i-Tree

Hydro

User's Manual

v. 4.0

i-Tree is a cooperative initiative

About i-Tree

i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban and community forestry analysis and benefits assessment tools. The i-Tree tools help communities of all sizes to strengthen their urban forest management and advocacy efforts by quantifying the environmental services that trees provide and assessing the structure of the urban forest.

i-Tree has been used by communities, non-profit organizations, consultants, volunteers, and students to report on the urban forest at all scales from individual trees to parcels, neighborhoods, cities, and entire states. By understanding the local, tangible ecosystem services that trees provide, i-Tree users can link urban forest management activities with environmental quality and community livability. Whether your interest is a single tree or an entire forest, i-Tree provides baseline data that you can use to demonstrate value and set priorities for more effective decision-making.

Developed by USDA Forest Service and numerous cooperators, i-Tree is in the public domain and available by request through the i-Tree website (www.itreetools.org). The Forest Service, Davey Tree Expert Company, the Arbor Day Foundation, Society of Municipal Arborists, the International Society of Arboriculture, and Casey Trees have entered into a cooperative partnership to further develop, disseminate, and provide technical support for the suite.

i-Tree Products

The i-Tree software suite v 4.0 includes the following urban forest analysis tools and utility programs.

i-Tree Eco provides a broad picture of the entire urban forest. It is designed to use field data from randomly located plots throughout a community along with local hourly air pollution and meteorological data to quantify urban forest structure, environmental effects, and value to communities.

i**-Tree Streets** focuses on the ecosystem services and structure of a municipality's street tree population. It makes use of a sample or complete inventory to quantify and put a dollar value on the trees' annual environmental and aesthetic benefits, including energy conservation, air quality improvement, carbon dioxide reduction, stormwater control, and property value increases.

i-Tree Hydro (Beta) is the first vegetation-specific urban hydrology model. It is designed to model the effects of changes in urban tree cover and impervious surfaces on hourly stream flows and water quality at the watershed level.

i-Tree Vue allows you to make use of freely available national land cover data maps to assess your community's land cover, including tree canopy, and some of the ecosystem services provided by your current urban forest. The effects of planting scenarios on future benefits can also be modeled.

i-Tree Species Selector is a free-standing utility designed to help urban foresters select the most appropriate tree species based on environmental function and geographic area.

i-Tree Storm helps you to assess widespread community damage in a simple, credible, and efficient manner immediately after a severe storm. It is adaptable to various community types and sizes and provides information on the time and funds needed to mitigate storm damage.

i-Tree Design (beta) is a simple online tool that provides a platform for assessments of individual trees at the parcel level. This tool links to Google Maps and allows you to see how tree selection, tree size, and placement around your home effects energy use and other benefits. This beta tool is the first stage in development of more sophisticated options that will be available in future versions.

i-Tree Canopy offers a quick and easy way to produce a statistically valid estimate of land cover types (e.g., tree cover) using aerial images available in Google Maps. The data can be used by urban forest managers to estimate tree canopy cover, set canopy goals, and track success; and to estimate inputs for use in i-Tree Hydro and elsewhere where land cover data are needed.

All beta programs are still in development, therefore feedback is particularly appreciated.

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 Software Suite v. 4.0" 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: http://www.itreetools.org/support/.

Acknowledgments

i-Tree

Components of the i-Tree software suite have been developed over the last few decades by the USDA Forest Service and numerous cooperators. Support for the development and release of i-Tree v. 4.0 has come from USDA Forest Service Research, State and Private Forestry, and their cooperators through the i-Tree Cooperative Partnership of Davey Tree Expert Company, the Arbor Day Foundation, Society of Municipal Arborists, the International Society of Arboriculture, and Casey Trees.

i-Tree Hydro

The i-Tree Hydro model was originally developed by Drs. Jun Wang (SUNY-ESF), Ted Endreny (SUNY-ESF), and David J. Nowak (USDA Forest Service). The model code has been improved and integrated within i-Tree based on the work of Michael Kerr (Davey Institute), Yang Yang (SUNY-ESF), Sanyam Chaudhary (Syracuse University), and Rahul Kumbhar (Syracuse University).

Many other individuals have contributed to the design, development, and testing process, including Andrew Lee (SUNY-ESF), Robert Hoehn (USDA Forest Service), Tian Zhou (SUNY-ESF), Alexis Ellis (Davey Institute), Mike Binkley (Davey Institute), Lianghu Tian (Davey Institute), and Scott Maco (Davey Institute). The manual was written and designed by Kelaine Vargas.

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Introduction

i-Tree Hydro is the first urban hydrology model that is specifically designed to model vegetation effects and to be calibrated against measured stream flow data. It is designed to model the effects of changes in urban tree cover and impervious surfaces on hourly stream flows and water quality at the watershed level.

Note: i-Tree Hydro differs from other i-Tree products in several ways:

- Its analysis area is confined to a watershed. Unlike other i-Tree tools, you cannot define your own boundary for analysis, rather you must pick a watershed with gauging station flow data.

- To make the best use of Hydro, you should have an understanding of hydrology and watersheds.

- Considerably more technical expertise is necessary for the data preparation in Hydro than in other i-Tree tools. In particular, you must be able to procure and properly format a digital elevation model (DEM) for the watershed.

- More technical expertise is necessary to make use of the outputs from Hydro. Results are presented as changes in hourly stream flow or water quality in tabular or graphic format.

This program is a beta version, i.e., it is still in development and feedback is appreciated.

Overview

The purpose of i-Tree Hydro is to simulate hourly changes in stream flow (and water quality) given changes in tree and impervious cover in the watershed. The following is an overview of the process:

1) Determine your watershed of analysis and stream gauge station. i-Tree Hydro works on a watershed basis with the watershed determined as the total drainage area upstream from a measured stream gauge. Stream gauge availability varies.

2) Download national digital elevation data. Once the area and location of the watershed are known, digital elevation data are downloaded from the USGS for an area that encompasses the entire watershed. ArcGIS software is then used to create a digital elevation map and to determine the exact boundary for the watershed upstream from the gauge station location.

3) Determine cover attributes of the watershed and gather other required data. i-Tree

Canopy and other sources can be used to determine the tree cover, shrub cover, impervious surface and other cover types. Information about other aspects of the watershed such as proportion of evergreen trees and shrubs, leaf area index, and a variety of hydrologic parameters must be collected.

4) Get started with Hydro. Once these input data are ready, they are loaded into Hydro to begin analysis.

5) Calibrate the model. The Hydro model contains an auto-calibration routine that tries to find the best fit between the stream flow predicted by the model and the stream flow measured at the stream gauge station given the various inputs. The model can also be manually calibrated to improve the fit by changing the parameters as needed.

6) Model new scenarios: Once the model is properly calibrated, tree and impervious cover parameters can be changed to illustrate the impact on stream flow and water quality.

For more information on the methodology that underlies Hydro, visit www.itreetools.org > **Resources** > **Archives** > **i-Tree Hydro (beta) Resources**.

About This Manual

This manual provides all the information needed to conduct a Hydro project. We start with installing the software and move on to the three project phases:

Phase I: Getting started. In this section, we'll talk about decisions you need to make right at the outset, how to choose your watershed, and what data need to be gathered.

Phase II: Getting started with the software. In this section, we'll explain how to input your data, how to configure a project, and how to calibrate the model.

Phase III: Modeling scenarios. In the third phase, we get to the crux of Hydro, running the model for your existing scenario, adjusting parameters and running alternative scenarios, and interpreting the results.

Appendix 1: The necessary tools and steps involved in creating a digital elevation model using ArcGIS are described here.

Appendix 2: The methodology associated with estimating how changes in hydrology affect water pollutant levels is presented here.

Installation

System Requirements

Requirements for desktop/laptop computers

Minimum hardware:

- Pentium or compatible 1600 Mhz or faster processor
- 512 MB of available RAM
- Hard drive with at least 500 MB free space
- Monitor with resolution of at least 800 x 600

Software:

- Windows XP service pack 2 or higher OS (including Windows 7)
- Microsoft Excel
- Microsoft Data Access Component (MDAC) 2.8 or higher (included in installation)
- .NET 2.0 framework (included in i-Tree installation)
- Adobe Reader 9.0
- ArcGIS with Spatial Analyst Extension

Installation

To install Hydro:

1 Visit www.itreetools.org to download the software or insert the i-Tree Installation CD into your CD-ROM drive.

2 Follow the on-screen instructions to run i-Tree setup.exe. This may take several minutes depending on which files need to be installed.

3 Follow the Installation Wizard instructions to complete the installation (default location recommended).

You can check for the latest updates at any time by clicking **Help** > **Check for Updates**.

Exploring Hydro with the Sample Project

Now that you've installed Hydro, you would probably like to see a little of what the software can do. To allow you to explore the program, we've included a sample project based on a watershed near Denver, CO.

1 You can begin by opening Hydro using your computer's **Start** menu > **(All) Programs** > **i-Tree** > **i-Tree Hydro**.

2 You will find the project under **File** > **Open Sample Project**.

   a Under **Input**, you can explore some of the data fields that can be edited.

   b Under **Reports** > **Water Flow Reports** > **Current Scenario**, you can run the model for the current conditions for this watershed. As an output, you will receive a graph showing how water flow and rainfall vary over time.

   c To adjust tree and impervious cover parameters and see how these changes affect the hydrology of the project area, click **Inputs** > **Management Scenario**. Choose **Management Scenario** from the drop-down menu.

   d Then, click **Reports** > **Water Flow Reports** > **Management Scenario** to run the model again and see how the graph output changes. Other reports allow you to compare the management and current conditions in one graph.

   e Under **Reports** > **Water Pollution Reports**, you can view tables and graphs presenting the pollutant load associated with existing and future hydrology.

We will, of course, explain all of these functions and more in greater detail, but for now feel free to explore and see what's available.

Phase I: Getting Started

Choosing Your Watershed and Gauging Station

The first, and perhaps most difficult, decision you have to make is what watershed to analyze. One challenge here is that many people are more accustomed to thinking in terms of political or parcel boundaries (e.g., a city or a university campus) and considering what impacts might result from changes to those areas. For Hydro, modeling occurs at the watershed level, which is unlikely to align with political or parcel boundaries.

A second challenge relates to the availability of data. Hydro makes use of hourly stream gauge data from the U.S. Geological Survey (USGS). Although there are many stream gauge stations across the country, data are not available for every stream and its associated watershed.

A third challenge relates to scale. Stream gauges are located in streams that capture water from watersheds of vastly different scales. A stream gauge in a small creek might be associated with a watershed of a few square kilometers. A stream gauge at the mouth of the Mississippi River would be associated with a watershed that includes half of the United States. Changes in tree cover and impervious surface are unlikely to have measurable effects over the scale of a very large watershed, therefore your goal should be to analyze a watershed that is of a size that can be influenced by changes in these factors.

With these limitations in mind, your goal in this first step is to choose the best stream gauge station in your area of interest and estimate the boundaries of the associated watershed. You'll use these boundaries for the next part of Phase I, obtaining digital elevation model data.

Tools for choosing the best stream gauge station and watershed

The easiest method for visualizing stream gauge stations and their associated watersheds is Google Earth. Begin by downloading the two files necessary:

1   At the EPA's Waters website (http://www.epa.gov/waters/tools/WATERSKMZ/WATERSKMZ.html), download the WATERS.KMZ file in vector format.

   NOTE: Links were correct at time of publication but may have changed. If necessary, please use an internet search engine and relevant key words to search for the correct links.

2   From www.itreetools.org > **Resources** > **Archives** under the Hydro section, download the KMZ file of the stream gauge stations available in Hydro: i-Tree_Hydro_Gauging Stations_2005.kmz.

3 Open Google Earth on your computer (you'll need at least version 5.0) and open the two files. Zoom in to your area of interest (see Fig. 1).

A few hints: (1) The EPA Waters file is live, i.e., it updates from the internet while you are using it. Therefore it can be very slow. You'll know it is gathering data when the little colored boxes next to the field names under Places are spinning. To speed things up, uncheck every box under Surfacewater Features, except Streams, and all boxes associated with Water Program Features and zoom in to your area. (2) The streams are only visible at very local scales. If you can't see them, continue zooming in until the scale at the bottom of the map is approximately 1" = 3 miles. Remember to wait for the data to load.
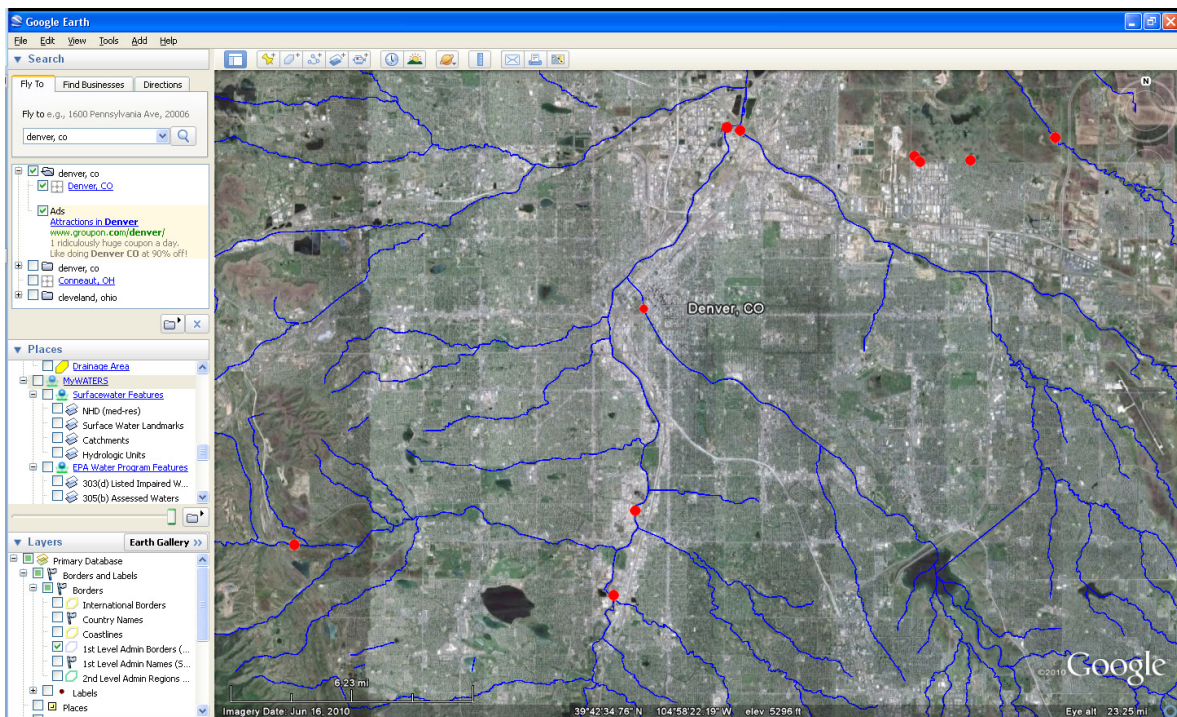

Fig. 1: Streams and stream gauge stations around Denver

4 The next step is to explore the watersheds associated with each station to choose the best one. To do this:

a Click on the stream itself just downstream of the station. A window will appear describing the features of the stream. At the bottom, under **Tools**, click **Drainage Area Delineation**.

b In the window that appears, choose **Stop When: Maximum Distance (KM) = 30** and click **Start Search**. The watershed upstream from that point for the first 30 km will be identified. You might have to redo this process a few times, increasing the maximum distance to capture the entire watershed (see Fig. 2).
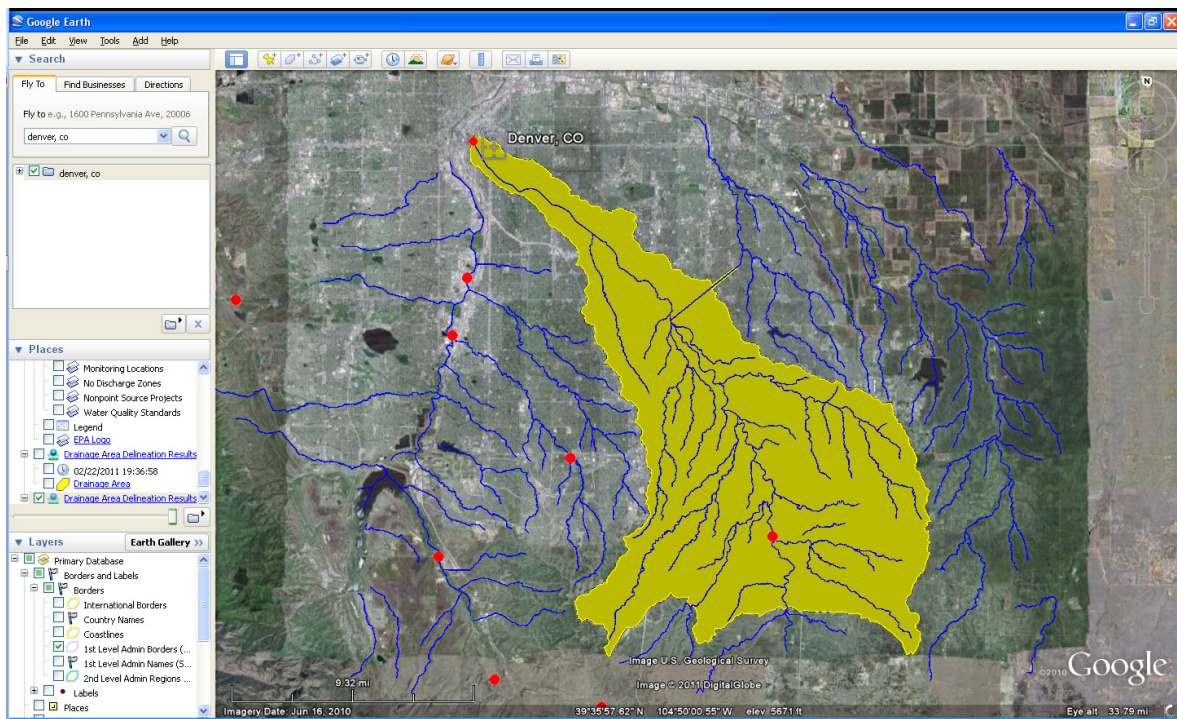
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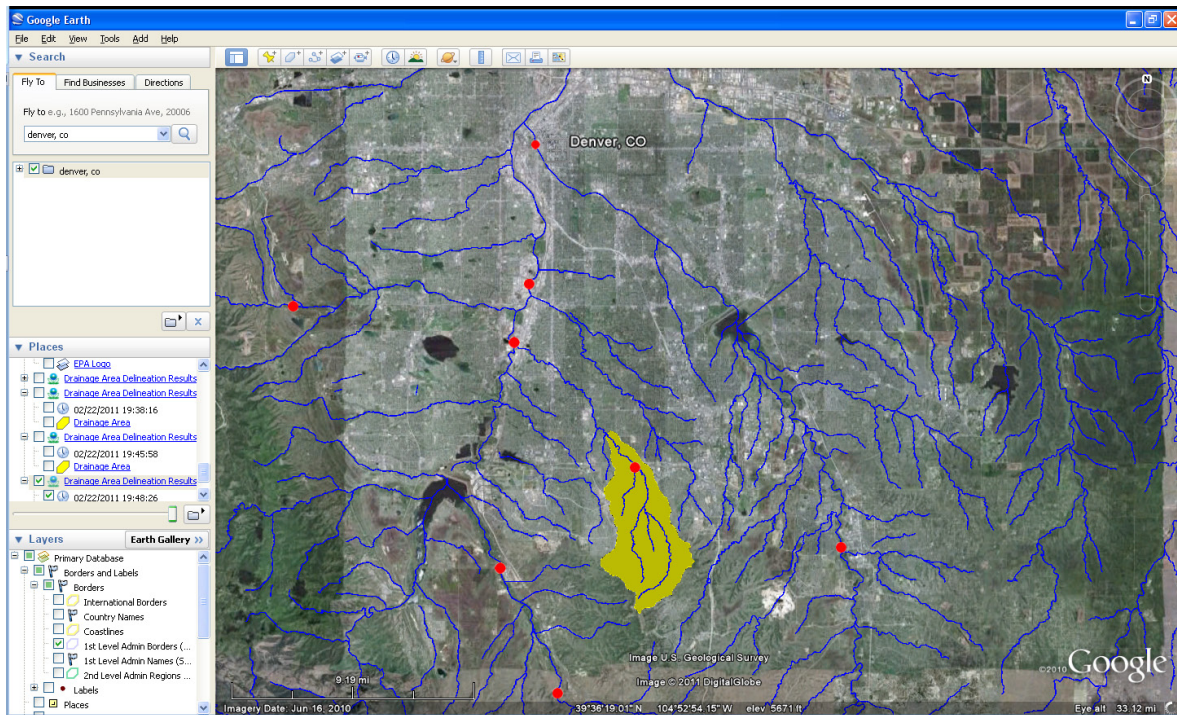**Fig. 2: A watershed near Denver**

Fig. 3: Another watershed near Denver

    c Once you have the outline of the watershed determined, judge whether it is appropriate for your study.

      Does it capture your area of interest?

      Is the watershed of a scale that would be appropriate for modeling changes in canopy and impervious cover? (In a watershed that is very large, changes in cover are likely to be overwhelmed by other influences.)

    d Delineate the drainage areas for other stream gauge stations until you have found the best one (see Fig. 3).

5 Once you have made your selection:

    a Note the name of the stream.

    b Note the ID number of the stream gauge station, by clicking on its red dot.

    c Capture an image of the stream gauge station and watershed using your computer's **Print Screen** function or Google Earth's **File** > **Save** > S**ave Image** function.

Creating a Digital Elevation Model

Once you have identified your watershed of interest and noted the stream gauge station number and stream name, your next step is to create a digital elevation model (DEM) of the watershed. The end product should be a DEM clipped to the boundaries of your watershed, projected in the proper UTM zone in meters, and converted to ASCII format.

For detailed instructions on this process, see Appendix 1.

Gathering General Data

Streamflow, weather, and evapotranspiration data

Hourly streamflow, weather, and evapotranspiration data are available as standardized, complete data sets within Hydro for the year 2005. If you are amenable to working with data from this year, your work (in this regard) is done. If you wish to run the model for a different year, you will need to gather and format the hourly data for your year of choice. Required weather data include wind direction and speed, cloud ceiling, sky cover, temperature, dewpoint, altimeter setting, pressure, and precipitation; for streamflow, hourly values are necessary. Custom streamflow and weather data must have the same start and end dates (and can be for less than the default option of 1 year.) More information and examples of correctly formatted data are provided at www.itreetools.org under Resources > Archives > Hydro.

Other data

There are a number of other pieces of information (required and optional) that are used to calibrate the model. The table below lists and defines the data to be collected, offers suggestion for where to find local information if desired, provides default values where available, and provides space for you to enter your own values to make it easier to keep track of your information.

Category	Source[a]	Default value	Local value
Watershed land area (m^2)	DEM	N/A	
Land Cover (should total 100%)			
Tree cover (%)	Eco , Canopy, UTC, GIS	N/A	
Shrub cover (%)	Eco , Canopy, UTC, GIS	N/A	
Herbaceous cover (%)	Eco , Canopy, UTC, GIS	N/A	
Water cover (%)	Eco , Canopy, UTC, GIS	N/A	
Impervious cover (%)	Eco , Canopy, UTC, GIS	N/A	
Soil cover (%)	Eco , Canopy, UTC, GIS	N/A	
Evergreen Contribution			
Evergreen tree cover as percentage of total tree cover (%)	Eco	10	
Evergreen shrub cover as percentage of total shrub cover (%)	Eco	10	
Leaf Area Index			
Tree leaf area index[b]	Eco, Literature	5.0	
Shrub leaf area index[b]	Eco, Literature	2.2	
Herbaceous leaf area index[b]	Eco, Literature	1.6	

Category	Source[a]	Default value	Local value
Cover Beneath Trees (should total 100%)			
Shrub cover beneath trees	Eco	12.3	
Herbaceous cover beneath trees	Eco	73.4	
Soil cover beneath trees	Eco	8.2	
Impervious cover beneath trees	Eco	6.1	
Percentage of impervious cover where drainage is directly connected to the stream via a pipe network[c]	GIS	65	
Other *optional* fields in Advanced Settings			
Leaf transition period (days) (number of days to convert from completely leaf off to full leaf area index or vice versa)	Literature	28	
Specific leaf storage (mm) (depth of water captured on leaf surfaces)	Literature	0.2	
Tree bark area index	Literature	1.7	
Shrub bark area index	Literature	0.5	
Leaf-on day (day of year 1–365) (average day of year that trees come into leaf; date is the mid-point of the leaf transition period)	Literature	Defaults are regionally specific	
Leaf off day (day of year 1–365) (average day of year that trees have lost their leaves; date is the mid-point of the leaf transition period)	Literature	Defaults are regionally specific	
Coefficient for effective precipitation (amp)	Literature	1	

[a] *DEM* = DEM data (see Appendix 1). *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. *UTC* = An existing urban tree canopy analysis. *GIS* = Your local government or university GIS department. *Literature* = Some data may be available for some areas in the scientific literature or from the appropriate university department.

[b] Leaf area indexes can be calculated from Eco results for leaf area. These results are presented in units of m^2/ha. To get LAI, divide by 10,000.

[c] This value can be particularly difficult to find. One strategy is to adjust the value in the calibration process until the best results are achieved.

Phase II: Getting Started with Hydro

Once you've created your DEM and gathered your data, it's time to get started with the software.

Creating a New Project

To begin working with Hydro, click your computer's **Start** menu > (**All**) **Programs** > **i-Tree** > **Hydro**.

To start a new project:

1 Click **File** > **New project** and then **Input** > **Raw Data Input**. The **i-Tree Hydro Raw Data Input** window will appear. In this window, you will load the appropriate stream gauge and weather data for your area and provide inputs that allow these files to be processed.

2 To locate your stream gauge and weather data, enter the state, county, and city that is closest to your watershed.

3 Enter the watershed land area in square meters (from the DEM process in Appendix 1) and the percent tree cover in the watershed, leaf area index, and percent of the tree and shrub cover that is evergreen. Note that percent evergreen tree and shrub cover can range from 0% (all of the tree or shrub cover is deciduous) to 100% (all of the tree or shrub cover is evergreen).

4 If you will be providing your own stream gauge and weather data, enter the start and end times of the data sets. Note that they must be the same for both sets. If you are using the standard option, leave the defaults as they are.

5 The next step relates to incorporating your stream gauge and weather data. Here you have two options:

    a If you will be using the standard Hydro data for 2005, click **Select by Map**. For both stream gauge and weather data, a map of local stations will appear. Either click on the appropriate station or enter the ID number directly in the ID field and click **OK**. A window will appear allowing you to choose the location and a name for the file. Navigate to the folder where your project will be saved, give the file a name (e.g., streamgauge_data.dat, weather_data.dat), and click **Save**. Processing will begin.

    b If you gathered your own data, choose **Select File** and browse to the location where you saved the file.

NOTE: If you should discover later that you made an error in any of the fields in this window, you should start over with a new project as changes to these fields require reprocessing of weather and stream gauge data.

Once you have finished in this window, click **OK** to close. It's a good idea to save your project at this time, so click **File** > **Save Project**, navigate to the folder where you want to save, give the project a name and click **Save**.

Configuring Your Project

The next step involves configuring the model by giving more specific details on your watershed. To begin click **Input** > **Configuration**.

1 On the **Initial Setup** tab:

a Choose a routing method. There are two options here: time constant routing and channel routing. The routing method is the means by which the program adjusts the timing of the flow to reach the watershed gauging station at the proper time (e.g., precipitation at the top of the watershed takes longer to reach the bottom of the watershed than precipitation that falls near the bottom of the watershed). The time constant routing method uses a physical function or equation to find the best fit for time and flow. The channel routing method divides the watershed into 16 zones and requires 18 parameters to be calibrated. The time constant routing method only requires one parameter to be calibrated and is more efficient. Both methods produce similar results.

b Load your DEM, weather, and stream gauge data by browsing to find the location of these files. If you chose the Channel Routing method in the step above, click **Create** next to the Channel Routing field. In the dialog box, navigate to the location where you want to save the file that will be created, give it a name, and click **Save**. Then click **Browse**, navigate again to the file, and click **Open**.

2 On the **Current Land Cover** tab, enter the data you collected in Phase I in each field. Use default values when data are unknown.

3 Check the **Show Advanced Settings** button, and an Advanced Settings tab will appear. If you have more local information for the fields on this tab, enter it now.

a If you would like to save and be able to view the many working files created by Hydro, specify the location for the files by checking the box next to **Use Specified Working Directory**, and browse to the location where the

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files should be saved. It's best to create a new folder for them, such as "Working."

b Click the **Hydrological Parameters** tab to begin the steps necessary to calibrate the model.

Calibrating the model

Calibrating the model is a multi-step process of adjusting model parameters until the model output for the stream flow is as close as possible to the actual stream flow. The model simulates various hydrologic processes (e.g., precipitation, interception, infiltration, evaporation, transpiration, flow routing and storage) to simulate stream flow at the gauging station and then checks how well it has performed by comparing estimated model flow against actual flow. Results are considered in terms of peak, base, and overall flow.

> NOTE: Model calibration can be significantly off if the local precipitation data do not match the watershed. For example, if the precipitation data were collected too far from the watershed or if the precipitation events are very localized, calibrations will be off as it may be raining in the watershed but not at the precipitation station or vice versa.

Begin the calibration process by auto-calibrating:

1 Click **Auto-Calibrate Parameters**.

NOTE: This process takes about 10 minutes. Your anti-virus software may show a warning regarding the file pest.exe. Allow that file to run.

2 Once the auto-calibration is complete, click **Check Calibration**. In the **Parameter Calibration Results** window that appears, the values for flow for the initial parameters are compared with those for the auto-calibrated parameters. With a very good fit, values will approach 1.0, but this often does not happen due to mismatches in the precipitation and flow data described above. Typically, values are 0.3 to 0.7, but higher is better.

NOTE: If calibration results are poor, you may need to find precipitation data that more closely matches the conditions in the watershed.

3 If you are not satisfied with the fit of the model, you can adjust some parameters to see the effects on the model.

a Begin by clicking **Save As New Parameter Set** and enter a name for the new set of parameters in the window that appears.

b Adjust any of the parameters (see Table 2 below for ranges of possible values), then click **Save**.

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c Click **Check Calibration**. The model will rerun (the process should only take a minute or two this time) and you can compare the results for the new set against the others. Continue in this way until you are satisfied with the calibration.

d Having too many parameter sets saved can slow down the modeling. You can delete sets by selecting the one to be deleted from the drop-down menu and clicking **Delete Parameter Set**.

Once you have successfully calibrated your model and entered the necessary data under each field, you have the option of saving all of your parameters, including the *currently visible* calibration values, land cover values, advanced settings, etc. so they can be viewed outside of Hydro or used in another project. To save for outside use, click **Save to File**. To load the saved parameters from a previous project, click **Load from File**.

To move on to the next phase be sure that the desired parameter set has been selected in the dropdown menu, click **OK** to close the Configuration window and be sure to *save your project*!

Table 2. Hydrological parameters used in calibration

Parameter	Range	Default
Scale parameter of power function (n)	–	2
Scale parameter of soil transmissivity [m]	0.001–0.25	0.03
Transmissivity at saturation (T_0) [m²/h]	0.001–100	0.2
Unsaturated zone time delay (T_d) [h]	0.01–200	10
Maximum root zone storage deficit	0.0001–0.5	0.022
Percent of watershed generating infiltration excess overland flow	0–100	30
Time constant of watershed (b) [h]	0.1–240	1
Initial stream discharge (Q_0) [m/h]	0.000001–0.00005	0.000015
Initial root zone deficit [m]	0.00001–0.03	0.0002
Main channel routing velocity [m/h]	500–3600	950
Internal channel routing velocity [m/h]	500–3600	950
Wetting front suction [m]	0.01–0.3	0.12

Parameter	Range	Default
Wetted moisture content [m]	0.1–0.7	0.48
Surface hydraulic conductivity [m/h]	0.00006–0.2	0.002
Impervious depression storage [mm]	0.1–3.0	1.5

Graphing the calibration results

The different calibration schemes can be compared in graph form under **Reports** > **Calibration Comparison**. A window will open allowing you to choose which calibration parameter sets to compare. Select the desired ones and click **OK**. The resulting graph shows rainfall at the top with rainfall values along the right y-axis. Measured stream flow (from the stream gauge station) and estimated stream flow according to the different parameter sets are on the bottom of the chart and are associated with the values on the left y-axis. The x-axis is time.

Phase III: Modeling Scenarios

Modeling the Current Scenario

Once you are satisfied with the calibration settings, you can run the model for your existing conditions.

1 Under **Reports** in the File menu, click **Water Flow Reports** > **Current Scenario**.

2 You can switch between English and metric units in the tool bar under **View**.

Understanding the Graphs and Tables

Graphs

The graph shows rainfall at the top with rainfall values along the right y-axis. Stream flow curves are on the bottom of the chart and are associated with the values on the left y-axis. The x-axis is time.

Stream flow is the amount of water moving past the gauging station and includes base flow (water in a stream provided by groundwater), overland flow (excess water that moves over pervious surfaces when precipitation rate is greater than infiltration rate and/or when the ground is saturated), impervious flow (water moving over impervious surfaces), and total flow (sum of the three component flows).

You can customize the line colors under Display in the top left corner of the window by clicking the colored box next to each component and then choosing your new color in the window that appears. To turn on and off any curves, click to remove the check box next to the name. (This takes a bit of time.) The legend can be turned on and off using the checkbox at the top of the window.

Graphs can be exported as GIF, JPG, or PNG formats by selecting the appropriate file type in the drop-down box and clicking **Export**.

Tables

Tables present the data numerically on an hourly basis.

Using the **Total** drop-down menu, you can choose to display weekly totals, monthly totals, or a total for the entire model run (usually, but not always, a year). Using the **Export** drop-down menu, you can choose to export your data in Excel format or as comma-separated values (CSV).

Modeling Alternative Scenarios

The goal of i-Tree Hydro is to show how changes in the amount of tree canopy cover or changes in the surface cover (transforming impervious surface into herbaceous cover, for example) affect the hydrology of your watershed. To model how different management scenarios affect a watershed's hydrology:

    1   Under **Inputs**, select **Management Scenario**. From the drop-down menu, select **Management Land Use**.

    2   Make any changes to the surface cover types, leaf area indexes, and cover types beneath tree cover. Be sure that the covers total 100%. Click **OK**.

    3   To view the results, under **Reports** in the File menu, select **Water Flow Reports** > **Management Scenario**. The Hydro Model Run window will appear.

A graph and table similar to those for the initial scenario will appear, showing the values for the new scenario.

Comparing the initial and management scenarios

The initial and management scenarios can be compared by choosing **Management vs. Current Scenario** under the **Reports** > **Waterflow Reports** menu. To illustrate the calculated differences in flows between the two scenarios, choose **Management – Current Scenario**.

Water Pollution Reports

i-Tree Hydro can also help clarify the impacts of changes in surface cover and vegetation on pollutant load in streams by making use of a statistical parameter known as event mean concentration (EMC) (see Appendix 2 for more information). An EMC value represents the flow-proportional average concentration of a given pollutant during a storm event and is 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. Changes in flow owing to changes in cover and tree canopy will therefore be reflected in changes in pollutant load. These are the results that Hydro presents.

> NOTE: EMC values can be derived from many sources, including actual measured data from your watershed. Because such actual data are hard to come by, Hydro makes use of average national values. More information about the methods used to estimate these values can be found in Appendix 2.
>
> It is important to note that these are national values and therefore do not take into account local pollutant conditions and local management actions (such as street cleaning). It is not known how well the national EMC values represent local conditions.

1 To model the pollutant load in your receiving body of water (i.e., in the water moving past your gauging station): under **Reports** in the File menu, click **Water Pollution Reports** > **Current Scenario**.

2 To model the pollutant load under your management scenario: under **Reports** in the File menu, click **Water Pollution Reports** > **Management Scenario**.

3 To compare the two, under **Reports** in the File menu, click **Water Pollution Reports** > **Management - Current Scenario**.

Graphs and tables

The graphs and tables for pollutant load are similar to those for hydrology. On the graphs, rainfall appears at the top and is associated with the values on the right y-axis. The ten modeled pollutants appear at the bottom of the graphs and are associated with values on the left y-axis.

As for the hydrology results, graphs and tables can be exported in a variety of formats.

NOTE: A limitation of the current beta version of Hydro is that only one management scenario can be saved at a time. If you wish to model several different scenarios, we suggest saving each as a new project, under **File** > **Save Project As** and giving each scenario a different name e.g., Denver_IncreaseTreeCover30Percent.iHydro. All variables, calibration settings, and inputs are saved with the project, so it easy to open each one after saving.

Appendix 1: Creating a Digital Elevation Model

In Phase I, we discussed criteria for choosing a watershed and some tools for doing so. This Appendix covers the steps necessary to create a digital elevation model (DEM) of that watershed using ArcGIS. These instructions assume that you are familiar with DEM data, watershed concepts, and ArcGIS tools.

The basic steps of this procedure are as follows:

1 Download DEM data from the USGS for an area that covers the watershed boundaries you determined in Phase I.

2 Use ArcGIS to build a DEM from the downloaded data and clip it to the borders of the watershed.

Tools

ArcGIS (v. 9.3.1. was used for this guide, but other version can be used)

ArcGIS Spatial Analyst

Results

The end product of the steps described here will be a DEM clipped to the boundaries of your watershed, projected in the proper UTM zone in meters, and converted to ASCII format.

Downloading DEM Data from USGS

With your watershed and stream gauge selected using the methods described in Phase I, the first step in creating a DEM is to download the necessary data from the USGS. If you have your own source of DEM data, it can certainly be used, but keep in mind that DEM data should have a resolution of 10–30 m. Finer resolution data are available, but are more likely to cause complications in modeling associated with bridges and elevated roadways.

1 Navigate to the USGS DEM website: http://seamless.usgs.gov/index.php.

NOTE: Links were correct at the time of publication but may have changed. If necessary, please use Google and the relevant key words to search for the correct links.

2 Click on the **Seamless Viewer** to launch the DEM Download Data tool.

3 Use the tools on the left to zoom and pan to your region.

4 You can use the **Display** tab on the right to manage visible layers to help with orientation. (These choices do not affect which data are downloaded.) The following are recommended:

> **a** Under Hydrography, turn on the National Atlas and NHD Streams option.

> **b** Under Boundaries, turn on National Atlas States and National Atlas Counties 2001.

5 Under the **Download** tab on the right, be sure that the **1" NED Elevation data** box is checked.

6 From the toolbar on the left, choose the **Define Rectangular Download Area** tool.

7 Now, comparing the image you saved from Google Earth of the streams in your region and your watershed of choice (Fig. 1), select an area of coverage that extends comfortably beyond the boundaries of your watershed (Fig. 2).

NOTE: It is much better to overestimate the size of your watershed when downloading the DEM data than to underestimate because if you miss even a small corner of the watershed you will have to begin again. Nevertheless, the larger your download size, the longer it will take and the more likely it is to timeout, forcing you to begin again, so don't go overboard.

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8 In the window that appears, click the **Download** button. Depending on server load and the size of your download, this request may take some time.
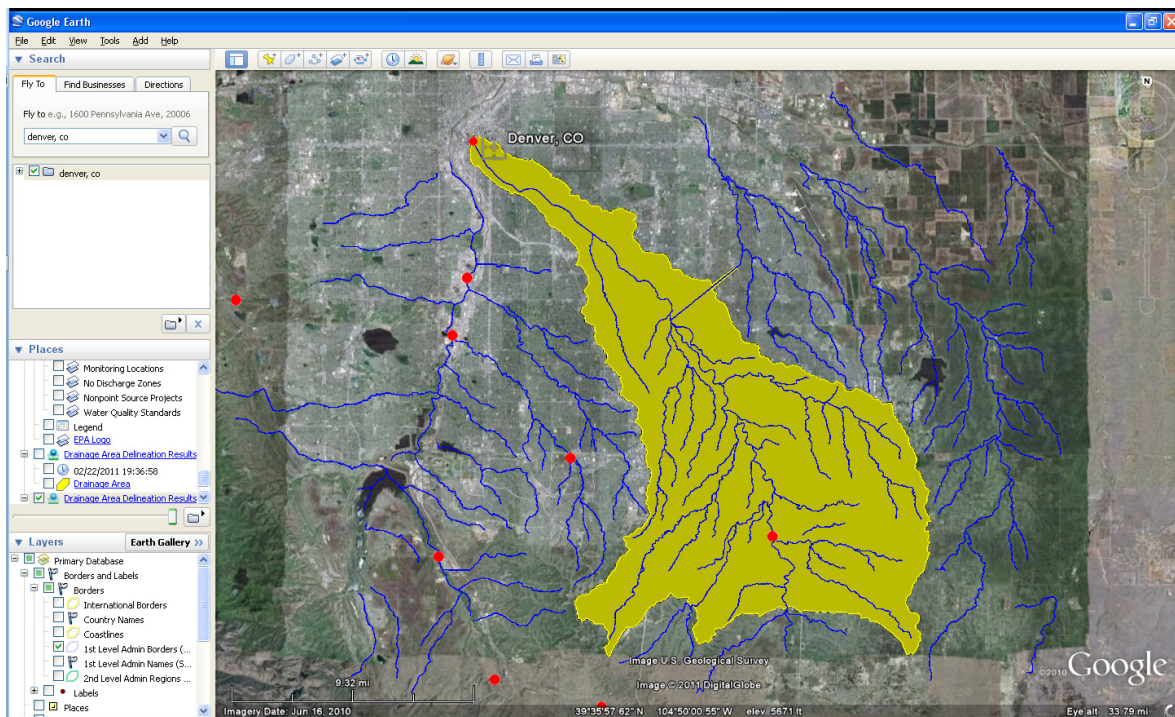
9 Save the file and unzip to a working folder.
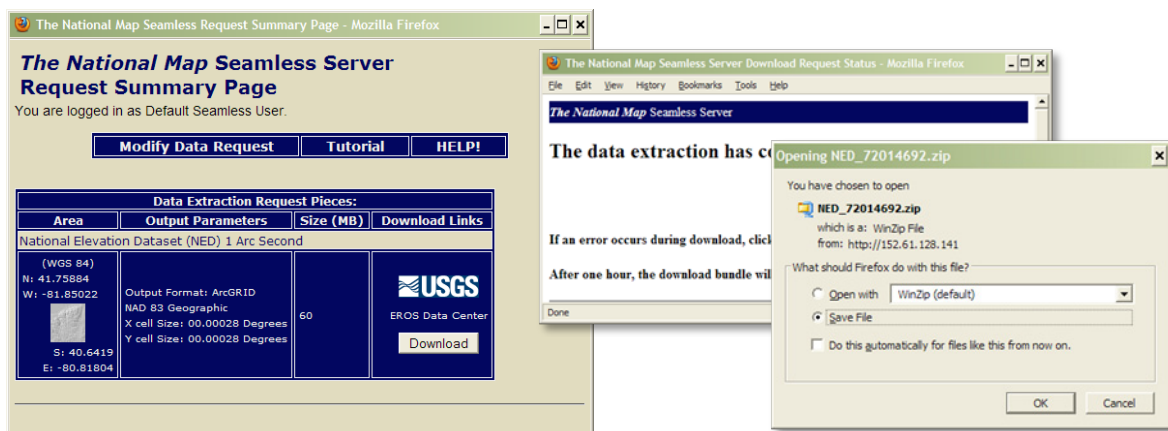
Fig. 1: Watershed boundaries determined in Phase I using Google Earth, EPA stream file, and Hydro stream gauge file.
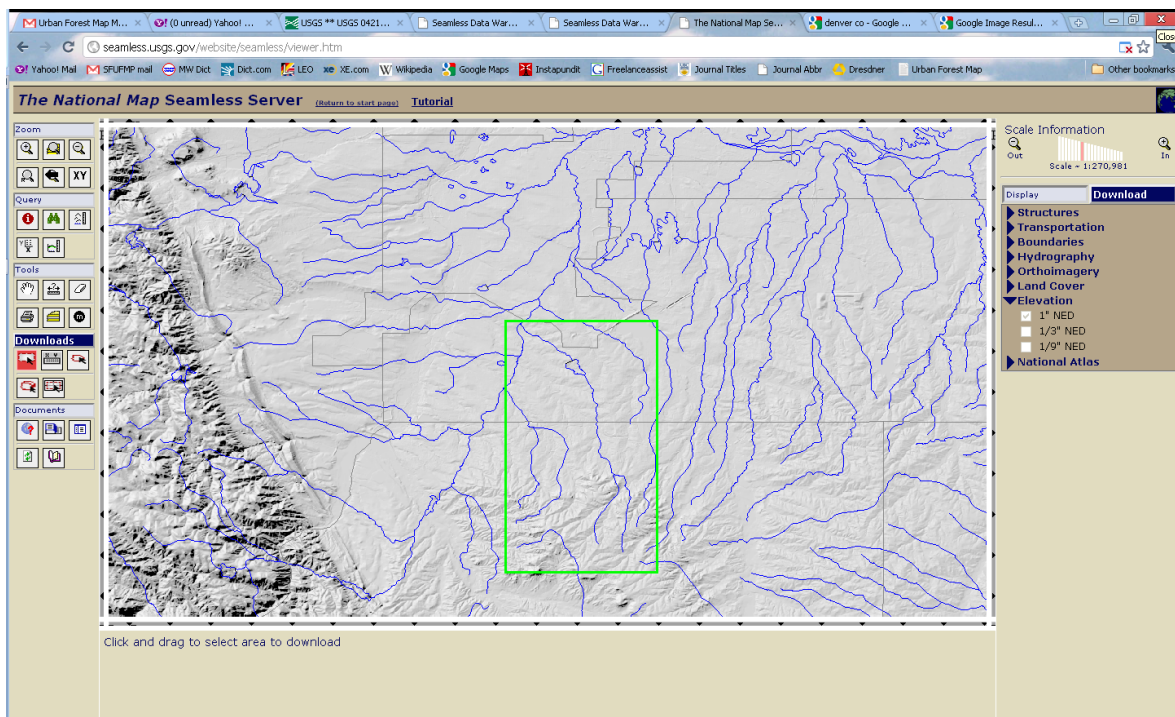

Fig. 2: The same stream system. The outlined area includes all of the yellow area in the figure above.

Once you have your data downloaded and unzipped, you can begin the process of transforming it into a hydrological model and clipping it in ArcGIS. You'll need to load and enable the ArcGIS Spatial Analyst Hydrology Tools.

1 Open the DEM data in ArcMap. Do NOT set any projection information at this time.

2 Open ArcToolBox and navigate to **Spatial Analyst Tools** > **Hydrology**.
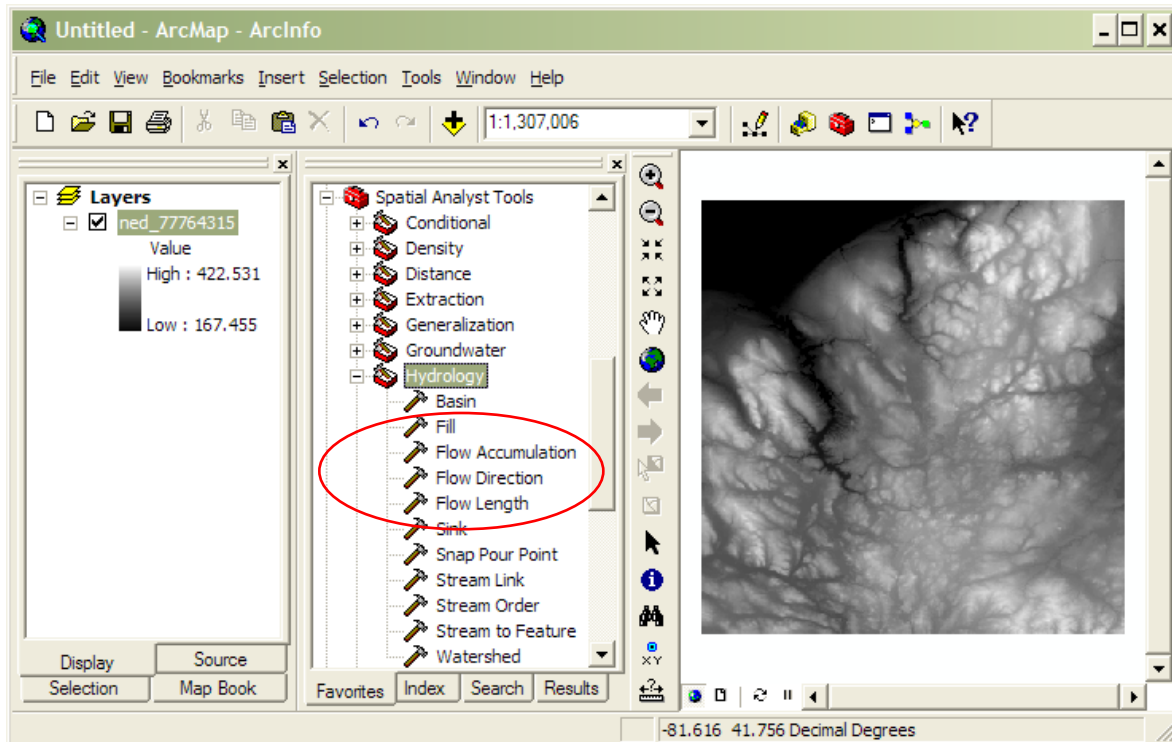
3 First choose the option to fill the DEM model, using the **Fill** tool.

4 Next, compute flow direction on the filled DEM layer (from step 3) using the **Flow Direction** tool.

5 Next, compute flow accumulation on the flow direction layer (from step 4) using the **Flow Accumulation** tool.

6 Create a "pour-point" for the watershed based on the location of your stream gauge station.

   **a** Under the ArcGIS **Edit** menu, select the **Go To XY** tool.
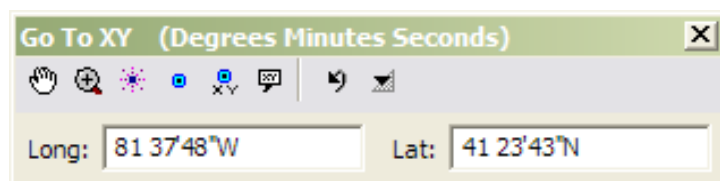
b Enter the degrees, minutes, and seconds of your stream gauge station in the following format: Long: 81 37'48"W Lat: 41 23'43"N. Use a space in place of the degree symbol, use single quotes for minutes, double quotes for seconds, and direction letters rather than negative signs.

c Select the **Add Point** button to place a marker on the stream gauge location/ watershed pour point.

d Because of the mechanics of creating a DEM, it is unlikely that your stream gauge marker will line up exactly with the stream created by the DEM. Drag the point so that it sits within the primary outlet stream of your watershed. The distance should be fairly small and the move obvious. If not, verify that you have entered the coordinates correctly. Now, drag the pour point slightly downstream ~50–100 feet to simplify later steps.
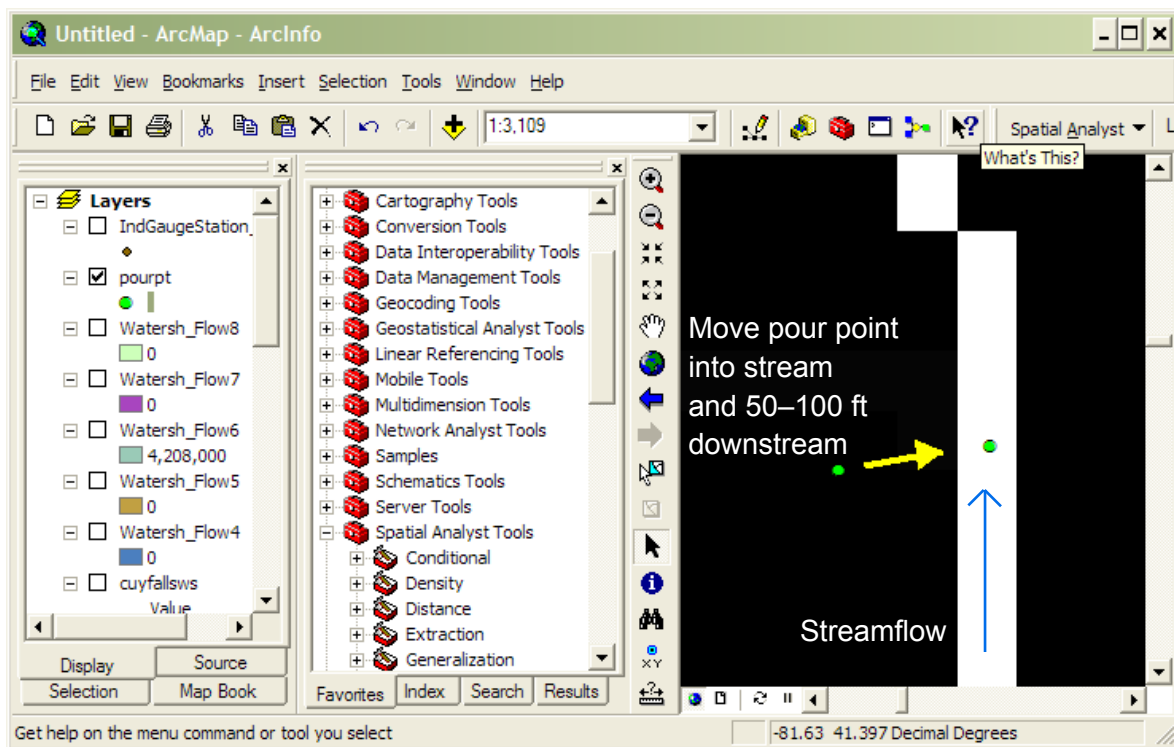
7 Capture this pour point within a shapefile.

a In ArcCatalog create a new POINT shapefile.

b Set the projection system to that of the original DEM data projection system via the **Create Shapefile** > **Spatial Reference** > **Edit** > **Import** > **Browse** to DEM data option.

**c** Open the Pour Point shapefile in the current ArcMap session.

d Edit the Pour Point shapefile and create a new point feature right on top of the Pour Point marker. Stop editing and save edits.

8 Compute the watershed using the flow direction layer (created in step 4) and the pour point layer (created in step 7), using the **Watershed** tool (not the Basins tool).

a For the pour point field, choose any of the numeric fields (although it says that this is optional, it isn't).

9 Compare the resulting image of the computed watershed with the image of your watershed that you found in Phase I. If they are not similar:

a Try moving the pour point another 50–100 ft downstream and repeating step 8.

b Verify that the spatial extent of the original downloaded DEM data covers the entire watershed. If it does not, you'll need to do another download and perform these steps again.
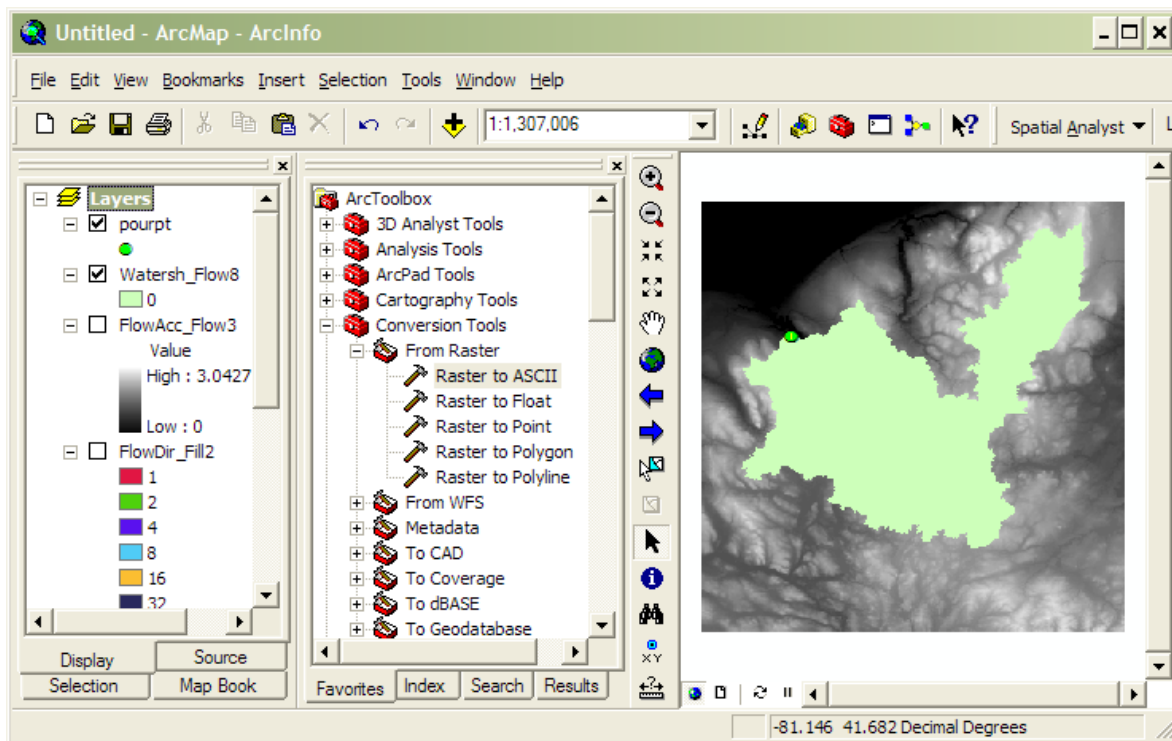
10 To calculate the area of the watershed, right-click the computed watershed layer and select **Open Attribute Table**. Use the table tools to add a new field for area, then right-click on the added field and select **Calculate Geometry**. Select Area and square meters.

11 Convert the derived watershed raster layer (from step 8) into a polygon using **ArcToolbox** > **Conversion Tools** > **From Raster** > **Raster to Polygon**.

12 Clip the *original DEM* (step 1) with the converted watershed polygon (from step 10) using **ArcToolbox** > **Spatial Analyst Tools** > **Extraction** > **Extract by Mask**.

NOTE: This is NOT the same process as ArcToolbox > Analysis Tools > Extract > Clip.
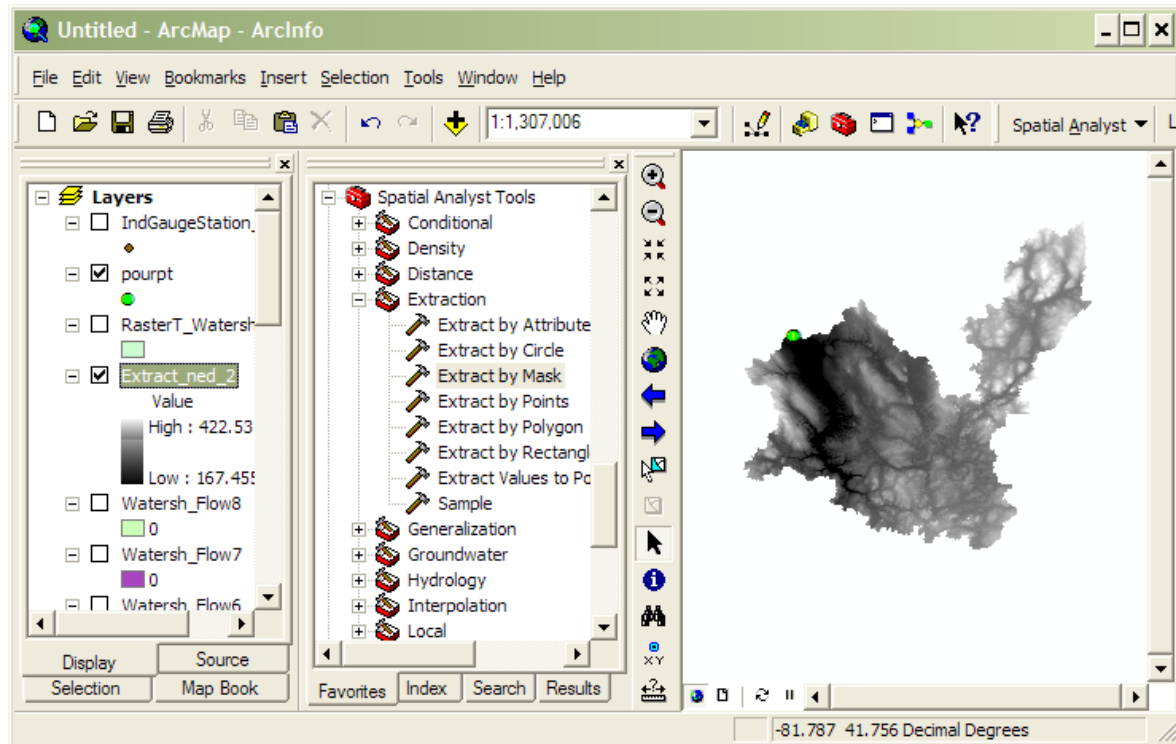
13 Re-project the clipped DEM (from step 11) to UTM meters using **ArcToolbox** > **Data Management Tools** > **Projections and Transformations** > **Raster** > **Project Raster**.

    a The UTM zone is dependent on the project area. For UTM zones guidance: http://egsc.usgs.gov/isb/pubs/factsheets/fs07701.html

    b Output coordinate system should be: WGS_1984 datum

    c Geographic transformation should be: NAD_1983_TO_WGS_1

    d Leave other values as defaults.

14 Export the clipped, re-projected DEM (from step 12) to ASCII format using **ArcToolBox** > **Conversion Tools** > **From Raster** > **Raster to ASCII**.

15 In Windows Explorer, change the file type extension of the ASCII file (from step 13) from .TXT to .DAT for use within i-Tree Hydro.

Appendix 2: Water Quality Effects – Event Mean Concentration to Calculate Pollution Load

The term event mean concentration (EMC) is a statistical parameter used to represent the flow-proportional average concentration of a given parameter during a storm event. It is defined as the total constituent mass divided by the total runoff volume, although EMC estimates are usually obtained from a flow-weighted composite of concentration samples taken during a storm. Mathematically (Sansalone and Buchberger, 1997; Charbeneau and Barretti, 1998):

$$EMC = \overline{C} = \frac{M}{V} = \frac{\int C(t)\,Q(t)\,dt}{\int Q(t)\,dt} \approx \frac{\sum C(t)\,Q(t)\Delta t}{\sum Q(t)\Delta t}$$

where $C(t)$ and $Q(t)$ are the time-variable concentration and flow measured during the runoff event, and M and V are pollutant mass and runoff volume as defined in Equation 1. It is clear that the EMC results from a flow-weighted average, not simply a time average of the concentration. EMC data is used for estimating pollutant loading into watersheds. EMCs are reported as a mass of pollutant per unit volume of water (usually mg/l).

The pollution load (L) calculation from the EMC method is

$$L = EMC * Q = EMC * d_\gamma * A$$

where EMC is event mean concentration (mg/l, mg/m^3, …), Q is runoff of a time period associated with EMC (l/h, m^3/day…), d_γ is runoff depth of unit area (mm/h, m/h, m/day…), A is the land area (m^2, …) which is catchment area in i-Tree Hydro.

Thus, when the EMC is multiplied by the runoff volume, an estimate of the loading to the receiving water is provided. As is evident from Fig. 3, the instantaneous concentration during a storm can be higher or lower than the EMC, but the use of the EMC as an event characterization replaces the actual time variation of C versus t in a storm with a pulse of constant concentration having equal mass and duration as the actual event. This process ensures that mass loadings from storms will be correctly represented. EMCs represent the concentration of a specific pollutant contained in stormwater runoff coming from a particular land use type or from the whole watershed. Under most circumstances, the EMC provides the most useful means for quantifying the level of pollution resulting from a runoff event (USEPA, 2002).

Since collecting the data necessary for calculating site-specific EMCs can be cost-prohibitive, researchers or regulators will often use values that are already available in the literature. If site-specific numbers are not available, regional or national averages can be
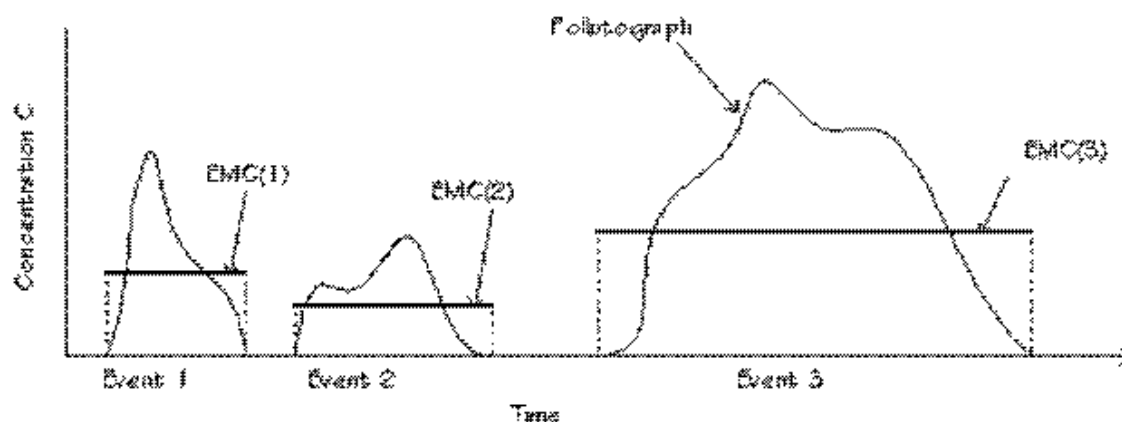
Fig. 3. Interstorm variation in pollutographs and EMCs.

used, although the accuracy of using these numbers is questionable. Due to the specific climatological and physiographic characteristics of individual watersheds, agricultural and urban land uses can exhibit a wide range of variability in nutrient export (Beaulac and Reckhow 1982).

To understand and control urban runoff pollution, The U.S. Congress included the establishment of the Nationwide Urban Runoff Program (NURP) in the 1977 Amendments of the Clean Water Act (PL 95-217). The U.S. Environmental Protection Agency developed the NURP to expand the state knowledge of urban runoff pollution by applying research projects and instituting data collection in selected urban areas throughout the country.

In 1983, the U.S. Environmental Protection Agency (U.S. EPA, 1983) published the results of the NURP, which nationally characterizes urban runoff for 10 standard water quality pollutants, based on data from 2,300 station-storms at 81 urban sites in 28 metropolitan areas.

Two important conclusions from NURP investigations:

- The variance of the EMCs when data from sites are grouped by land use type or geographic region is so great that difference in measures of central tendency among groups statistically are not significant;

- Statistically, the entire sample of EMCs, and the medians of all EMCs among sites, are lognormally distributed.

Thus the numbers in Table 3 do not distinguish between different urban land use types.

Subsequently, the USGS created another urban stormwater runoff base (Driver et al. 1985), based on data measured through mid-1980s for over 1,100 stations at 97 urban sites located in 21 metropolitan areas. Additionally, many major cities in the United States

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collected urban runoff quality data as part of the application requirements for stormwater discharge permits under the National Pollutant Discharge Elimination System (NPDES). The NPDES data are from over 30 cities and more than 800 station-storms for over 150 paramaters (Smullen et al, 1999).

The data from the three sources (NURP, USGS and NPDES) were used to compute new estimates of EMC population means and medians for the 10 pollutants with many more degrees of freedom than were available to the NURP investigators (Smullen et al, 1999). A "pooled" mean was calculated representing the mean of the total population of sample data. The NURP and pooled mean EMCs for the 10 constitutes are listed in Table 3 (Smullen et al, 1999). NURP or pooled mean EMCs were selected because they are based on field data collected from thousands of storm events. These estimates are based on nationwide data, however, so they do not account for regional variation in soil types, climate, and other factors.

Table 3. National pooled EMCs and NURP EMCs

Constituent	Data source[a]	EMCs		No. of events
		Mean	Median	
Total suspended solids: TSS	Pooled	78.4	54.5	3047
	NURP	17.4	113	2000
Biochemical oxygen demand: BOD_5	Pooled[b]	14.1	11.5	1035
	NURP	10.4	8.39	474
Chemical oxygen demand: COD	Pooled	52.8	44.7	2639
	NURP	66.1	55	1538
Total phosphorus: TP	Pooled	0.315	0.259	3094
	NURP	0.337	0.266	1902
Soluble phosphorus: soluble P	Pooled[c]	0.129	0.103	1091
	NURP	0.1	0.078	767
Total Kjeldhal nitrogen: TKN	Pooled	1.73	1.47	2693
	NURP	1.67	1.41	1601
Nitrite and nitrate: NO_2 and NO_3	Pooled	0.658	0.533	2016
	NURP	0.837	0.666	1234

Constituent	Data source[a]	EMCs		No. of events
		Mean	Median	
Copper: Cu	Pooled	13.5	11.1	1657
	NURP	66.6	54.8	849
Lead: Pb	Pooled	67.5	50.7	2713
	NURP	175	131	1579
Zinc: Zn	Pooled	162	129	2234
	NURP	176	140	1281

[a]Polled data sources include: NURP, USGS, NPDES

[b]No BOD_5 data available in the USGS dataset; pooled includes NURP+NPDES

[c]No TS data available in NPDES dataset; pooled includes NURP+USGS

For Hydro, the pooled median and mean EMC value for each pollutant (Table 3) were applied to the runoff regenerated from pervious and impervious surface flow, not the base flow values, to estimate effects on pollutant load across the entire modeling time frame. All rain events are treated equally using the EMC value, which means some events may be overestimated and others underestimated. In addition, local management actions (e.g., street sweeping) can affect these values. However, across the entire season, if the EMC value is representative of the watershed, the estimate of cumulative effects on water quality should be relatively accurate. Accuracy of pollution estimates will be increased by using locally derived coefficients. It is not known how well the national EMC values represent local conditions.

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