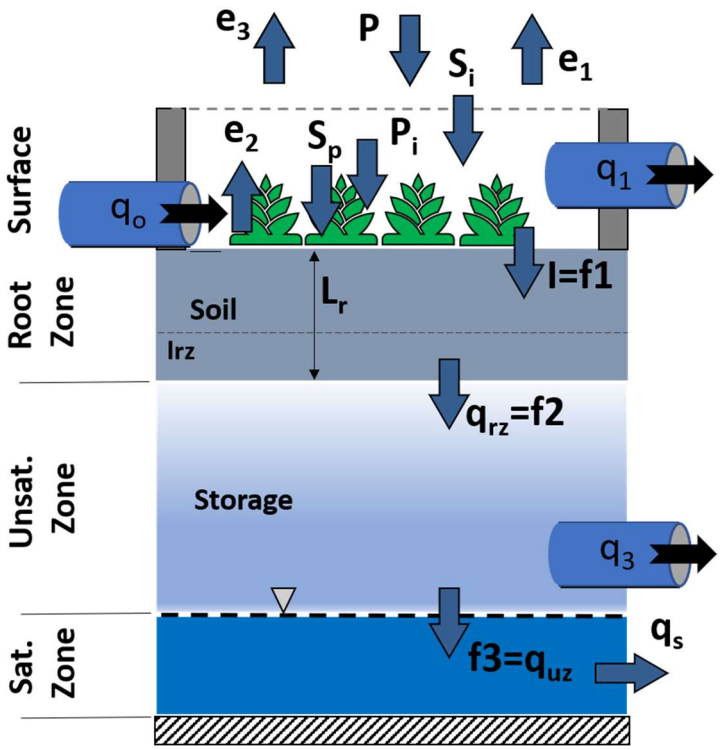


Fig 2. The schematic of the flow variables in i-Tree Hydro and SWMM overlaid with the i-Tree Hydro model structure. In the figure P is the precipitation, P_i is the canopy interception, S_p is the pervious depression storage, S_i is the impervious depression storage e_3 is the vegetation evaporation, q_s is the base flow, I is the infiltration, L_r is the maximum root zone depth, I_{rz} is the root zone storage, q_{rz} is the root zone to unsaturated zone percolation, and q_{uz} is the unsaturated zone to saturated zone percolation. The terms f_1, f_2, and f_3 referred the infiltration, percolation, and exfiltration respectively in SWMM.

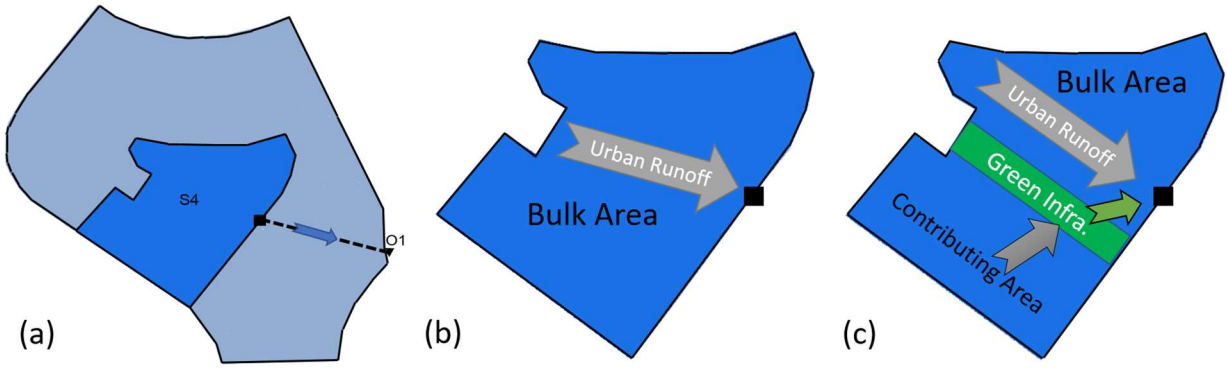


Fig. 3. The sub-catchment S4 (a) has been used in the simulations without applying the GI devices (b) and after adding the GI devices (c).

GI parameter descriptions

```
        <Type>TYPE</Type> <!-- Options: RainGarden; BioRetention; InfilTrench; Swale; PermeablePavement;
GreenRoof; RoofDisconnect; RainBarrel -->
        <Area_m2>AREA</Area_m2> <!-- Options: 0 to CatchmentArea_m2; Area of all GI units or devices in
DataFolder; units m^2 -->
```

```
        <Count_GI_Units>0</Count_GI_Units> <!-- Options: >= 0; Number of GI devices in this DataFolder;
unitless -->
        <Flag_Exfiltration_to_Catchment>1</Flag_Exfiltration_to_Catchment><!--Options: 0 or 1; 0=no
exfiltration for GI; 1=exfiltration; unitless -->
        <ImpAreaTreated_frac>0.0</ImpAreaTreated_frac> <!-- Options: 0 to 1; Fraction of BulkArea
impervious captured by GI; units fraction -->
        <PerAreaTreated_frac>0.0</PerAreaTreated_frac> <!-- Options: 0 to 1; Fraction of BulkArea pervious
captured by GI; units fraction -->
        <WaterAreaTreated_frac>0.0</WaterAreaTreated_frac><!--Options: 0 to 1; Fraction of BulkArea water
captured by GI units-->
        <TreeCanopyCover_overPervious_frac>0.0</TreeCanopyCover_overPervious_frac> <!-- Options: >= 0;
tree canopy over pervious; units fraction -->
        <TreeCanopyCover_overImpervious_frac>0.0</TreeCanopyCover_overImpervious_frac> <!-- Options: >= 0;
tree canopy over impervious; units fraction -->
        <ShortVegCover_noTreeCanopy_frac>0.0</ShortVegCover_noTreeCanopy_frac> <!-- Options: >= 0; short
vegetation no tree canopy; units fraction -->
        <SoilCover_noTreeCanopy_frac>0.0</SoilCover_noTreeCanopy_frac> <!-- Options: >= 0; soil no tree
canopy; units fraction -->
        <WaterCover_noTreeCanopy_frac>0.0</WaterCover_noTreeCanopy_frac> <!-- Options: >= 0; water no tree
canopy; units fraction -->
        <ImperviousCover_noTreeCanopy_frac>0.0</ImperviousCover_noTreeCanopy_frac> <!-- Options: >= 0;
impervious no tree canopy; units fraction -->
        <DCIA_frac>0.0</DCIA_frac> <!-- Options: 0 to 1; directly connected impervious area draining to
outlet; units fraction -->
        <PerviousDepressionStorage_mm>1.0</PerviousDepressionStorage_mm> <!-- Options: >=0; average
ponding depth; units mm-->
        <ImperviousDepressionStorage_mm>2.5</ImperviousDepressionStorage_mm><!-- Options: >=0; average
storage depth; units mm -->
        <WaterDepressionStorage_mm>0.0</WaterDepressionStorage_mm><!-- Options: >=0; average storage
depth; units mm -->
        <Soil_Macropore_frac>0.1</Soil_Macropore_frac> <!-- Options: 0 to 1; soil macropore fraction,
units fraction -->
        <InfiltExcessGovernedArea_frac>1.0</InfiltExcessGovernedArea_frac> <!-- Options: 0 to 1; area with
Green-Ampt infiltration; units fraction -->
        <K0_mph>0.0127</K0_mph> <!-- Defines soil hydraulic conductivity at saturation; units m/h -->
        <WFS_m>0.12</WFS_m> <!-- Options: > 0; soil wetting front suction for Green-Ampt infiltration;
units m -->
        <Soil_MoistureInitial_m3pm3>0.2</Soil_MoistureInitial_m3pm3><!--Options: 0 to 1; initial moisture
point; units m3/m3 -->
        <Soil_FieldCapacity_m3pm3>0.2</Soil_FieldCapacity_m3pm3> <!--  Options: 0 to 1; soil field
capacity; units m3/m3 -->
        <Soil_SaturationPoint_m3pm3>0.4</Soil_SaturationPoint_m3pm3><!-- Options: 0 to 1; soil saturation
point; units m3/m3 -->
        <Soil_Porosity_m3pm3>0.4</Soil_Porosity_m3pm3> <!-- Options: 0 to 1; soil porosity; units m3/m3 --
>
        <Soil_WiltingPoint_m3pm3>0.05</Soil_WiltingPoint_m3pm3> <!-- Options: 0 to 1; soil wilting point;
units m3/m3 -->
        <Evapotranspiration_Depth_m>1.0</Evapotranspiration_Depth_m><!--Options: >=0; depth accessible to
evapotranspiration demand; units m-->
        <TreeLAI>5.0</TreeLAI> <!-- Options: >= 0; Leaf area index, LAI, for canopy area w/ units m^2/m^2
-->
        <ShortVegLAI>2.2</ShortVegLAI> <!-- Options: >= 0; Leaf area index, LAI, for veg area w/ units
m^2/m^2 -->
        <LeafOnDay>1</LeafOnDay> <!-- Option: 1 to maximum Julian Day in Year; day when tree reaches
maximum LAI -->
        <LeafOffDay>365</LeafOffDay> <!-- Option: value > LeafOnDay; day when deciduous leaf has LAI = 0 -
->
        <LeafTransDays>28</LeafTransDays> <!-- Option: >= 0; days prior to LeafOnDay when LAI transitions
min to max-->
```

```
        <EvergreenTreeCover_frac>0.05</EvergreenTreeCover_frac> <!-- Options: 0 to 1; Portion of tree
cover that is evergreen -->
        <TreeBAI>1.7</TreeBAI> <!-- Options: >= 0; Bark area index, BAI, for canopy area w/ units m^2/m^2
-->
        <EverGreenShrubCover_frac>0.05</EverGreenShrubCover_frac> <!-- Options: 0 to 1; Portion of veg
cover that is evergreen -->
        <ShrubBAI>0.5</ShrubBAI> <!-- Options: >= 0; Bark area index, BAI, for canopy area w/ units
m^2/m^2 -->
        <TreeLeafStorage_mm>0.2</TreeLeafStorage_mm> <!-- Options: >= 0; Average depth of water on LAI w/
units mm -->
        <Surface_Berm_Height_m>0.8</Surface_Berm_Height_m><!--Options: >= 0; Height of GI surface berm
above which water spills out; units m-->
        <Surface_Outlet_Offset_m>0.1</Surface_Outlet_Offset_m><!--Options: >= 0; Height of GI surface
outlet above which water discharges out; units m-->
        <Surface_Outlet_LongSlope_mpm>0.015</Surface_Outlet_LongSlope_mpm><!--Options: >= 0; longitudinal
slope of outlet; units m/m-->
        <Surface_Outlet_SideSlope_HtoV_mpm>0.0</Surface_Outlet_SideSlope_HtoV_mpm><!--Options: >= 0; Side
slope H:V of swale or outlet; units m/m-->
        <Surface_Outlet_ManningRoughness>0.02</Surface_Outlet_ManningRoughness><!--Options: >= 0; Manning
n roughness value for outlet; unitless-->
        <Surface_Porosity_m3pm3>0.9</Surface_Porosity_m3pm3><!--Options: 0 to 1; porosity of GI surface
volume due to plants etc.; units m3/m3-->
        <Surface_Outlet_Width_m>5.0</Surface_Outlet_Width_m><!--Options: >= 0; bottom width of GI surface
outlet; units m-->
        <Pavement_Thickness_m>0.2</Pavement_Thickness_m><!--Options: >= 0; thickness of GI pavement layer
above soil; units m-->
        <Pavement_HydraulicConductivity_mph>2.12</Pavement_HydraulicConductivity_mph><!--Options: > 0;
hydraulic conductivity for infiltration; units m/hr-->
        <Pavement_Porosity_m3pm3>0.3</Pavement_Porosity_m3pm3><!--Options: >= 0; porosity of GI pavement;
units m3/m3-->
        <Pavement_Drainage_Limit_m>6.0</Pavement_Drainage_Limit_m><!--Options: >= 0; stormwater depth
treated before completely clogged; units m-->
        <Pavement_Drainage_Renewed_d>365</Pavement_Drainage_Renewed_d><!--Options: >= 0; number of days
between treatments for pavement regeneration; unit days-->
        <Soil_Thickness_m>0.20</Soil_Thickness_m><!--Options: >= 0; thickness of GI soil layer; units m-->
        <Soil_PercolationDecay_Coeff>10.0</Soil_PercolationDecay_Coeff><!--Options: >= 0; Reduces GI soil
percolation rate in negative exp term; 0=no reduction; unitless-->
        <Vault_Thickness_m>0.8</Vault_Thickness_m><!--Options: >= 0; thickness of GI subsurface storage
layer; units m-->
        <Vault_Porosity_m3pm3>0.4</Vault_Porosity_m3pm3><!--Options: 0 to 1; porosity of GI subsurface
storage; units m3/m3-->
        <Exfiltration_Limit_m>1E4</Exfiltration_Limit_m><!--Options: >= 0; stormwater depth treated before
completely clogged; units m-->
        <Vault_Outlet_Offset_m>0.05</Vault_Outlet_Offset_m><!--Options: >= 0; height of drainage pipe
invert above GI subsurface storage layer base; units m-->
        <Vault_Outlet_Discharge_Coeff>0.3</Vault_Outlet_Discharge_Coeff><!--Options: >= 0; Increases
drainage pipe rate; 0=no drainage 0.3=moderate etc.; unitless-->
        <Vault_Outlet_Discharge_Exponent>0.9</Vault_Outlet_Discharge_Exponent><!--Options: 0 to 1; Reduces
drainage pipe rate; 0=less drainage; unitless-->
        <Vault_Outlet_ManningRoughness>0.12</Vault_Outlet_ManningRoughness><!--Options: >= 0; Manning n
roughness value for outlet; unitless-->
        <Vault_Outlet_Delay_hr>0</Vault_Outlet_Delay_hr> <!-- Options: >= 0; Time after rain stops when
drain is opened; units hr -->
        <Tss>80</Tss><!-- Option: 0 to 100; Removal efficiency (%) for pollutant Tss, total suspended
solids; units % -->
        <BOD>25</BOD><!-- Option: 0 to 100; Removal efficiency (%) for pollutant BOD, biochemical oxygen
demand; units % -->
        <COD>40</COD><!-- Option: 0 to 100; Removal efficiency (%) for pollutant COD, chemical oxygen
demand; units % -->
```

```
        <TP>45</TP><!-- Option: 0 to 100; Removal efficiency (%) for pollutant TP, total phosphorus; units
% -->
        <SolP>24</SolP><!-- Option: 0 to 100; Removal efficiency (%) for pollutant SolP, soluble
phosphorus; units % -->
        <TKN>30</TKN><!-- Option: 0 to 100; Removal efficiency (%) for pollutant TKN, total Kjeldahl
nitrogen (organic N + ammonia N); units % -->
        <NO2_3>20</NO2_3><!-- Option: 0 to 100; Removal efficiency (%) for pollutant NO2_3, nitrite and
nitrate; units % -->
        <Cu>30</Cu><!-- Option: 0 to 100; Removal efficiency (%) for pollutant Cu, copper; units % -->
        <Pb>30</Pb><!-- Option: 0 to 100; Removal efficiency (%) for pollutant Pb, lead; units % -->
        <Zn>30</Zn>     <!-- Option: 0 to 100; Removal efficiency (%) for pollutant Zn, zinc; units % -->
```

Simulating Multiple Hydrologic Structures

Each <DataFolder> represents a hydrologic structure within the project, and most projects are represented entirely by the BulkArea parameters of a single DataFolder. When simulating Green Infrastructure), multiple DataDrawer or DataFolder tags may be setup to represent different GI structure types and individual GI structures.

Config File settings for Cool Air

The temperature model gathers hydrological parameters from the first DataFolder in the config file. That DataFolder generally represents the Bulk Area, which is the entire project area for most Hydro projects. For parameters included in Cool Air-specific inputs, such as treecover.txt, the Cool Air-specific input option is used instead of inputs from the DataFolder.

TemperatureLocationParams orient the model about the raster inputs. The inputs in the config file should match what would be in the header of raster input files. The required TemperatureLocationParams are nCols, nRows, cellsize, xllcorner, yllcorner. If NODATA_value is defined for raster inputs, it should also be defined with a NODATA tag in this config file parameter group. NODATA values other than -9999 will not work for iTree Cool Air. See Processing Land Cover Data for more information about NODATA values.

TemperatureExecutionParams is the parameter group in the config file that defines the weather station and what outputs are written. RefWeatherLocation is an important input for the model. The conditions associated with the RefWeatherLocation in the gridded spatial inputs should match the conditions at the observed weather data source. In most cases weather inputs come from airport weather stations with an NLCD LC=21, Impervious Cover=25%, and Tree Cover=0%.

Config file tags for Cool Air output options are listed below. Any row in the example below can be included or left out from your config file, except RefWeatherLocation. Copy config file rows from here and add them to your file to add an output option. For more information about what values are available for these different output options, see the Temperature model outputs section.

```
<TemperatureLocationParams>
    <nCols>##</nCols> <!-- Defines number of columns in input map files; Use value from map header -->
    <nRows>##</nRows> <!-- Defines number of rows in input map files; Use value from map header -->
    <xllcorner>##</xllcorner> <!-- Defines x lower left corner value in input map files; Use value from
map header -->
    <yllcorner>##</yllcorner> <!-- Defines y lower left corner value in input map files; Use value from
map header -->
    <cellsize>##</cellsize> <!-- Defines cell size value in input map files; Use value from map header -->
    <NODATA>-9999</NODATA> <!-- Defines no data value in input map files; Use value from map header -->
 </TemperatureLocationParams>
 <TemperatureCalculationParams>
    <Flag_AdiabaticLapseRate>0</Flag_AdiabaticLapseRate> <!--Options: 0 or 1; 1 = simulate temperature
variation with elevation-->
    <Flag_UrbanCanyon>0</Flag_UrbanCanyon> <!--Options: 0 or 1; 1 = limit range of heating to cooling w
canyon resistance-->
    <IterationCount>40</IterationCount> <!-- Options: > 0; iterations attempted by numerical solver for
energy balance -->
    <Urban21height>1</Urban21height> <!-- Options: > 0; roughness height and canyon height in width ratio;
units m -->
    <Urban21roadwidth>100</Urban21roadwidth> <!-- Options: > 0; urban canyon for height to width ratio;
units m -->
    <Urban21albedo>0.14</Urban21albedo> <!-- Options: 0 to 1; fraction of shortwave radiation reflected --
>
    <Urban21emissivity>.95</Urban21emissivity> <!-- Options: 0 to 1; fraction of longwave radiation
transmitted -->
    <Urban21a1>0.81</Urban21a1> <!--Options: 0 to 1; sets magnitude of heat flux storage to net radiation
NR; units frac -->
    <Urban21a2>0.48</Urban21a2> <!--Options: 0 to 1; sets phase of heat flux storage 0=in phase; units hr
-->
    <Urban21a3>-79.9</Urban21a3> <!--Options: 0 to -100; sets value of heat flux storage when NR=0; units
W/m2 -->
    <Urban21buildingP>0.1</Urban21buildingP> <!-- Options: 0 to 1; fraction of grid cell with buildings --
>
    <Urban22height>5</Urban22height> <!-- Options: > 0; roughness height and canyon height in width ratio;
units m -->
    <Urban22roadwidth>10</Urban22roadwidth> <!-- Options: > 0; urban canyon for height to width ratio;
units m -->
    <Urban22albedo>0.13</Urban22albedo> <!-- Options: 0 to 1; fraction of shortwave radiation reflected --
>
    <Urban22emissivity>0.95</Urban22emissivity> <!-- Options: 0 to 1; fraction of longwave radiation
transmitted -->
    <Urban22a1>0.81</Urban22a1> <!--Options: 0 to 1; sets magnitude of heat flux storage to net radiation
NR; units frac -->
    <Urban22a2>0.48</Urban22a2> <!--Options: 0 to 1; sets phase of heat flux storage 0=in phase; units hr
-->
    <Urban22a3>-79.9</Urban22a3> <!--Options: 0 to -100; sets value of heat flux storage when NR=0; units
W/m2 -->
    <Urban22buildingP>0.20</Urban22buildingP> <!-- Options: 0 to 1; fraction of grid cell with buildings -
->
    <Urban23height>10</Urban23height> <!-- Options: > 0; roughness height and canyon height in width
ratio; units m -->
    <Urban23roadwidth>12.5</Urban23roadwidth> <!-- Options: 0 to 1; fraction of grid cell with buildings -
->
    <Urban23albedo>0.12</Urban23albedo> <!-- Options: 0 to 1; fraction of shortwave radiation reflected --
>
    <Urban23emissivity>0.95</Urban23emissivity> <!-- Options: 0 to 1; fraction of longwave radiation
transmitted -->
    <Urban23a1>0.81</Urban23a1> <!--Options: 0 to 1; sets magnitude of heat flux storage to net radiation
NR; units frac -->
```

```
    <Urban23a2>0.48</Urban23a2> <!--Options: 0 to 1; sets phase of heat flux storage 0=in phase; units hr
-->
    <Urban23a3>-79.9</Urban23a3> <!--Options: 0 to -100; sets value of heat flux storage when NR=0; units
W/m2 -->
    <Urban23buildingP>0.40</Urban23buildingP> <!-- Options: 0 to 1; fraction of grid cell with buildings -
->
    <Urban24height>15</Urban24height> <!-- Options: > 0; roughness height and canyon height in width
ratio; units m -->
    <Urban24roadwidth>12.5</Urban24roadwidth> <!-- Options: > 0; urban canyon for height to width ratio;
units m -->
    <Urban24albedo>0.1</Urban24albedo> <!-- Options: 0 to 1; fraction of shortwave radiation reflected -->
    <Urban24emissivity>0.95</Urban24emissivity> <!-- Options: 0 to 1; fraction of longwave radiation
transmitted -->
    <Urban24a1>0.81</Urban24a1> <!--Options: 0 to 1; sets magnitude of heat flux storage to net radiation
NR; units frac -->
    <Urban24a2>0.48</Urban24a2> <!--Options: 0 to 1; sets phase of heat flux storage 0=in phase; units hr
-->
    <Urban24a3>-79.9</Urban24a3> <!--Options: 0 to -100; sets value of heat flux storage when NR=0; units
W/m2 -->
    <Urban24buildingP>0.60</Urban24buildingP> <!-- Options: 0 to 1; fraction of grid cell with buildings -
->
    <Treeheight>11</Treeheight> <!-- Options: > 0; roughness height for evaporation resistance; units m --
>
    <Treealbedo>0.15</Treealbedo> <!-- Options: 0 to 1; fraction of shortwave radiation reflected -->
    <Treeemissivity>0.97</Treeemissivity> <!-- Options: 0 to 1; fraction of longwave radiation transmitted
-->
    <TreeLeafWidth>0.05</TreeLeafWidth> <!-- Options: > 0; width used in evaporation resistance; units m -
->
    <TreeMinimumResistance>100</TreeMinimumResistance> <!-- Options: > 0; lowest resistance for
transpiration; units s/m -->
    <Treea1>0.215</Treea1> <!--Options: 0 to 1; sets magnitude of heat flux storage to net radiation NR;
units frac -->
    <Treea2>0.325</Treea2> <!--Options: 0 to 1; sets phase of heat flux storage 0=in phase; units hr -->
    <Treea3>-19.9</Treea3> <!--Options: 0 to -100; sets value of heat flux storage when NR=0; units W/m2 -
->
    <ShortVegetationheight>0.1</ShortVegetationheight> <!-- Options: > 0; roughness height for evaporation
resistance; units m -->
    <ShortVegetationalbedo>0.21</ShortVegetationalbedo> <!-- Options: 0 to 1; fraction of shortwave
radiation reflected -->
    <ShortVegetationemissivity>0.97</ShortVegetationemissivity> <!-- Options: 0 to 1; fraction of longwave
radiation transmitted -->
    <ShortVegetationLeafWidth>0.02</ShortVegetationLeafWidth> <!-- Options: > 0; width used in evaporation
resistance; units m -->
    <ShortVegetationMinimumResistance>100</ShortVegetationMinimumResistance> <!-- Options: > 0; lowest
resistance for transpiration; units s/m -->
    <ShortVegetationa1>0.215</ShortVegetationa1> <!--Options: 0 to 1; sets magnitude of heat flux storage
to net radiation NR; units frac -->
    <ShortVegetationa2>0.325</ShortVegetationa2> <!--Options: 0 to 1; sets phase of heat flux storage 0=in
phase; units hr -->
    <ShortVegetationa3>-19.9</ShortVegetationa3> <!--Options: 0 to -100; sets value of heat flux storage
when NR=0; units W/m2 -->
    <Soilheight>0.1</Soilheight> <!-- Options: > 0; roughness height for evaporation resistance; units m -
->
    <Soilalbedo>0.14</Soilalbedo> <!-- Options: 0 to 1; fraction of shortwave radiation reflected -->
    <Soilemissivity>0.95</Soilemissivity> <!-- Options: 0 to 1; fraction of longwave radiation transmitted
-->
    <Soila1>0.355</Soila1> <!--Options: 0 to 1; sets magnitude of heat flux storage to net radiation NR;
units frac -->
    <Soila2>0.335</Soila2> <!--Options: 0 to 1; sets phase of heat flux storage 0=in phase; units hr -->
```

```
    <Soila3>-35.3</Soila3> <!--Options: 0 to -100; sets value of heat flux storage when NR=0; units W/m2 -
->
    <Waterheight>0.001</Waterheight> <!-- Options: > 0; roughness height for evaporation resistance; units
m -->
    <Wateralbedo>0.13</Wateralbedo> <!-- Options: 0 to 1; fraction of shortwave radiation reflected -->
    <Wateremissivity>0.9</Wateremissivity>
    <Watera1>0.5</Watera1> <!--Options: 0 to 1; sets magnitude of heat flux storage to net radiation NR;
units frac -->
    <Watera2>0.21</Watera2> <!--Options: 0 to 1; sets phase of heat flux storage 0=in phase; units hr -->
    <Watera3>-39.1</Watera3> <!--Options: 0 to -100; sets value of heat flux storage when NR=0; units W/m2
-->
    <WeatherWindHeight>10.0</WeatherWindHeight><!-- Options: > 0; height at which wind speed measured;
units m-->
 </TemperatureCalculationParams>
 <TemperatureExecutionParams>
    <RefWeatherLocationRowCol>0,0</RefWeatherLocationRowCol> <!-- row column pair as csv w 0=first;
Defines Reference weather station-->
    <RefWeatherLocationElevation_m>DEM</RefWeatherLocationElevation_m><!--Options: "DEM" or value <> 0;
DEM uses DEM.dat value; units m-->
    <RefWeatherLocationSlope_deg>DEM</RefWeatherLocationSlope_deg><!--Options: "DEM" or value >= 0.001;
DEM uses DEM.dat value; units deg-->
    <RefWeatherLocationAspect_deg>DEM</RefWeatherLocationAspect_deg><!--Options: "DEM" or value 1 to 360;
DEM uses DEM.dat value; units deg-->
    <RefWeatherLocationTopographicIndex>DEM</RefWeatherLocationTopographicIndex><!--Options: "DEM" or
"Avg"; Avg uses TI_avg | DEM uses DEM.dat value; unitless-->
    <PrintTimeBasedResults>Tair_K</PrintTimeBasedResults> <!-- Options: empty, Tair_K or All; map outputs
-->
    <PrintRowCol0>0,0</PrintRowCol0> <!-- row column pair as csv w 0=first; Defines cell time series
output location -->
    <RowColOutputPeriod>All</RowColOutputPeriod> <!-- Options: empty, All, or 2 YYYMMMDDHH as csv; cell
time series period -->
    <PrintBlockGroupDailyAndHourly>True</PrintBlockGroupDailyAndHourly> <!-- Options: True or False; if
blockgroup output -->
    <PrintBlockGroupRange0>1,2</PrintBlockGroupRange0> <!-- Options: Start, End; blockgroup(s) for output
-->
    <AH4GUC_HourlyValue_to_MaxValue_frac></AH4GUC_HourlyValue_to_MaxValue_frac> <!-- Options: If
Flag_CoolAir_AnthropogenicHeat=1 then 24 csv as hour_v to max_v; fraction-->
</TemperatureExecutionParams>
```

Weather data

Weather data acquisition and preprocessing has changed as of Spring 2020 to accommodate changes from our weather data provider, U.S. NOAA. The latest procedure works for i-Tree Hydro and Cool Air models. It generates three files, two of which are required by Hydro and all three of which are required by Cool Air. That procedure is documented in an i-Tree Support forum FAQ on Weather Data Inputs, under the “Using a raw weather file” section: https://forums.itreetools.org/viewtopic.php?f=35&t=1248

Auto-calibration from a Command Line Interface (CLI)

Autocalibration for iTree Hydro has been overhauled from the Hydro Graphical User Interface (GUI) for use with a command line interface (CLI). A CLI approach offers greater transparency, easier code maintenance, greater flexibility, and greater capacity for users to troubleshoot their own projects, which are qualities prioritized for advanced models in the i-Tree Research Suite.

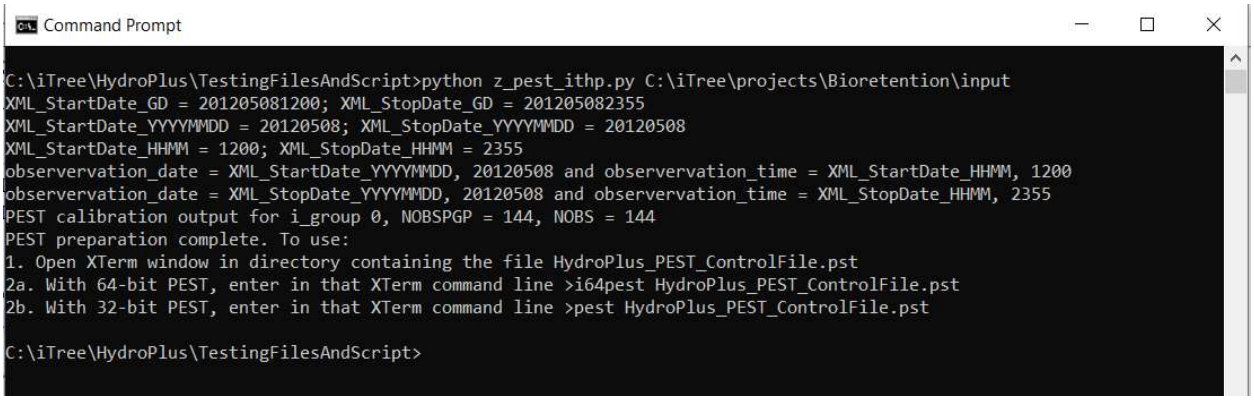
Autocalibration has been simplified with the python script located at TestingFilesandScript/z_pest_ithp.py. Examples of required inputs for Hydro calibration are located at TestingFilesandScript/TestCases/Calibration.

Use the following steps for calibration with the z_pest_ithp.py script:

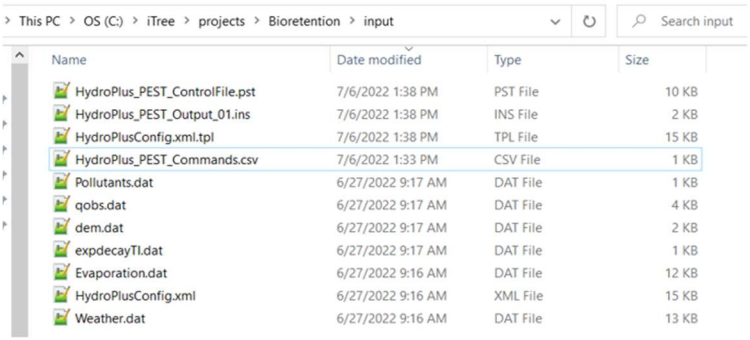
1. Download PEST.exe from https://pesthomepage.org/programs
2. Copy HydroPlus_PEST_Commmands.csv from TestingFilesandScript/TestCases/Calibration/ExponentialTI/input/ into project input folder
3. Edit HydroPlus_PEST_Commands.csv:
    a. HydroPlus_exe: path to HydroPlus executable
    b. HydroPlus_input: path to input project folder
    c. Pestdate: Start and end dates in YYYYMMDDHHMM format
    d. PEST_parameter: HydroPlusConfig.xml folder, followed by default value, lowest value, highest value
    e. PEST_observation: qobs.dat stream gauge data
    f. HydroPlus_prediction: path to Runoff_Predicted_for_Calibration.dat, generated in next step
4. Run HydroPlus with Flag_ExtendedOutputs set to 1 and set CalibrationTimeStep to the respective calibration timestep – hourly will produce the most accuracy. This generates Runoff_Predicted_for_Calibration.dat.

```
<SimulationStringParams>
   <OutputDirectory>C:\iTree\HydroPlus\TestingFilesAndScript\Was_DC_Validation\output\</OutputDirectory>
   <OutputTimeStep>Hourly</OutputTimeStep> <!-- Options: Hourly, Daily, Weekly, Monthly -->
   <CalibrationTimeStep>Hourly</CalibrationTimeStep> <!-- Options: NoCalibration, Hourly, Daily, Weekly,
   <Model>StatisticalHydro</Model> <!-- Options: StatisticalHydro, SpatialTemperatureHydro, ECDynamic, LC
   <Infiltration>ExponentialDecay</Infiltration> <!-- Options: ExponentialDecay, PowerDecay -->
   <FlowPathAlgorithm>DInfinity</FlowPathAlgorithm> <!-- Options: DInfinity, MFD, D8; Describes DEM flow
   <Flag_ExtendedOutputs>1</Flag_ExtendedOutputs> <!-- Options: 0=None 1=Time series written -->
```

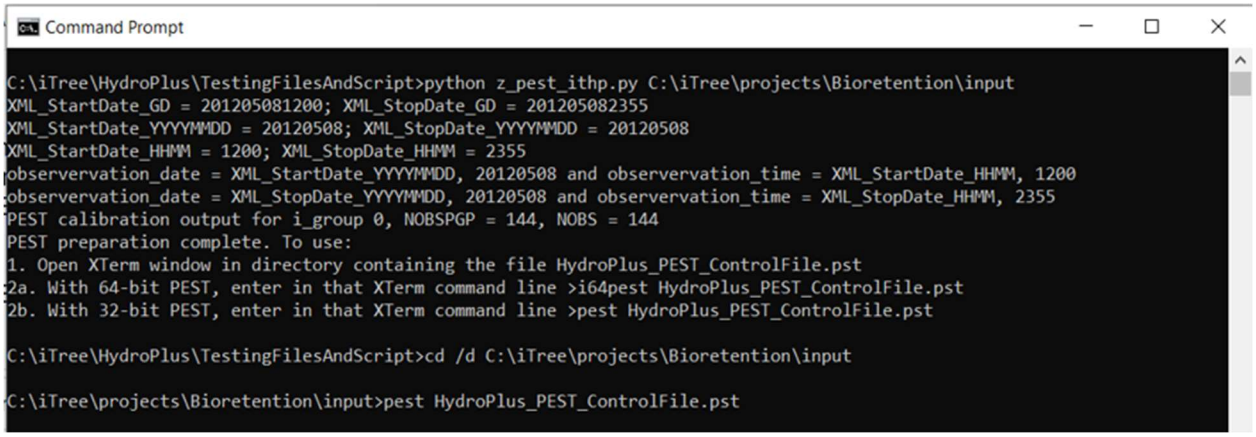
5. From the command prompt, run *python (path to z_pest_ithp.py) (path to input folder)*. The following image has the working directory set to the same path as z_pest_ithp.py.



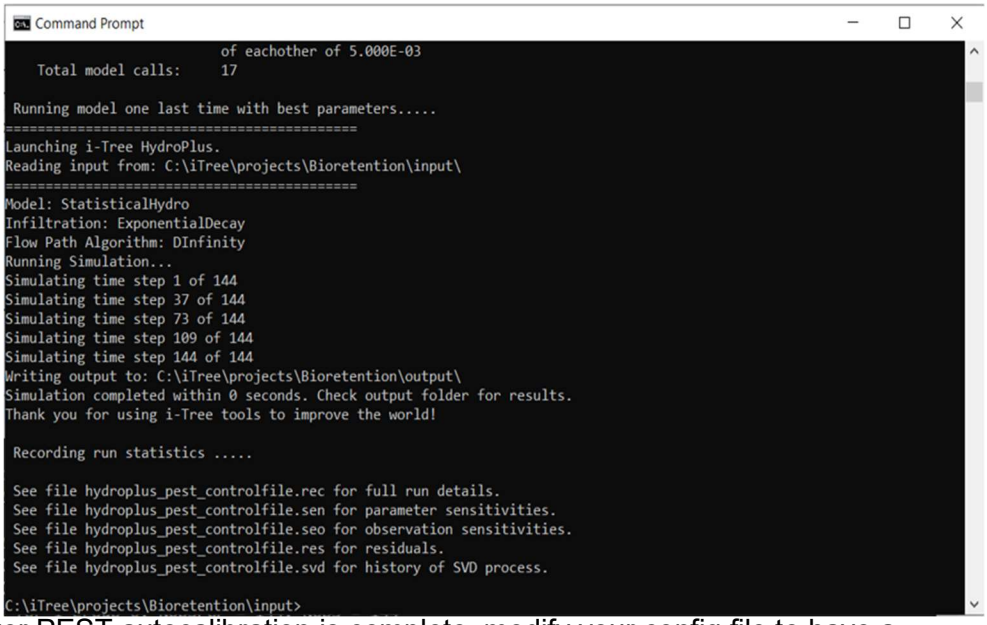
6. Copy PEST.exe downloaded in step 1 into the project folder. Changing the working directory to the project input folder (using cd /d *(directory)*), enter into the command prompt *pest HydroPlus_PEST_ControlFile.pst*. The pest.exe directory is copied into the input folder, so no path is needed.



Required files generated by z_pest_ithp.py



7. After running PEST, parameters will be adjusted in HydroPlusConfig.xml for best fit, and output files with full run details will be generated.



8. After PEST autocalibration is complete, modify your config file to have a CalibrationTimeStep other than NoCalibration if you have not already, then rerun HydroPlus.exe to get an Output.dat that shows goodness-of-fit (CRF) values comparing simulation outputs using autocalibrated parameters versus observed flow.

Outputs

After you've run the simulations you are interested in, find outputs in the OutputDirectory (defined in HydroPlusConfig.xml) for the simulation of interest.

Hydrology model outputs

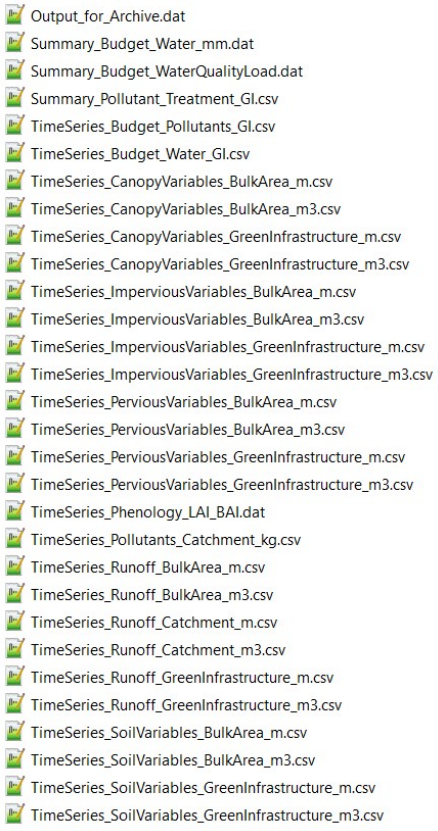
The following is a list highlighting and explaining some standard Hydro outputs and extended outputs (enabled in HydroPlusConfig.xml) of interest. Standard outputs include the Summary_Budget_Water_mm.dat and TimeSeries_Runoff_Catchment_m.csv and TimeSeries_Runoff_Catchment_m3.csv, the last two files reporting runoff either as a depth (m) or volume (m^3). If the model was run with the input file Pollutants.dat, then standard output includes Summary_Budget_WaterQualityLoad.dat. The extended output files are illustrated below, and typically are .csv files with names starting with "TimeSeries", and with a middle word describing the hydrologic focus, e.g., "CanopyVariables" and an ending name for the area of analysis, either "BulkArea" or a green infrastructure device, and a unit of measurement concludes the file name, such as_"m" for depth or "m3" for volume.

The variable names within the files often use abbreviations to describe common cover types or conditions such as:

- BS for bare soil cover
- IA for impervious area
- Imp for impervious cover
- PA for pervious area
- SV or SVeg for short vegetation cover
- SWE for snow water equivalent
- TC or Tree for tree cover
- TCIA for tree cover over impervious area
- TCPA for tree cover over pervious area
- W for rain water
- WB for water balance

Screenshot below show files from Standard and Extended Output for StatisticalHydro model without Green Infrastructure:

Screenshot below shows files from Standard and Extended Output for StatisticalHydro model with Green Infrastructure:



Temperature model outputs

This section lists potential outputs from the Cool Air model. To configure Cool Air outputs, see the Settings for Cool Air section and use the information below as a guide on available output options.

Two main types of output are available from the temperature model:

- Cell-based Output: results specific to a location on the gridded spatial inputs, referred to as a cell. These outputs are a timeseries of results for the specified cell.
- Time-based Output: results specific to a timestep during the simulation period, displayed as an ASCII raster map of outputs for all cells during the specified timestep.

There are also Blockgroup-based Output available but not yet stable, as the output metrics included in those files are unique and still in development. Land Cover Scaling-specific output is written by the Land Cover Scaling C# program.

Cell-based Output

The following gives examples of potential TemperatureExecutionParams options to generate different varieties of Cell-based Output. For a complete list of potential config file output tags, see Example of all options for TemperatureExecutionParams.

```
	Example C:
	Print Row#Col#Heat.txt and Row#Col#Hydro.txt for all locations in the DEM for the
time range specified. June 24, 2015 from the 1st hour/time step to the last hour/timestep
of that day; and June 26-28, 2015.
	<TemperatureExecutionParams>
		<RefWeatherLocation>1,42</RefWeatherLocation>
		<PrintRowCol>All</PrintRowCol>
		<RowColOutputPeriod0>2015062400,2015062423</RowColOutputPeriod0>
		<RowColOutputPeriod1>2015062600,2015062823</RowColOutputPeriod1>
	</TemperatureExecutionParams>

	Example D: Print Row#Col#Heat.txt for specific locations in the DEM for all
timesteps in the simulation (RowColOutputPeriod = All).

	<TemperatureExecutionParams>
		<RefWeatherLocation>1,42</RefWeatherLocation>
		<PrintRowCol0>5,3</PrintRowCol0>
		<PrintRowCol1>2,2</PrintRowCol1>
		<RowColOutputPeriod>All</RowColOutputPeriod>
	</TemperatureExecutionParams>
```

Description of Cell-based Output in Source Code: TemperatureOutputWriter.h

```
2. RowCol Output

*Functions related to the creation of Row#Col#Heat.txt # is a placeholder for DEM
location row number and col number
	ts	Ta	Td	Ea	ImpNR	TreeNR	ShortVegNR	SoilNR	ImpH	ImpLE
TreeH	TreeLE	TreeLEE	TreeLET	ShortH	ShortLE	ShortLEE	ShortLET
SoilH	SoilLE	H	LE
```

2015062409 297.025 288.089 0.012781 68.0026 74.0514 60.2795 0 85.4408 0 -171.964 222.164 189.708 32.4559 -180.26 240.489 187.167 53.3219 0 0 35.794 43.7463

static void createHeatRowColFile(int i, int j, std::string outDirectory);

-The above function creates the file and adds the header line

static void writeToHeatRowColFile(int timeStep, int i, int j, DataFolder *folder, std::string outDirectory);

-The above function writes output for a specific DEM location for a specific time step

*Functions related to the creation of Row#Col#Hydro.txt # is a placeholder for DEM location row number and col number

These are currently not in use!!!

-static void createHydroRowColFile(int i, int j, std::string outDirectory, Inputs *input);

-static void writeToHydroRowColFile(int i, int j, DataFolder *folder, std::string outDirectory);

*Helper functions for generating row#col# files

-static void rowColFileBatchProcessor(int timeStep, int organizerLocationIndex, DataFolder *folder, std::string outDirectory, Inputs *input);

The above function determines if the data for a location at a specific time step is written to its

corresponding heat file

-static void generateRowColFiles(DataOrganizer *organizer, Inputs *input);

The above function creates all rowcol files for the simulation run

Time-based Output

Example E:

For each timestep within 2015062400,2015062423 range, print a file for a specific variable such as AirT#.txt (where # is the timestep#). When PrintTimeBasedResults is set to All, All variable files will be created containing that value for each location in the DEM. (See [below in Time-Based Output Variables Available section, or] function TemperatureOutputWriter::timeStepResultsFileProcessor for complete list of variables.)

```
<TemperatureExecutionParams>
	<RefWeatherLocation>1,42</RefWeatherLocation>
	<PrintTimeBasedResults>All</PrintTimeBasedResults>
	<TimeBasedOutputPeriod0>2015062400,2015062423</TimeBasedOutputPeriod0>
<TemperatureExecutionParams>
```

Example F:

When PrintAllTimeBasedResults is set to AirT, only AirT#.txt files will be printed for the following three time periods.

```
<TemperatureExecutionParams>
	<RefWeatherLocation>1,42</RefWeatherLocation>
	<PrintTimeBasedResults>AirT</PrintTimeBasedResults>
	<TimeBasedOutputPeriod0>2015062400,2015062423</TimeBasedOutputPeriod0>
	<TimeBasedOutputPeriod1>2015062600,2015062723</TimeBasedOutputPeriod1>
	<TimeBasedOutputPeriod2>2015062800,2015063000</TimeBasedOutputPeriod2>
<TemperatureExecutionParams>
```

Example G:

In the below example, all variable files AirT#.txt, TD#.txt, ect. files will be printed for every timestep in the simulation.

```
<TemperatureExecutionParams>
	<RefWeatherLocation>1,42</RefWeatherLocation>
```

```
        <PrintTimeBasedResults>All</PrintTimeBasedResults>
        <TimeBasedOutputPeriod>All</TimeBasedOutputPeriod>
    <TemperatureExecutionParams>
```

Time-Based Output Variables Available

All equations referenced in the table below are from Yang et al. (2013).

Variable ID used in Config File	**Meaning**
AirE	Air absolute humidity (kg/m^3); Eq 18
AirT	Air temperature (K)
Td	Dew-point temperature (K)
H	Total sensible heat flux (W/m^2); Eq 1; 12
ImperviousH	Impervious sensible heat flux (W/m^2); Eq 3, 19
ImperviousLE	Impervious latent heat flux (W/m^2); Eq 4; 19
ImpNR	Impervious net radiation (W/m^2); Eq 9, 24
LE	Total latent heat flux (W/m^2); Eq 2; 13
ShortVegH	Short veg sensible heat flux (W/m^2); Eq 5, 22 & 23
ShortVegLE	Short veg latent heat flux (W/m^2); Eq 6, 21
ShortVegLEE	Short veg latent heat flux from evaporation (W/m^2); Eq 22
ShortVegLET	Short veg latent heat flux from transpiration (W/m^2); Eq 23
ShortVegNR	Short veg net radiation (W/m^2); Eq 10, 24
SoilH	Soil sensible heat flux (W/m^2); Eq 7, 20
SoilLE	Soil latent heat flux (W/m^2); Eq 8, 20
SoilNR	Soil net radiation (W/m^2); Eq 11, 24
TreeH	Tree sensible heat flux (W/m^2); Eq 5, 22 & 23
TreeLE	Tree latent heat flux (W/m^2); Eq 6, 21
TreeLEE	Tree latent heat flux from evaporation (W/m^2); Eq 22
TreeLET	Tree latent heat flux from transpiration (W/m^2); Eq 23
TreeNR	Tree net radiation (W/m^2); Eq 10, 24

Description of Time-based Output in Source Code: TemperatureOutputWriter.h

```
3. Time Based output

*Functions related to the creation of timestep files containing the specified variable
value for each location
in the DEM.
       -static void createTimeStepResultFile(std::string outputVarName, std::string date,
Inputs *input);
```

```
	The above function creates the file for a specific result and date
	-static void writeToTimeStepResultFile(std::string outputVarName, std::string
date, std::string & outDirectory, double val, bool newLine);
	The above function adds the value for a specific location's variable value to
appropriate file. The value is written
	to the same DEM row/col location.
	-static void timeStepResultsFileProcessor(int timeStep, int
organizerLocationIndex, DataFolder *folder, std::string outDirectory, Inputs *input);
	The above function coordinates the creation of all result files and addition of
each locations results to created files
```

Tips & Troubleshooting

Local work environment

- The **filepath** to your working copy of the code should not have any spaces in it. It's been found that a space in the filepath will cause the testing scripts to fail.
    - OK: C:\Users\coviller**Dev_Files**\SVN\hydrologyv6\branches\HydroPlus
    - Not OK: C:\Users\coviller**Dev Files**\SVN\hydrologyv6\branches\HydroPlus

Input Errors

When there are improper input files, iTree HydroPlus may not run, or will run improperly. If you run into a scenario where iTree HydroPlus is not producing an error message, or outputs, first check HydroPlusConfig.xml. Particularly sensitive parameters preventing outputs is StartDay and EndDay, OutputDirectory, CalibrationTimeStep, and Model.

The absence of weather data, or improper formatting of weather data YYYYMMDDHH will prevent generation of outputs.

Dem.dat will prevent running of HydroPlus, or generate erroneous outputs, when cell size is not equal to an integer. Any float values (or decimals) in cell size will result in errors. Further, make sure NODATA is -9999. When a dataset does not have a predefined NODATA value, it may default to 0.

In i-Tree Cool Air, inputs of land cover, impervious cover, and tree cover can cause issues where iTree HydroPlus will run but not produce any output or error message. Ensure that all cover the same extents, have the same cell size, and have NODATA values of -9999. For more information about processing NLCD data, see Processing Land Cover Data.

Version Control and Testing

To maintain working code that can support further development and troubleshooting, we rely on 3 code management strategies.

- **Version Control**: keeping track of different iterations, variations, and checkpoints of the code.
- **Standard Operating Procedure for Testing Code**: a consistent and efficient way to check of a reliable set of inputs produces the expected set of outputs in various modes and conditions.
- **Standard Operating Procedure for Updating Code**: a consistent and reliable way to build upon stable code with minimal introduction of bugs or divergence from the stable code.

Version Control

The two major systems for version control are SVN and git. i-Tree projects first version controlled in 2018 or later tend to be stored on git at https://code.itreetools.org while older projects are stored on SVN at https://svn.itreetools.org/usvn.

If you are beginning to work on HydroPlus R&D and need access to SVN, please register a new account at https://code.itreetools.org and notify project leader Jay.Heppler@davey.com.

Version control is generally organized in a hierarchy with 'repositories' or 'projects' at the top level of each version control tree.

Locations

HydroPlus – the C++ model code for i-Tree Hydro, i-Tree Cool Air, and related models and modes – is version controlled using SVN. Its repository is at https://code.itreetools.org/svn/HydroPlus and https://code.itreetools.org/svn/HydroPlus/trunk.

LocalizeEMCs – two Python models for extracting event mean concentration (EMC) or export coefficient (EC) values from the White et al. (2015) database, creating output needed by Buffer.py– is version controlled on git at https://code.itreetools.org/ESF/Hydro/LocalizeEMCs_git

Buffer – the Python model for identifying non-point source runoff pollution loading hotspots – is version controlled on git at https://code.itreetools.org/ESF/Hydro/Buffer_git.

Energy – the Python model for mechanistically predicting shade tree benefit for building heating & cooling loads – is version controlled on git at https://code.itreetools.org/ESF/Hydro/Energy_git

SVN Concepts and Definitions

TortoiseSVN is used to interact with the SVN repository for HydroPlus. This TortoiseSVN software should be installed on the local machine, and integrated into the Windows apps and programs so it is available from File Explorer.

The TortoiseSVN manual is useful reference:
https://tortoisesvn.net/docs/release/TortoiseSVN_en/index.html

TortoiseSVN Subversion Control Procedures

TortoiseSVN offers SVN commands, and those most frequently used are discussed below.

1. SVNCheckout (right click on new local folder from File Explorer) is used once on a folder to establish the link between the local folder and the itreetools SVN URL and obtain the files from the server. The SVNCheckout process will default download the head or latest revision of entire solution from the URL to the local folder. An older revision can be selected, and revisions can be explored by using the Show Log features in this command.
2. SVN Update (right click on new local folder from File Explorer) is used each day after establishing a connected folder with SVNCheckout, in order to get the latest revision, presuming someone had made and committed changes. It will automatically update to the latest revision, or head.
3. SVN Commit (right click on new local folder from File Explorer) is used after each local revision has been made and the standard operating procedures of checking test cases. This command provides a text window to enter comments, which should include details on the what, why, how of files that were modified, and a confirmation that the test cases pass. This command also allows for selecting which files should be committed to the SVN URL.
4. TortoiseSVN (right click on new local folder from File Explorer) will open another list of commands in File Explorer, including Show Log, Repo – browser, Merge, Update to Revision, and many others. All are potentially useful for some situations.

When using SVN, it is important to understand the difference between local content versus server-side content. Given the differences between those two storage areas, the following should never be included in version control:

- Build output from project (can always be rebuilt from source)
- Nuget local packages directory (should always be downloaded)
- *.suo and *.user files for Visual Studio repositories (these are only used by VS to retain current development layout.. E.g. which files are open and their position.. committing these will lead to many merge conflicts)

Git Subversion Control Procedures

TortoiseSVN offers git commands and those most frequently used are discussed below. Commonly used Xterm window or DOS git commands are also presented below.

TortoiseSVN

1. Git Clone (right click on new local folder from File Explorer) is used once on a folder to establish the link between the local folder and the itreetools Git URL and obtain the files from the server. The Git Clone process will default download the head or latest revision of entire solution from the URL to the local folder. Open the .git config file to confirm the

clone was successful, and there is the proper URL and a "merge" field, with the path to the branch or master.
2. TortoiseGit > Pull (right click on new local folder from File Explorer) is used each day after establishing a connected folder with Git Clone, in order to get the latest revision, presuming someone had made and committed changes. It will automatically update to the latest revision, or head.
3. Git Commit-> <target> (right click on new local folder from File Explorer) will open window to enter comments, add files with changes, and click on Commit & Push button
4. TortoiseGit (right click on new local folder from File Explorer) will open new window within File Explorer with many commands, including Diff, Revert, and Show Log to explore local and URL issues

Xterm DOS

1. git clone <URL> or git clone -b <branch> <URL> is used once on a folder to establish the link between the local folder and the itreetools Git URL and obtain the files from the server. The git clone process will default download the head or latest revision of entire solution from the URL to the local folder. Open the .git config file to confirm the clone was successful, and there is the proper URL and a "merge" field, with the path to the branch or master.
2. git pull, git diff, and git status within the git folder explore local and URL issues
3. To commit, three steps are required:
    a. git add <filename> or git add –a to place one file or all files into staging area
    b. git commit -m "comments on changes" with –m indicating a message in “” follows
    c. git push will move staged files to URL.

Utilities and models related to HydroPlus are developed and stored on git repositories. Below is an example workflow for development of code on one of our git repositories. Other git notes follow.

1. Checkout a local copy of GLRI_AutoRR
2. Modify, delete, add content on local copy
4. Use "git status" to confirm changes are as expected
5. Use "git add ." to stage all changes for commit
6. Use "git commit -m <message in quotes>" to commit changes with brief description of revision's changes. E.g. git commit -m "Changing DEM delineation module to use function from external"
7. Use "git push" to send your local revisions/commits to the server. For this command to work you may need to setup your git working space. If so, use "git remote get-url" to confirm your remote (server-side) URL and "git remote set-url <full URL>" to (re)set it if needed. Other common issues include other git remote settings or credential commands needed.

Caution: Be careful with big files on version control. Once something is committed to the version control server, it's stored even if deleted in a future revision, as intended by version control tracking old versions. It is difficult or unfeasible to free up storage space from old

revisions. As an alternative to committing large files, consider using a placeholder documentation file instead, so users could checkout the program and use the documentation to reproduce/source any large files needed. i-Tree Buffer has an example of this: https://code.itreetools.org/ESF/Hydro/Buffer_git in the Constants folder, which in a fully-functioning working copy is ~180GB but on version control is kept smaller with a descriptive xlsx file to provide guidance about large files that would be included off version control.

A comprehensive list of files to be ignored for git-based version control is available here, which can serve as a reference for SVN use: https://github.com/github/gitignore/blob/master/VisualStudio.gitignore

SOP for Testing Code

A test script with sample inputs and expected outputs are setup to streamline model testing. The standard test procedure will compile a working copy of the HydroPlus code and run it against the tests defined in \HydroPlus\TestingFilesAndScript\ListOfTests.txt.

Procedure for Running Test Script

1. If you have not yet set up Visual Studio 2022 and compiled a new copy of the HydroPlus EXE, follow the instructions in the Development Notes section "Visual Studio setup for developing & testing code" to prepare for running the test script.
2. Go to the /TestingFilesAndScript/ directory (e.g. https://svn.itreetools.org/svn/hydrologyv6/trunk/TestingFilesAndScript/) and open ListOfTests.txt.
3. Within ListOfTests.txt, confirm that the first line of the file defining the Executable location points to the correct location for the compiled HydroPlus.exe to be tested: "Executable,..\HydroPlus\Release\HydroPlus.exe" This should be the case by default so that Steps 1 & 2 require no action. Close ListOfTests.txt.
4. Run the Python 3 script "TestToCompareHPOutputToStandards.py" from a command prompt or your preferred Python IDE.
    a. Nothing in this file or standard inputs should need to be changed; the script will use the HydroPlus.exe in /HydroPlus/Release/ along with the various input and expected output sets to test that EXE against standard results, ensuring all HydroPlusConfig.xml files are set to appropriate input/output paths.
    b. This script will not pause between simulations for users to view terminal output, but a log.txt file will be generated in the same directory as the script for users to review terminal output after all simulations are complete.
5. The script will create a new directory named "Testing_YYYY_MM_DD_hh_mm_ss". In that directory, the "results.txt" file will identify which files in which test cases failed if any. If any tests failed, compare the specified output file to the expected output file to begin troubleshooting. Notepad++ offers a comparison tool for side-by-side difference identification in each output.

6. If outputs are only slightly different that may be acceptable, or if certain expected outputs are not yet reliable it may be OK if the code being tested doesn't match. On the other hand, seemingly minor differences in formatting could cause problems in production, so carefully consider any differences.
7. Once all differences are resolved and the working copy of the code is performing as expected, you can commit it to SVN, and in the SVN commit message summarize the changes that have been made in this revision. Try to use key words that may be searched for later on, making it easier for future development to browse revision history for specific changes.

SOP for Developing New Features

During development, the following procedure should be followed to maintain stable code and minimize divergence from the stable code. Note that this procedure was developed for GI development going on simultaneously with HydroPlus development; a more relaxed procedure might work during less challenging development conditions.

Each day during development:

1. Begin by updating your working copy to the latest revision of the main code, to ensure your work is in sync with that.
2. Develop features as needed. Try to avoid writing redundant code (e.g. if the function you need exists for a different model mode, find a way to use it or use functors to use a variation of it) and try to keep things modular and parsimonious. Importantly: test and troubleshoot as you go; do not try to build upon broken code.
3. Run the standard test scripts to ensure that the day's work has not broken the stable code.
4. If the scripted tests show that the working copy of the code fails to produce expected outputs in stable model modes, then you need to restore the code to working order before committing it each day. (Restoring the code to working order could be as simple as commenting out the newer work for the day, or just commenting out the troublesome parts of it.)
5. Once the code is in working order, commit your work for the day, every day that you work on it. That way a record and backups of work in progress is maintained, keeping new development in sync with the main code and ensuring new code isn't being built on broken code.

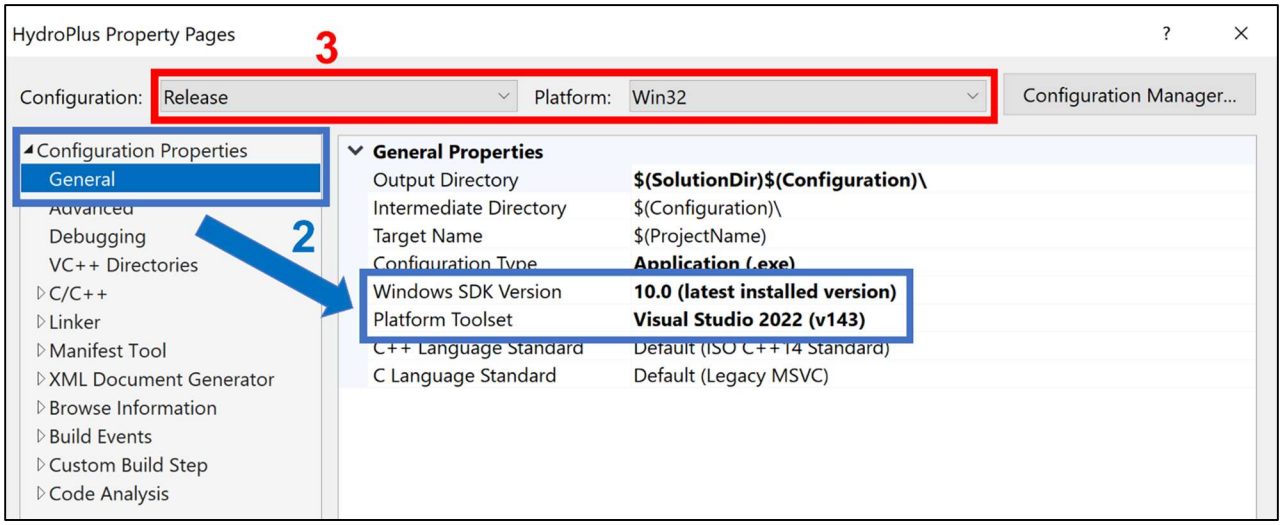
When making comments (at least for temporarily-commented out code), sign with author and latest date. Indicating latest date will help us estimate if 'old' commented out code can be deleted from future revisions, or if it is freshly commented out code we'll know to leave it in case it is work-in-progress.

Development Notes

Visual Studio setup for developing & testing code

The HydroPlus development team uses Visual Studio 2022 to view, edit, and compile the C++ source code. The VS software plays a critical role in how HydroPlus is developed and tested. The “Community Edition” of VS 2022 is free to download and use.

1. Install Visual Studio 2022 Community Edition if you have not already. In the installation you will need certain development components to compile HydroPlus. To change what components have been installed, open the Visual Studio Installer, go to the ‘Installed’ tab, then select the ‘Modify’ button on VS 2022.
    a. Select the “Desktop development with C++” workload, leaving all default sub-components selected.
    b. Select the “Universal Windows Platform development” workload, leaving all default sub-components selected.
2. Open the HydroPlus solution (e.g. https://svn.itreetools.org/svn/hydrologyv6/trunk/HydroPlus/HydroPlus.sln) in Visual Studio.
    a. Ensure that the HydroPlus project is set to compile with the needed configuration properties. To do so, right click on the Hydro project in Visual Studio’s Solution Explorer, and select Properties. In the window that appears, click the ‘General’ option under ‘Configuration Properties’. Implement the settings shown below:
        i. Windows SDK Version = 10.0.19041.0 (or later)
        ii. Platform Toolset = Visual Studio 2022 (v143)



3. At the top of the same window, set the Configuration to “Release” mode and Platform to “Win32” (usually it will be in Debug, Win32 mode during development). Close the Properties window, and make sure the same configuration options are selected in the top toolbar.
4. Go to Build > Rebuild Solution to compile a fresh copy of HydroPlus.exe. The Output window in Visual Studio should show compilation processes and will end by stating if the solution compiled successfully or failed.
    a. If the Build fails due to errors related to missing math.h or other basic libraries, consider following advice in StackExchange, using the Visual Studio Installer > Individual components > and under the heading “Compilers, build tools, and runtimes” check the box for “Windows Universal CRT SDK”.
5. Find the /Release/ folder in the same directory as the HydroPlus.sln file, and in that /Release/ folder confirm there is a HydroPlus.exe created as recently as expected.

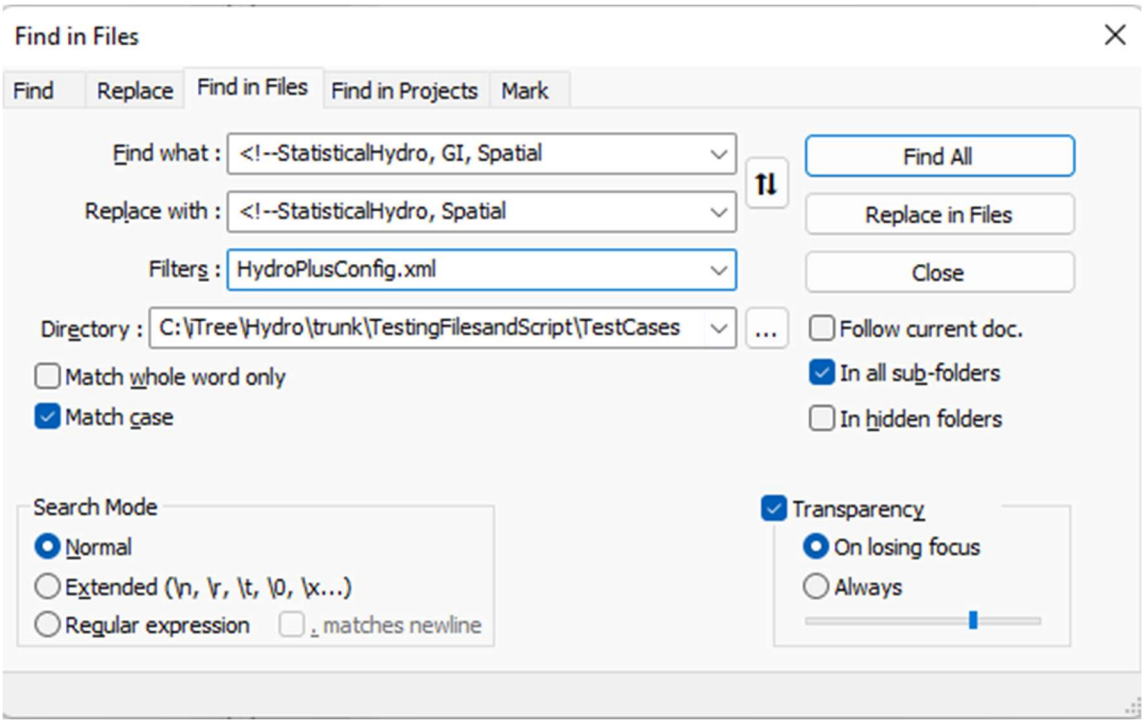
Config file modifications

The config files included in /TestingFilesAndScript/TestCases/ serve as ‘master copy’ config files; as we update HydroPlus, users can compare older config files with the latest in TestCases to get their files up-to-speed with the latest config file features.

Because we have numerous TestCases, config file changes need to be made in batch. Superficial changes are those that only affect the config file (e.g. changing comments), as compared with other changes (e.g. changing tag names) that require accompanying code changes.

Batch superficial changes (file only, no code changes)

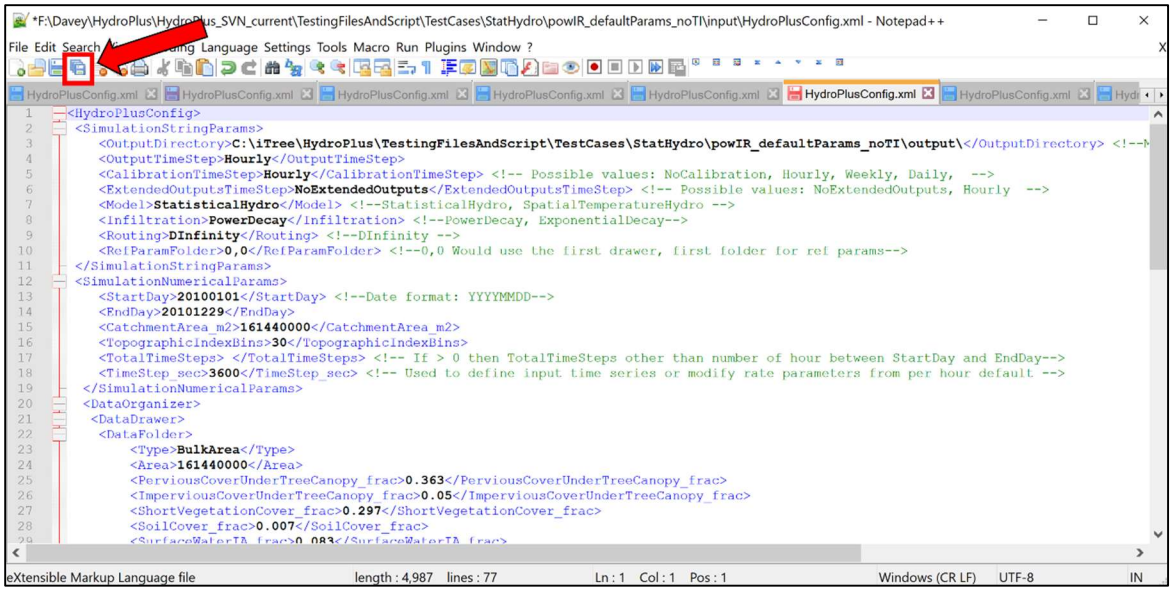
1. Open a HydroPlusConfig.xml file contained in /TestingFilesAndScript/TestCases/
2. Use Find + Replace in files feature: Find to identify a string to be modified or to anchor a modification; and Replace to change that string or add content before or after it. In the example below, an outdated comment about available Model tag values is being changed to remove GI (since the GI model mode is now built into StatisticalHydro model mode).



With find in files, Notepad++ can filter by directory and file type. Use * to filter by partial name – for example "*.xml" will search all XML files, while "Hydro*" will search for all files starting with Hydro.

Be careful to use a "Find" value detailed enough to ensure you only edit around the string you intend to. For example, if you searched for a string that occurs in multiple different tags, your Replace action might affect unintended tags. To be extra careful, you can use Find All to identify all strings to be affected before choosing to Replace All. To check your work, you can use TortoiseSVN>Revert… or Commit… to view a list of files you've modified in your working copy of the SVN code repository, and you can right-click each file to view each specific difference highlighted. That way you'll see if the differences are what you intended or not before moving forward with development or committing your work.

3. Save changes to open file (all others save automatically).



4. Follow SOP for Testing Code to confirm your changes have not unintentionally affected results.

Code changes associated with config file changes

Basic workflow:

1. Find and replace all instances of relevant input-parsing code for config file tag being modified. Example: find and replace all *folder->ParamDict["Area"]* with *folder->ParamDict["BAorGIArea_m2"]* in HydroPlus.sln
2. Open all config files as tabs within a single Notepad++ window. Find and replace all, in all open documents. Example: *Area>* with *BAorGIArea_m2>*. That > symbol captures the necessary part of *<Area>* as well as *</Area>.*
3. Save all modified config files. Run test SOP. Parameter name changes should not require expectedoutputs change. If expectedoutputs do need to change, carefully check the new output and then commit that as the expectedoutputs if suitable.

Running HydroPlus in sub-hourly timesteps (Jan 21, 2019)

The parameter which controls all the timesteps related operations is the "SimulationNumericalParams["TotalTimeSteps"]". In the UH, we have the following line:

Inputs.cpp
#63, 64, & 65

```
d1 = ToJulianDate(SimulationNumericalParams["StartDay"]);
d2 = ToJulianDate(SimulationNumericalParams["EndDay"])+1;
SimulationNumericalParams["TotalTimeSteps"] = (d2 - d1) * 24;
```

Therefore, by modifying the TotalTimeSteps we can run the model in different timesteps. For example, to run a 5-min interval scenario for 2 hours, manually changing the TotalTimeSteps to

24 ((60/5)*2) in the code works. If we add the TotalTimeSteps parameter to the config file, the users could run the code in finer resolution than hourly based intervals.

yyyymmdd	hh:mm:ss	Precipitation	Total run off	Base flow(m)	Pervious flow	Impervious flow
20120508	12:00:00	0	1.6e-05	2.93245e-32	0	0
20120508	12:05:00	0	3.2094e-17	3.2094e-17	0	0
20120508	12:10:00	0	1.47769e-13	1.47769e-13	0	0
20120508	12:15:00	0	7.30526e-12	7.30526e-12	0	0
20120508	12:20:00	0	7.17038e-11	7.17038e-11	0	0
20120508	12:25:00	0	3.24432e-10	3.24432e-10	0	0
20120508	12:30:00	0	9.51454e-10	9.51454e-10	0	0
20120508	12:35:00	0	2.13408e-09	2.13408e-09	0	0
20120508	12:40:00	0	4.00736e-09	4.00736e-09	0	0
20120508	12:45:00	0	6.64721e-09	6.64721e-09	0	0
20120508	12:50:00	0	1.0076e-08	1.0076e-08	0	0
20120508	12:55:00	0	1.42753e-08	1.42753e-08	0	0
20120508	13:00:00	0	1.91993e-08	1.91993e-08	0	0
20120508	13:05:00	0	2.47856e-08	2.47856e-08	0	0
20120508	13:10:00	0	3.09641e-08	3.09641e-08	0	0
20120508	13:15:00	0	3.76624e-08	3.76624e-08	0	0
20120508	13:20:00	0	4.48097e-08	4.48097e-08	0	0
20120508	13:25:00	0	5.23391e-08	5.23391e-08	0	0
20120508	13:30:00	0	6.01887e-08	6.01887e-08	0	0
20120508	13:35:00	0	6.83024e-08	6.83024e-08	0	0
20120508	13:40:00	0	7.66298e-08	7.66298e-08	0	0
20120508	13:45:00	0	8.51262e-08	8.51262e-08	0	0
20120508	13:50:00	0	9.3752e-08	9.3752e-08	0	0
20120508	13:55:00	0	1.02472e-07	1.02472e-07	0	0

Land cover scaling simulations (LCscaling utility)

Hydro LCscaling analysis

HydroPlus was modified in early 2019 to interface with the “LCscaling” utility, which batch runs UH through increments of tree cover and impervious cover to assess a gradient of land cover change effects. This ‘land cover scaling’ analysis has been used since before 2015 with the semi-distributed Hydro model, using a tool called ‘AutoRun’. The ‘new and improved’ LCscaling utility is designed to work with the semi-distributed Hydro model as well as the fully-distributed Cool Air model.

To use that LCscaling tool:

1. Check it out from https://code.itreetools.org/ESF/Hydro/LCscaling_CLI
2. Follow the README.txt to run LCScaling.py

History

This utility was developed by Thomas Taggart (SUNY-ESF) and Pallavi Iyengar (Syracuse University) beginning June 2014 (or potentially earlier with Yang Yang (SUNY-ESF)), to produce results for EPA EnviroAtlas datasets, collaborating with David Nowak (USFS) and Theodore Endreny (SUNY-ESF) on utility design and I/O goals. Shannon Conley (Davey Institute) worked with Robert Coville (Davey Institute) and Theodore Endreny (SUNY-ESF) to update AutoRun for use with HydroPlus.exe, which began April 2019 with the initiation of the LCscaling branch of the Hydro SVN repository (referenced above). Nakul Sahayata (Syracuse University) began to assist with LCscaling development in March 2020. The most recent LCScaling.py was created by James Kruegler (Davey Institute). This utility continues to be developed for use in GLRI Shoreline Health & NUCFAC Temperature-Health R&D projects.

Cool Air LCscaling analysis

Note that for Cool Air, an alternative to the LCscaling utility was developed. That uses LCscaling input grids in a single program execution instead, and uses blockgroup hourly outputs and a new <LCScalingOutput>Yes</LCScalingOutput> option in Cool Air config file's <TemperatureExecutionParams> section, to execute a batch interpolation feature for results from all 1% increments of TC & IC from 0-100%.

For example, Cool Air will run LCscaling interpolation using 2x2 input grids of edge case conditions and the following config file settings:

```
<TemperatureExecutionParams>
        <RefWeatherLocation>1,1</RefWeatherLocation>
        <PrintBlockGroupDailyAndHourly>True</PrintBlockGroupDailyAndHourly>
        <PrintBlockGroupRange0>1,4</PrintBlockGroupRange0>
        <LCScalingOutput>Yes</LCScalingOutput>
</TemperatureExecutionParams>
```

Conditions for TC+IC != 100%

In the Statistical Hydro model, all land cover parameters are explicitly defined and are expected to sum to 100%.

In the Spatial Temperature model, land cover for each dataFolder (a.k.a. cell, pixel in the area of interest raster grid) is defined by a raster layer for tree cover % (treecover.dat), impervious cover % (imperviousCover.dat), and NLCD Land Cover Class (landcover.dat). NLCD Land Cover (LC) classes are associated with different parameters for model subroutines, and these LC classes inform what other land cover is present when TC+IC<100%.

The conditions for TC+IC>100% or TC+IC<100% are defined (as of revision 1088) in HydroPlus's ResistanceCal.cpp file, in the ResistanceCal::SurfaceResistance_LandCover function. Comments in this section describe methods. In short, the excess when TC+IC>100% is assumed to be TreeOnImp (tree canopy covering impervious cover). The deficiency when TC+IC<100% is defined according to LC class, where special LC classes dictate what is filled in

(e.g. in a ‘open water’ cell, water is filled in) or a standard method is used (as for LC21, filling the gap with ShortVeg and/or Soil).

Functors

Functors are used instead of complicated switches to plug in certain functions depending on a given condition. For example, whether the semi-distributed hydrology model is run or the spatially-distributed temperature model is run, most of the same functions will be called but certain processes will require different functions depending on the specific model. Functors can control which functions are run depending on which model is being run.

In RootZoneETCalc::calculate a functor is called:

```
void RootZoneETCalc::calculate(Inputs *input, DataFolder *folder, int timeStep, std::map<std::string, void(*)(Inputs *input, DataFolder *folder, int timeStep)> &functors)
{
    // Resetting the SumET for each timestep/folder - run against V5 to make sure it works the same in semi-distributed mode (11/5/14) - it does ! 11/9/14
    folder->VarDict["sumET"] = 0.0;

    // rzMSD = Maximum root zone storage deficit - set in the param file
    double rzMSD = input->SoilParams["MSD_MaximumRootZoneStorageDeficit_meters"];

    // This for loop runs for each member of the Topographic Index Distribution - typically 30 values
    for(int ia=0; ia< input->IndexAreaSize; ia++)
    {
        if (timeStep == 0)
        {
            folder->VarVecDict["rET_TI"].push_back(0.0);
        }
        // Setting the rootzone ET equal to 0, for this index value
        folder->VarVecDict["rET_TI"][ia] = 0.0;
        input->RepoDict["iA"] = ia;
        functors["calculateRootzoneET"](input, folder, timeStep);
        // Total ET - for the whole run period? - was (incorrectly) but isn't now due to resetting the value at the beginning of this function
        // Total ET - For this timestep is previous ET value + the amount of ET from this index value * the fraction of the watershed area for this index value
        folder->VarDict["sumET"] += folder->VarVecDict["rET_TI"][ia] * input->IndexArea[ia];            // calculate total ET from the subcatchment
        // In affect this appears to be averaging the ET across the watershed (by Index areas - when in sem-dist mode) while summing it to total ET
    }
```

To find what this functor is doing, I searched “functor” in the entire solution and looked for where many appear to be defined. That’s in TestSimulation.cpp within the definition of runBulkAreaCalculations

```
void TestSimulation::runBulkAreaCalculations(DataFolder *folder, Inputs *input, int timeStep, std::vector<DataFolder*> &drawer)
{
    std::map<std::string, void(*)(Inputs *input, DataFolder *folder, int timeStep)> functors;
    if (input->InputOutputParams["Model"] == "StatisticalHydro")
    {
        functors.emplace("calculateTreeEvaporation", TreeEvaporationCalc::calculateTreeEvaporationStatistical);
        functors.emplace("calculateShortVegEvaporation", ShortVegEvaporationCalc::calculateShortVegEvaporationStatistical);
        functors.emplace("calculatePerDepEvap", PerviousDepressionStorageCalc::calculatePerDepEvapStatistical);
        functors.emplace("calculateImpEvap", ImperviousDepressionStorageCalc::calculateImpEvapStatistical);
        functors.emplace("calculateRootzoneET", RootZoneETCalc::calculateRootzoneETStatistical);
    }
    if (input->InputOutputParams["Model"] == "SpatialTemperatureHydro")
    {
        functors.emplace("calculateTreeEvaporation", TreeEvaporationCalc::calculateTreeEvaporationTemperature);
        functors.emplace("calculateShortVegEvaporation", ShortVegEvaporationCalc::calculateShortVegEvaporationTemperature);
        functors.emplace("calculatePerDepEvap", PerviousDepressionStorageCalc::calculatePerDepEvapTemperature);
        functors.emplace("calculateImpEvap", ImperviousDepressionStorageCalc::calculateImpEvapTemperature);
        functors.emplace("calculateRootzoneET", RootZoneETCalc::calculateRootzoneETTemperature);
    }
    if (input->InputOutputParams["Infiltration"] == "PowerDecay")
    {
        functors.emplace("calculateInfiltration", SoilInfiltrationPowDecayCalc::calculate);
        functors.emplace("calculateUnsatZoneSoilMoistureDeficit", UnsatZoneSoilMoistureDeficitPowDecayCalc::calculate);
```

What we see here is that, within the runBulkAreaCalculations function, there is basically as switch board saying what a functor should do depending on a certain input or condition. In the

calculateRootzoneET functor highlighted above, depending on what model is being run, a different actual function (either calculateRootzoneETStatistical or calculateRootzoneETTemperature) is assigned to that functor. That way, back in RootZonETCalc::calculate, the functor calculateRootzoneET can be called and it will automatically activate the appropriate function depending on which model is running.

Build settings

In August 2020 it was observed that the Visual Studio setting for Whole Program Optimization was resulting in build failures for some developers. Whole Program Optimization is disabled moving forward for two reasons: 1) disabling that feature resolves the build errors some developers faced, and 2) this feature is not recommended for development cases like ours, where libraries may be shared across different versions of Visual Studio, resulting in unexpected behavior when this feature is enabled. More information about this feature is available at https://devblogs.microsoft.com/cppblog/quick-tips-on-using-whole-program-optimization/.

Feedback on C++ methods for GI dev (Oct 18, 2018)

The content below was shared by Shannon Conley in Oct ’18 as feedback for Reza Abdi as rev279 had many compilation errors. Shannon resolved many of those errors and provided this feedback in rev280. Reza was simultaneously working on resolving many of those errors with feedback Robbie Coville provided, and Reza committed his changes to rev281. Content below provided as reference, eventually to be cleaned up & integrated into the rest of this manual.

Calculation Classes

These classes should contain only static function members. Highlighted in yellow is a static function declaration. Marked in red is not-static. A static function cannot call a non-static function. This results in a compilation error. Also, static functions cannot access data members. such as inflowFromGI_mm. This is by design. All data should be read from or stored in either the *input or *folder. If data is specific to a GI unit or bulk area it should be stored in one of the *folder dictionaries (will explain more below). If data is read from an input file or related to more than one unit then it would be stored in *input.

```
#include "../Inputs/Inputs.h"
#include "../DataFolder.h"

class WaterOnImperviousAreaCalc
{
    public:
        static void calculate(Inputs *input, DataFolder *folder, int timeStep);
        static void storeValues(Inputs *input, DataFolder *folder, int timeStep);
        double inflowFromGI_Imp();

    private:

        double inflowFromGI_mm = 0;

};
```

A static member function is used without creating an instance of the class exist and the static functions are accessed using only the class name and the scope resolution operator ::. Below are some examples.

```
TreeInterceptionCalc::calculate(input, folder, timeStep);
ShortVegInterceptionCalc::calculate(input, folder, timeStep);
functors["calculateTreeEvaporation"](input, folder, timeStep);
functors["calculateShortVegEvaporation"](input, folder, timeStep);
PerviousAreaThroughFlowCalc::calculate(input, folder, timeStep);
SnowMeltOpenAreaCalc::calculate(input, folder, timeStep);
SnowMeltUnderTreeCalc::calculate(input, folder, timeStep);
SnowMeltUnderShortVegCalc::calculate(input, folder, timeStep);
WaterOnImperviousAreaCalc::calculate(input, folder, timeStep);
ImperviousDepressionStorageCalc::calculate(input, folder, timeStep, functors);
WaterOnPerviousAreaCalc::calculate(input, folder, timeStep, drawer);
PerviousDepressionStorageCalc::calculate(input, folder, timeStep, functors);
SemiAveSMDCalc::calculate(input, folder, timeStep);
functors["calculateInfiltration"](input, folder, timeStep);
```

This is a nice link explaining static concepts in C++.
https://www.tutorialspoint.com/cplusplus/cpp_static_members.htm

The DataFolder class

Originally, this class was called Cell, but it seems to be a loaded term. A DataFolder can be created for each GIUnit. For instance, BulkArea will have its own instance of a DataFolder class. Only info specific to this unit should be stored here. There are four options for storing data.

1. std::map<std::string, double> ParamDict; This stores input data specific to the unit with the double datatype. So in a calculation, you can access PerDepStorage as highlighted below.

```
- <DataOrganizer>
    - <DataDrawer>
        - <DataFolder>
            <Type>BulkArea</Type>
            <AreaPer>1.0000</AreaPer>
            <Area>161440000</Area>
            <TreePerviousCover>0.363</TreePerviousCover>
            <TreeImperviousCover>0.05</TreeImperviousCover>
            <ShortVegCover>0.297</ShortVegCover>
            <SoilCover>0.007</SoilCover>
            <ImperviousCover>0.283</ImperviousCover>
            <DCIA>0.2685</DCIA>
            <ImpDepStorage>2.5</ImpDepStorage>
            <PerDepStorage>1.0</PerDepStorage>
        </DataFolder>
```

```
void PerviousDepressionStorageCalc::calculate(Inputs *input, DataFolder *folder, int timeStep, std::map<std::string,
{

    // perviousStorageMax = param.dat pervious storage maximum value (in mm) * 0.001 -> to convert to meters
    folder->VarDict["perDepStorMax"] = 0.001 * folder->ParamDict["PerDepStorage"];
    // perDepStorPrev = impDepStor  (Shifts the current pervious depression storage to the temp variable)
    double perDepStorPrev =  folder->VarDict["perDepStor"];
    double perPrecip =  folder->VarDict["waterToPerDep"];
    // increment in pervious Storage
```

2. std::map<std::string, std::string> ParamStringDict; This is the same as above, but stores data in string format.

3. This is used to store data created/used by calculations. As opposed to creating class data member. All data specific to a unit such as BulkArea should be stored here. You can create a new entry/start using it without explicitly declaring/defining it. By default, all values will be zero.

std::map<std::string, double> VarDict;

```
void PerviousDepressionStorageCalc::calculate(Inputs *input, DataFolder *folder, int timeStep, std::map<std:
{

  // perviousStorageMax = param.dat pervious storage maximum value (in mm) * 0.001 -> to convert to meters
  folder->VarDict["perDepStorMax"] = 0.001 * folder->ParamDict["PerDepStorage"];
```

4. std::map<std::string, std::vector<double> > VarVecDict; These store vectors unique to a unit. Use sparingly/can grow quite large/cause memory issues. Most should be deleted/legacy for writing extended output.

```
void PerviousDepressionStorageCalc::storeValues(Inputs *input, DataFolder *folder, int timeStep)
{
    folder->VarDict["totalperDepEvap"] += folder->VarDict["perDepEvap"];
    folder->VarDict["totalrunoffToInfil"] += folder->VarDict["runoffToInfil"];
    if (input->InputOutputParams["Model"]=="StatisticalHydro")
    {
        folder->VarVecDict["perDepEvap"].emplace_back(folder->VarDict["perDepEvap"]);
        folder->VarVecDict["perDepStor"].emplace_back(folder->VarDict["perDepStor"]);
        folder->VarVecDict["runoffToInfil"].emplace_back(folder->VarDict["runoffToInfil"]);
    }
}
```

If calculation data needs to be shared/passed between units, store it in input->RepoDict or input->RepoVecDict (Use RepoVectDict sparingly same issues as VarVecDict.)

StoreTimeStepTotalsCalc.cpp | StatisticalOutputWriter.cpp | SpatialOutputWriter.cpp | GlOutputWriter.cpp | TestS

0UnifiedHydro → StoreTimeStepTotalsCalc

```
108
109                 totalImpDepEvap += folder->VarDict["impEvap"] * fArea;
110                 totalImpDepStor += folder->VarDict["impDepStor"] * fArea;
111                 totalImpFlowToSoil += folder->VarDict["impRunoffToSoil"] * fArea;
112
113                 totalPerDepEvap += folder->VarDict["perDepEvap"] * fArea;
114                 totalPerDepStor += folder->VarDict["perDepStor"] * fArea;
115                 totalPerFlowToInfil += folder->VarDict["runoffToInfil"] * fArea;
116
117                 totalWaterToSoil += folder->VarDict["waterToPerDep"] * fArea;
118
119                 totalFlowToDCIA += folder->VarDict["impRunoffDCIA"] * fArea;
120
121                 totalInfilExQ += folder->VarDict["infilExRunoff"] * fArea;
122                 totalSatExQ += folder->VarDict["satExRunoff"] * fArea;
123             }
124         }
125
126     }
127
128     input->RepoVecDict["totalTreeIntRain_TS"].push_back(totalTreeIntRain);
129     input->RepoDict["totalTreeIntRain"] += totalTreeIntRain;
130
131     input->RepoVecDict["totalTreeIntSWE_TS"].push_back(totalTreeIntSWE);
132     input->RepoDict["totalTreeIntSWE"] += totalTreeIntSWE;
133
134     input->RepoVecDict["totalShortVegIntRain_TS"].push_back(totalShortVegIntRain);
135     input->RepoDict["totalShortVegIntRain"] += totalShortVegIntRain;
136
137
138
139     input->RepoVecDict["totalShortVegIntSWE_TS"].push_back(totalShortVegIntSWE);
140     input->RepoDict["totalShortVegIntSWE"] += totalShortVegIntSWE;
141
142     input->RepoVecDict["totalTreeThruQ_TS"].push_back(totalTreeThruQ);
143     input->RepoDict["totalTreeThruQ"] += totalTreeThruQ;
```

Development method and troubleshooting

If a large amount of code has been added and is not compiling, strongly consider starting over from the most recent stable checkpoint on the [HydroPlus webpage](). First create functions that print the desired inputs to the console. Program a single-line calculation/compile/run/repeat.

Afterwards, remove or comment out the print statements. Always make sure the code is working. Do not program with errors. If code cannot compile, you cannot debug. Even if the code compiles, this does not mean it is behaving as expected.

Architecture development Q&A for GI (Oct 26, 2018)

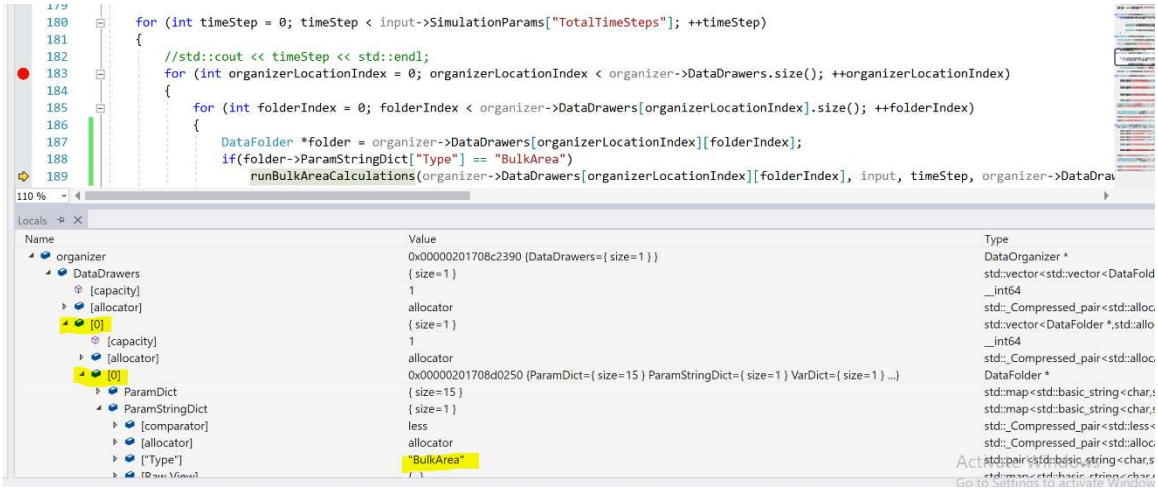
Questions from Reza Abdi & Robbie Coville, answers from Shannon Conley

1. Where in the code do we begin running GI calcs? A potentially simple answer: in TestSimulation::RunStatisticalModel, after calling runBulkAreaCalculations, we call runGICalculations. The rationale for having a separate set of calculations to run for bulk area vs. GI is that, though most of the calcs will be the same, GI may want to call a few extra processes; maybe this can be handled all within runBulkAreaCalculations using a functor based on the condition of what type of structure the code is currently running (Bulk Area vs. a GI type). That raises the next question (#2).

We use functors when the calculation has sections of code that differ. If the calculation is completely different, then we do not need a functor. Can just use 'if else'. We should rename runBulkAreaCalculations though. I have mapped this out in the GI code over the summer and need more time to explain it in detail.

2) What tells the code to grab inputs from the GI structure in the config file rather than bulk area, and how does the code keep track of which structure it is running? For example, bulk area vs. rain garden vs. rain barrel. We can start with just bulk area & rain garden only, but we should keep in mind the need for multiple GI types and even multiple instances of each structure type.

The 'type' tag determines how the code will treat the structure. All data related to a structure is stored within a data folder. To get the type, folder->ParamStringDict["Type"] (see code below). We can easily have multiple types and more than one of each. In the config file, DataOrganizer corresponds to an instance of the DataOrganizer *organizer class. This class contains a container called DataDrawers. For each DataDrawer tag in the config, a new vector of folders is added to this container. The size of each vector corresponds to the number of DataFolder xml elements enclosed. In the below xml example, there is only one DataDrawer with one DataFolder of type BulkArea. We keep track of each folder by its position within the vector of vectors. So we can think of this BulkArea folder as in the first position in the first drawer. Think of a filing cabinet where you open up the first drawer and pull out the first filing folder. If you want to add RainGarden you can place it in the same drawer or a different one. If you place in the same drawer, then the size of DataDrawers would remain 1 and the size of the vector at position 0 would increase to 2.



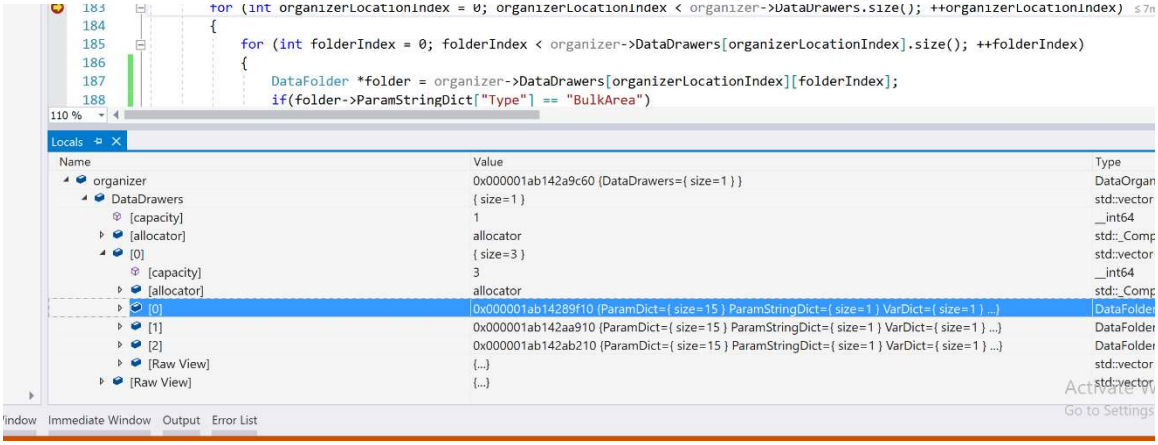

```
<DataOrganizer>
<DataDrawer>
<DataFolder>
    <Type>BulkArea</Type>
    <AreaPer>1.0000</AreaPer>
    <Area>161440000</Area>
    <TreePerviousCover>0.363</TreePerviousCover>
    <TreeImperviousCover>0.05</TreeImperviousCover>
    <ShortVegCover>0.297</ShortVegCover>
    <SoilCover>0.007</SoilCover>
    <ImperviousCover>0.283</ImperviousCover>
    <DCIA>0.2685</DCIA>
    <ImpDepStorage>2.5</ImpDepStorage>
    <PerDepStorage>1.0</PerDepStorage>
  </DataFolder>
</DataDrawer>
</DataOrganizer>
```

If you want to add two more BulkArea structures you can place it in the same drawer or a different one. If you place in the same drawer, then the size of DataDrawers would remain 1 and the size of the vector at position 0 would increase to 3. You distinguish between the three

organizer->DataDrawers[0][0]

organizer->DataDrawers[0][1]

organizer->DataDrawers[0][2]




```
<DataOrganizer>
  <DataDrawer>
  <DataFolder>
     <Type>BulkArea</Type>
     <AreaPer>1.0000</AreaPer>
     <Area>161440000</Area>
     <TreePerviousCover>0.363</TreePerviousCover>
     <TreeImperviousCover>0.05</TreeImperviousCover>
     <ShortVegCover>0.297</ShortVegCover>
     <SoilCover>0.007</SoilCover>
     <ImperviousCover>0.283</ImperviousCover>
     <DCIA>0.2685</DCIA>
     <ImpDepStorage>2.5</ImpDepStorage>
     <PerDepStorage>1.0</PerDepStorage>
   </DataFolder>
<DataFolder>
     <Type>BulkArea</Type>
     <AreaPer>1.0000</AreaPer>
     <Area>161440000</Area>
     <TreePerviousCover>0.363</TreePerviousCover>
     <TreeImperviousCover>0.05</TreeImperviousCover>
     <ShortVegCover>0.297</ShortVegCover>
     <SoilCover>0.007</SoilCover>
     <ImperviousCover>0.283</ImperviousCover>
     <DCIA>0.2685</DCIA>
     <ImpDepStorage>2.5</ImpDepStorage>
     <PerDepStorage>1.0</PerDepStorage>
   </DataFolder>
   <DataFolder>
     <Type>BulkArea</Type>
     <AreaPer>1.0000</AreaPer>
     <Area>161440000</Area>
     <TreePerviousCover>0.363</TreePerviousCover>
     <TreeImperviousCover>0.05</TreeImperviousCover>
     <ShortVegCover>0.297</ShortVegCover>
     <SoilCover>0.007</SoilCover>
     <ImperviousCover>0.283</ImperviousCover>
     <DCIA>0.2685</DCIA>
     <ImpDepStorage>2.5</ImpDepStorage>
     <PerDepStorage>1.0</PerDepStorage>
   </DataFolder>
  </DataDrawer>
  </DataOrganizer>
```

In the main branch of the Unified code in BuildDataOrganizer class, it not possible to add a folder with any other type than BulkArea (Oct 2018). This stop is in place because over the summer how to handler land cover hadn't yet been ironed out.

```
void BuildDataOrganizer::BuildStatisticalDataOrganizer(DataOrganizer *organizer, Inputs *input)
{
    int index = 0;
    for (int j = 0; j < input->DataDrawers.size(); ++j)
    {
        std::vector<DataFolder*> dataDrawer;
        for (int i = 0; i < input->DataDrawers[j].size(); ++i)
        {
            std::map<std::string, double> folderInfo = input->DataDrawers[j][i];
            if (input->StringDataDrawers[j][i]["Type"] == "BulkArea")
            {
                DataFolder *folder = new DataFolder;
                folder->ParamDict = folderInfo;
                folder->ParamStringDict = input->StringDataDrawers[j][i];
                folder->VarDict["aveSMD"] = input->AveSMD;
                AddBulkAreaStatisticalCoverData(folder);
                dataDrawer.push_back(folder);
            }
            ++index;
        }
        organizer->DataDrawers.push_back(dataDrawer);
    }

}
```

You can refer to BuildGrid.cpp in the GI code to see how I was thinking this might be straightened out.

GI Config Instruction (Dec 23, 2021)

GI Surface Layer

The Surface Layer is used to describe the surface properties of Bioretention, Green Roofs, Rain Gardens, Permeable Pavement, Infiltration Trenches, Roof Disconnections, and vegetative Swales. These properties are:

1. Surface Berm Height (or Storage Depth, m)

When berms are present, the berm height (surfaceBermHeight_m, in m) is the maximum depth to which water can pond above the surface of the unit before emergency flow (overflow) occurs. For Vegetative Swales it is the height of the trapezoidal cross section. Rain Barrel with berm height will send flow to the storage via berm outlet, Rain Barrel without berm height will get the flow directly from the downspout.

2. Surface Outlet Height (m)

Height of GI surface outlet, below the Surface Berm Height, above which water discharges out (outflow).

3. Surface Void Ratio

Range from 0 to 1, defines void space in GI surface layer. surfaceVoidRatio = 1 if all surface volume is voids, surfaceVoidRatio = 0 if all surface volume is solids or vegetation. This value may be as high as 0.8 to 0.9 for very dense vegetative growth.

4. Surface Roughness

Range from 0 to 1, Manning's n for surface outflow, it must be larger than zero to compute surface outflow velocity.

5. Surface Slope (m/m)

Range from 0 to 1, slope of surface layer, used to compute surface outflow velocity.

6. Swale Side Slope (m/m)

Side slope (H:V) of of the side walls of a swale unit's cross section, units m/m. This value is ignored for other types of GIs.

GI Pavement Layer

1. Pave Thickness

The thickness of the pavement layer (m). Typical values are 0.1 to 0.15 m.

2. Pavement Void Ratio

Range from 0 to 1, defines porosity of GI pavement as ratio of void volume to total volume. Typical values for pavements are 0.11 to 0.18, units m^3/m^3.

3. Impervious Surface Fraction

Range from 0 to 1, unit fraction. It's the ratio of impervious paver material to total area for modular systems; 0 for continuous porous pavement systems.

4. Pavement Permeability

Permeability of the concrete or asphalt used in continuous systems or hydraulic conductivity of the fill material (gravel or sand) used in modular systems. The permeability of new porous concrete or asphalt is very high (e.g., tens of m/hr) but can drop off over time due to clogging by fine particulates in the runoff. Units m/hr.

5. Pavement Clogging Factor

Defines number of pavement void depths treated before completely clogged. Use a value of 0 to ignore clogging. Clogging progressively reduces the pavement's permeability in direct proportion to the cumulative volume of runoff treated.

If one has an estimate of the number of years Y_{clog} it takes to fractionally clog the system to a degree F_{clog}, then the Clogging Factor (CF) can be computed as:

$$CF = Y_{c\log} P_a (1+CR)(1+VR) / \left[VR(1-ISF) F_{c\log} T \right]$$

where P_a is the annual rainfall amount over the site, CR is the pavement's capture ratio (area that contributes runoff to the pavement divided by area of the pavement itself), VR is the system's Void Ratio, ISF is the Impervious Surface Fraction, and T is the pavement layer Thickness.

As an example, suppose it takes 5 years to completely clog a continuous porous pavement system that serves an area where the annual rainfall is 36 cm/year. If the pavement is 6 cm thick, has a void ratio of 0.2 and captures runoff only from its own surface (so that CR = 0), then the Clogging Factor is 5 x 36 x 1 x (1 + 0.2) / 0.2 / 1 / 6 / 1 = 180.

6. Pavement Regeneration Days (Regeneration Interval)

The number of days that the pavement layer is allowed to clog before its permeability is restored, typically by vacuuming its surface. A value of 0 (the default) indicates that no permeability regeneration occurs.

7. Pavement Regeneration Fraction

The fractional degree to which the pavement's permeability is restored when a regeneration interval is reached. A value of 1 indicates complete restoration to the original permeability value. Once a regeneration occurs the pavement begins to clog once again at a rate determined by the Clogging Factor.

GI Soil Layer

This part describes the properties of the engineered soil mixture used in Bioretention, Rain Garden, Infiltration Trench types, Green Roof and the optional sand layer beneath permeable pavement. These properties are:

1. Soil Thickness

The thickness of the soil layer, units m. Typical values range from 0.45 to 0.9 m for Rain Gardens, Bioretention units, but only 0.075 to 0.15 m for green roofs.

2. Soil Porosity

Range from 0 to 1, defines the volume of pore space relative to total volume of soil (as a fraction).

3. Soil Field Capacity

Range from 0 to 1, defines the volume of pore water relative to total volume after the soil has been allowed to drain fully (as a fraction). Below this level, vertical drainage of water through the soil layer does not occur.

4. Soil Wilting Point

Range from 0 to 1, defines the volume of pore water relative to total volume for a well dried soil where only bound water remains (as a fraction). The moisture content of the soil cannot fall below this limit.

5. Soil Conductivity

Hydraulic conductivity K0 for the fully saturated soil (m/hr).

6. Soil Conductivity Slope

Reduces GI soil percolation rate in negative exp term; 0 = no reduction. Unitless.

Note that SoilPercolation_m = SoilHydraulicConductivity_m_p_dt * exp(SoilSaturation_Deficit_m3_p_m3 * soilCondSlope)

7. Wetting Front Suction

WFS is the average value of soil capillary suction along the wetting front (m). This is the same parameter as used in the Green-Ampt infiltration model.

GI Storage Layer

This part describes the properties of the crushed stone or gravel layer used in all GI devices. For Roof Disconnection, storage is optional, it can be rain barrel.

1. Storage Thickness (or Barrel Height)

This is the thickness of a gravel layer or the height of a rain barrel (inches or mm). Crushed stone and gravel layers are typically 0.15 to 0.450 m. Height of a rain barrel for single family home range from 0.6 to 0.90 m.

2. Storage Void Ratio

The volume of void space relative to the total volume in the layer. Typical values range from 0.5 to 0.75 for gravel beds. For Rain Barrel, it's 1.

The following data fields do not apply to Rain Barrels (remove or set to 0).

3. Seepage Rate

The rate at which water seeps into the native soil below the layer (m/hour). This would typically be the Saturated Hydraulic Conductivity of the surrounding subcatchment if Green-Ampt infiltration is used or the Minimum Infiltration Rate for Horton infiltration. If there is an impermeable floor or liner below the layer then use a value of 0.

4. Clogging Factor

Total volume of treated runoff it takes to completely clog the bottom of the layer divided by the void volume of the layer. Use a value of 0 to ignore clogging. Clogging progressively reduces the Infiltration Rate in direct proportion to the cumulative volume of runoff treated and may only be of concern for infiltration trenches with permeable bottoms and no underdrains. Refer to the Pavement Layer page for more discussion of the Clogging Factor.

GI Drain System

GI storage layers can contain an optional drainage system that collects water entering the layer and conveys it to a conventional storm drain or other location, which can be different than the outlet of the GI's subcatchment. Drain flow can also be returned it to the pervious area of the GI's subcatchment. The drain can be offset some distance above the bottom of the storage layer, to allow some volume of runoff to be stored (and eventually infiltrated) before any excess is captured by the drain. For Rooftop Disconnection, the drain system consists of the roof's gutters and downspouts that have some maximum conveyance capacity.

1. Drain Coefficient

Increases drainage rate, unitless. drainOrificeQ_coef > 0 means storage drain is open and draining groundwater, drainOrificeQ_coef = 0 means storage drain is closed and retaining groundwater.

2. Drain Exponent

Range from 0 to 1, increases drainage rate, unitless. A typical value for n would be 0.5 (making the drain act like an orifice).

Note that runoffStorageDrain = drainOrificeQ_coef * storageDepthHead ^ drainOrificeQ_exponent

3. Drain Offset Height

This is the height of the drain line above the bottom of a storage layer or rain barrel (m).

4. Rain Barrel Drain delay (for Rain Barrels only)

Time after rain stops when rain barrel drain is opened, in hr. A value of 0 signifies that the barrel's drain is always open and drains continuously. This parameter is ignored for other types of GI practices.

GI Drainage Mat

Green Roofs usually contain a drainage mat below the soil media and above the roof structure. Its purpose is to convey any water that drains through the soil layer off of the roof.

1. Drainage Mat Thickness

The thickness of the mat, in m. It typically ranges from 2 to 5 cm (0.002 to 0.005 m).

2. Drainage Void Fraction

Range from 0 to 1, the ratio of void volume to total volume in the mat. It typically ranges from 0.5 to 0.6.

3. Drainage Roughness

This is the Manning's n constant used to compute the horizontal flow rate of drained water through the mat.

GI Pollutant Removal

This part allows one to specify the degree to which pollutants are removed by an GI control as seen by the flow leaving the unit through its underdrain system. Thus it only applies to GI practices that contain an underdrain.

Pollutant (TSS, BOD, COD, TP, SolP, TKN, NO2_3, Cu, Pb and Zn) percent removal efficiency need to be given in %, range from 0 to 100.

As an example, if the runoff treated by the GI unit had a TSS concentration of 50 mg/L and a removal percentage of 90, then if 1 m3/s flowed from its drain into a conveyance system node the mass loading contribution to the node would be 50mg/L x (100 - 90)/100 x 1m3/s *1000 L/m3= 5000 mg/s.

Appendix 1:
Preparing Digital Elevation Model (DEM) Data

Introduction

Digital Elevation Models (DEM) are a required input for iTree HydroPlus. This Appendix covers the necessary steps to create a DEM using ArcGIS. These instructions assume that one is familiar with DEM data and ArcGIS tools. These instructions are reliant on a shapefile for an area of interest (AOI) – frequently, municipal boundaries or watershed delineations.

The basic steps of this procedure are as follows:

1. Download DEM data from NHDPlusV2 for an area that covers the boundaries of your AOI.
2. Use ArcGIS to process the DEM with projecting (optional), clipping, and recalculating from centimeters to meters
3. Export as an ASCII file and change the file extension to dem.dat

Tools

ArcGIS Desktop or Pro

ArcGIS Spatial Analyst Tools

Results

The end product of the steps described here will be a DEM clipped to the boundaries of your watershed, projected in meters, and converted to ASCII format ready for use in i-Tree Hydro Plus.

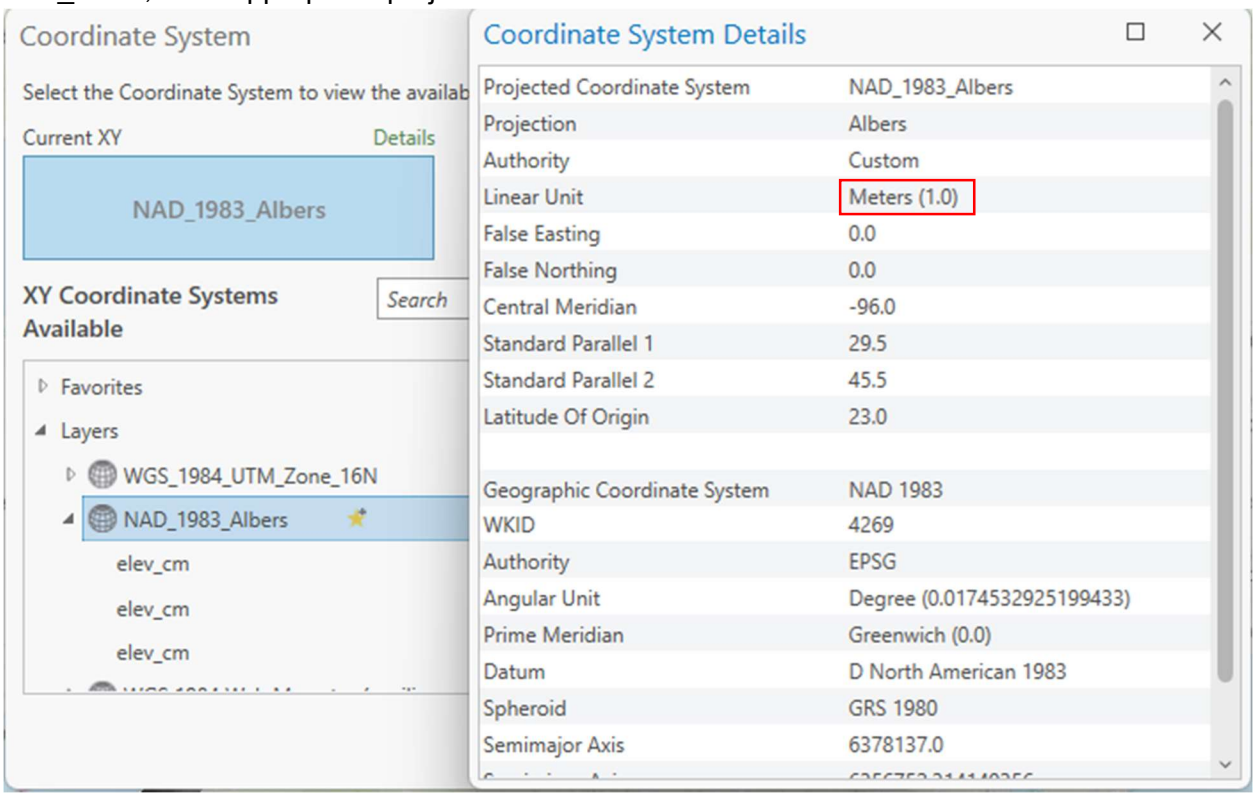
Downloading & Processing DEM Data from NHDPlusV2

With the AOI selected, one of the first steps is to create a DEM for use with iTree HydroPlus. For HydroPlus projects, DEM can have a resolution between 10m and 300m, but 30m is recommended to match the resolution of the NLCD land cover data. NHDPlusV2 is recommended given its usage of both National Elevation Data (NED) and National Hydrography Data (NHD), and it's resolution of 30 meters.

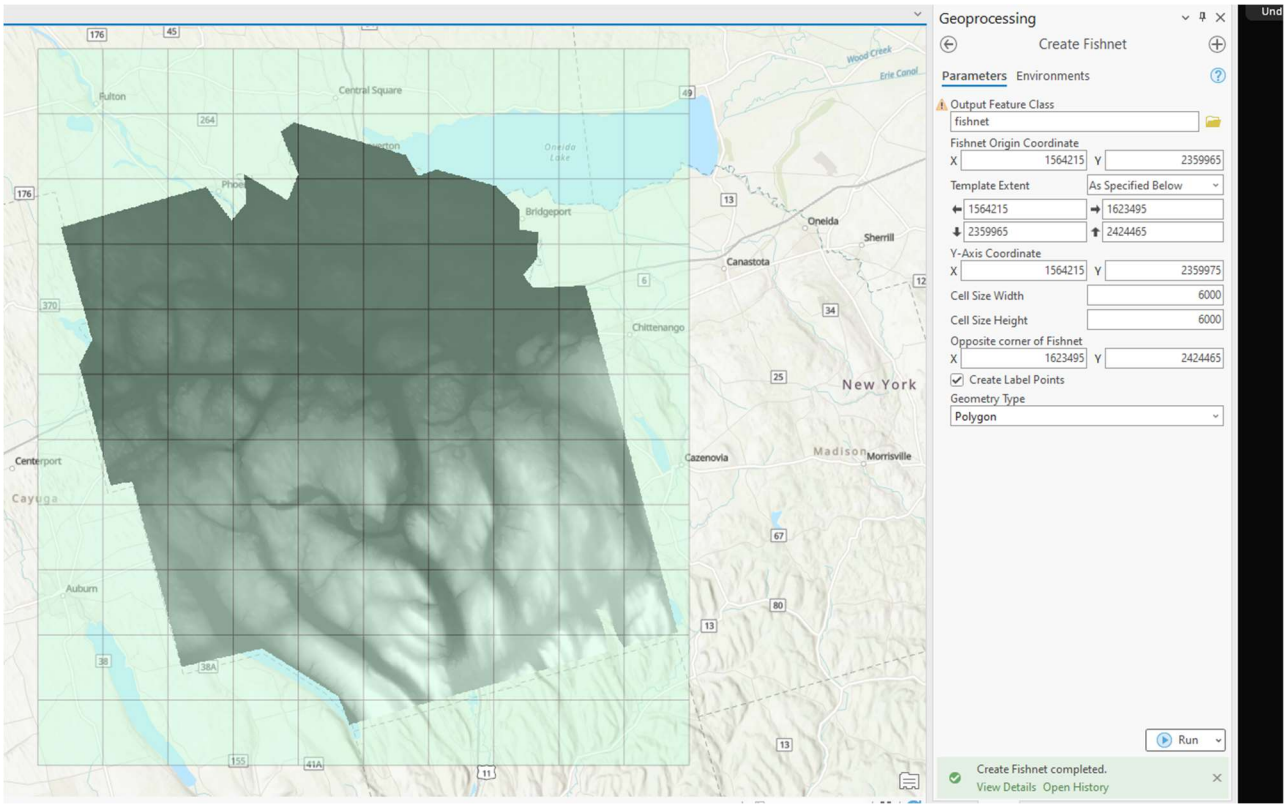
1. Navigate to the NHDPlusV2 Website: https://nhdplus.com/NHDPlus/NHDPlusV2_data.php

NOTE: If the NHDPlusV2 website is down, downloads are also available at the EPA's website: https://www.epa.gov/waterdata/get-nhdplus-national-hydrography-dataset-plus-data

2. Choose the HUC2 that contains the AOI and download the NED Snapshot
3. Unzip using a file archiver such as 7zip, WinRAR, or tools that come with Windows File Explorer
4. Open the DEM in ArcGIS
5. If projecting to another coordinate system, do so now in **Projections and Transformations > Project**
   NOTE: Coordinate system must be a projected coordinate system in meters for correct conversion to ASCII. NAD_1983_Albers, the default projection of NHDPlusV2's elev_cm.tif, is an appropriate projection.

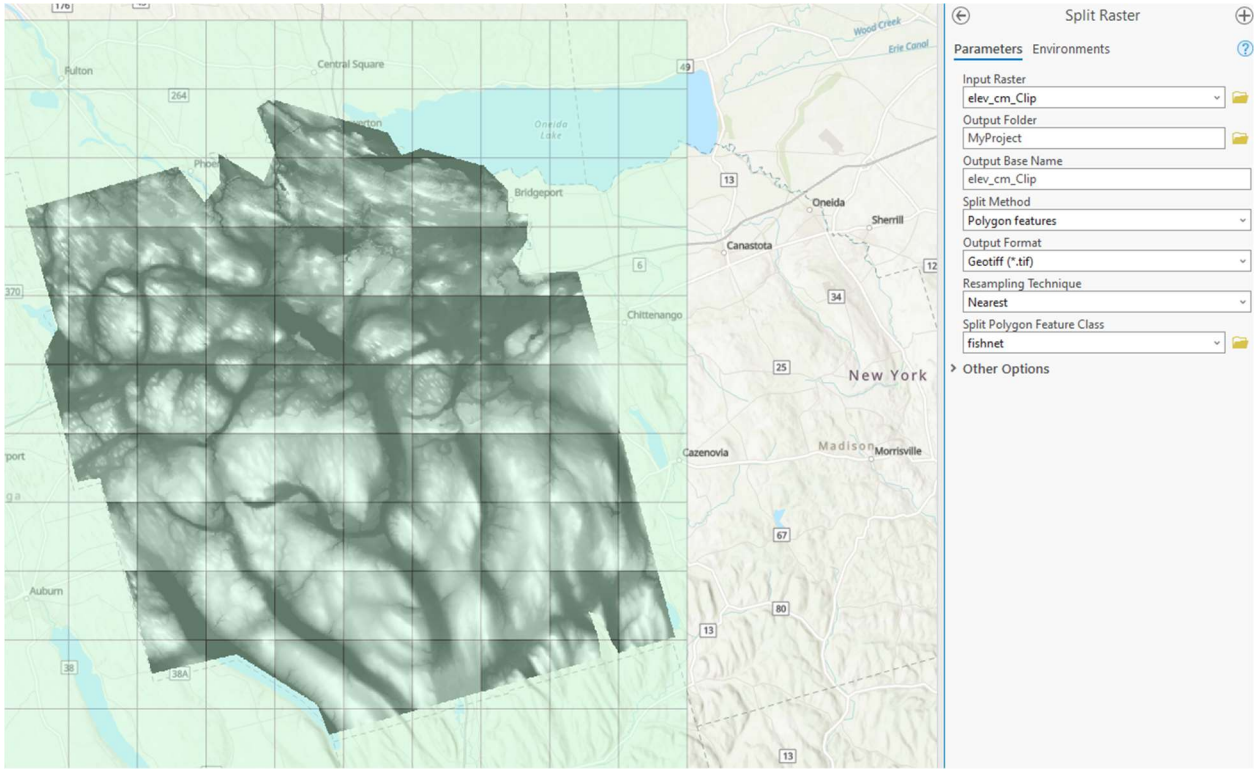


6. Clip to AOI shapefile in the same projection via **Data Management Tools > Raster > Raster Processing > Clip Raster.** Set NODATA to -9999.
   NOTE: It is recommended to check "Use Input Features for Clipping Geometry" to avoid NODATA values.
7. If using with the StatisticalHydro model, export to ASCII by **Conversion Tools > From Raster > Raster to ASCII**
8. **If using with SpatialTemperatureHydro, the maximum ASCII size accepted by the code is 310 x 310 cells**. However, it is recommended for memory to use 100 x 100, 200 x 200, or 300 x 300 resolutions. The maximum cells do not change with decreased resolution. This can be accomplished through python code, or with ArcGIS **Data Management > Sampling > Create Fishnet.**



Example of fishnet creation. Cell width and height are calculated by (max number of cols/rows) * (cell size of raster). In this case, for a 200x200 ASCII, the cell width and height are 200 * 30m resolution = 6000 m.

9. From this fishnet, use **Raster > Raster Processing > Split Raster** by polygon features.



10. Export Raster to ASCII as in Step 8. For fishnets, this process can be sped up by using a batch tool by right-clicking on the tool in ArcToolbox.

Appendix 2: Downloading & Processing NLCD Data

Introduction

Landcover.txt, imperviouscover.txt, and treecover.txt arrequired inputs for iTree HydroPlus. This Appendix covers the necessary steps to create these land cover ASCIIs using ArcGIS. These instructions assume that one is familiar with data acquisition ArcGIS tools. These instructions are reliant on a shapefile for an area of interest (AOI).

The basic steps of this procedure are as follows:

1. Download Multi-Resolution Land Characteristics (MRLC) data from MRLC NLCD for an area that covers the boundaries of your AOI.
2. Use ArcGIS to process rasters with projecting (optional) and clipping
3. Export as an ASCII file into project input folder

Tools

ArcGIS Desktop or Pro

ArcGIS Spatial Analyst Tools

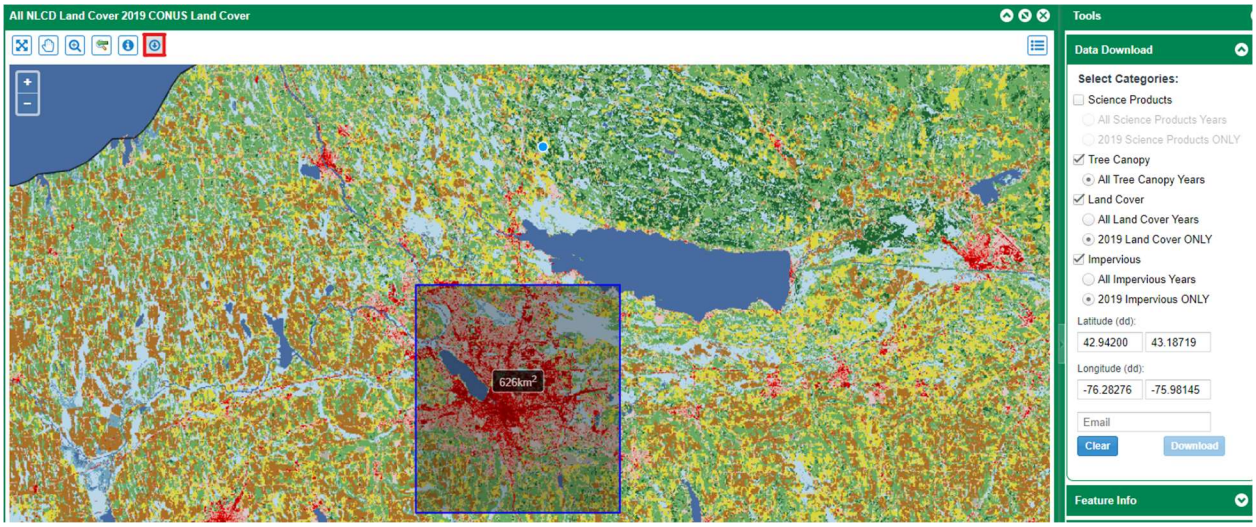
Results

The end product of the steps described here will be landcover.txt, imperviouscover.txt, and treecover.txt clipped to the boundaries of your watershed, projected in meters, and converted to ASCII format ready for use in i-Tree Hydro Plus.

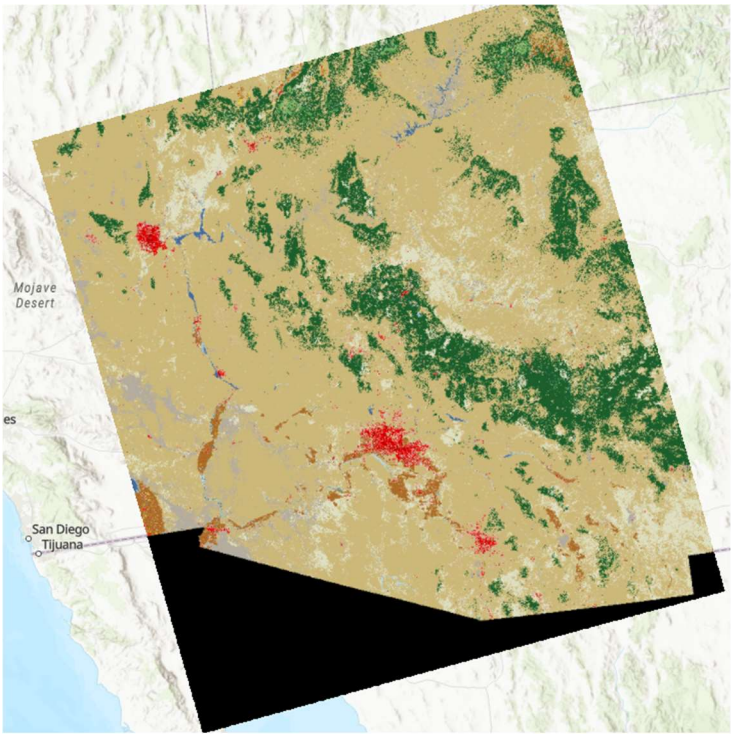
Downloading and Processing NLCD Data from MRLC

HydroPlus inputs can have a resolution between 10m and 300m, but 30m is recommended to prevent resampling. NLCD data is only available for the United States. See International Support for more information on processing land cover data outside of the United States.

1. Navigate to the MRLC website tools page and select ‘MRLC NLCD Viewer’: https://www.mrlc.gov/tools
2. Select the download button on the top left of the page and click twice to create a bounding box for your AOI. Download the most recent years of Tree Canopy, Land Cover, and Impervious data



3. Unzip using a file archiver such as 7zip, WinRAR, or tools that come with Windows File Explorer
4. If projecting to another coordinate system, do so now in **Projections and Transformations > Project**
   NOTE: Coordinate system must be a projected coordinate system in meters for correct conversion to ASCII. It must also be in the same coordinate system as the DEM and AOI.
5. Optional: If your extent is over the edge of the United States, it is recommended to use SetNull in the raster calculator for your NLCD products. Otherwise, ArcGIS sometimes defaults the NoData value to 0, regardless of your NODATA value selection when clipping. The equations to enter into **Spatial Analyst Tools > Map Algebra > Raster Calculator** is as follows:
   SetNull ((*impervious file)* > 100, (*impervious file))*
   SetNull ((*tree cover file)* > 100, (*tree cover file))*
   SetNull ((*land cover file)* == 0, (*land cover file))*
   This is done because the 8-bit unsigned data of tree and impervious cover defaults to a NODATA value of 255, while land cover defaults to 0 given the absence of a "0" class.
   Followed by, for each file:
   Con(IsNull (*file),* -9999, (*file))*
   This sets the Null data from NODATA to -9999 for use in HydroPlus.



1: Example of a map that requires SetNull

6. Clip to AOI shapefile in the same projection via **Data Management Tools > Raster > Raster Processing > Clip Raster.** Set NODATA to -9999.
   NOTE: It is recommended to check "Use Input Features for Clipping Geometry" to avoid NODATA values.
7. If the AOI is greater than 9000 m^2, follow the fishnet steps from DEM. Otherwise, export to ASCII by **Conversion Tools > From Raster > Raster to ASCII.**

Appendix 3: Preparing Weather Data

Introduction

Weather.dat and Evaporation.dat are required inputs for all iTree HydroPlus models, with SolarRadiation.dat being an added requirement for iTree Cool Air. These instructions will guide the conversion from raw NOAA weather data to processed weather data for use with iTree. The basic steps of this procedure are as follows:

1. Retrieve NOAA weather data from the FTP website
2. Process weather with ishapp2.exe
3. Configure WeatherPrepConfig.xml and run WeatherPrep.exe

Tools

FTP Client

WeatherPrep.zip from https://www.itreetools.org/tools/research-suite/hydro-plus

Results

The end product of the steps described here will be weather.dat, evaporation.dat, solarradiation.dat, LAI.csv, and Meteo.csv.

Processing Weather Data with WeatherPrep

Processing raw weather data requires an FTP client to access the NOAA website. These same instructions exist in WeatherPrep_r134/weather_data_NOAA_tool/ReadMe.txt and WeatherPrep_r134/TestCases/ReadMe.txt

1. Obtain the weather station 6-digit USAF ID and 5-digit NCDC WBAN number for the area of interest. The USAF ID followed by the WBAN number comprise the last 11-digits of StationID listed in Results of search with NCEI CDO Map browser for hourly time series data at https://www.ncei.noaa.gov/maps/hourly/. The USAF ID and WBAN number can also be identified from the isd-history.txt file in this project folder C:\iTree\WeatherPrep\weather_data_NOAA_tool\WBAN_Guide, also at

ftp://ftp.ncdc.noaa.gov/pub/data/noaa/isd-history.txt. As an example USAF and WBAN code for the Hancock Internatonal Airport at Syracuse, NY: 725190 14771.

2. Access the NCDC NOAA archive of raw weather data using an FTP client, such as FileZilla. In FileZilla, enter into the Host window this FTP address: ftp://ftp.ncdc.noaa.gov/pub/data/noaa/ or ftp://ftp.ncei.noaa.gov/pub/data/noaa/, and allow for Insecure FTP connection. No Username, Password, or Port need to be entered. The connection to these sites should be made through an FTP application; connections are not supported through a URL browser. In FileZilla browser, the remote site will be on the right side of the window, and the local site of your computer on the left side, e.g., C:\iTree\WeatherPrep\weather_data_NOAA_tool\TestCase\syracuse\.
3. Browse the NCDC NOAA archive of raw weather data for the folder containing the year of interest, and then within that folder find the compressed raw weather data file with named for the USAF and WBAN code and year, USAF##-WBAN#-YYYY.gz.
4. Download the file of interest to a folder on your local site (e.g., C:\iTree\WeatherPrep\weather_data_NOAA_tool\TestCase\syracuse\) by navigating the FileZilla browser to enter a target folder on your local machine. Then double click on the chosen remote file, e.g., USAF##-WBAN#-YYYY.gz, and it will download from the remote to the local site. Exit the FTP FileZilla browser.
5. Unzip downloaded NCDC NOAA raw weather data file, e.g., C:\iTree\WeatherPrep\weather_data_NOAA_tool\TestCase\syracuse\725190-14771-2019.gz, by using a Windows File Explorer to navigate to the local site folder on your machine and then using 7-Zip or another tool to Extract Here, into the same folder.
6. Rename this unzipped NCDC NOAA raw weather data file to have a .txt extension. This is an ASCII text file, and can have a .txt extension added by renaming, or be left without an extension. It should become, USAF##-WBAN#-YYYY.txt, e.g., 725190-14771-2019.txt
7. Reformat the unzipped NCDC NOAA file from its raw weather data format to the ISH format, by running the NCDC NOAA executable program ishapp2.exe. This program is provided by NOAA, and in this project folder *C:\iTree\WeatherPrep\weather_data_NOAA_tool\ishapp2.exe.* Copy the ishapp2.exe file into the local site folder containing the unzipped NCDC NOAA raw weather data, e.g., *C:\iTree\WeatherPrep\weather_data_NOAA_tool\TestCase\syracuse\725190-14771-2019.txt.*
8. Open a Command Prompt and navigate to the local site folder by typing the path into the prompt and hitting return, as in *C:\>cd /d C:\iTree\WeatherPrep\weather_data_NOAA_tool\TestCase\syracuse*, which should generate a new path for the Command Prompt, *C:\iTree\WeatherPrep\weather_data_NOAA_tool\TestCase\syracuse>*
9. Reformat by typing into the prompt the executable program ishapp2.exe followed by USAF##-WBAN#-YYYY.txt input and a new name for output, such as USAF##-WBAN#-YYYY-out.txt, as *C:\iTree\WeatherPrep\weather_data_NOAA_tool\TestCase\syracuse>ishapp2.exe 725190-14771-2019.txt 725190-14771-2019-out.txt*

10. Copy WeatherPrepConfig.xml from a TestCase into the same folder as your "out.txt" file, and adjust the Country, State, County and City from the i-Tree Location Database: https://database.itreetools.org/#/locationSearch
    For more information on WeatherPrepConfig.xml, see WeatherPrep_r134/TestCases/ReadMe.txt
11. Build WeatherPrep.sln in VisualStudio** in Release Mode
12. Run the program by giving the path to inputs at the command prompt, i.e.
    C:\iTree\WeatherPrep\WeatherPrep\bin\Release>WeatherPrep.exe C:\iTree\WeatherPrep\TestCase
13. Copy the appropriate weather files into the project inputs folder.

Appendix 4: Preparing Stream Gauge Data

Stream gauge data is required for calibration of the iTree StatisticalHydro Model. Raw stream gauge data can be obtained in text-delimited format at https://waterdata.usgs.gov/nwis/nwis

A stream gauge preprocessor is currently being developed by the i-Tree Team. To see the required format of qobs.dat, see TestingFilesandScript/TestCases/Calibration/ExponentialDecay/input/qobs.dat

Appendix 5: International Support

We recognize that users outside of the United States may wish to experiment with i-Tree Hydro. It should be noted that the application and model have been built with specific U.S. data in mind. Users in other countries will need to find and format appropriate data to meet the requirements of i-Tree Hydro. This can be a difficult process; please review the following suggestions for guidance. Please also periodically visit the online forums at forums.itreetools.org to see if other users have posted additional information. Technical support for users outside the U.S. is not currently available but may be added in future as our resources permit.

1. A DEM file should be created for the project with GIS software. Steps to create a DEM in ArcGIS are available in the retired iTree Hydro Manual at https://www.itreetools.org/tools/research-suite/hydro-plus

2. Land cover data can be obtained using i-Tree Canopy.

3. The user should select a U.S. location similar to the project location based on latitude and elevation. The parameters affected by project location are used to process weather data (specifically, project location defines latitude; longitude; elevation; GMTOffset; Leaf-on/off; albedo; ozone; coeffA; coeffC; and coeffPHI for weather pre-processing).

4. Weather data is required with the following fields:

- DIR (wind direction)
- SPD (wind speed in mph)
- CLG (cloud ceiling – lowest opaque layer with 5/8 or greater coverage, in hundreds of feet)
- SKC (sky cover)
- TEMP (temperature in Fahrenheit)
- DEWP (dew point in Fahrenheit)
- STP (station pressure in millibars; can be converted from ALT) or
- ALT (altimeter setting in inches; can be converted to STP)
- PCP01 (hourly precipitation in inches and hundredths)

The weather file must be a fixed-width text file. The model will interpolate gaps in the data, though they should be kept under 72 hours. This data should be in GMT.

Example:

```
      USAF  WBAN YR--MODAHRMN DIR SPD GUS CLG SKC L M H  VSB WW WW WW W TEMP DEWP    SLP   ALT    STP MAX MIN
PCP01 PCP06 PCP24 PCPXX SD
      703080 25713 200401010953 220  18 *** 722 SCT * * * 10.0 00 ** ** *   36   26 1019.0 30.09 ****** *** ***  0.00 ***** ***** ***** **
      703080 25713 200401011053 220  18  23  47 BKN * * *  7.0 00 ** ** *   36   27 1020.0 30.12 ****** *** ***  0.00 ***** ***** ***** **
```

5. Stream gage data* is required if the user wants to calibrate the model. The file must be tab-delimited and contain headers similar to the U.S. data.

Example:

```
# column                    column definition
# ----------- ---------------------------------------------
# site_no                   USGS site identification number
# date_time         date and time in format (YYYYMMDDhhmmss)
# tz_cd             time zone
# dd                internal USGS sensor designation ("data descriptor")
# accuracy_cd       accuracy code
#                           0 - A daily mean discharge calculated from the instantaneous
#                               data on this day is 0.01 cubic feet per second
#                               or less and the published daily mean is zero.
#                           1 - A daily mean discharge calculated from the instantaneous
#                               data on this day matches the published daily mean
#                               within 1 percent.
#                           2 - A daily mean discharge calculated from the instantaneous
#                               data on this day matches the published daily mean
#                               from greater than 1 to 5 percent.
#                           3 - A daily mean discharge calculated from the instantaneous
#                               values on this day matches the published daily mean
#                               from greater than 5 to 10 percent.
#                           9 - The instantaneous value is considered correct by the
#                                collecting USGS Water Science Center. A published daily
#                               mean value does not exist and/or no comparison was made.
#                                value discharge in cubic feet per second
#
#
site_no         date_time       tz_cd dd        accuracy_cd     value   prec    remark
15N     14N     6S      2N      5S      16N     1S      1S
06710150        20070101000000          MST     2       1       2.4     2
06710150        20070101001500          MST     2       1       2.7     2
06710150        20070101003000          MST     2       1       2.7     2
06710150        20070101004500          MST     2       1       2.9     2
```

* NOTE: The date_time value for the streamflow file should match the local time of the project location you specified above. Raw stream gage data are expected to be in local time, while raw weather data are expected to be in UTC and are automatically converted to local time upon processing in order to synchronize the two files.

Appendix 6: Glossary

Alternative Case: The scenario being modeled at the same time as the base case; the two are directly compared in several of the model outputs. The alternative cases based on the base case but has different land cover distribution. Often the alternative case is set up to model the addition of green infrastructure, alternative management schemes, or the planting of trees.

Base Case: The current or initial situation to be modeled. The base case typically represents current watershed or project area parameters to allow for calibration of the model.

Base Flow: The primary source of water during periods of low flow. Usually groundwater fed, but also fueled by water slowly draining from the subsurface into the river over time. Simply put, base flow is defined as the portion of surface water supplied by groundwater.

Catchment: The area of land where all the water that drains off of it or is under it goes into the same discharge point. Synonymous with “watershed”.

Max Depth of Water in Upper Soil Zone: The average depth of water which acts as the interface between surface and subsurface flows. The Upper Soil Zone is involved in infiltration, saturation, percolation, and evapotranspiration processes. This parameter describes the maximum depth of the water column in the Upper Soil Zone, not the depth of that soil zone itself. This parameter was previously referred to as “Depth of Root Zone”, and synonyms for this parameter include Max Storage Deficit and Mean Subcatchment Deficit, the latter term being used in USGS TOPMODEL.

Digital Elevation Model (DEM): A digital model or 3D representation of terrain, showing elevation, often represented as a grid containing z values.

Directly Connected Impervious Area (DCIA): The portion of impervious cover that drains directly to a stream or any of its tributaries. “Drains directly” describes a situation where precipitation that falls on a portion of the watershed’s impervious cover is conveyed, overland or through a storm sewer network, directly into the stream or its tributaries.

Evaporation: The vaporization of a liquid into a gas. Occurs on the surface of that liquid. In the hydrologic cycle, this means the vaporization of water from lakes, rivers, etc. into the atmosphere.

Evapotranspiration: The transport of water into the atmosphere from surfaces such as soil, vegetation (transpiration), wet canopy surfaces, and vegetation-covered water surface in wetlands.

Event Mean Concentration (EMC): The flow-proportional average concentration of a given pollutant during a storm event. Measured in units of mass per volume (usually milligrams per liter), EMC can be multiplied by actual flow to estimate the mass of pollutants entering a body of water.

Groundwater Recharge: The process of water moving from the surface to the water table. Maintains the supply of fresh water that flows through the groundwater system to wells, streams, springs, and wetlands.

Hydrologic Cycle: The water cycle. Describes the continuous movement of water on, above, and below the surface of the Earth. Represented as a figure in the i-Tree Hydro program. Specific terms defined in Glossary.

Impervious Cover: Roads, buildings, parking lots and other hard surfaces that prevent rainfall from naturally infiltrating into the soil.

Impervious Depression Storage: The impervious area depression storage found across the watershed. This depth is filled before runoff generation from the impervious area begins. Examples: potholes, low-lying impervious areas (sinks), street curbs that are blocked by debris, etc.

Infiltration: The process by which water on the ground surface enters the soil.

Infiltration Excess Overland Flow: also known as *Hortonian Flow*. Occurs when water enters a soil system faster than the soil can absorb or move it, such as when precipitation exceeds the infiltration capacity of the soil.

Infiltration Rate: a measure of the rate at which soil can absorb rainfall or irrigation.

Initial Soil Saturation: The amount of water storage in the soil at the start of the simulation. This affects infiltration. An initial soil saturation value of 0% represents soil that is absolutely dry; an initial soil saturation value of 100% represents soil that is completely saturated.

Leaf Area Index (LAI): The one-sided green leaf area per unit canopy area in broadleaf canopies or the projected needleleaf area per unit canopy area in needle canopies. Standing in a 1-meter square area, looking up into the tree canopy, the LAI represents the surface area (1-sided) of the leaves present directly above this 1-meter square area. Typical LAI values range from 1-7, representing 1-7 square meters of leaf area (1-sided) above this 1-meter square area. Shrub and herbaceous LAI are typically less than Tree LAI due to the decreased canopy size and density of typical shrub and herbaceous canopies. LAI can be calculated as the total one-sided green leaf area (m2), divided by the total canopy area of the study (m2, total study area multiplied by the percent tree cover).

Leaf On Day: The day of the year where the leaves begin the transition from the minimum LAI, experienced by deciduous trees in the winter (represented by the bark area index), to the maximum LAI, which represents a full canopy in the spring and summer.

Leaf Off Day: The day of the year where the leaves end the transition from the maximum LAI, which represents a full canopy in the spring and summer, to the minimum LAI, experienced by deciduous trees in the winter (represented by the bark area index).

Leaf Storage: The maximum water depth that a single leaf in the tree or shrub canopy can hold. Intercepted precipitation that increases the depth of water stored on leaf above this threshold is shed as throughfall in the interception and throughfall processes.

Leaf Transition Period: The number of days for the leaves to transition from the minimum LAI experienced by deciduous trees in the winter (represented by the bark LAI) to the maximum LAI that represents a full canopy in the spring and summer.

Percolation: The movement of water through the soil profile

Pervious: The quality of allowing water to pass through. In the context of stormwater, pervious generally implies allowing water to pass into subsurface zones. For example, soil or herbaceous cover generally allows water to percolate into subsurface flows and are therefore considered pervious.

Pervious Depression Storage: The pervious area depression storage found across the watershed. This depth is filled before runoff generation from the pervious area begins. Examples: low-lying pervious areas (sinks), depressions caused by landscaping or tree growth, areas of compacted soil found in parks, fields, etc.

Precipitation: Any product of the condensation of atmospheric water that falls under gravity. Mainly rain and snow.

Runoff: The water flow that occurs when the soil is infiltrated to full capacity and excess water from precipitation, meltwater, or other sources flows over land. Also occurs on impervious surfaces, as these have no infiltration capacity.

Saturated Zone: The soil layer where all pores are filled with water.

Saturation Excess Overland Flow: Occurs when the soil is saturated and depression storage is filled, in which case any additional precipitation or irrigation immediately causes runoff.

Scale Parameter of Power Function: The power used in the power function formulation of the Green and Ampt infiltration equation used in i-Tree Hydro. These equations (below) model the decay of infiltration rates as infiltration occurs. Refer to Wang, Endreny, and Nowak, 2008 for more information.

$$I = \frac{dI}{dt} = \frac{\Delta\psi + Z}{\int_{z=0}^{z=z} \frac{d_z}{K_z}} \qquad (\mathbf{Eqn.\ 7})$$

$$K_z = K_0(1 - fz)^n \qquad (\mathbf{Eqn.\ 8})$$

Scale Parameter of Soil Transmissivity: A scaling parameter describing the change of soil transmissivity with soil depth. It affects saturated zone baseflow recession. It is estimated through knowledge of the watershed recession rates, which relate to unsaturated zone maximum water storage depth, and optimized in its role as a calibrated parameter. The equation is below. Refer to Wang, Endreny, and Hasset, 2006 for more information.

$$T_z = T_0(1 - {}^{S}/_{m})^2 \qquad (\mathbf{Eqn.\ 9})$$

Shrub Bark Area Index: The minimum LAI, represented by leafless canopy coverage of deciduous shrubs in the winter, which is defined as the shrub bark area index.

Surface Hydraulic Conductivity: Controls infiltration rates. For horizontal flow, this is the maximum rate water flows in the unsaturated zone, but for vertical flow at infiltration, it is the minimum infiltration rate. The decrease of hydraulic conductivity with depth follows exponential law or power law profiles. It is estimated from soil physical properties used in Green-Ampt lookup tables.

Throughfall: The process which describes how wet leaves shed excess water onto the ground surface.

Time Constant for Surface Flow: Alpha: This parameter controls the distribution of flows in the surface hydrograph. It is calibrated as part of the modeling process. The equation is below. Refer to Yang and Endreny, 2013 for more information.

$$\alpha = \frac{4D}{c^2} \qquad (\mathbf{Eqn.\,10})$$

Time Constant for Surface Flow: Beta: This parameter controls the distribution of flows in the surface hydrograph. It is calibrated as part of the modeling process. The equation is below. Refer to Yang and Endreny, 2013 for more information.

$$\beta = \frac{x^2}{4D} \qquad (\mathbf{Eqn.\,11})$$

Topographic Index (TI): A grid of indices derived from a DEM that assumes topography drives flow. It is calculated using the upslope contributing area (α) and the slope of the grid cell (β) (see equation below). TI influences flow accumulation, soil moisture, distribution of saturation zones, depth of water table, evapotranspiration, thickness of soil horizons, organic matter, pH, silt and sand content, and plant cover distribution.

$$\lambda = \ln\left(\frac{\alpha}{\tan\beta}\right) \qquad (\mathbf{Eqn.\,12})$$

Transmissivity at Saturation: Transmissivity of the saturated zone, controls base flow rates and represents product of saturated depth and hydraulic conductivity in the saturated zone. It is estimated by physical knowledge of depth and conductivity which can be collected from inputs.

Tree Canopy: The upper layer of the tree leaves, formed by mature tree crowns.

Tree Bark Area Index: The minimum LAI, represented by leafless canopy coverage of deciduous trees in the winter, which is defined as the tree bark area index.

Unsaturated Zone: Also known as the Vadose Zone. The soil above the groundwater table, which has both water and air in the soil pores.

Unsaturated Zone Time Delay: Controls the travel time for unsaturated zone water to move to the saturated zone. It is estimated from knowledge of the soil's hydraulic conductivity and soil layer depths and then calibrated as part of the modeling process.

Watershed: The area of land where all of the water that drains off of it or is under it goes into the same discharge point. Synonymous with “catchment”.

Wetting Front Suction: Controls the maximum infiltration rates. It is used to describe the rate at which water is pulled into the soil when it is dry during the early part of the infiltration process. It is estimated from soil physical properties used in Green-Ampt lookup tables.

Wetted Moisture Content: The difference between the initial volumetric moisture content value below the infiltration wetting front and the volumetric water content within the wetting front (unitless, ranges from 0 to 1.0). In other words, it is the difference between the soil moisture content at saturation and the initial (typical) soil moisture content. It affects the infiltration rate. It is estimated from soil physical properties used in Green-Ampt lookup tables.

Appendix 7: Additional Resources

i-Tree Hydro Documents

Main i-Tree Hydro website: http://www.itreetools.org/hydro/index.php

iTree FAQ: https://forums.itreetools.org/viewforum.php?f=35

Journal Articles

iTree Hydro Journals: https://www.itreetools.org/support/resources-overview/i-tree-methods-and-files/hydro-method-descriptions-and-related-journal-articles

A physically based analytical spatial air temperature and humidity model. Wang, Endreny, and Nowak, 2013: https://www.fs.fed.us/nrs/pubs/jrnl/2013/nrs_2013_yang-y_001.pdf

Mechanistic simulation of tree effects in an urban water balance model. Wang, Endreny, and Nowak, 2008: http://www.itreetools.org/hydro/resources/Hydro%20Model%20Methodology.pdf

i-Tree Hydro: Snow Hydrology Update for the Urban Forest Hydrology Model. Yang, Endreny, and Nowak, 2011: http://www.itreetools.org/hydro/resources/iTree_Hydro_Snow_Hydrology_Model_Update_JAWRA.pdf

Watershed hydrograph model based on surface flow diffusion. Yang and Endreny, 2013: http://www.itreetools.org/hydro/resources/Watershed_hydrograph_model_based_on_surface_flow_diffusion.pdf

Surface and Upper Weather Pre-processor for i-Tree Eco and Hydro. Hirabayashi and Endreny, 2013: http://www.itreetools.org/eco/resources/Surface_weather_and_upper_air_preprocessor_description.pdf

Modeling the Impact of Urban Trees on Hydrology. Coville, Endreny, and Nowak, 2020: https://www.fs.fed.us/nrs/pubs/jrnl/2020/nrs_2020_coville_001.pdf

ArcGIS Help

Main website: http://www.esri.com/software/arcgis

Main help and resources page: http://resources.arcgis.com/en/help/

Main help forum: http://forums.arcgis.com/

Data Sources

Map Data

NHDPlusV2 DEM Website: https://nhdplus.com/NHDPlus/NHDPlusV2_data.php

UTM zones guidance: http://pubs.usgs.gov/fs/2001/0077/report.pdf

USDA NRCS Geospatial Data Gateway: http://datagateway.nrcs.usda.gov/

NYS GIS Clearinghouse: http://gis.ny.gov/gateway/mg/?nysgis=

HUC watersheds: http://water.usgs.gov/GIS/huc.html

GAGES-II dataset of USGS stream gage basins:
http://water.usgs.gov/GIS/metadata/usgswrd/XML/gagesII_Sept2011.xml
NLCD Land Cover Website: https://www.mrlc.gov/data

Soils Data

USDA NRCS Web Soil Survey to inform local soil parameters:
http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Stream Data

USGS stream gage data: http://maps.waterdata.usgs.gov/mapper/index.html

EPA's Waters website - WATERS Data 1.5(Vector).kmz file:
http://water.epa.gov/scitech/datait/tools/waters/tools/waters_kmz.cfm

i-Tree Hydro Gauging Stations 2005 - A zip file containing a Google Earth (.kmz) file of stream gauging stations available in i-Tree Hydro:
http://www.itreetools.org/hydro/resources/iTree_Hydro_Gauging_Stations_2005.zip

i-Tree Hydro model raw stream data example:
http://www.itreetools.org/hydro/resources/Hydro_stream_data_example.txt

Weather Data

NOAA Climate Data Online, our source of raw weather data (from the Intergrated Surface Database, Hourly Precipitation records): http://www.ncdc.noaa.gov/cdo-web/

i-Tree Hydro model raw weather data example:
http://www.itreetools.org/hydro/resources/Hydro_weather_data_example.txt

i-Tree Hydro weather abbreviation codes: http://www.itreetools.org/hydro/resources/ish-abbreviated.txt

Other Data

Excel VBA Parameter Conversion macro: http://www.esf.edu/ere/endreny/GI-iTree/Parameter%20Conversion.xlsm

Other Resources

Main i-Tree website: http://www.itreetools.org/

i-Tree support page: www.itreetools.org/support

i-Tree Canopy main page: http://www.itreetools.org/canopy/index.php

i-Tree Canopy (8) cover class version for i-Tree Hydro:
http://www.itreetools.org/hydro/resources/Hydro_Canopy_survey_cover_classes_example1_long

i-Tree Workshop Information: http://www.itreetools.org/resources/training/index.php

Information about green infrastructure techniques:
http://www.esf.edu/ere/endreny/GICalculator/TechniquesHome.html

Runoff calculator: http://www.esf.edu/ere/endreny/GICalculator/RunoffHome.html

Topographic Index information and creation: http://soilandwater.bee.cornell.edu/tools/TI.pdf

References

Beaulac, M. N., and Reckhow, K. H. 1982. **An examination of land use-nutrient export relationships**. Water Resources Bulletin, 18(6), 1013-1024.

Charbeneau, R. J., and Barretti, M. 1998. **Evaluation of methods for estimating stormwater pollutant loads**. Water Environ Res. 70: 1295-1302.

Chesapeake Stormwater Network. 2009. **CSN Technical Bulletin No. 4: Technical Support for the Bay-wide Runoff Reduction Method Version 2.0**. Retrieved April 2017 from http://chesapeakestormwater.net/2012/01/technical-bulletin-no-4-baywide-runoff-reduction-method

Driver, N. E., Mustard, M. H., Rhinesmith, R. B., and Middelburg, R. F. 1985. **U.S. Geological Survey urban-stormwater data base for 22 metropolitan areas throughout the United States**. United States Geological Survey, Open-File Report 85-337, Lakewood, CO.

Lindsay JB. 2016. **Whitebox GAT: A case study in geomorphometric analysis.** Computers & Geosciences, 95: 75-84. DOI: 10.1016/j.cageo.2016.07.003

Minnesota Stormwater Manual contributors. 2017. **Design criteria for permeable pavement.** Minnesota Stormwater Manual. Retrieved April 2017 from https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_permeable_pavement&oldid=31563

Schueler, T. 2009. **Guidance for meeting NPDES Permit Requirement in Montgomery County, MD**.

Sansalone, J. J., and Buchberger, S.G. 1997. **Partitioning and first flush of metals in urban roadway storm water**. J Environ Eng ASCE 123: 134-143.

Smullen, J. T., Shallcross,A. L., and Cave, K. A. 1999. **Updating the U.S. nationwide urban runoff quality database**. Water Science Technology 39(12), 9-16.

Sutherland. 2000. **Methods for Estimating Effective Impervious Cover**. Article 32 in *The Practice of Watershed Protection*, Center for Watershed Protection, Ellicott City, MD.

U.S. Environmental Protection Agency (USEPA). 1983. **Results of the Nationwide Urban Runoff Program: Volume I – final report**. U.S. Environmental Protection Agency, PB84-185552, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2002. **Urban Stormwater BMP Performance Monitoring, A Guidance Manual for Meeting the National Stormwater BMP Database Requirements**.

U.S. Environmental Protection Agency (USEPA). 2011a. **Estimating Change in Impervious Area (IA) and Directly Connected Impervious Areas (DCIA) for Massachusetts Small MS4 Permit**. USEPA Small MS4 Permit Technical Support Document.

U.S. Environmental Protection Agency (USEPA). 2011b. **Estimating Change in Impervious Area (IA) and Directly Connected Impervious Areas (DCIA) for New Hampshire Small MS4 Permit**. USEPA Small MS4 Permit Technical Support Document.

Wang, J., Endreny, T. A., and Hassett, J. M. 2006. **Power function decay of hydraulic conductivity for a TOPMODEL-based infiltration routine**. Hydrol. Process. 20, 3825 – 3834. DOI: 10.1002/hyp.6159

Wang, J., Endreny, T. A., and Nowak, D. J. 2008. **Mechanistic simulation of tree effects in an urban water balance model**. JAWRA. 44(1), 75-85.

Wolock, D. M., and McCabe, G. J. 2000. **Differences in topographic characteristics computed from 100- and 1000-m resolution digital elevation model data**. Hydrol. Process. 14, 987±1002.

Wolock, D. M., and Price, C. V. 1994. **Effects of digital elevation model map scale and data resolution on a topography-based watershed model**. Water Resources Research, 30(11), 3041-3052.

Yang, Y and Endreny, T. A.. 2013. **Watershed hydrograph model based on surface flow diffusion**. Water Resources Research. 49, 507–516, doi:10.1029/2012WR012186.