

Modelling of Carbon Storage and sequestration using the InVEST model: A step by step guide for the Little River Watershed, Brazos River Basin, Texas.

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Note: This guide describes the steps taken using InVEST version 3.7.0 for Windows 10.
A copy of this guide can be downloaded from <https://hydrologicmodels.tamu.edu/>

1. Introduction

Carbon in the terrestrial biosphere is stored in living and dead organic matter above and below the ground. Annually, plants remove approximately one-fifth of the carbon present in the atmosphere (Keenan and Williams, 2018) through photosynthesis, converting it into short-liveable pools such as in leaves and humus, to long-lived pools in soils. Managing landscapes for carbon storage and sequestration requires information about how much and where carbon is stored, how much carbon is sequestered or lost over time, and how shifts in land use affect the amount of carbon stored and sequestered over time (Sharp et al., 2018). This information can guide the decision-making processes during the selection of sites for conservation, restoration and other decisions that influence ecosystem services.

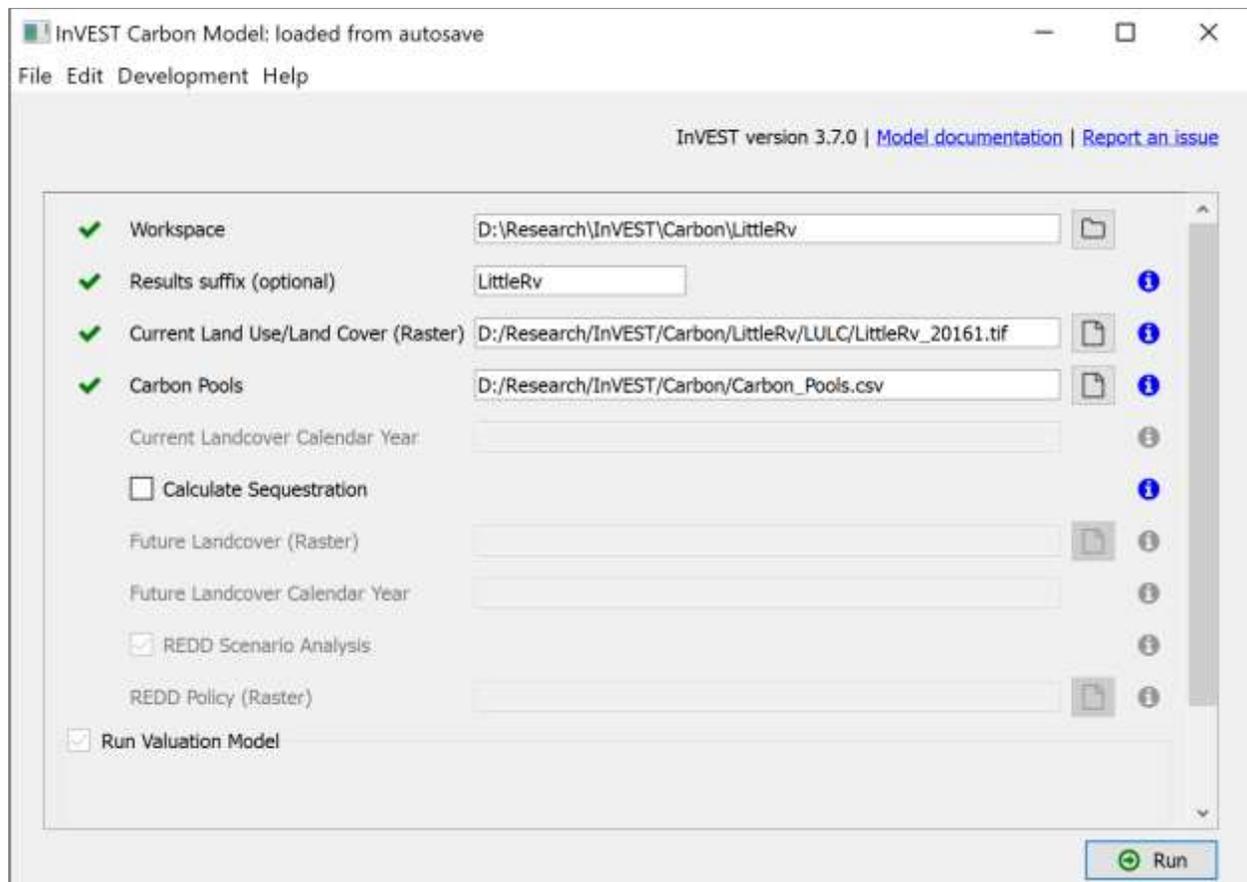
The Integrated Valuation of Ecosystem Services and Tradeoffs- Carbon Sequestration and Storage (InVEST-CCS) (R. Sharp et al., 2018) module can estimate the total carbon stored in the landscape by aggregating carbon in the above and below-ground biomass, dead organic matter and soil sinks. Aboveground biomass comprises all living plant material above the soil (e.g., bark, trunks, branches, leaves). Belowground biomass encompasses the living root systems of aboveground biomass. Soil organic matter is the organic component of soil and represents the largest terrestrial carbon pool. Dead organic matter includes litter as well as lying and standing deadwood. Using maps of land use and land cover types and the amount of carbon stored in carbon pools, this model estimates the net amount of carbon stored in a land parcel over time. The model maps carbon storage densities to land use/land cover (LULC) maps and generates raster outputs of storage, sequestration as well as aggregate totals, expressed as Mg of carbon per pixel. If a current and future LULC map are provided, then the net change in carbon storage over time (sequestration or loss) can be calculated.

2. Getting started. Model Installation

The InVEST model was developed by Stanford University, the Chinese Academy of Sciences, the University of Minnesota, The Nature Conservancy, and the World Wildlife Fund under the Natural Capital Project. The InVEST model can be downloaded using the link <https://naturalcapitalproject.stanford.edu/invest/>. You need to download the software (preferably the latest version) compatible with your operating system (Windows or Mac). Once the download is completed, click the downloaded setup file to install the software. You may install all the accompanying datasets although the storage requirements will be greater (4GB). When the installation is complete, the downloaded datasets, user manual and other folders and files are automatically downloaded to the installation folder. The executing file for each of the ecosystem services can be found under the start menu.

3. Running the model

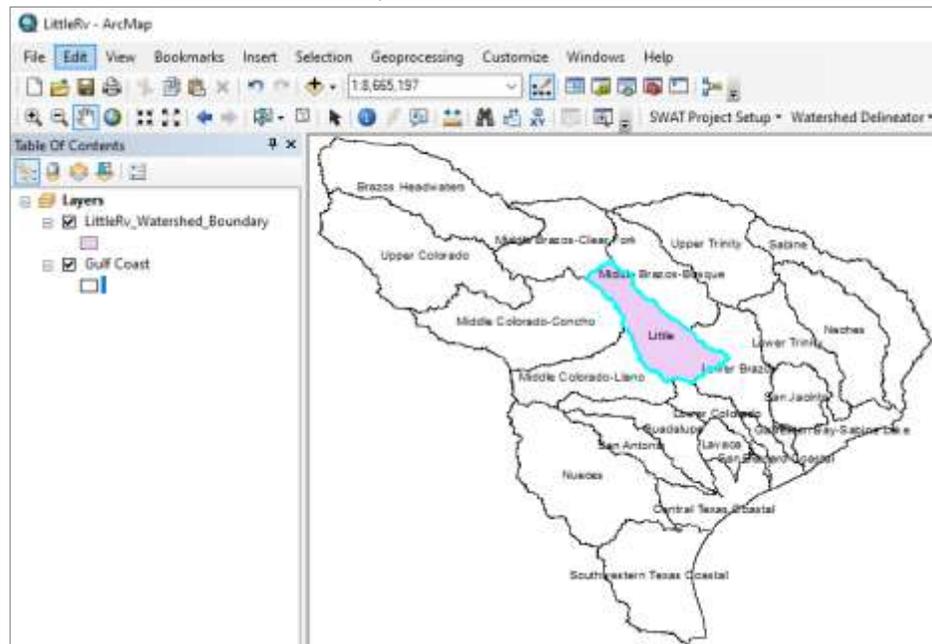
Click on “Carbon app” under the start menu to activate the carbon modelling interface. Specify / input data as described in the proceeding section. If the correct format is selected, a green tick mark will appear.



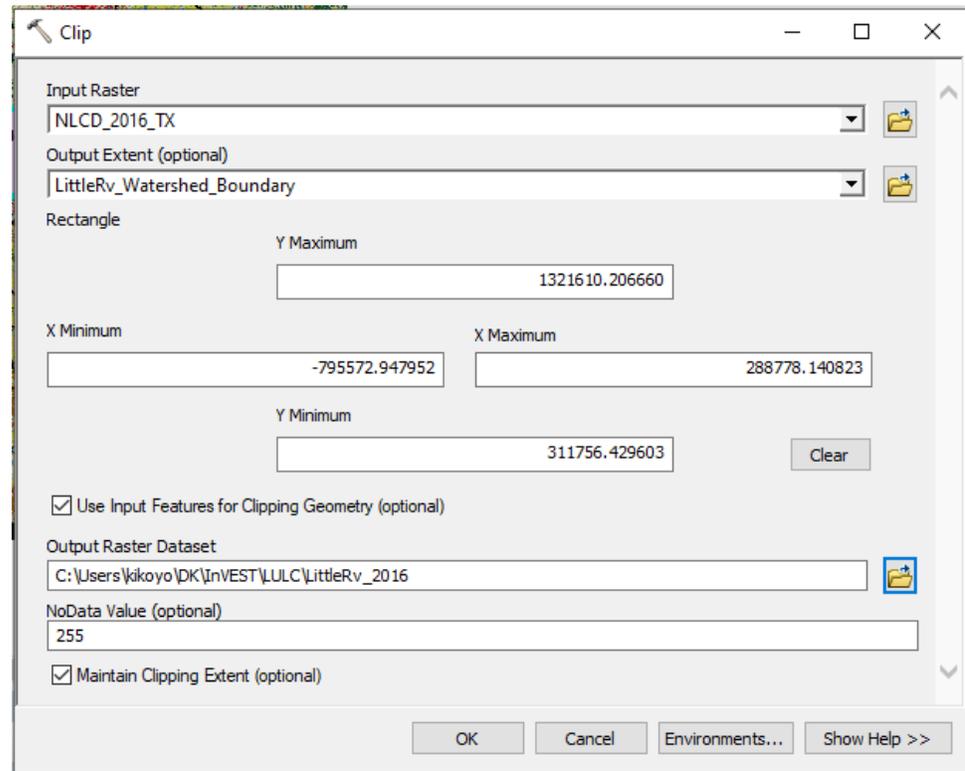
4. Inputting required data.

- i. Select your preferred workspace (can be different from the installation folder). This is where your output files will be stored. In this exercise, the workspace is under this directory *D:\Research\InVEST\Carbon\TX*
- ii. Specify a string that will be added to the end of the output file paths for easily identifying different projects. (*LittleRv*)
- iii. The next step requires you to specify the directory for the land use / landcover (LULC) scenario raster being studied. Ideally, this map should be prepared in advance since it may need to be projected and clipped from a larger LULC raster. Detailed LULC maps for the conterminous US can be downloaded from the National Land Cover Database (NLCD) (<https://www.mrlc.gov/data>) which provides nationwide data on land cover and land cover change at a 30m resolution. LULC maps for Texas can also be downloaded from <https://data.tnris.org/>. You need to clip your area of interest from the downloaded map as shown below.
 - o First, you need to get the polygon boundaries (watersheds, states, counties, etc.) of the study area which shall be used to clip for clipping the LULC raster. The polygon boundary itself may need to be clipped from a larger dataset. Since this guide uses watersheds, the USGS Watershed Boundary Dataset (WBD) available at <https://viewer.nationalmap.gov/basic/> is being used. The Little River Watershed in the Brazos basin is located in the HUC 12 Texas Gulf Region. Only the WBD for his region should be downloaded. Note that you may be required to download more than one region if your study area is very large. For instance, when the whole of Texas is needed, both the Texas Gulf, HUC 13 Rio Grande and HUC 11 Arkansas-White-Red regions needed to be downloaded.
Note: You will need a compression software such as 7zip to unzip most of the downloaded data.
 - o You will need GIS for visualisation and editing of both WBD and LULC maps. The same software will also be required to visualise the raster outputs by the InVEST model. Commonly used software include ArcGIS and QGIS. QGIS is open source. Here, we use ArcGIS since it is already installed on the Lab Computers. Click on ArcMap from the start menu. Add the downloaded WBD file. Select the watershed

of interest from the attribute table. Create a layer of the selected file. Rename the file with an appropriate name. In this case, LittleRv Watershed Boundary.



- While still in ArcGIS, Add the raster layer of the downloaded LULC map. Use the clipping tool under “Data management tools-Raster-Raster Processing” to clip the required LULC from the larger LULC map.



- You may decide to re-classify the clipped map or use the map as-is. Save the clipped LUC map in your working folder and close ArcGIS. The LULC map is ready for use in InVEST.

- iv. Specify the location of the table that maps the LULC IDs to carbon pools. The values of carbon in the different carbon pools can be got from literature or experimentally determined. The table, in .csv format, should look like the one below.

C_above	C_below	C_soil	C_dead	lucode	LULC_Name
0	0	0	0	0	NA
0	0	0	0	11	WATR
15	10	60	1	21	URLD
5	3	20	0	22	URMD
2	1	5	0	23	URHD
0	0	0	0	24	UIDU
1	1	10	0	31	SWRN
80	50	100	25	41	FRSD
90	60	95	29	42	FRSE
90	60	110	30	43	FRST
8	8	25	3	52	RNGB
6	6	20	2	71	RNGE
5	4	25	1	81	HAY
3	2	8	1	82	AGRR
7	3	25	0	90	WETF
10	5	20	0	95	WETN

- v. Skip steps (v) and (vi) if you are only determining carbon storage for one specific period. If comparing scenarios, proceed to (v) and (vi) if you are valuing the carbon sequestered.
- vi. The model can determine the carbon sequestered by calculating the gain / loss in carbon stored between two periods by inputting LULC maps for the same area at different time periods. If this scenario analysis is of interest, prepare both maps (current and future) as described in (iv) and input them into the model by specifying their location.
- vii. Clicking on the ‘calculate sequestration’ also activates ‘Run valuation Model’. If the market prices and discount rates of carbon are known, they can be input so that the model calculates the monetary value of sequestered carbon between two scenarios.
- viii. Run the model and close the program.

5. Interpreting model results.

The results are in the model’s workspace specified in 4(i). the file names include the suffix defined in 4(ii). The workspace includes the following files;

- i. parameter log: a .txt file listing the parameter values and output messages for that run.
- ii. report_[Suffix].html: includes descriptions of output files produced and a summary of the data computed.
- iii. tot_c_cur_[Suffix].tif/tot_c_fut_[Suffix].tif/tot_c_redd_[Suffix].tif: Raster maps with carbon stored in Mg in each pixel for the current, future and REDD scenarios.
- iv. delta_cur_fut_[Suffix].tif/delta_cur_redd_[Suffix].tif: Raster maps showing the difference in carbon (Mg per pixel) stored between the future/REDD landscape scenarios and the current landscape. Values can be negative or positive. Positive values indicate sequestered carbon, negative values indicate carbon that was lost.
- v. npv_fut_[Suffix].tif/npv_redd_[Suffix].tif:** Raster maps showing the economic value of carbon sequestered (currency per pixel) between the current and the future/REDD landscape dates.
- vi. An intermediate folder “[Workspace]\intermediate_outputs” that has the following files:
 - a. c_above_[Suffix].tif: Raster of aboveground carbon values
 - b. c_below_[Suffix].tif: Raster of belowground carbon values
 - c. c_dead_[Suffix].tif: Raster of dead carbon values
 - d. c_soil_[Suffix].tif: A raster of soil carbon values

All maps can be visualised and explored in a GIS platform such as ArcGIS or QGIS. A final map classified using ArcGIS is shown in the figure below.

