

i-Tree Hydro

Training Workshop Georgia Tech Hotel and Conference Center Atlanta, GA

> Emily Stephan, EIT Thomas Taggart, EIT Ted Endreny, PhD, PE, PH SUNY College of Environmental Science and Forestry



Cooperative













i-Tree Hydro



Model History

- Born out of discussions between ESF (Ted Endreny) and USDA FS (David Nowak)
- Wanted to replace curve number based runoff models with process based hydrological models
- TOPMODEL -> OBJTOP -> UFORE -> i-Tree Hydro















i-Tree Hydro



Model History

- Based on Topographic Index and TOPMODEL concepts
 - TI Beven and Kirkby, 1979; TOPMODEL Beven (1995, 1997)

Processes and routines added to TI/TOPMODEL framework

- Publications:
 - Wang et al., 2006; Wang et al., 2008; Wang, Endreny, et al., 2005; Wang, Hassett, et al., 2005; Yang et al., 2011; Yang and Endreny, 2013
- > Ongoing model development
 - New i-Tree Hydro versions approx. yearly
 - Research by Yang Yang, Tom Taggart and Emily Stephan

















i-Tree Hydro Introduction to Stormwater Management (ISM)

















Introduction to Stormwater Management (ISM)



Why is stormwater management important?





















ISM: Regulatory & Other Drivers Quantity/Quality



> FEMA

FIRMs

> CWA

- MS4 NPDES permitting
- **CSOs**

> Others (NEPA, DOT, ...)

Ordinances

 \geq New v. existing construction









Arbor Day Foundation

84° 22' 30'

a 1% chance o the area subject include Zones A elevation of the	f being equak t to flooding A, AE, AH, AO 1% annual o	(200-year hous), each hanne is the value room of the house hanne has do re-exceeded in any given year. The Special Flood Hazard Area is by the 1% annual chance flood. Areas of Special Flood Hazard AR, 409, V, and VE. The Base Flood Elevation is the water-surface hance flood.
ZONE A No Base		Flood Elevations determined.
ZONE AE	Base Flo	od Elevations determined.
ZONE AH	Flood de determin	pths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations red.
ZONE AO	Flood de depths d	pths of 1 to 3 feet (usually sheet flow on sloping terrain); average letermined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special F flood by AR indic protectio	Flood Hazard Areas formerly protected from the 1% annual chance a flood control system that was subsequently decertified. Zone tasks that the former flood control system is being restored to provide an from the 1% annual chance or greater flood.
ZONE A99	Area to protectio	be protected from 1% annual chance flood by a Federal flood on system under construction; no Base Flood Elevations determined.
ZONE V	Coastal determin	food zone with velocity hazard (wave action); no Base Flood Elevations red.
ZONE VE	Coastal determin	food zone with velocity hazard (wave action); Base Rood Elevations red.
////	FLOODW/	AY AREAS IN ZONE AE
flood heights.	OTHER FL	OOD AREAS
ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.	
	OTHER A	REAS
ZONE X Areas determ		mined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in whi	ich flood hazards are undetermined, but possible.
7772	COASTAL	BARRIER RESOURCES SYSTEM (CBRS) AREAS
	OTHERW	ISE PROTECTED AREAS (OPAs)
OBRS areas and	d OPAs are no	rmally located within or adjacent to Special Flood Hazard Areas. 1% Annual Chance Floodplain Boundary
		0.2% Annual Chance Floodplain Boundary
	_	Roodway boundary
		Zone D boundary
		CBRS and OPA boundary
000000000	500 -	Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths, or flood velocities.
~~513~~~		Base Flood Elevation line and value; elevation in feet*
(EL 987)		Base Flood Elevation value where uniform within zone; elevation in feet*

LEGEND SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO

INUNDATION BY THE 1% ANNUAL CHANCE FLOOD









ISM: Prior Perspective (Pre-MS4 Regulation)



- Goals
 - Quantity
 - Quality
- Infrastructure (Gray)
 - Impervious Areas
 - Storage
 - Streets
 - Storm drains
 - Storm sewers
 - > CSOs



















ISM: Current Perspective



Goals
 Quality & Quantity
 CWA MS4
 Sustainability

Infrastructure



- I, S⁴, C + f(GI, LID, SCM, BMP)
- Hydrologic cycle
 - e.g., Retain, Infiltrate, Restore/maintain baseflow
 - e.g., Save the Rain, Green City Clean Waters, NYC Green Infrastructure Plan.















ISM: Role of Managers





ISM: Role of Managers



What issues have you faced?





















Stormwater Modeling Hydrologic Principles

















HP: Urban Forest Hydrology

Natural vs. Disturbed Hydrological Cycle





🕈 Rainfall – runoff model

Transformation of rainfall into runoff

- Effective precip -> Infiltration -> runoff generation
- Runoff partitioning
 - baseflow, overland flow, shallow subsurface flow, etc.



- Routing of runoff through watershed / to the outlet
 - Building of the hydrograph, timing of flow arrival















🕈 Inputs

- Weather Precip, temp, wind speed, net radiation, etc.
- Streamflow Hourly (or finer) discharge
- Topography error free , high res. DEMs
- Land cover High resolution aerial imagery, field surveys
- Soil data WS wide field data: K_{sat}, depth to water table, etc.
- Potential Evaporation/ET For all vegetation, weather

Unlimited! Complete!

















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HP: Conceptual Models

Processes

Interception

- Different LAI values for diff species
- Different leaf water storage depths

Stemflow

Throughfall process

Measured instead of estimated







- Processes (cont.)
 - Depression Storage
 - Storage depths change with landcover type, seasons?



Infiltration

- Governed by saturation vs. infiltration excess
- Variable soil properties temporally, spatially
- Know the underlying geomorphology







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Processes (cont.)

Soil Moisture

Root zone / Unsaturated zone / Saturated Zone processes



Evaporation/Evapotranspiration (ET)

- Values for each species, measured vs. estimated
- Varies temporally (hourly, daily, seasonally)















Processes (cont.)

Runoff generation

- Changes as saturated areas expand/contract
- Perched water tables
- Precip intensity driven seeps

Baseflow generation

- Tracer experiments old vs. new water
- Quick flow surface runoff vs. shallow subsurface
- Rates of flow between soil zones



















Outputs

Main: Predicted streamflow

- Baseflow + Overland flow (Pervious + Impervious area flows)
- Near perfect response across full domain of inputs

Others: Soil moisture, canopy interception, evaporation/ET, pollution loading/concentration, etc.

Broken up by time, space, landcover types, etc.





















HP: Mathematical Model - Inputs



Landcover

Distinct and well understood classes

For example, NLCD classes

- Agriculture pasture/hay, cultivated crops
- Forest mixed, deciduous, evergreen
- Developed High, Med, Low Density, Open space

















HP: Mathematical Model - Inputs

i-Tree

Canopy Properties

- Leaf Area Index (LAI) One sided leaf area per square meter of canopy
 - Tree LAI + Tree bark LAI
 - Shrub/Herbaceous LAI + Bark LAI
- Deciduous vs. Coniferous makeup
- Leaf On/Off days
 - Dependent on local/regional weather

















Interception

- > For a given LAI, given species, max storage depth
- Drip rate contributing to throughfall





Duration of Event



Tree is a















Depression storage

- Simple store concept
- Max storage depth
 values for different
 landcover types
- Values are updated from precip/evaporation





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Infiltration

- > Which governing equation?
 - Green-Ampt
 - Darcy's Law
 - Richard's
- Macropore flow?
- Capillary Fringe?



🕈 Soil moisture

- Depth of and rates of flow between zones
- Root zone Unsaturated zone Saturated zone

















Surface runoff

- Impervious runoff
 - Throughfall/precip on impervious cover > depression storage
- Pervious runoff
 - Precip/throughfall on infiltration/saturation excess runoff
- > Area weighted averages vs. tracking volumes
 - Depth/m² or total volume per area

















Evaporation and ET

- What relationship governs
 - potential vs actual evaporation



Water balance vs. energy balance

Either could drive the model – typically not both















Subsurface flow/Infiltration

Equation governing the changes in hydraulic conductivity/transmissivity

vertically and horizontally

















HP: Mathematical Model - Outputs



- Predicted streamflow
 - Need equation governing the summation of different flows
 - Arriving at the correct place in the correct time?

Pollution

- Event Mean concentration values
- Build-up/wash-off routines
- Export coefficients















HP: Hydraulic Considerations



- Pipes
- 🕈 Pumps
- Channels
- Storm drains



- Stormwater storage tanks
- Water quality deterioration/treatment
- Water quantity accumulation/dispersal















HP: SWMM



- Hydraulic and hydrologic model
 - Dynamic rainfall-runoff simulation
 - Single event or long-term (continuous) simulation
 - Water quantity and quality
- 2 main components
 - Rain falls and runoff is generated on sub-catchment areas
 - Hydrologic routines/process
 - Routing portion transports runoff through a conveyance system
 - Pipes, channels, storage/treatment devices, pumps, and regulators
 - Hydraulic routines/processes















- **HP: Modeling Metrics**
- Calibration
 - Method:
 - Determining optimal model parameter set
 - Optimization algorithm PEST
 - Repeated model runs
 - Comparing predicted and observed values
 - Maximize goodness of fit metrics

Problems:

- Equifinality Different parameter sets, same optimum
- Disagreement between field data and model parameters

















Validation

Using optimized parameter set to predict forward

- Without further alteration/optimization
- Necessary to build confidence in the model
 - Trust structure and calibrated parameter set

Verification

- > Alter model structure or routines
 - Switch model routines different governing equations
 - Revise model code numerical solutions, code structure

















Calibration Metrics

- ➤ Values range from -∞ to 1
 - Negative Worse than observed average value
 - Zero Equal to observed average value
 - Positive Better than observed average value
- Volumetric Efficiency
 - Criss and Winston, 2008
- Baseflow fit
 - Perrin et al., 2001
- Peak flow fit
 - Nash Sutcliffe Efficiency (1970)
- Overall fit
 - Ye et al., 1997









 $NSE = 1 - \frac{\sum (Q_{\text{calc}} - Q_{\text{obs}})^2}{\sum (\overline{Q}_{\text{obs}} - Q_{\text{obs}})^2}$







Flow (cfs)



- Common calibration problems
 - Weather station isn't representative, gage errors



Check weather station location, dominant weather patterns

Check input data period for errors





- Common calibration problems
 - > High base flow, too little evapotranspiration


HP: Modeling Metrics



- Common calibration problems
 - Incorrect partitioning of baseflow/overland flows





i-Tree Hydro An Introduction to the Model

















i-Tree Hydro: An Introduction

Model interfaces

Model inputs

Model outputs



















i-Tree Hydro: New model interface



File Steps Outputs Help

Welcome to i-Tree Hydro!

What is Hydro? How to Run i-Tree Hydro About the Sample Project New Project Steps

General References:

i-Tree Hydro webpage Hydrologic Cycle Soil Profile User's Manual

What is Hydro?

i-Tree Hydro is a simulation tool that analyzes how land cover influences the volume and quality of runoff. It can analyze historical or future hydrological events and allow the user to contrast runoff volume and quality from existing land cover (referred to as the Base Case) with runoff from the Alternative Case land cover. The i-Tree Hydro model differs from other i-Tree products in the following ways:

- The model simulation area is loaded into the program either as a digital
 elevation model (DEM) file or as a topographic index (TI) file. It is not
 hand-delineated in the program by the user. If the user is interested in a
 watershed, they can load a DEM or TI file. If the user is interested in a city
 or parcel that is not defined by a single watershed they load a TI file.
- The model simulation can be run in calibration mode or non-calibration mode. For calibration runs the user loads observed streamflow data from a gauging station and the model will identify the optimal hydrological parameters to fit the observed streamflow data. Observed streamflow data are provided for thousands of watershed areas. For non-calibration runs the user can use previously calibrated parameters or independently set the land cover and hydrological parameter values by adjusting the default values that the model provides.



Current Project:

i-Tree

х

No project loaded.























🕈 Step 1

- Project Location
- Basic WS Info
- Streamflow
- Weather
- Topographic





i-Tree Hydro: Project Locations







Initiative

































i-Tree Hydro: Land Cover Data (via i-Tree Canopy)





					Ju	10	РJ		i-Tree
	eport by	Area	Pe	rcent C	over (±S	SE)			Canapy
	38.3	7.45	34.0	8.51	3.19	4.26	3.19	1.06	
50-	±5.01	±2.81	±4.89	±3.01	±1.84	±2.13	±1.84	±1.06	
40-	Ξ		I						
20- 10- 0-	00 8/ 000	I.	lorbood R	T	T	T	T.	TARA LINE	
Id	20-7620P	Cov	er Clas	isi amezizai S	auersszerenn	Latitud	le	Long	gitude
81	Tree -	Pervio	us			44.42693			73.052
82	Herba	ceous				44.43781			73.110
83	Tree -	Pervio	us			44.	43136	82	73.090
84	Herba	ceous				44.	44449		73.108
85	Imper	vious -	Buildin	g		44.46066			73.108
86	Herba	ceous				44.41338			73.078
87	Tree -	Pervio	us			44.39344			73.075
88	Herbaceous					44.44426			73.054
20	Impe	ervious	- Road	, Sidew	alk	44.	43173		73.063
09	Herbaceous								

































i-Tree Hydro: Stream Data





















i-Tree Hydro: Weather Data





🧾 WeatherData	dat - Notepad						
File Edit For	mat View Help						
ууууmmdd	Hr:Min:Sec	Tair(F)	Tdew(F)	NetRad(W/m^2)	WndSpd(m/s)	Precip(m/hr)	Snow(m/hr)
20110101	00:00:00	42.70000000	34.90000000	0.00000000	3.44210997	0.00000000	0.00000000
20110101	01:00:00	40.00000000	34.00000000	0.00000000	2.23513634	0.00000000	0.00000000
20110101	02:00:00	42.10000000	34.10000000	0.00000000	3.48681270	0.00000000	0.00000000
20110101	03:00:00	42.90000000	35.00000000	0.00000000	2.68216361	0.00000000	0.00000000
20110101	04:00:00	42.00000000	35.00000000	0.00000000	2.68216361	0.00000000	0.00000000
20110101	05:00:00	36.85000000	36.00000000	0.00000000	0.00000000	0.00025400	0.00000000
20110101	06:00:00	36.76000000	36.00000000	0.00000000	1.01922217	0.00000000	0.00000000
20110101	07:00:00	36.00000000	36.00000000	0.00000000	1.34108181	0.00000000	0.00000000
20110101	08:00:00	35.31578947	35.31578947	12.50021015	0.00000000	0.00000000	0.00000000
20110101	09:00:00	36.00000000	36.00000000	53.31007742	0.44702727	0.00000000	0.00000000
20110101	10:00:00	37.00000000	37.00000000	88.96392811	0.00000000	0.00000000	0.00000000
20110101	11:00:00	47.00000000	41.00000000	180.3095209	2.77156907	0.00000000	0.00000000
20110101	12:00:00	47.20000000	41.10000000	382.4534808	3.48681270	0.00000000	0.00000000
20110101	13:00:00	49.00000000	42.00000000	174.0454807	2.68216361	0.00000000	0.02540000
20110101	14:00:00	49.90000000	42.90000000	131.4296478	3.17389361	0.00000000	0.00000000
20110101	15:00:00	49.00000000	42.00000000	159.7079611	3.71032633	0.00000000	0.00000000
20110101	16:00:00	49.00000000	42.00000000	27.88483690	4.91729996	0.00000000	0.00000000
20110101	17:00:00	46.00000000	41.90000000	0.00000000	3.57621815	0.00000000	0.00000000
20110101	18:00:00	46.30000000	41.10000000	0.00000000	3.63582179	0.00000000	0.00000000
20110101	19:00:00	49.00000000	42.00000000	0.00000000	3.12919088	0.00000000	0.02540000
20110101	20:00:00	49.10000000	40.90000000	0.00000000	3.71032633	0.00000000	0.00000000
20110101	21:00:00	50.00000000	40.00000000	0.00000000	5.05140814	0.00000000	0.00000000
20110101	22:00:00	50.00000000	40.00000000	0.00000000	6.25838176	0.00000000	0.00000000
20110101	23:00:00	49.00000000	39.00000000	0.00000000	6.79481448	0.00000000	0.00000000
20110102	00:00:00	48.90000000	39.10000000	0.00000000	7.42065266	0.00000000	0.02540000
20110102	01:00:00	48.00000000	40.00000000	0.00000000	5.81135449	0.00000000	0.02540000



























i-Tree Hydro: DEM vs Topographic Index Option





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i-Tree Hydro: Land Cover Parameters



Step 2) i-Tree Hydro Land Cover Parameters



on: Atlanta, Georgia Help for items on this page:

Shrub Leaf Area Index

- 23

Leaf Area Index (LAI) is defined as the one sided green leaf area per unit ground area in broadleaf canopies, or as the projected needleleaf area per unit ground area in needle canopies. I-Tree Eco users: Leaf area indexes can be calculated from Eco results for leaf area. These results are presented in units of m2/ha. To get LAI, divide by 10,000. way to think about LAI is to imagine drawing a square on the ground under a tree canopy, with sides 1 meter in length. Standing in this 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

Next: Step 3) i-Tree Hydro Hydrological Parameters

Cancel



Pervious Cover (%)

Impervious Cover (%)



Total Cover (%)

(Should = 100)



86.4

13.6

100.0







OK





i-Tree Hydro: Land Cover Parameters

Step 2) i-Tree Hydro Land Cover Parameters

These parameter values describe the study area land cover conditions.





And it is important to know what typically is going on beneath areas of tree canopy.

Cover Types beneath	Tree Cover	the ground under a tre
Pervious Cover (%)	86.4	with sides 1 meter in l
Impervious Cover (%)	13.6	Standing in this 1-met area, looking up into the
		canopy, the LAI repres surface area (1-sided)
		leaves present directly
Total Cover (%) (Should = 100)	100.0	this 1 meter square ar Typical LAI values ran
		1-7, representing 1-7

Project Location: Atlanta, Georgia Help for items on this page:

Shrub Leaf Area Index

X

=

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Next: Step 3) i-Tree Hydro Hydrological Parameters

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-Tree is a

Initiative











OK







i-Tree Hydro: Land Cover Parameters

Step 2) i-Tree Hydro Land Cover Parameters

These parameter values describe the study area land cover conditions.

Surface Cover Types





And it is important to know what typically is going on beneath areas of tree canopy.

Cover Types beneath	Free Cover	the around und
Pervious Cover (%)	86.4	with sides 1 me
Impervious Cover (%)	13.6	Standing in this area, looking up
		canopy, the LAI
		leaves present of
Total Cover (%) (Should = 100)	100.0	this 1 meter squ Typical LAI valu
		1-7, representir

Project Location: Atlanta, Georgia Help for items on this page:

Shrub Leaf Area Index

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Next: Step 3) i-Tree Hydro Hydrological Parameters

Cancel



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OK



Step 3) i-Tree Hydro Hydrological Parameters

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These parameters define study area soil, vegetation, and water conditions. The goal is to adjust them until modeled streamflow resembles observed streamflow.

You may create and compare multiple parameter sets. Start by Auto-Calibrating with the Suggested Default Values, and then Compare the Parameter Set Calibration Results, You modify these parameter sets by FIRST Retaining and Editing a NEW Parameter Set. At any time, run the Auto-Calibration routine with any Current Parameter set to create new Auto-Calibrated Parameters which may then be further adjusted.

Note: Auto-calibration is availabl	e only when modeling	a watershed.				Parameters that
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Retain and Edit as NE parameter set	W Delete this	parameter set	Auto-Calibrate this Parameter Set	Compare Para Calibration	meter Set Results	your model input observed stream
Parameters:			Advance	d Settings]	stream gage. T
We start with a preliminary value coming through the gauge.	for the amount of wa	ter	Leaf Transitio	on Period (days)	28	be used in either
Appual Average Flow at Cau	aina Station (cms)	0.4525422500	Leaf On Day <mark>(</mark> Day	of year 1-365)	75	Calibration routi
Annual Average Flow at Gau	ging station (cms)	0.1535422500	Leaf Off Day (Day	of year 1-365)	311	against other pa
			Tree B	Bark Area Index	1.7	that you may cho
Then we select a soil type to acco into and through the ground	ount for the way water	r moves	Shrub B	Bark Area Index	0.5	scenario.
Ref Trues Ref.			Lea	af Storage (mm)	0.2	Upon exiting this
Soli Type Blende	ed lexture	· · · · · · · · · · · · · · · · · · ·	Pervious Depressio	n Storage (mm)	0.8012	hydrological para
Wetting	Front Suction (m)	0.1200000	Impervious Depressio	n Storage (mm)	1.7239615	displayed will be
Wetted Moi	sture Content (m)	0.4800000	Scale Parameter of	Power Function	2	model.
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burrace riyuradile o			Transmissivity at Sa	aturation (m²/h)	0.057036	information
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Donth	of Poot Zone (m)	0.014960	Time Constant for Surface	Flow: Alpha (h)	1.175744289	
Берсі		0.014009	Time Constant for Surface	e Flow: Beta (h)	47.0259259	
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			Ne	ext: Step 4) i-1	Tree Hydro Alterna	tive Case OK
i-Tree is a Cooperative		VEY 🏶 🤇	Arbor Day Found	dation™	SOLETY OF MUNICIPAL	ISA



Help for items on this page:

Project Location: Atlanta, Georgia

Current Parameter Set

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lasev Trees



Step 3) i-Tree Hydro Hydrological Parameters

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These parameters define study area soil, vegetation, and water conditions. The goal is to adjust them until modeled streamflow resembles observed streamflow.

DAVEY

You may create and compare multiple parameter sets. Start by Auto-Calibrating with the Suggested Default Values, and then Compare the Parameter Set Calibration Results. You modify these parameter sets by FIRST Retaining and Editing a NEW Parameter Set. At any time, run the Auto-Calibration routine with any Current Parameter set to create new Auto-Calibrated Parameters which may then be further adjusted.

Note: Auto-calibration is available only when modeling a watershed.

Parameters:	Advanced Settings	stream
We start with a preliminary value for the amount of water coming through the gauge.	Leaf Transition Period (days)	28 be us
Annual Average Flow at Gauging Station (cms) 0.1535422500	Leaf On Day (Day of year 1-365) Leaf Off Day (Day of year 1-365)	75 Calibr 311 again that y
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Condition of the soil in terms of root penetration and water content is set next.	Transmissivity at Saturation (m²/h) Unsaturated Zone Time Delay (h) Time Constant for Surface Flow: Alpha (h)	10.0000 inform 1.175744289
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	Next: Step 4) i-1	Tree Hydro Alternative Case

i-Tree

x

Help for items on this page:

Project Location: Atlanta, Georgia

Current Parameter Set

These are the Hydrological Parameters that i-Tree Hydro it attempts to create enario between all inputs and the reamflow at the e. The parameters rrently displayed will either the Autoroutine or compared er parameter sets so y choose the best-fit

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manual for more

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Step 3) i-Tree Hydro Hydrological Parameters

> Cooperative Initiative

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Current paramete	r set: AutoC	alibrated Para	meters 🔹				a best-fit sce
Retain and Ed paramete	lit as NEW er set	Delete this	parameter set	Auto-Calibrate this Parameter Set	Compare Para Calibration	ameter Set Results	your model in observed stre
Parameters:				Advance	d Settings]	stream gage.
We start with a preliminal coming through the gaug	ry value for the a e,	amount of wat	er	Leaf Transitio	on Period (days)	28	be used in ei
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Annual Average 110W	at dauging 50	acion (cris)	0.1333422300	Leaf Off Day (Day	of year 1-365)	311	against other
				Tree B	Bark Area Index	1.7	that you may
Then we select a soil type into and through the gray	e to account for i	the way water	moves	Shrub B	Bark Area Index	0.5	scendrio.
	(Lea	af Storage (mm)	0.2	Upon exiting
Soil Type	Blended Textur	e		Pervious Depressio	n Storage (mm)	0.8012	hydrological (
W	/etting Front S	Suction (m)	0.1200000	Impervious Depressio	n Storage (mm)	1.7239615	displayed will
Wett	ted Moisture C	ontent (m)	0.4800000	Scale Parameter of	Power Function	2	model.
Surface Hyd	raulic Conducti	vitv (cm/h)	0.2970000	Scale Parameter of So	il Transmissivity	0.027938	Defer to the
Surface Hydr		ncy (enginy	012370000	Transmissivity at Sa	aturation (m²/h)	0.057036	information
Condition of the soil in ter	rms of root pene	tration		Unsaturated Zone	e Time Delay (h)	10.0000	information.
and water content is set i	Depth of Poot	t Zono (m)	0.014960	Time Constant for Surface	Flow: Alpha (h)	1.175744289	
	Depth of Root		0.011009	Time Constant for Surface	e Flow: Beta (h)	47.0259259	
Initial Soil	Saturation Cor	ndition (%)	35.75160	Watershed area who can exceed infil	ere rainfall rate tration rate (%)	100	
				N	ext: Step 4) i-1	Tree Hydro Alterr	native Case
i-Tree is a			/EV	Arbor Day Found	dation™	sma®	ISA



x

Help for items on this page:

Project Location: Atlanta, Georgia

Current Parameter Set

These are the Hydrological Parameters that i-Tree Hydro will use as it attempts to create nario between all nputs and the eamflow at the The parameters ently displayed will ther the Autoputine or compared parameter sets so choose the best-fit

this screen, the parameters last be used within the

manual for more

Cancel



🐅 Step 3) i-Tree Hydro Hydrological Parameters

These parameters define study area soil, vegetation, and water conditions. The goal is to adjust them until modeled streamflow resembles observed streamflow.

You may create and compare multiple parameter sets. Start by Auto-Calibrating with the Suggested Default Values, and then Compare the Parameter Set Calibration Results. You modify these parameter sets by FIRST Retaining and Editing a NEW Parameter Set. At any time, run the Auto-Calibration routine with any Current Parameter set to create new Auto-Calibrated Parameters which may then be further adjusted.

Note: Auto-calibration is available only when modeling a watershed. Current parameter set: AutoCalibrated Parameters Retain and Edit as NEW Auto-Calibrate this Compare Parameter Set Delete this parameter set parameter set Parameter Set Calibration Results Advanced Settings Parameters: We start with a preliminary value for the amount of water Leaf Transition Period (days) 28 coming through the gauge. Leaf On Day (Day of year 1-365) 75 Annual Average Flow at Gauging Station (cms) 0.1535422500 311 Leaf Off Day (Day of year 1-365) 1.7 Tree Bark Area Index Then we select a soil type to account for the way water moves Shrub Bark Area Index 0.5 into and through the ground. Leaf Storage (mm) 0.2 Soil Type Blended Texture 0.8012 Pervious Depression Storage (mm) Wetting Front Suction (m) 0.1200000 Impervious Depression Storage (mm) 1.7239615 Wetted Moisture Content (m) Scale Parameter of Power Function 0.4800000 0.027938 Scale Parameter of Soil Transmissivity Surface Hydraulic Conductivity (cm/h) 0.2970000 0.057036 Transmissivity at Saturation (m²/h) Condition of the soil in terms of root penetration 10.0000 Unsaturated Zone Time Delay (h) and water content is set next. Time Constant for Surface Flow: Alpha (h) 1.175744289 Depth of Root Zone (m) 0.014869 Time Constant for Surface Flow: Beta (h) 47.0259259 Initial Soil Saturation Condition (%) 35.75160 Watershed area where rainfall rate 100 can exceed infiltration rate (%)

Project Location: Atlanta, Georgia

Current Parameter Set

Help for items on this page:

These are the Hydrological Parameters that i-Tree Hydro will use as it attempts to create a best-fit scenario between all your model inputs and the observed streamflow at the stream gage. The parameters that are currently displayed will be used in either the Auto-Calibration routine or compared against other parameter sets so that you may choose the best-fit scenario.

Upon exiting this screen, the hydrological parameters last displayed will be used within the model.

Refer to the manual for more information.

OK

Next: Step 4) i-Tree Hydro Alternative Case

Cancel

















x

Step 3) i-Tree Hydro Hydrological Parameters

Cooperative Initiative

These parameters define study area soil, vegetation, and water conditions. The goal is to adjust them until modeled streamflow resembles observed streamflow.

DAVEY"

You may create and compare multiple parameter sets. Start by Auto-Calibrating with the Suggested Default Values, and then Compare the Parameter Set Calibration Results. You modify these parameter sets by FIRST Retaining and Editing a NEW Parameter Set. At any time, run the Auto-Calibration routine with any Current Parameter set to create new Auto-Calibrated Parameters which may then be further adjusted.

Note: Auto-calibration is available only when modeling a watershed.

parameter set Delete this parameter set	Parameter Set Compare Pa	n Results
meters:	Advanced Settings	
t with a preliminary value for the amount of water	Leaf Transition Period (days	28
Average Flow at Coursing Station (cmm) (a (configuration)	Leaf On Day (Day of year 1-365	75
Average Flow at Gauging Station (cms) 0.1535422500	Leaf Off Day (Day of year 1-365	311
	Tree Bark Area Index	1.7
e select a soil type to account for the way water moves I through the ground.	Shrub Bark Area Index	0.5
	Leaf Storage (mm	0.2
	Pervious Depression Storage (mm	0.8012
Wetting Front Suction (m) 0.1200000	Impervious Depression Storage (mm	1.7239615
Wetted Moisture Content (m) 0.4800000	Scale Parameter of Power Function	2
Surface Hydraulic Conductivity (cm/h) 0.2970000	Scale Parameter of Soil Transmissivity	0.027938
	Transmissivity at Saturation (m²/h	0.057036
on of the soil in terms of root penetration ter content is set next.	Unsaturated Zone Time Delay (h	10.0000
Depth of Root Zone (m) 0.014869	Time Constant for Surface Flow: Alpha (h	1.175744289
	Time Constant for Surface Flow: Beta (h	47.0259259
Initial Soil Saturation Condition (%) 35.75160	Watershed area where rainfall rate can exceed infiltration rate (%	100
	Next: Step 4)	Tree Hydro Alterr



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Help for items on this page: Project Location: Atlanta, Georgia

Current Parameter Set

These are the Hydrological Parameters that i-Tree Hydro will use as it attempts to create scenario between all el inputs and the streamflow at the age. The parameters urrently displayed will n either the Auton routine or compared ther parameter sets so may choose the best-fit

ing this screen, the cal parameters last will be used within the

he manual for more on.

OK

ION

Cancel



i-Tree Hydro: Alternative Case

Step 4) Define an i-Tree Hydro Alternative Case

i-Tree is a Cooperative

Initiative

Input the Cover Type values below to reflect the Alternative Land Use Scenario you wish to model. Example: increase your tree canopy and decrease your impervious cover. Remember: all the cover types must add to 100%

DAVEY

	Base Case	Alternative Case	1		Base Case	Alternative Case	How much of your
Tree Cover (%)	36.8	20.0	•	Tree Leaf Area Index	5	5	watershed area is c
Shrub Cover (%)	14.2	14.2	b	Shrub Leaf Area Index	2.2	2.2	by tree canopy? Her
Herbaceous Cover (%)	14.2	14.2)	Herbaceous Leaf Area	1.6	1.6	This percentage rep
Water Cover (%)	0.2	0.2]	Index			tree canopy found or
Impervious Cover (%)	33.6	50.4	•	Directly Connected Impervious Cover (%)	20.9	40.0	cover. For example
Soil Cover (%)	1.0	1.0]				planted in a parking
Total Cover (%) (Should = 100)	100.0	100.0					canopy might be ove
							trees planted in park
Cover Types beneath	Tree Cove	r					trees planted in part where the canopy is
Cover Types beneath	Tree Cove	Alternative					trees planted in parl where the canopy is pervious soil/grass, included in this perc
Cover Types beneath	Tree Cove Base Case 86.4	Alternative Case 70.0]				trees planted in parl where the canopy is pervious soil/grass, included in this perc This percentage cou
Cover Types beneath Soil Cover (%) Impervious Cover (%)	Base Case 86.4 13.6	Alternative Case 70.0 30.0]				trees planted in park where the canopy is pervious soil/grass, included in this perc This percentage cou from data sources y already compiled or
Cover Types beneath Soil Cover (%) Impervious Cover (%)	Tree Cove Base Case 86.4 13.6	Alternative Case 70.0 30.0					trees planted in parl where the canopy is pervious soil/grass, included in this perc This percentage cou from data sources y already compiled or could make use of o Tree tools, such as i Canopy
Cover Types beneath Soil Cover (%) Impervious Cover (%) <i>Total Cover (%)</i> <i>(Should = 100)</i>	Base Case 86.4 13.6 100.0 100.0	Alternative Case 70.0 30.0 100.0]				trees planted in parl where the canopy is pervious soil/grass, included in this perc This percentage cou from data sources y already compiled or could make use of o Tree tools, such as i Canopy (<u>www.itreetools.org</u> , to create a statistic

Arbor Day Foundation



23

Help for items on this page:

rea is covered py? Here you this percentage. age represents found over both impervious example, trees parking lot, ajority of the t be over sphalt, and d in parks, anopy is over /grass, are both his percentage. tage could come ources you have piled or you use of other iuch as i-Tree ools.org/canopy) statistical

Cancel

CasevTrees

ISA



i-Tree Hydro: Alternative Case

Step 4) Define an i-Tree Hydro Alternative Case

Initiative

i-Tree

Input the Cover Type values below to reflect the Alternative Land Use Scenario you wish to model. Example: increase your tree canopy and decrease your impervious cover. Remember: all the cover types must add to 100%

	Base	Alternative			Base	Alternative	
Tree Cover (%)	36.8	20.0		Tree Leaf Area Index	5	5	How much of your watershed area is covered
Shrub Cover (%)	14.2	14.2	3	Shrub Leaf Area Index	2.2	2.2	by tree canopy? Here you
Herbaceous Cover (%)	14.2	14.2	5	Herbaceous Leaf Area	1.6	1.6	would enter this percentage This percentage represents
Water Cover (%)	0.2	0.2		Index			tree canopy found over both
Impervious Cover (%)	33.6	50.4		Directly Connected	20.9	40.0	pervious and impervious cover. For example, trees
Soil Cover (%)	1.0	1.0	10.00	Impervious cover (70)			planted in a parking lot,
Total Cover (%) (Should = 100)	100.0	100.0					where the majority of the canopy might be over impervious asphalt, and
Cover Types beneath	Tree Cove	r Alternative					trees planted in parks, where the canopy is over pervious soil/grass, are both
	Case	Case					included in this percentage.
Soil Cover (%)	86.4	70.0					This percentage could come from data sources you have
Impervious Cover (%)	13.6	30.0					already compiled or you
							could make use of other i- Tree tools, such as i-Tree Canopy
Total Cover (%) (Should = 100)	100.0	100.0					(<u>www.itreetools.org/canopy</u> , to create a statistical
				Next: Sten 4)	Run the i-Tr	ee Modell Re	set OK Cance
				NEAL, DLEP + f	Null Life Fill		



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Help for items on this page:

i-Tree Hydro: Alternative Case



Initiative

i-Tree

Input the Cover Type values below to reflect the Alternative Land Use Scenario you wish to model. Example: increase your tree canopy and decrease your impervious cover. Remember: all the cover types must add to 100%

Surface Cover Types							Percent Tree Cover
	Base	Alternative			Base	Alternative Case	Haw much of your
Tree Cover (%)	36.8	20.0	•	Tree Leaf Area Index	5	5	watershed area is covered
Shrub Cover (%)	14.2	14.2	-	Shrub Leaf Area Index	2.2	2.2	by tree canopy? Here you
Herbaceous Cover (%)	14.2	14.2	•	Herbaceous Leaf Area	1.6	1.6	This percentage represents
Water Cover (%)	0.2	0.2		Index			tree canopy found over both
Impervious Cover (%)	33.6	50.4	•	Directly Connected Impervious Cover (%)	20.9	40.0	cover. For example, trees
Soil Cover (%)	1.0	1.0					planted in a parking lot,
Total Cover (%) (Should = 100)	100.0	100.0					where the majority of the canopy might be over impervious asphalt, and
Cover Types beneath	Tree Cove	r					trees planted in parks, where the canopy is over
	Base Case	Alternative Case					included in this percentage.
Soil Cover (%)	86.4	70.0					This percentage could come
Impervious Cover (%)	13.6	30.0					already compiled or you
							Tree tools, such as i-Tree Canopy
Total Cover (%) (Should = 100)	100.0	100.0					(<u>www.itreetools.org/canopy</u> , to create a statistical
				Next: Step 4)	Run the i-Tr	ree Model! Re	set OK Cancel
i-Tree is a Cooperative -		VEY [®] (Arbor Day Found	lation [®]	SMa [®]	ISA 🚓

i-Tree

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Casey Trees

Help for items on this page:

Calibration Time Step





















i-Tree Hydro A Stormwater Management Model

















Participant Introductions



🕈 Name

Position

Reason for interest in i-Tree Hydro

- What you hope to model?
- What stormwater issues you hope to address?

















i-Tree Canopy









UAS













HP: Focus of i-Tree Hydro

Watershed scale 1st level analyses

vegetation and impervious cover effects on hydrology

Model different tree cover/vegetative cover scenarios

- Increase/decrease TC
- Increase/decrease IC
- Increase/decrease other WS landcover types

Hydro quantifies hourly and total changes stream flow, water quality

















Topographic index

Affected by DEM resolution

Increasing DEM resolution – small cell sizes

- TI values decrease for most cells
 - Minimum, median values decrease
- TI values may increase for river/stream network cells
 - Maximum value may increase
- Decreasing DEM resolution larger cell sizes
 - Has the opposite effect

























NY













Topographic index

Table 8. Minimum, Median, and Maximum Values of $\ln(a)$, $\ln(1/\tan B)$, and $\ln(a/\tan B)$ Distributions Computed at Grid Cell Resolutions for a Section of the 1:24,000-Scale Nuremburg Quadrangle Digital Elevation Model

	D	Distribution Statistic					
Variable	Data Resolution, m	Minimum	Median	Maximum			
Total change		0.48	0.34	0.90			
$\ln(a/\tan B)$	30	2.93	5.76	16.14			
$\ln(a/\tan B)$	60	3.74	6.70	16.11			
$\ln(a/\tan B)$	90	4.41	7.00	16.03			
$\ln(a/\tan B)$	120	4.72	7.10	15.96			
Total change		1.79	1.34	-1.97			

Source: Wolock and Price, 1994.



















Hydraulic Conductivity – Transmissivity

- Same everywhere in the watershed
- Decay profiles decays with soil depth
 - Exponential vs. Power

 $K_s(z) = K_o \exp(-fz)$

$$K_s(z) = K_o (1 - fz)^n$$

- Default model setting is power law decay
- Changed in hydrological parameters screen

















- Effects pervious areas
 - Tree cover over pervious, shrub/herbaceous, bare soil
- Percentage of watershed area that is controlled by infiltration excess – rest is saturation excess

Land cover

- Average or sampled typically only an estimation
- DCIA value estimated
- Problems with NLCD resolution

















Hydro: Hydro Conceptual Models

Initiative




Hydro: Mathematical Model – Inputs

Landcover

- 5 main classes:
 - Bare Soil
 - Shrub/Grass/Herbaceous (SV)
 - Impervious Area
 - Tree Cover over Impervious Area
 - Tree Cover over Pervious Area



















Hydro: Mathematical Model – Inputs

Canopy Properties

- Leaf Area Index (LAI) One sided leaf area per square meter of canopy
 - Tree LAI + Tree bark LAI
 - Shrub/Herbaceous LAI + Bark LAI
- Deciduous vs. Coniferous makeup
- Leaf On/Off days



Source: Aguilar, M.A. et al., 2010



















Interception

- >f(TC%, SV%, LAI)
 - Open space vs. canopy coverage, leaf on/off days, etc.

Depression storage

- >f(Landcover type, Depression depth)
 - Pervious vs. Impervious Different depression storage maxes















free



Surface runoff

- f(Depression storage, Infiltration process, Soil moisture status)
 - Depression storage filled?
 - Saturated soil? Rainfall intensity greater than infiltration rate?
 - Model user sets ratio of infiltration to saturation excess soils















Hydro: Mathematical Model – Processes (cont.)



Infiltration

- f(K_{sat}, Rainfall intensity, Infiltration process)
- Infiltration excess Modified Green-Ampt routine
- Saturation excess unconstrained flow into rootzone

🕈 Soil moisture

- Root zone Unsaturated zone Saturated zone
- f(Infiltrated water, ET, Intra-zone flow rates, Baseflow generation, etc.)

















Hydro: Mathematical Model – Processes (cont.)



- Evaporation and ET
 Tree > Shrub > ET
 - Potential Rates
 - Penman-Montieth



- Evap f(temp, net radiation, wind speed, etc.)
- ET f(temp,..., soil + canopy resistances)

Actual Rates

f(water availability, Storage/Rootzone depth, LAI, etc.)















Hydro: Mathematical Model – Processes (cont.)



Subsurface flow

f(K_{sat}, Average soil moisture deficit, Recession rate)

Streamflow Prediction

- Baseflow f(Subsurface flow)
 - Specific discharge
- > Overland runoff f(Pervious and Impervious flow)
 - Per landcover percentage/area















Hydro: Mathematical Model - Outputs

Outputs

- Predicted streamflow
 - Baseflow + Overland flow (Pervious + Impervious area flows)

Pollution – Loading estimates

- Total pollutant mass
- Based on EMC values from NURP

















User Guided Development



TRansparent And Comprehensive Ecological (TRACE)



- 1. Model development
 - Problem formulation
 - Design and formulation
 - Model description
 - Parameterization
 - Calibration
- 2. Model testing and analysis
 - Verification
 - Sensitivity analysis
 - Validation
- 3. Model application
 - Results
 - Uncertainty analysis
 - Recommendation







Arbor Day Foundation









Current Model Development

- Semi-Distributed Green Infrastructure
 - Extend current model for specific GI processes

Arbor Day Foundation

Percentage of the watershed with GI

Land Cover Types

Pervious

i-Tree is a Cooperative Initiative

- Impervious
- Green Infrastructure
 - Retention/Detention Ponds
 - Rain Barrels
 - Rain Gardens
 - Green Roofs
 - Stormwater storage infrastructure



Proctor Creek Project



- Watershed area:
 34.83 km²
- USGS stream
 gauge: 02336526
 Proctor Creek at
 Jackson Parkway,
 Atlanta, GA
- Weather station: Atlanta Hartsfield Int'l 722190-13874



















Proctor Creek Project

















ISA



Proctor Creek Project



Catalog	Feature			Counts	Percentage
1	Grass/herbaceous			142	28.40%
2	Tree/shrub - pervious			159	31.80%
3	Tree/shrub - imperviou	us		25	5.00%
4	impervious-building			62	12.40%
5	impervious-road			87	17.40%
6	impervious-other			1	0.20%
7	water			1	0.20%
8	soil/bare ground			23	4.60%
9	agricultural land			0	0.00%
10	shrub			0	0.00%
			Total:	500	100.00%

5 subject	catalog	
	Statistics (number)	
	Tree+Impervious	25
	Tree/shrub - pervious	159
	Impervious	151
	Soil	23
	Short Vegetation	142
	Total	500
	Statistics (percentage)	
	Tree+Impervious	5.00%
	Tree	31.80%
	Impervious	30.20%
	Soil	1.00%
	Short Vegetation	28.40%
	Total	100.00%
	Evergreen %	44.8







UAS













Georgia Tech Campus

- Boundary file
 Shape file provided
- 🕈 Area: 1.695 sq km
- Land cover inputs
 - > 1000 points in i-Tree Canopy
 - Total TC = 19%
 Total IC = 64.3%

≻SV - 21.3%

► IC - 55.1%

► TPC - 9.8%

≻ TIC - 9.2%

≻BS - 4.6%















i-Tree

Georgia Tech Campus – Sample Points





















Georgia Tech Campus

- Hydrologic Parameters
 - Pulled from the calibrated Proctor Creek data set
 - Can be adjusted Field tests, soils maps, etc.

Alternative scenario

- Replace some grass/shrubs with trees
- Replace impervious cover with trees and grass/shrubs
- Reduce DCIA through disconnecting IA areas





















Chamble

Decatu

Candle Panthe

Brookhaven

Buckhead

Station

Atlanta



Tree is a Cooperative









Atlanta Municipal Area

- Hydrologic Parameters
 - Pulled from the calibrated Proctor Creek data set
 - Can be adjusted Field tests, soils maps, etc.

Alternative scenario

- Replace some grass/shrubs with trees
- Replace impervious cover with trees and grass/shrubs
- Reduce DCIA through disconnecting IA areas

















Make your own project

- From provided project datasets
 - Watershed area
 - Non-watershed area
- 🕈 Discharge data
 - Watershed may have associated gage data
 - Match USGS gage ID with watershed ID
 - Non-watershed area will not have discharge data
- 🕈 Weather data
 - From provided NCDC dataset















