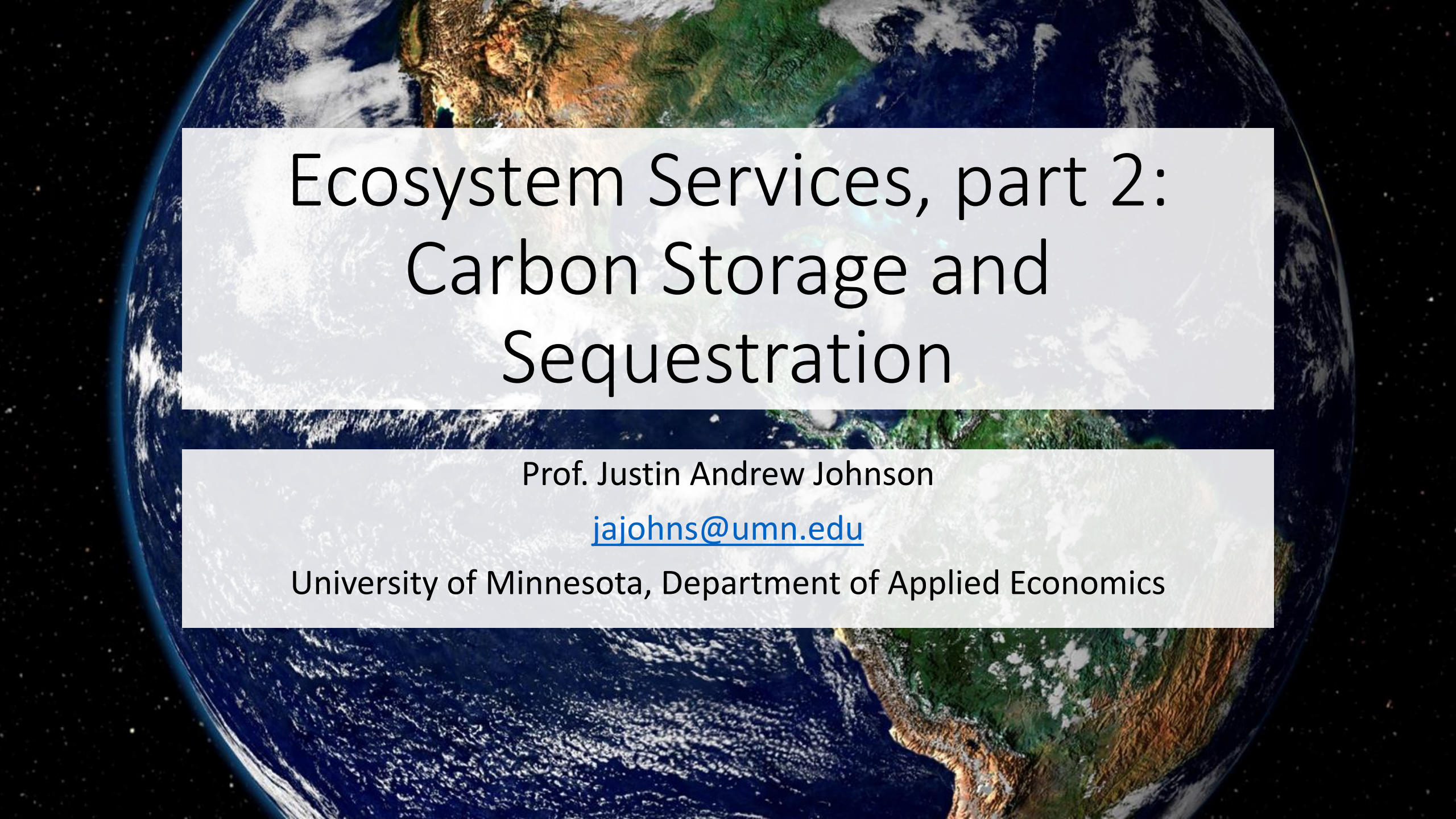

Ecosystem Services, part 2: Carbon Storage and Sequestration

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Agenda

- Introduce the theory behind the carbon model
- Use the carbon model as an easy entry-point for running an InVEST model
- Hands-on exercises with the carbon model and QGIS for visualizing results.
  - Throughout, a bonus goal of this workshop is to give a crash-course in GIS and visualization of results.

InVEST Carbon Storage and Sequestration model

InVEST

integrated valuation of ecosystem services and tradeoffs

natural capital PROJECT

Decision contexts

- How do changes in land use affect carbon storage and sequestration?
    - Carbon markets
    - NDCs (Paris Agreement)
    - Corporate metrics

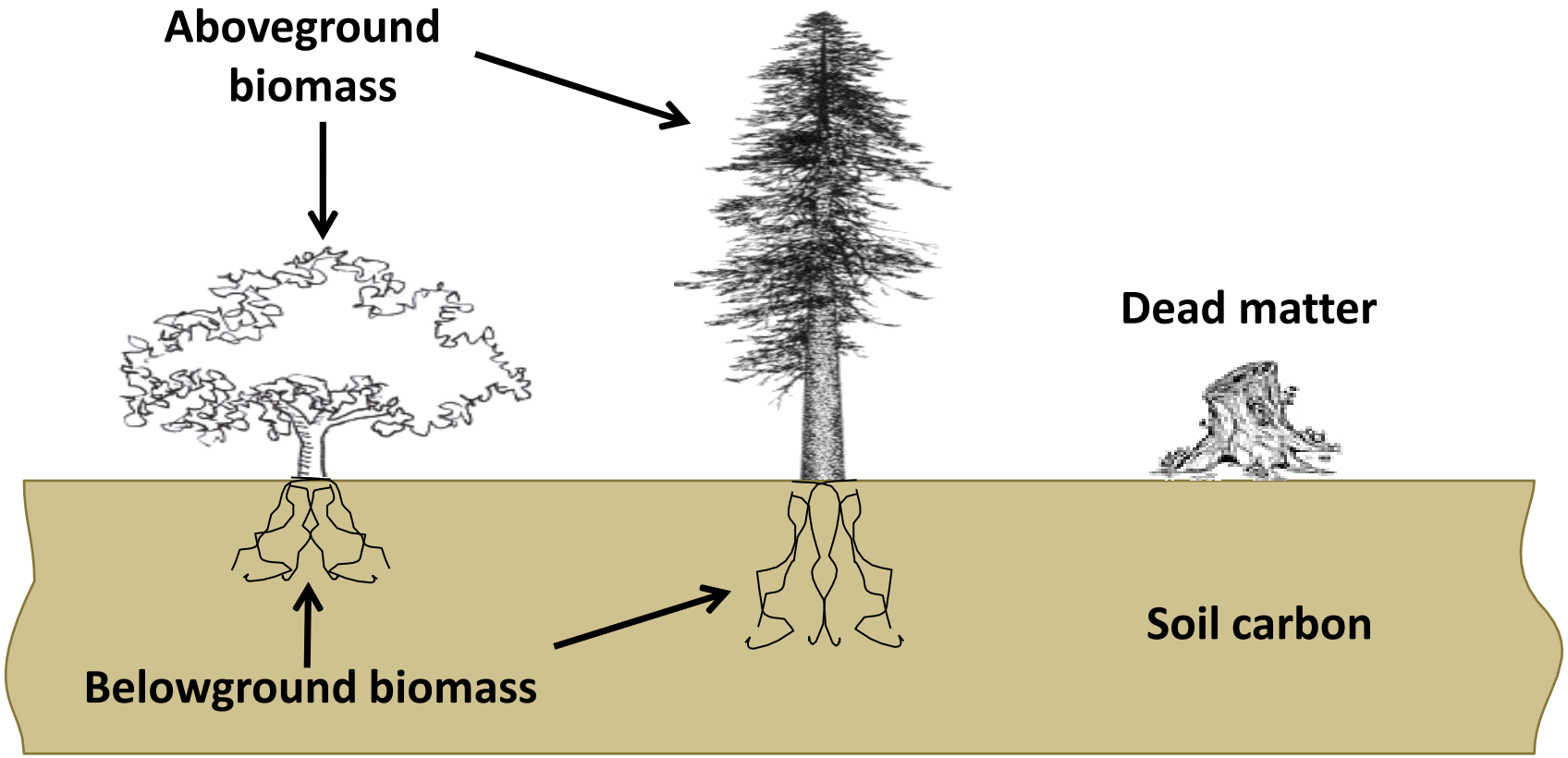
- Target payments for conservation

- Look for overlaps with other ecosystem services (co-benefits)

InVEST Carbon Storage and Sequestration model

- Carbon stock estimated as a function of land use/land cover
- *Storage* indicates the mass of carbon in a landscape at any given point in time
- *Sequestration* indicates the change in carbon storage over time
    - Valuation is only applied to sequestration

Carbon pools



CARBON STORAGE = Sum of all 4 pools

SEQUESTRATION = $storage_{t+1}$ – $storage_t$

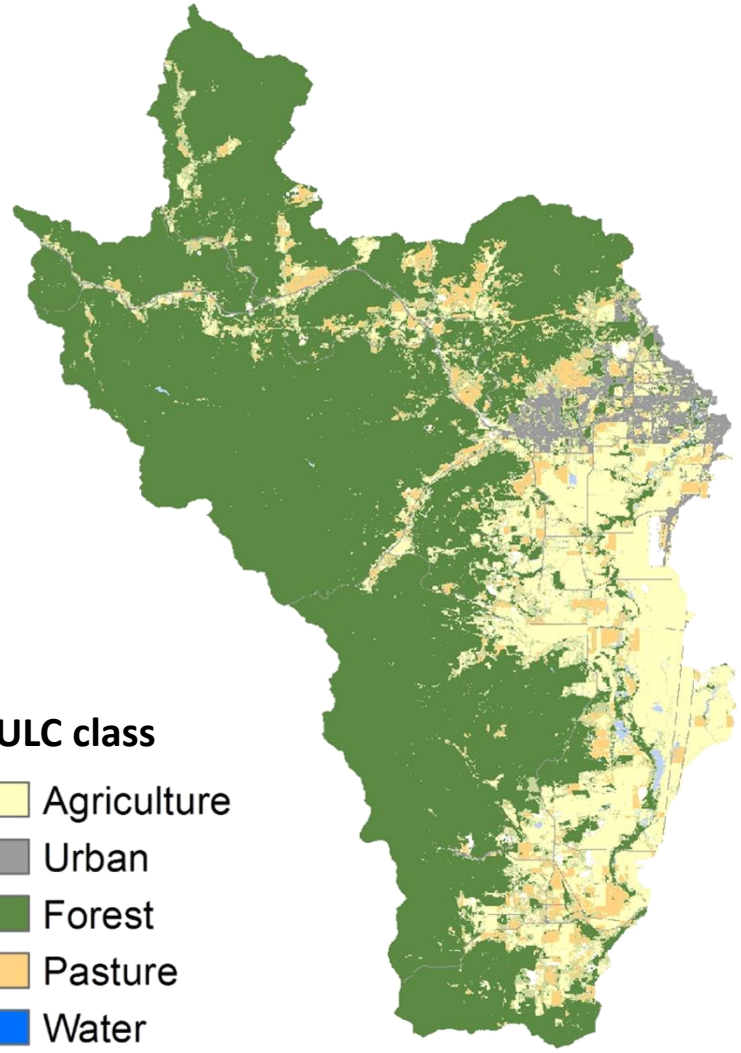
Model inputs

Required:

- Land use / land cover (LULC) map
- Table of the 4 carbon pools
- The model simply assigns the values for each carbon pool to the land-use, land-cover classes present.

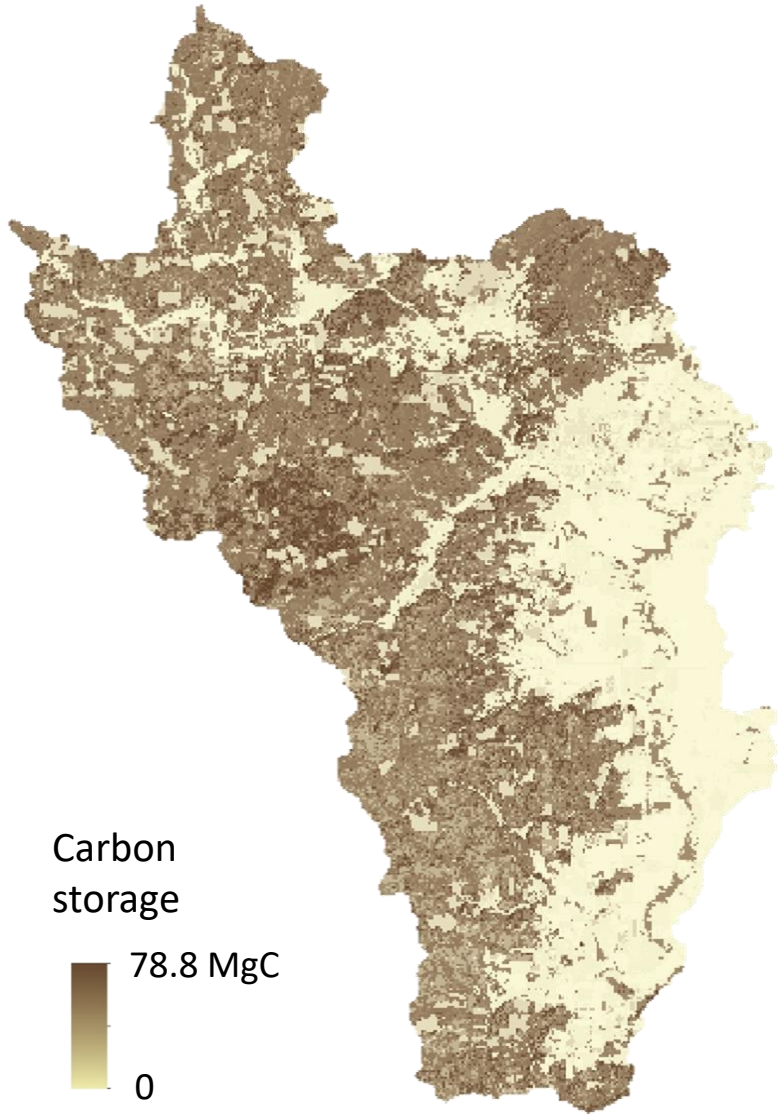
Optional:

- Timber harvest land parcels
- Future land use map
- REDD policy map
- Economic data
- Carbon pool uncertainty data



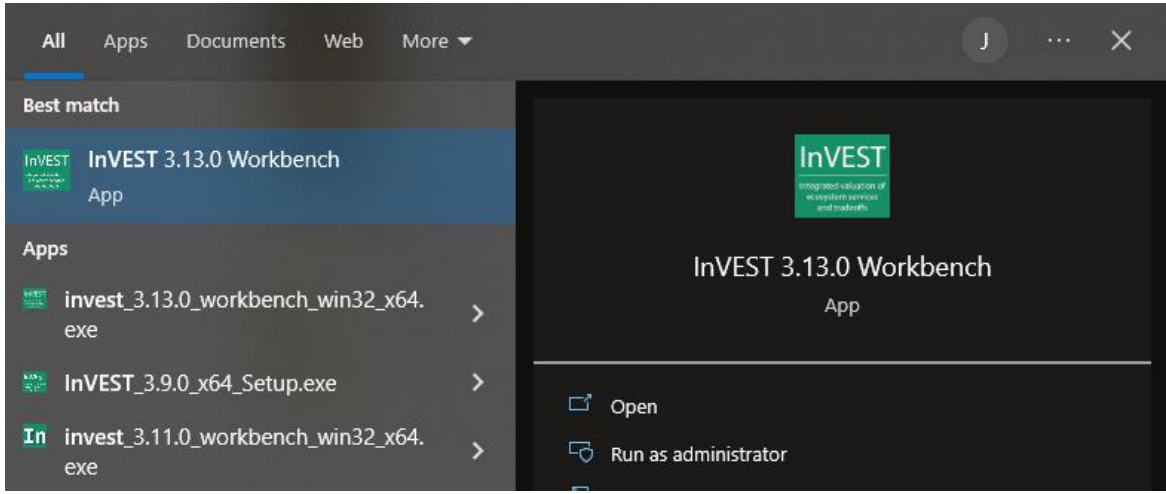
Model outputs

- Current/future carbon storage
- Carbon sequestration
- Sequestration map for REDD scenario
- Economic value of carbon sequestered
- Uncertainty results



Diving into the software

- Hopefully, everyone here has already installed all of the required software
  - InVEST
  - QGIS
- If you haven't, refer back to your invitation and the setup instructions there.
- Assuming you have installed it, open InVEST!
  - Find wherever you installed it, or (on Windows), just press the start button and type "invest"

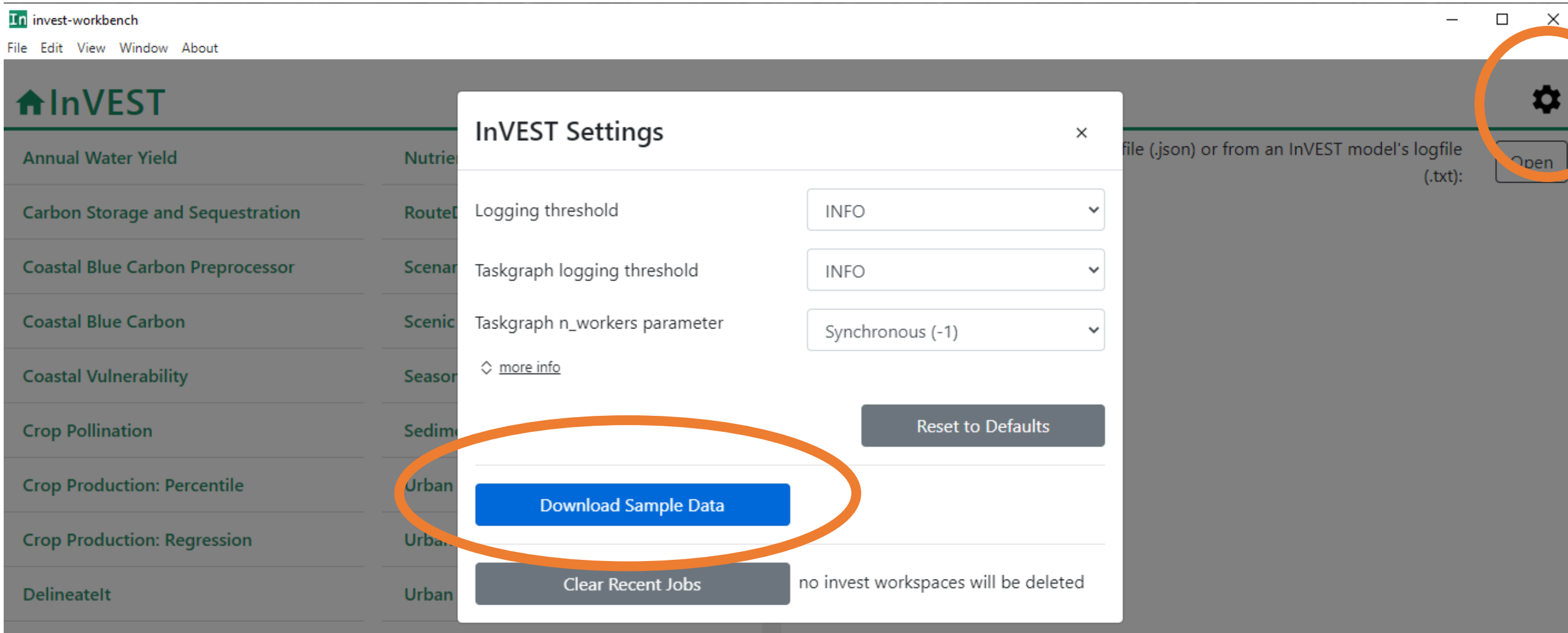


This is the InVEST menu of models/tools

InVEST

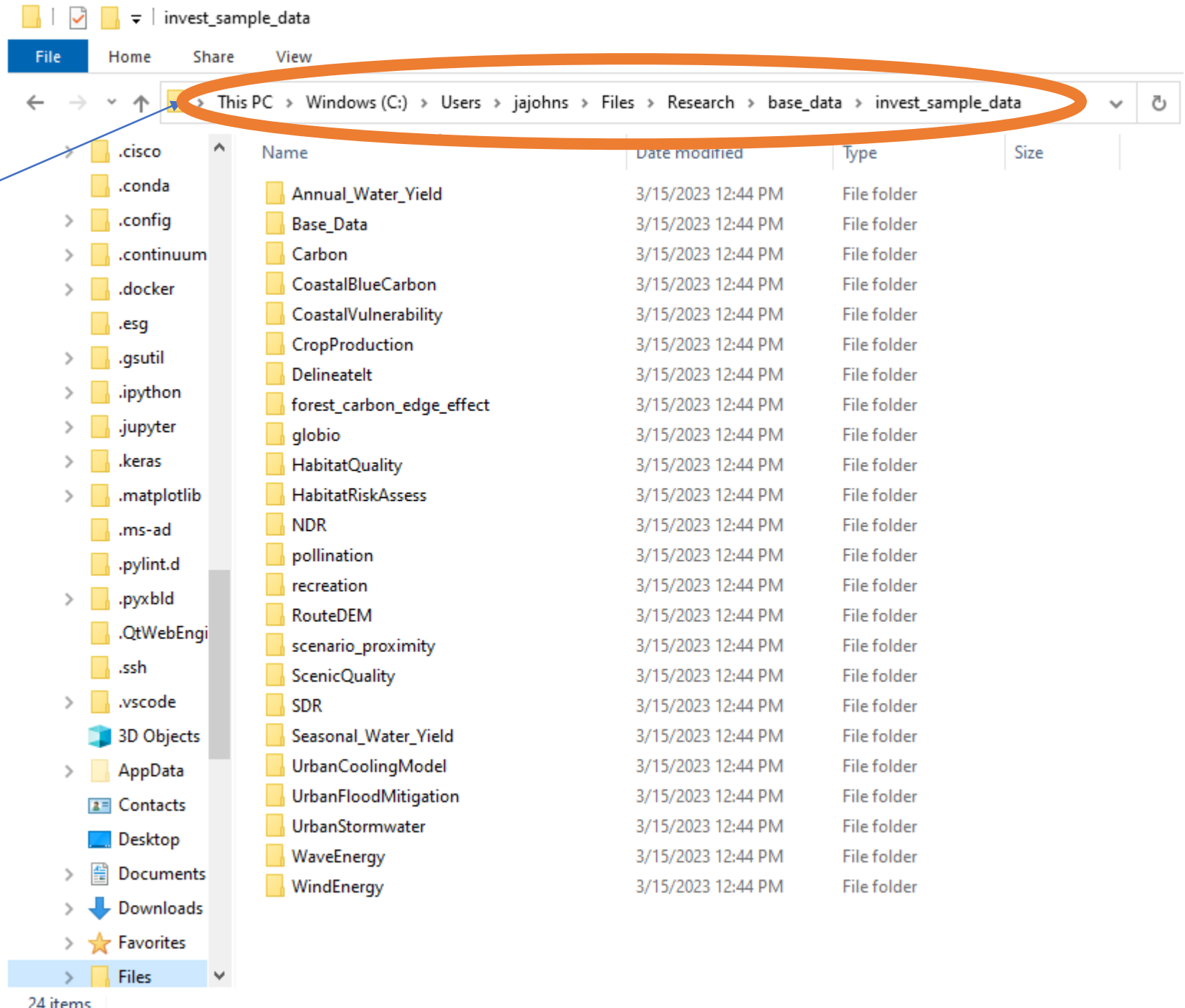
- Annual Water Yield
- Carbon Storage and Sequestration
- Coastal Blue Carbon Preprocessor
- Coastal Blue Carbon
- Coastal Vulnerability
- Crop Pollination
- Crop Production: Percentile
- Crop Production: Regression
- DelineateIt
- Forest Carbon Edge Effect
- GLOBIO
- Habitat Quality
- Habitat Risk Assessment
- Nutrient Delivery Ratio
- RouteDEM
- Scenario Generator: Proximity Based
- Scenic Quality
- Seasonal Water Yield
- Sediment Delivery Ratio
- Urban Cooling
- Urban Flood Risk Mitigation
- Urban Stormwater Retention
- Visitation: Recreation and Tourism
- Wave Energy Production
- Wind Energy Production

Reminder: Download the sample data from the Gear icon.



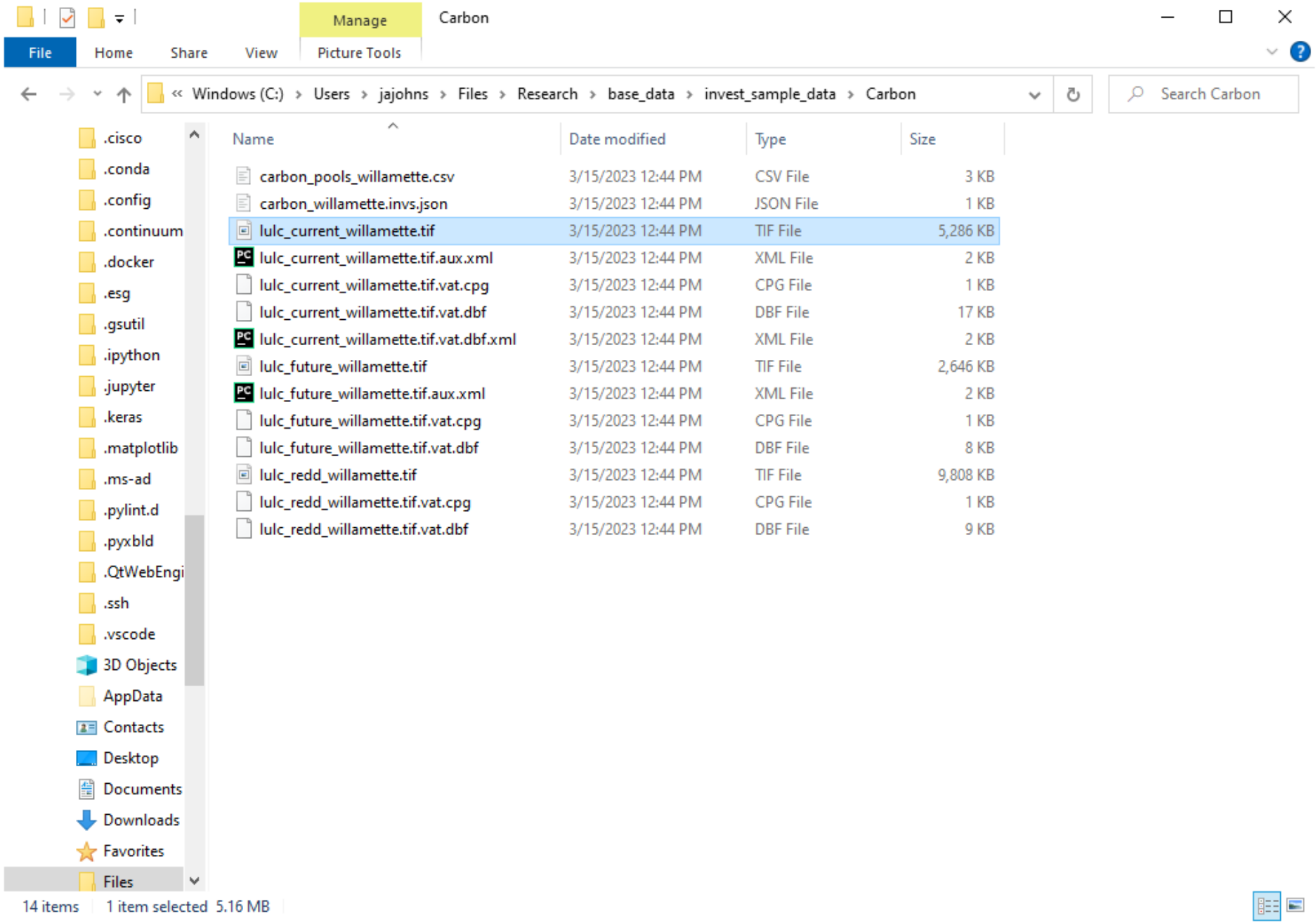
Open the folder where you saved it

Each model has a directory. Open the Carbon Folder.



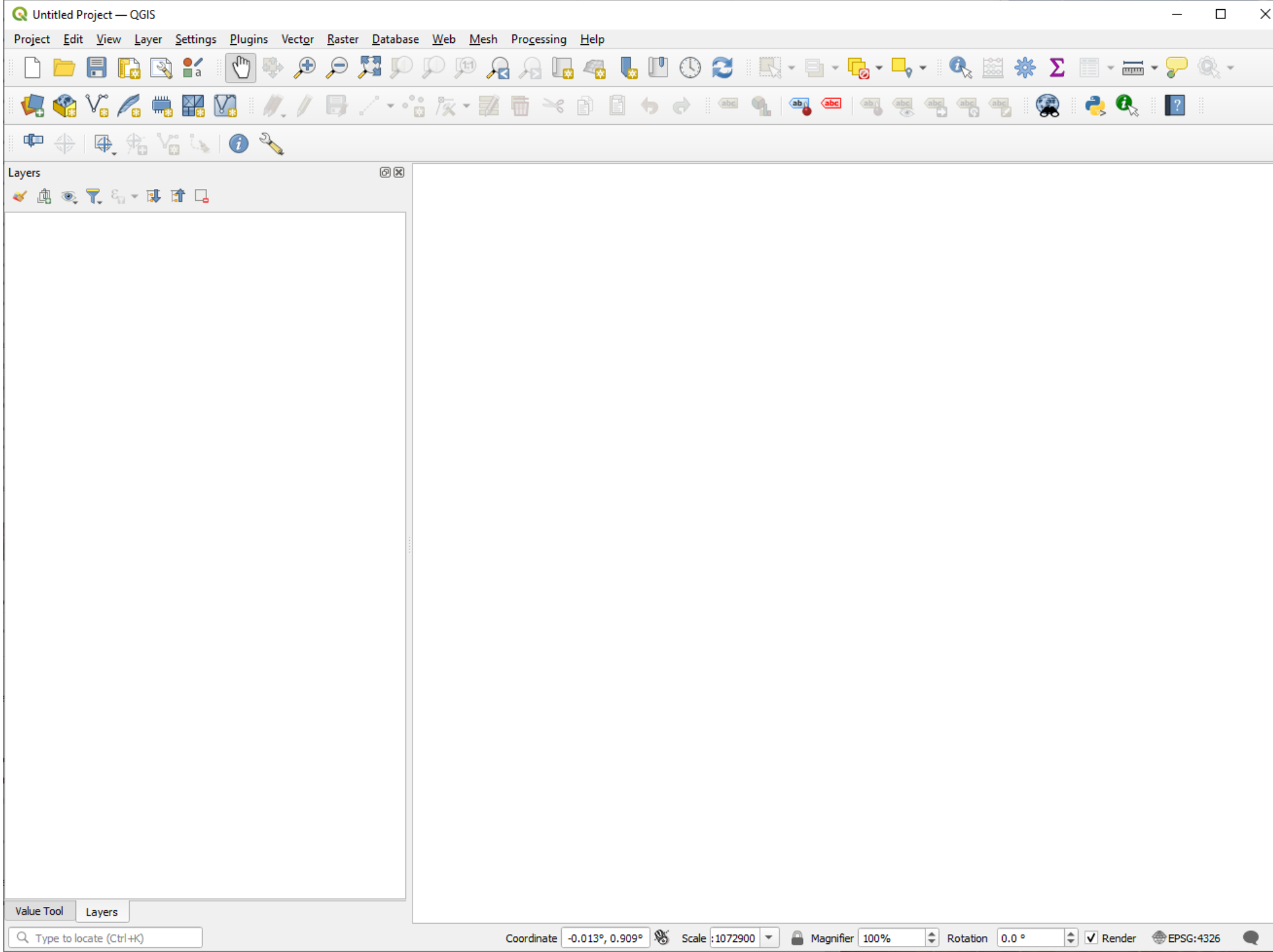
Find the land-use, land-cover file for the current time period

Named “lulc_current_willamette.tif”



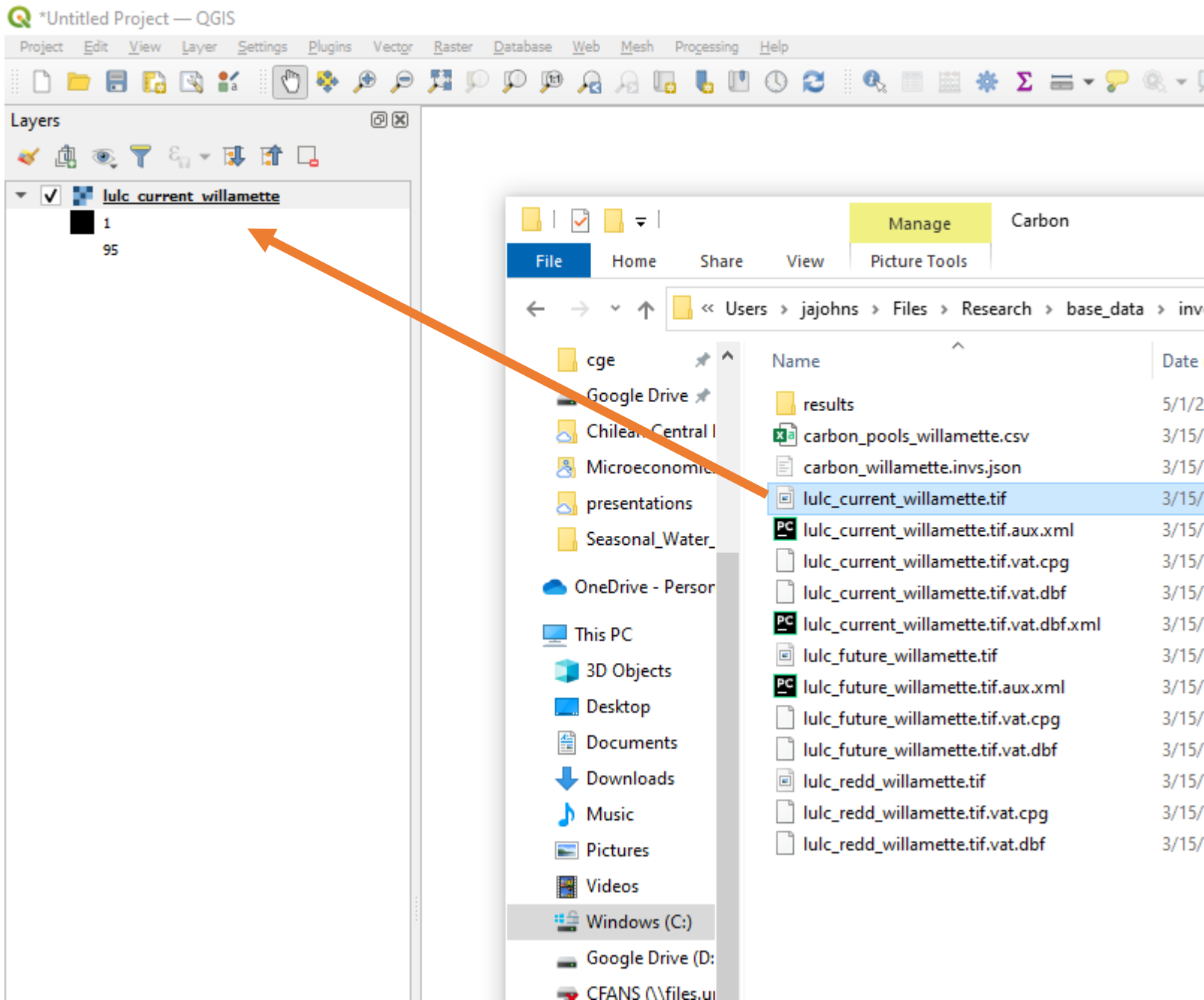
Before we use InVEST, let's take a look at our input data.

- Open QGIS.



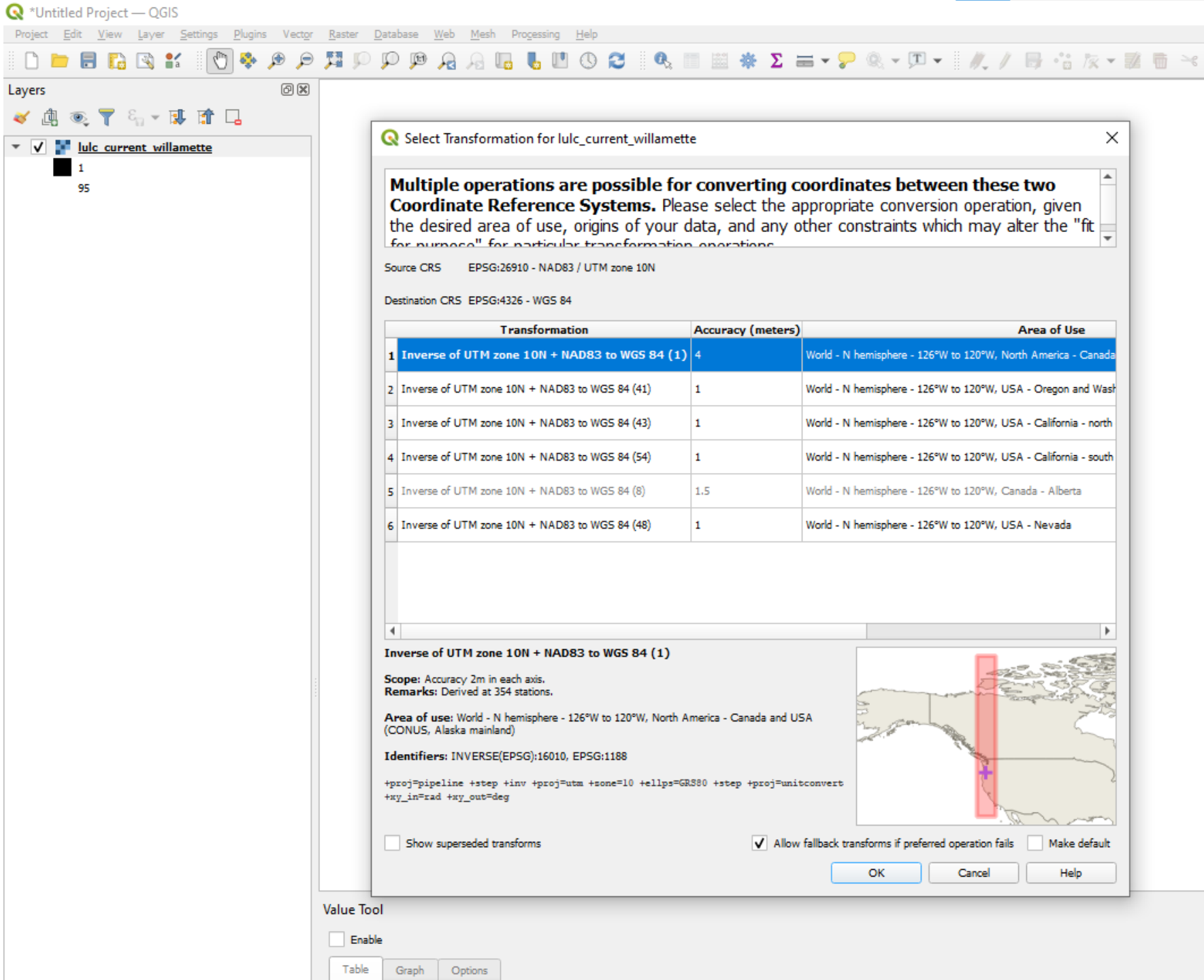
LULC map

- The easiest way to add data is to just drag it from your sample_data folder into QGIS
- Add the lulc_current_willamette.tif file



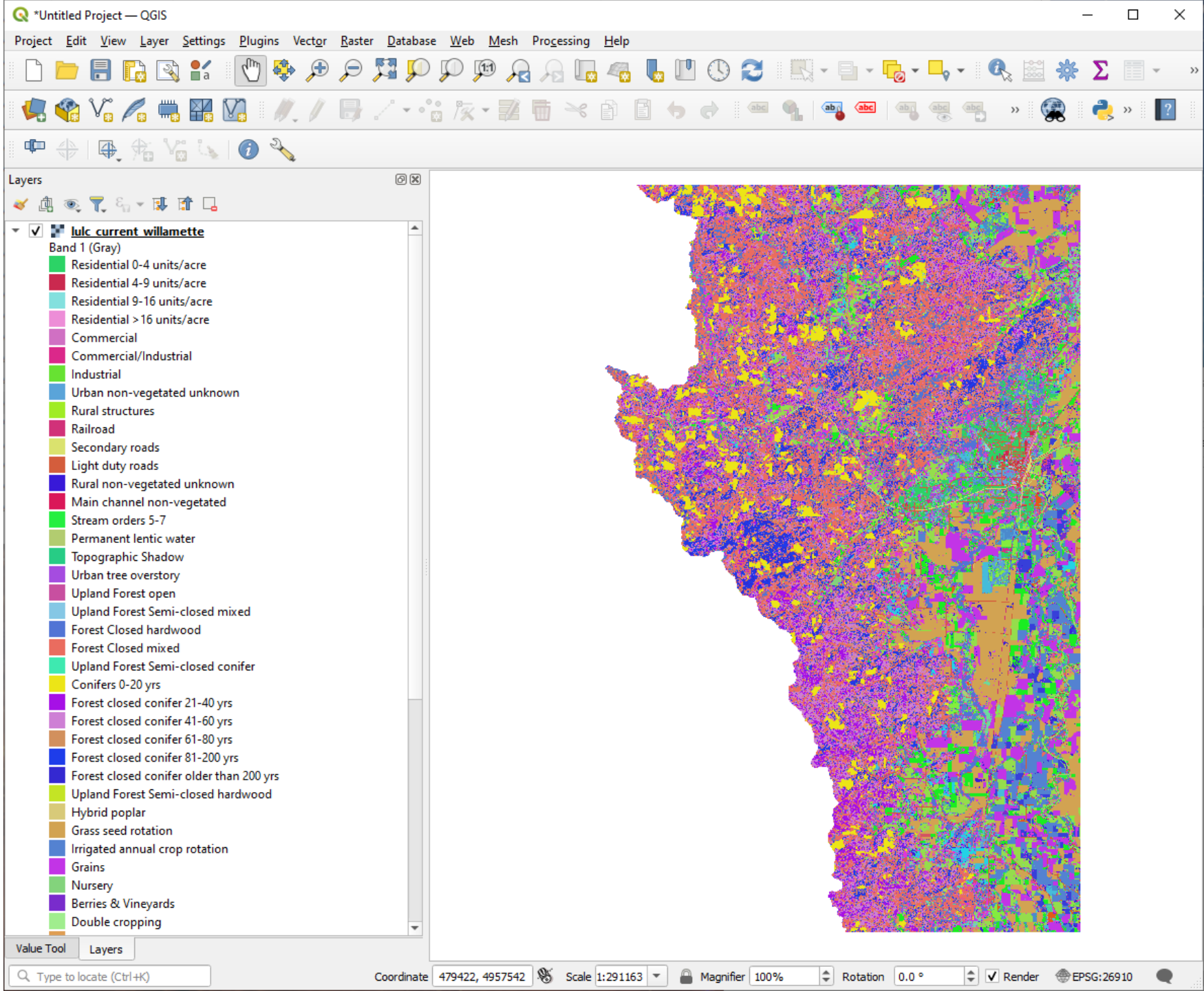
LULC map

- Depending on your QGIS setup, it may ask you about coordinate reference systems
  - This is almost certainly the most time-consuming and annoying part of GIS
- So we're going to ignore it.
  - Just select the top one if this happens.



LULC map

- What is an LULC map?
  - A numeric value (a class) in each grid-cell (pixel)
  - Each class corresponds to some type of land-use/land-cover
- Here I have added a legend to the LULC map

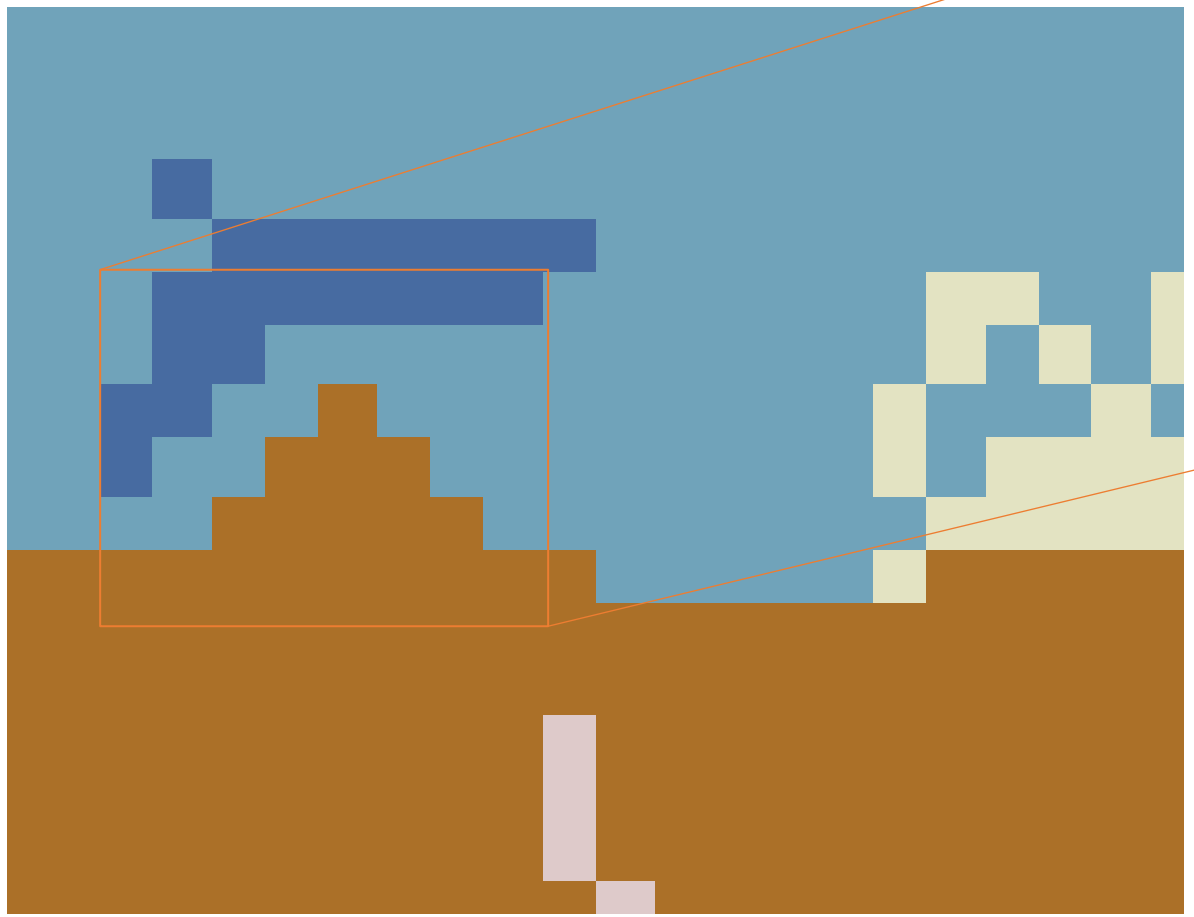


What is a ".tif" file? What is an LULC map?

NLCD Land Cover Classification Legend

- 11 Open Water
- 12 Perennial Ice/ Snow
- 21 Developed, Open Space
- 22 Developed, Low Intensity
- 23 Developed, Medium Intensity
- 24 Developed, High Intensity
- 31 Barren Land (Rock/Sand/Clay)
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest
- 51 Dwarf Scrub*
- 52 Shrub/Scrub
- 71 Grassland/Herbaceous
- 72 Sedge/Herbaceous*
- 73 Lichens*
- 74 Moss*
- 81 Pasture/Hay
- 82 Cultivated Crops
- 90 Woody Wetlands
- 95 Emergent Herbaceous Wetlands

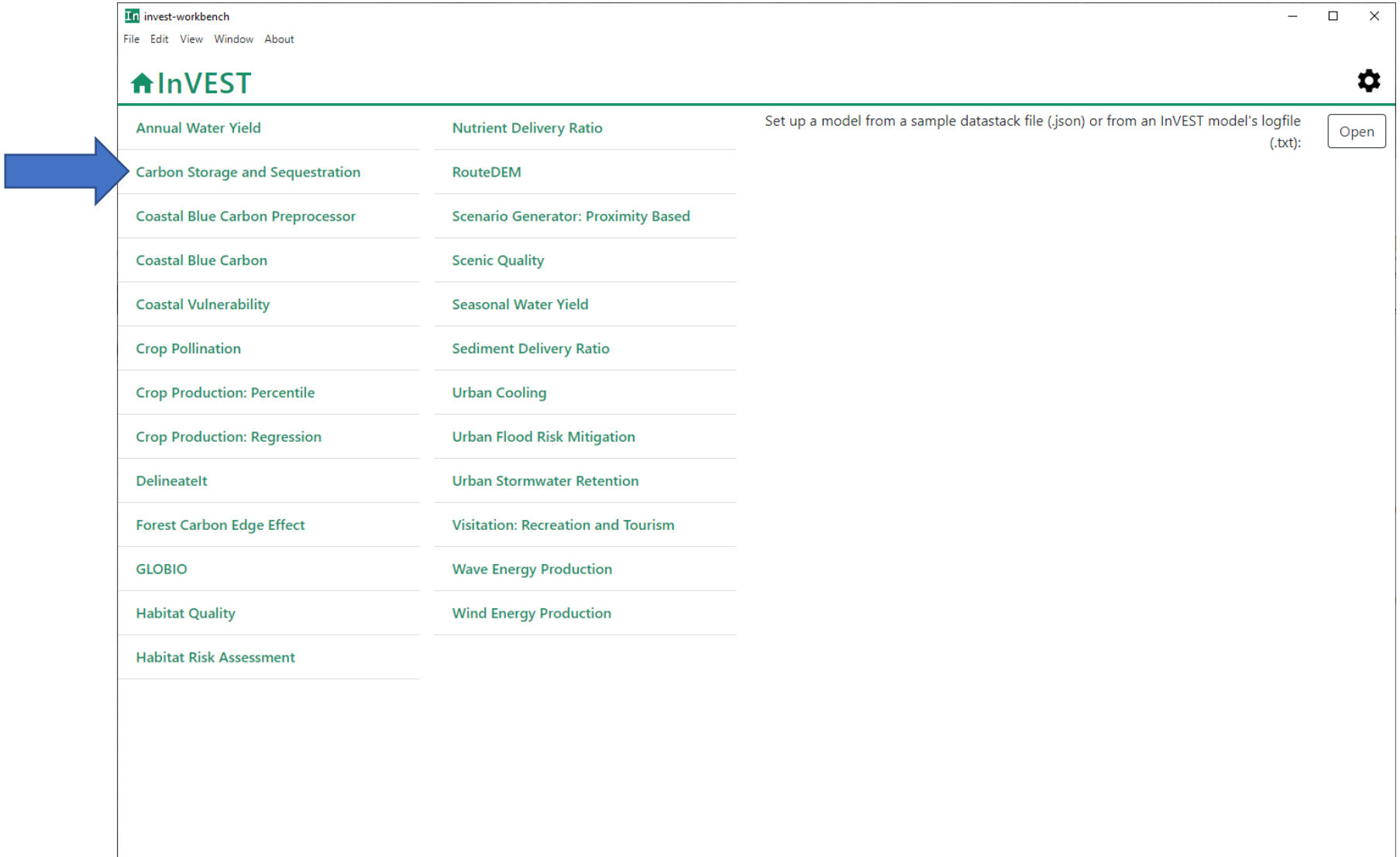
* Alaska only



90	11	11	11	11	11	11	11
90	11	11	90	90	90	90	90
11	11	90	90	82	90	90	90
11	90	90	82	82	82	90	90
90	90	82	82	82	82	82	90
82	82	82	82	82	82	82	82

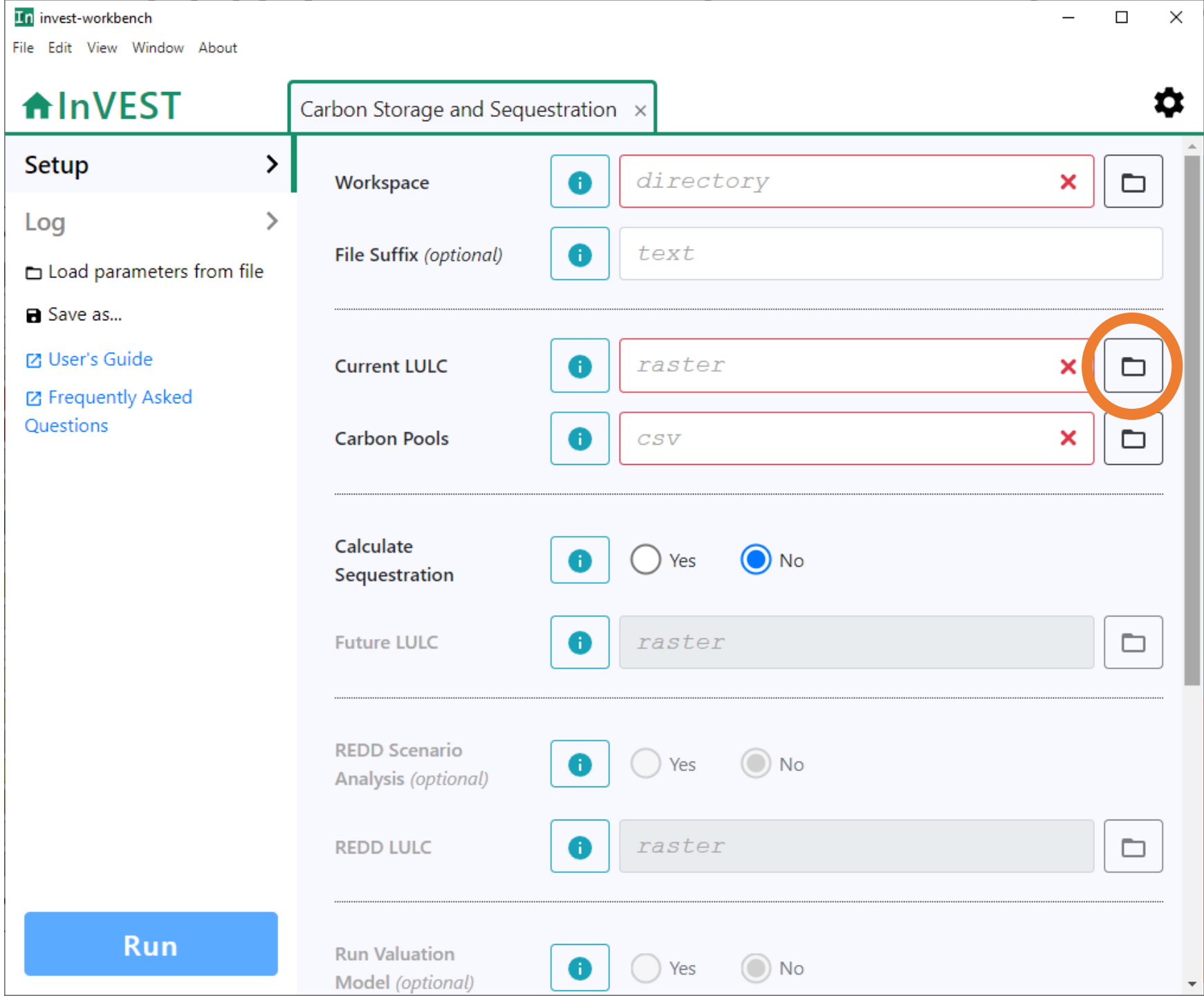
- A .tif file is literally just a 2-dimensional array (matrix) of numbers
- Each number corresponds to a type of land-cover

Open the Carbon Storage and Sequestration Model

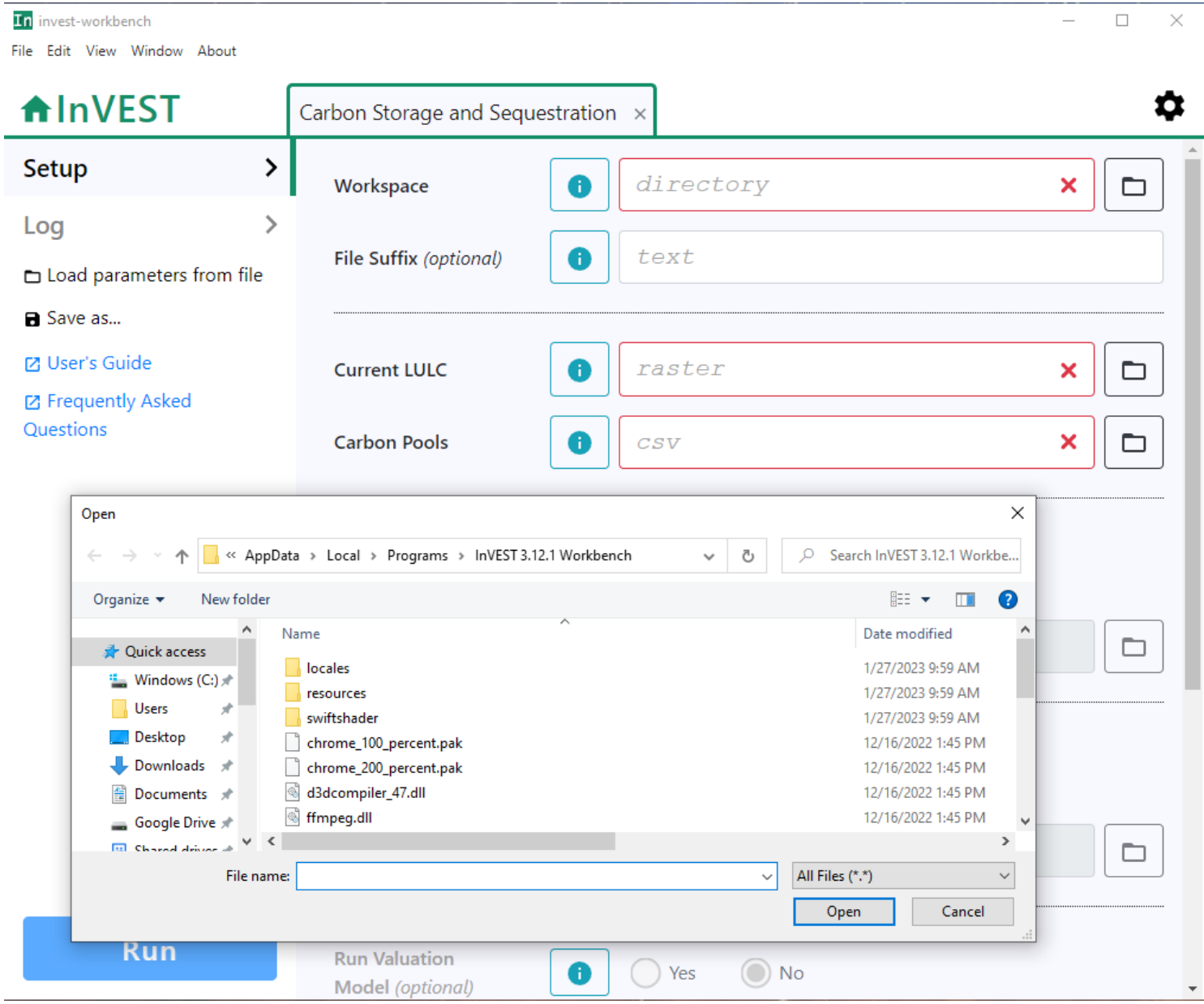


Setup the carbon model

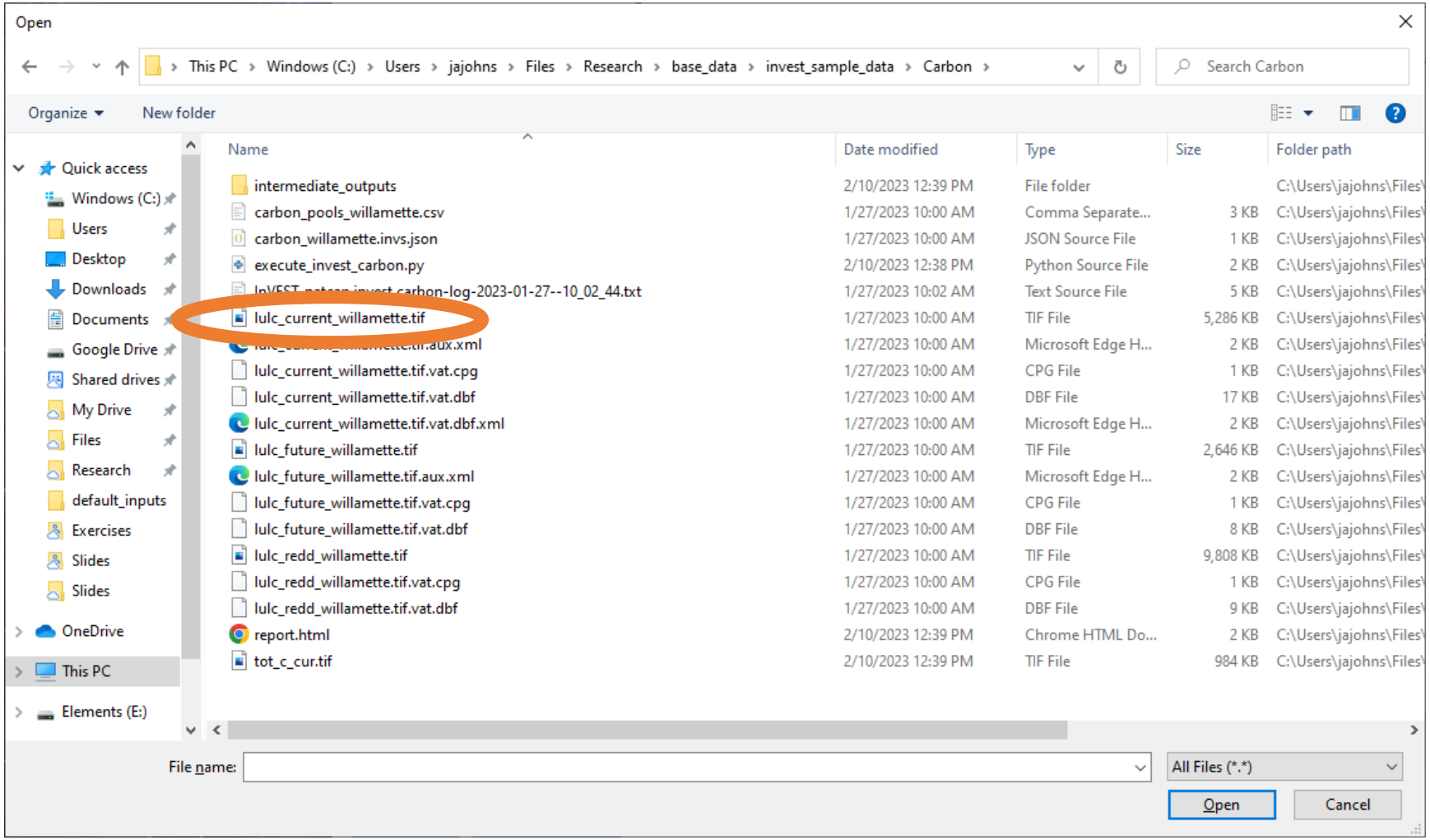
- The first thing we're going to do is point InVEST to the Current LULC map we were just looking at.
  - Click the Open button.



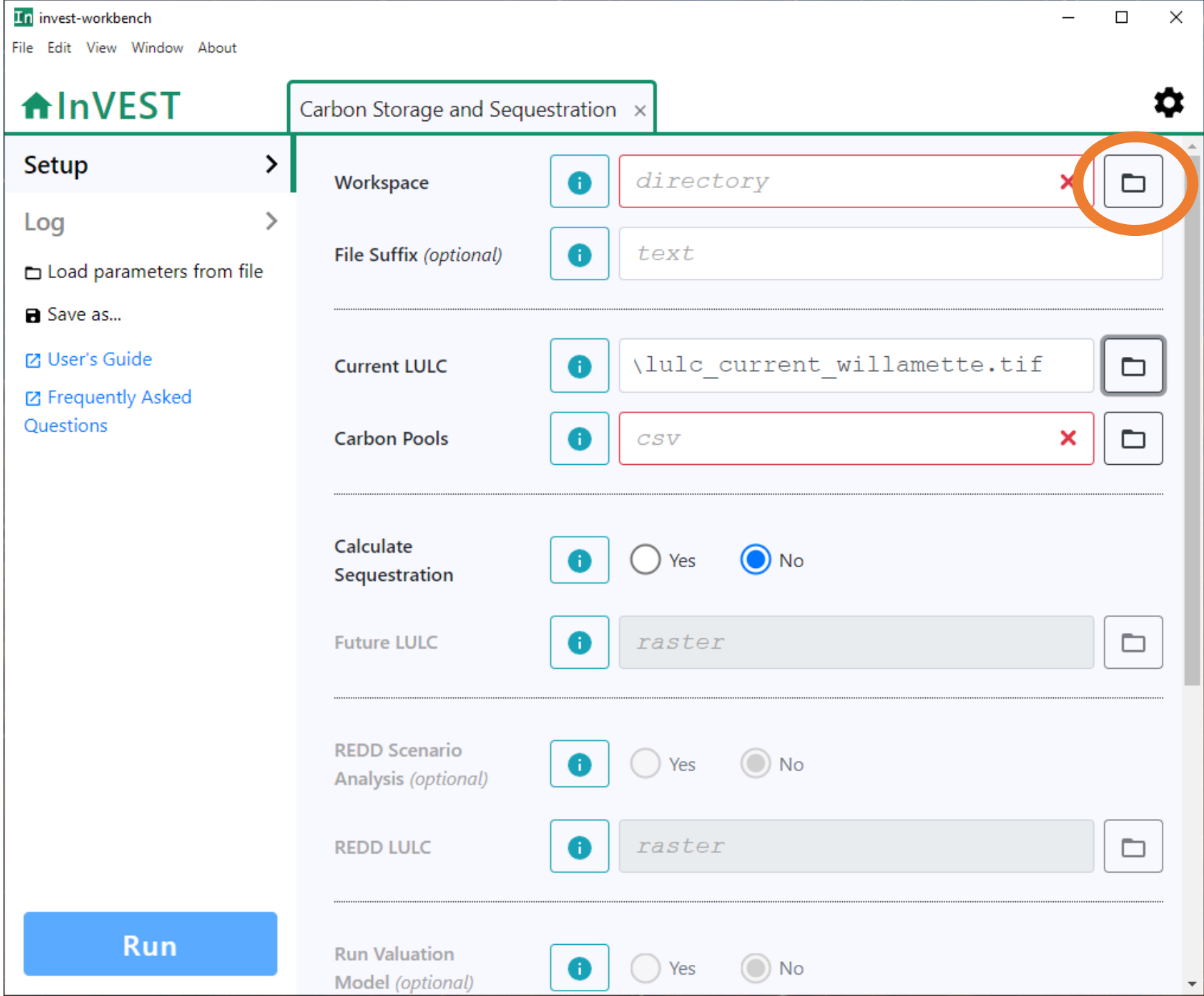
- This will open the folder where you installed InVEST.



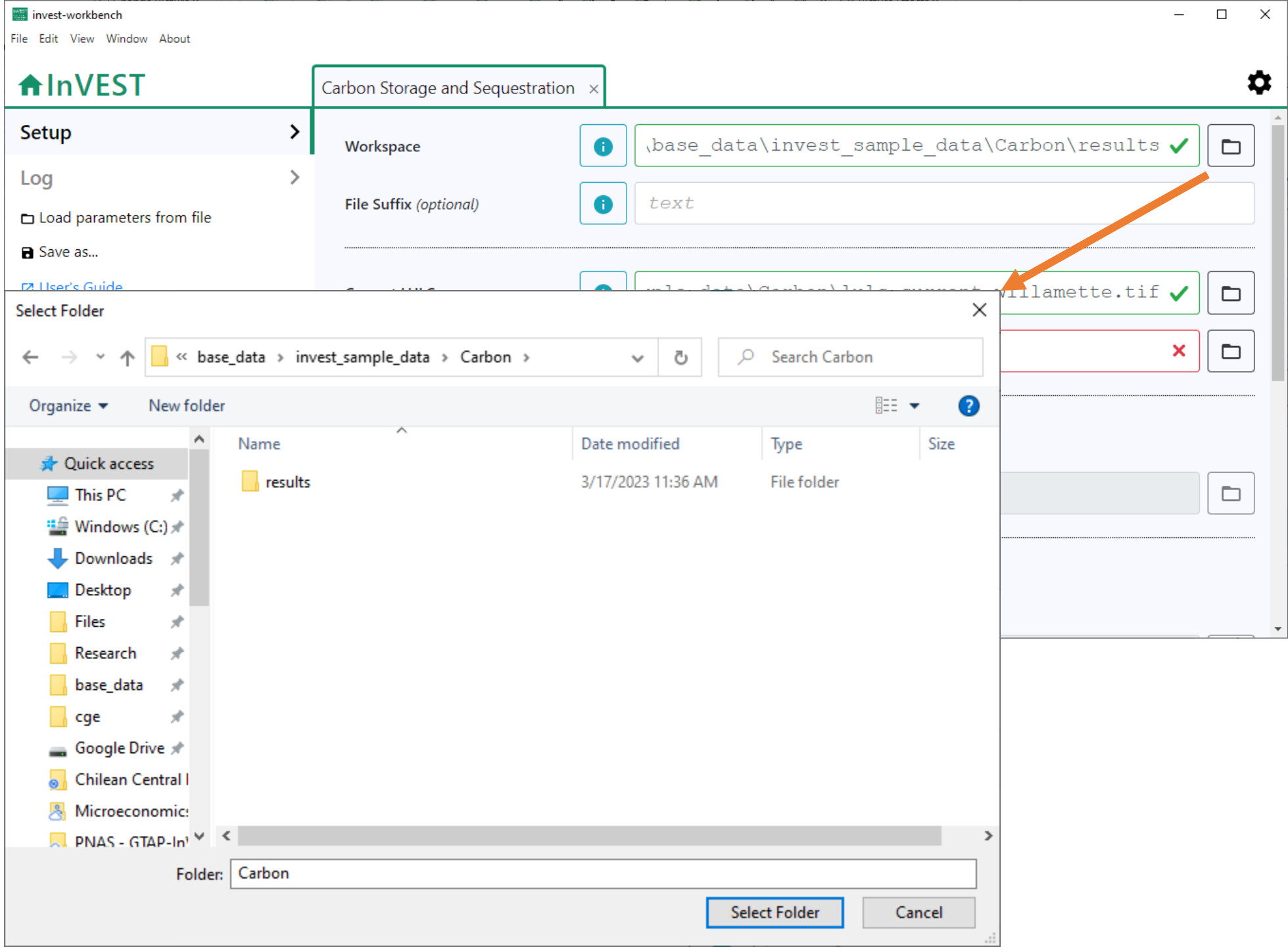
- Navigate to where you downloaded the Sample Data.
- Select the current lulc map.
- Click Open



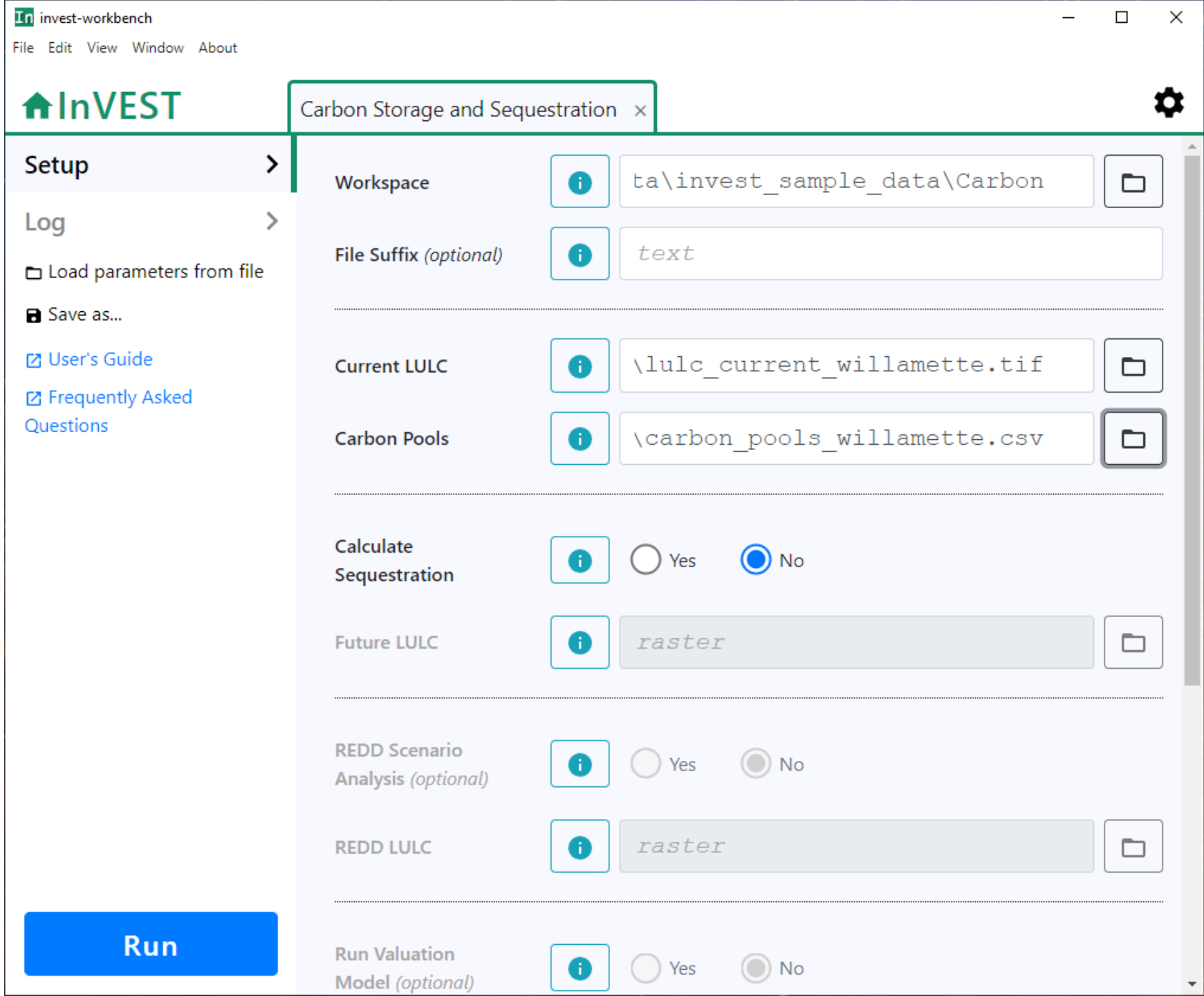
- Now it have the filename entered correctly.
- Next we will specify the “Workspace”.
  - This is where it will save all the output files.
  - Click the Open button for the Workspace.



- Select the Carbon folder we just used.
- Create a new folder called Results in the carbon folder.
- Set this as our Workspace.

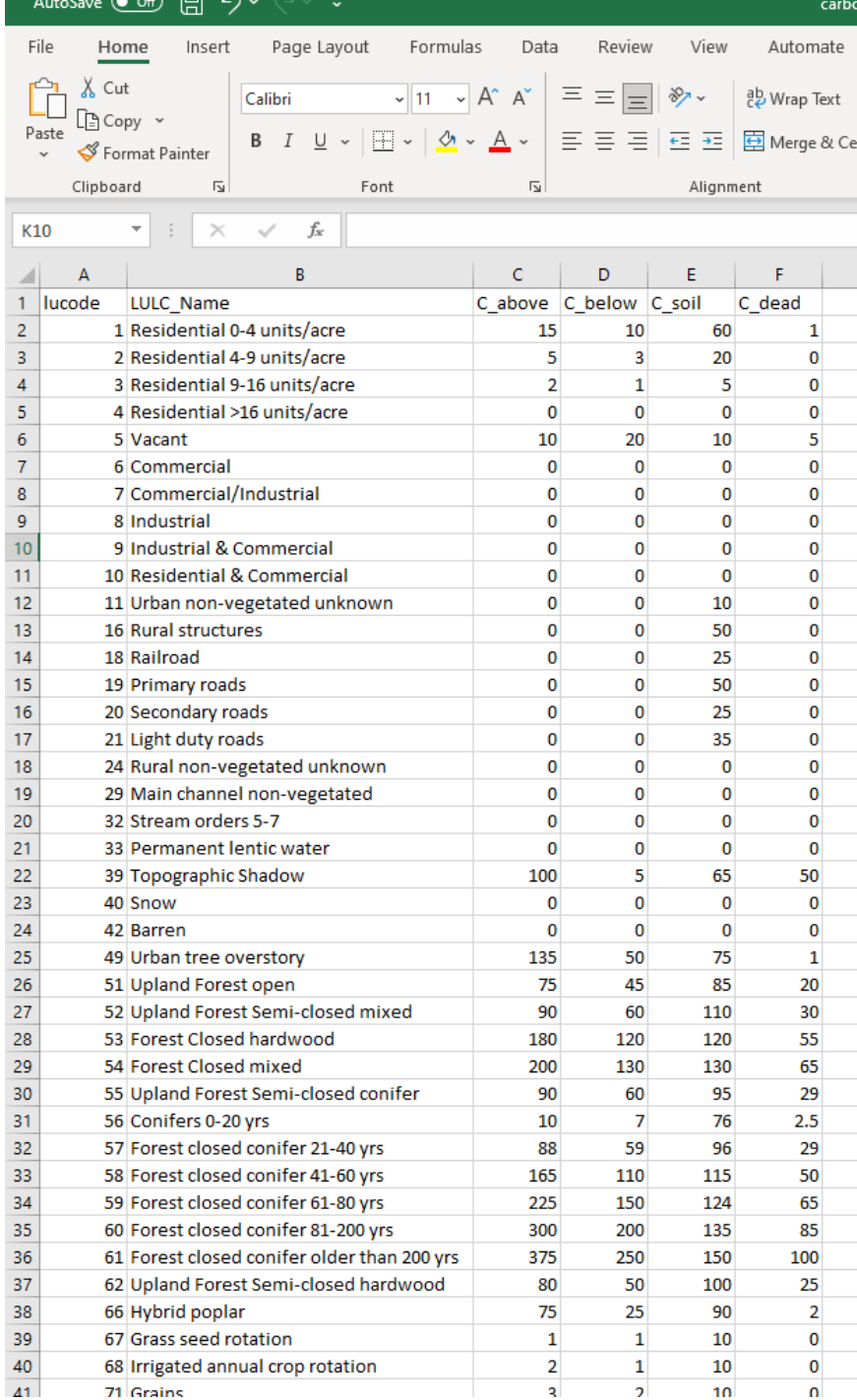


- There is one last file that is required: the carbon pools table.
- Select open for Carbon Pools and select “carbon_pools_willamette.csv”



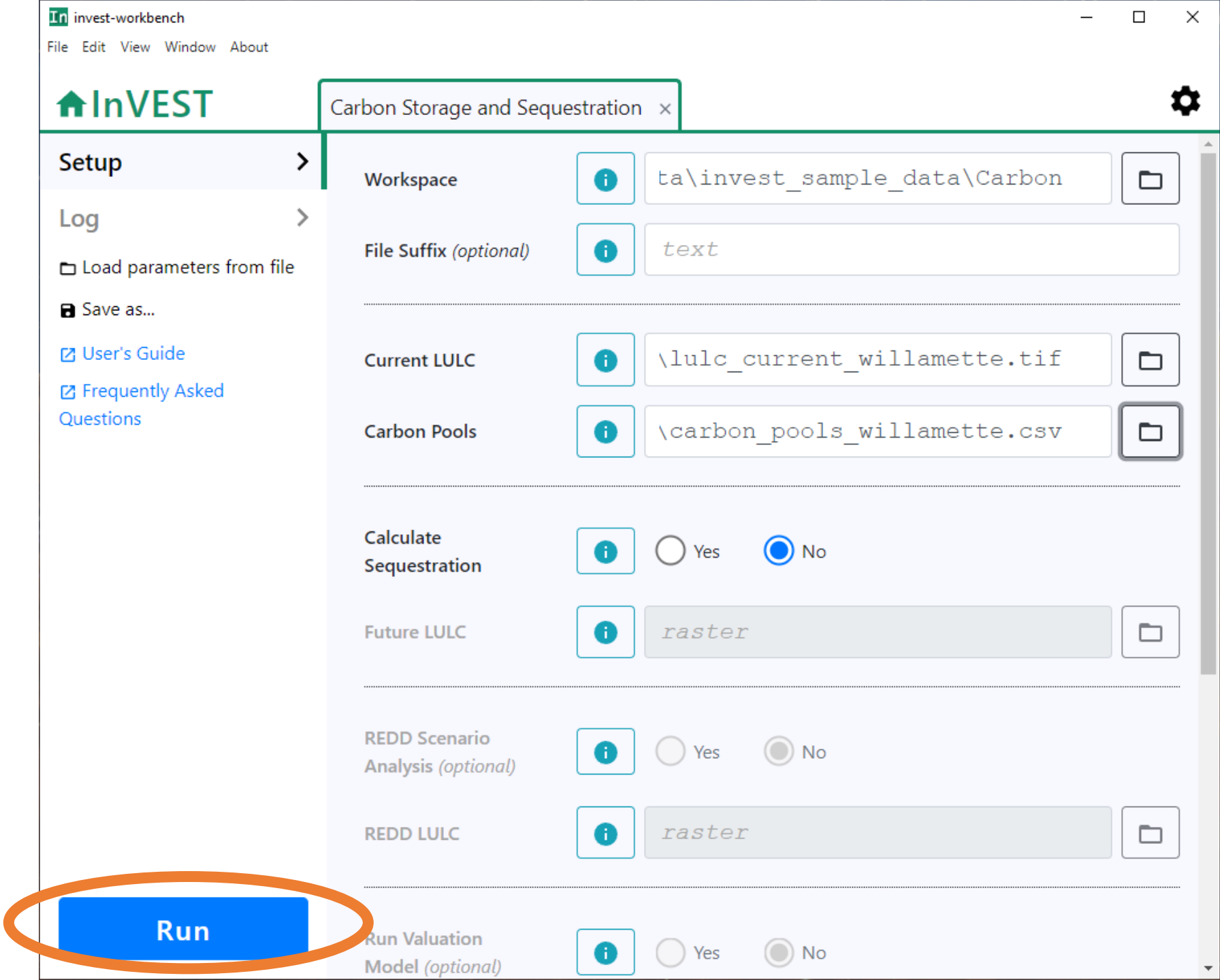
Look at the carbon pools table

- Open up the carbon pools CSV file in Excel (or whatever).
- Notice two key columns:
  - Lucode: This is the lucode that was saved in our LULC map!.
  - C_above: This is the carbon stored in the above-ground carbon pool for this LULC type.
    - Where did these values come from? A *massive* literature review (Ruesch and Gibbs 2008) of field studies.

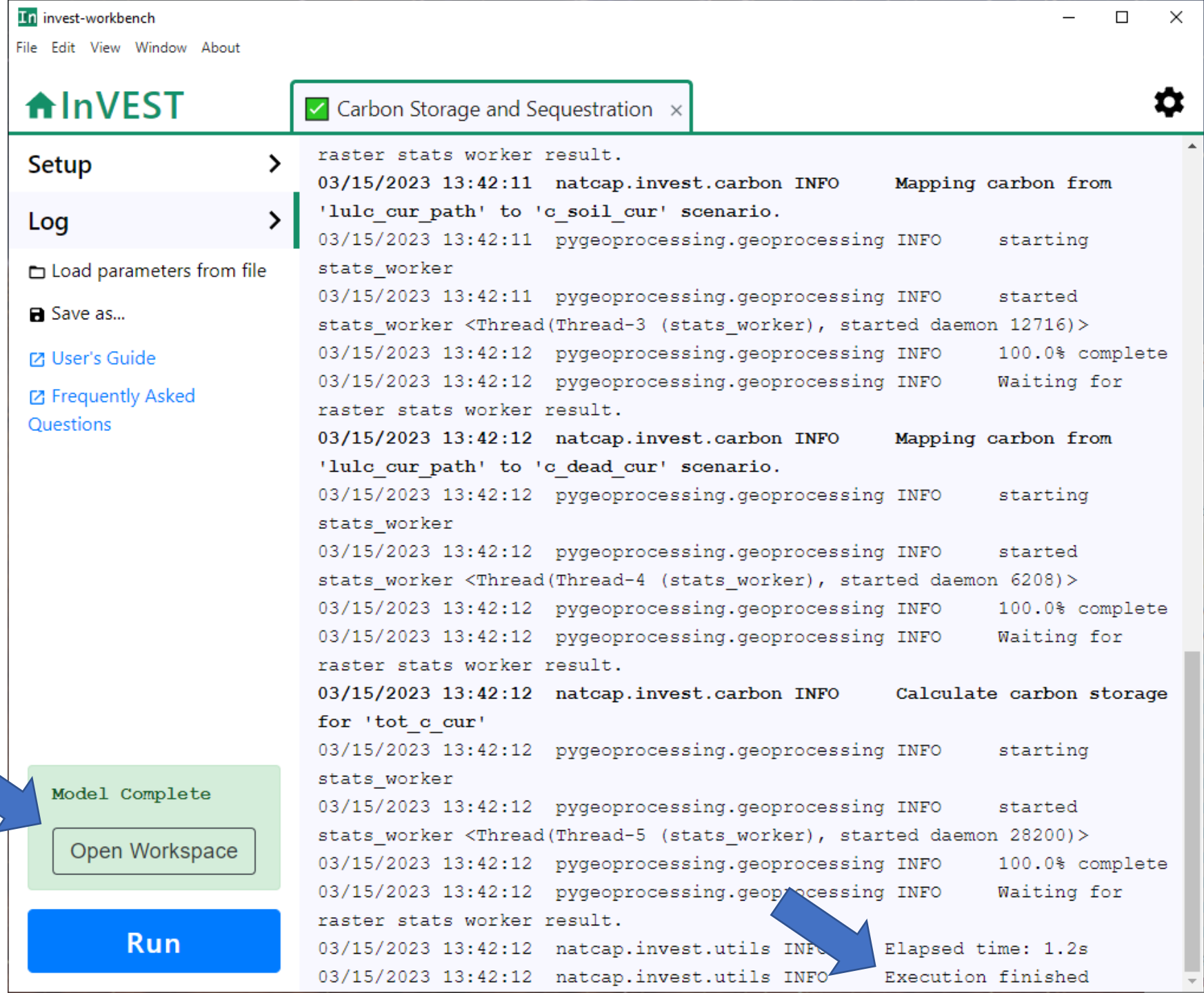


	A	B	C	D	E	F
1	lucode	LULC_Name	C_above	C_below	C_soil	C_dead
2	1	Residential 0-4 units/acre	15	10	60	1
3	2	Residential 4-9 units/acre	5	3	20	0
4	3	Residential 9-16 units/acre	2	1	5	0
5	4	Residential >16 units/acre	0	0	0	0
6	5	Vacant	10	20	10	5
7	6	Commercial	0	0	0	0
8	7	Commercial/Industrial	0	0	0	0
9	8	Industrial	0	0	0	0
10	9	Industrial & Commercial	0	0	0	0
11	10	Residential & Commercial	0	0	0	0
12	11	Urban non-vegetated unknown	0	0	10	0
13	16	Rural structures	0	0	50	0
14	18	Railroad	0	0	25	0
15	19	Primary roads	0	0	50	0
16	20	Secondary roads	0	0	25	0
17	21	Light duty roads	0	0	35	0
18	24	Rural non-vegetated unknown	0	0	0	0
19	29	Main channel non-vegetated	0	0	0	0
20	32	Stream orders 5-7	0	0	0	0
21	33	Permanent lentic water	0	0	0	0
22	39	Topographic Shadow	100	5	65	50
23	40	Snow	0	0	0	0
24	42	Barren	0	0	0	0
25	49	Urban tree overstory	135	50	75	1
26	51	Upland Forest open	75	45	85	20
27	52	Upland Forest Semi-closed mixed	90	60	110	30
28	53	Forest Closed hardwood	180	120	120	55
29	54	Forest Closed mixed	200	130	130	65
30	55	Upland Forest Semi-closed conifer	90	60	95	29
31	56	Conifers 0-20 yrs	10	7	76	2.5
32	57	Forest closed conifer 21-40 yrs	88	59	96	29
33	58	Forest closed conifer 41-60 yrs	165	110	115	50
34	59	Forest closed conifer 61-80 yrs	225	150	124	65
35	60	Forest closed conifer 81-200 yrs	300	200	135	85
36	61	Forest closed conifer older than 200 yrs	375	250	150	100
37	62	Upland Forest Semi-closed hardwood	80	50	100	25
38	66	Hybrid poplar	75	25	90	2
39	67	Grass seed rotation	1	1	10	0
40	68	Irrigated annual crop rotation	2	1	10	0
41	71	Grains	3	2	10	0

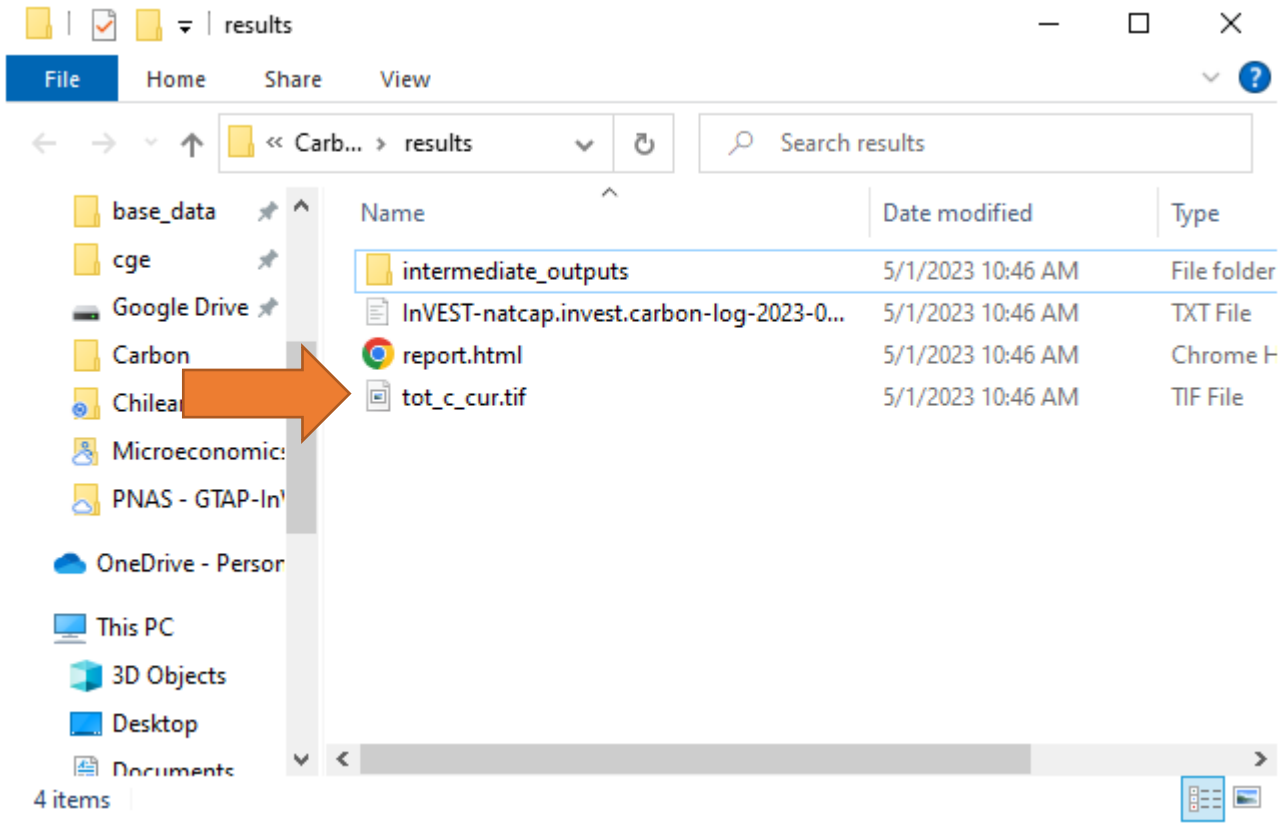
- Running the InVEST model here will combine the information from the table with the LULC map to calculate how much carbon is present.
- Do it by selecting Run!



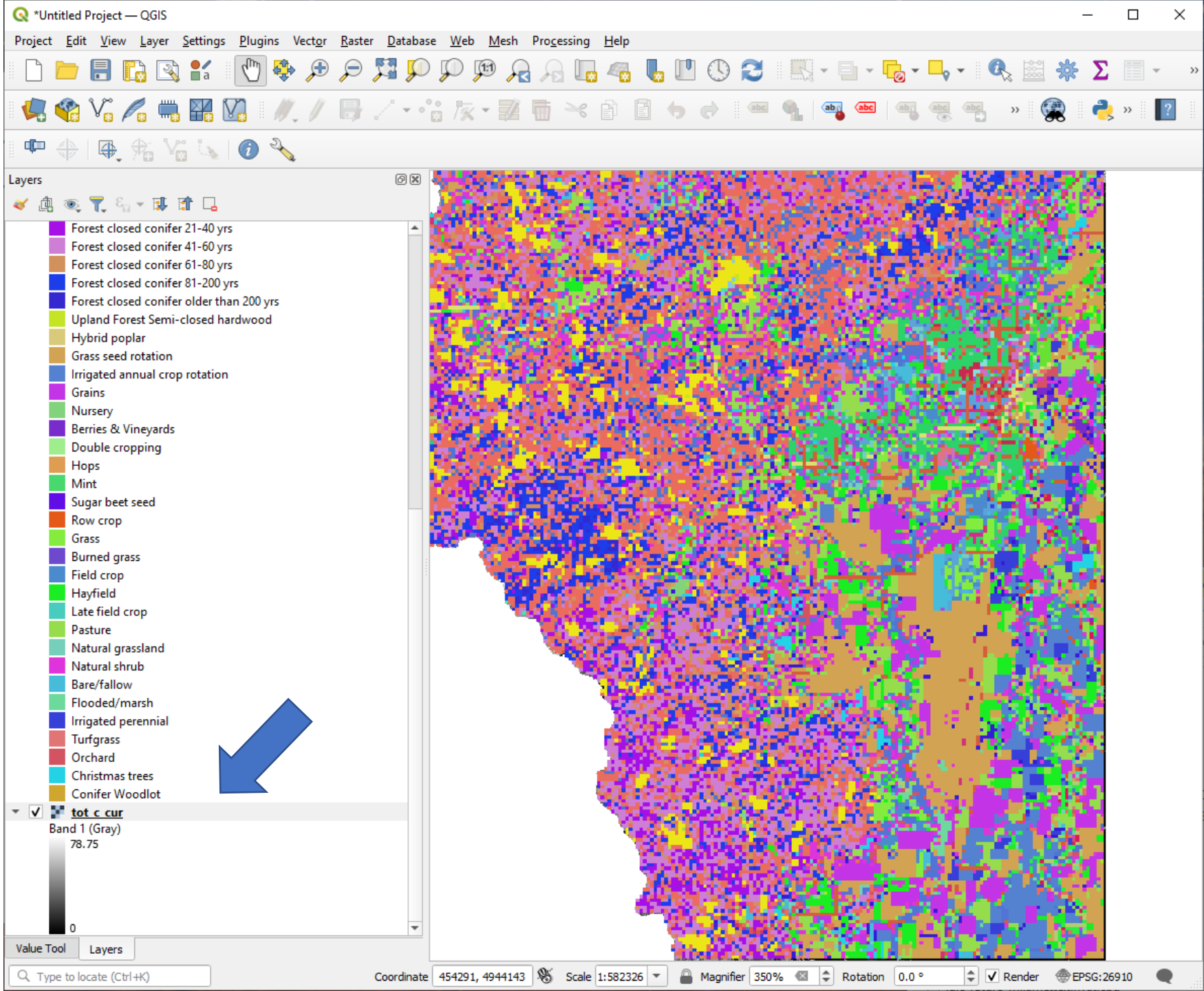
- A bunch of math just happened.
- You should now see a Log from the code that was just run.
- If it was successful, you should see “Execution Finished.”
- Now click on the Open Workspace button.



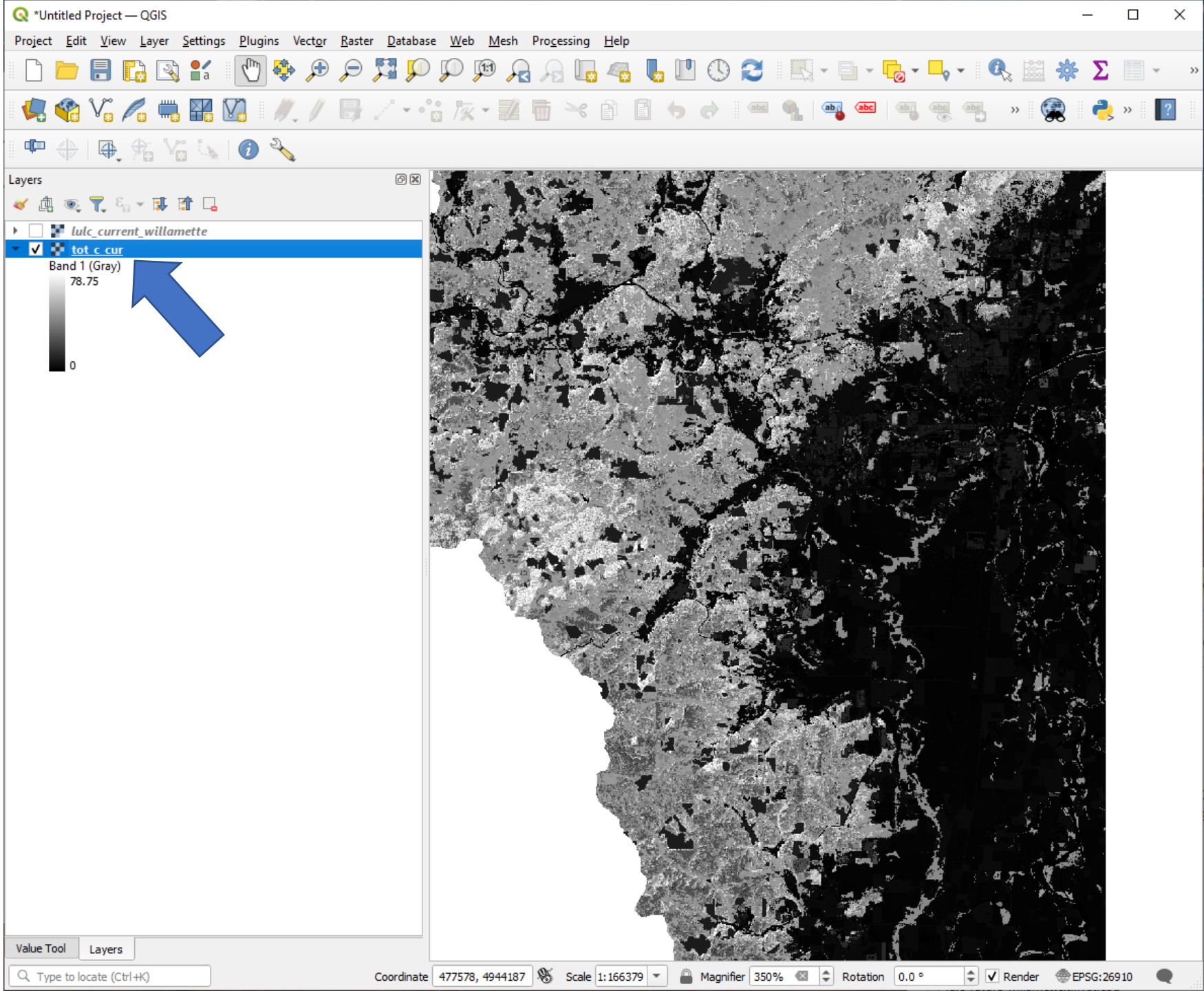
- The Open Workspace button opened the folder where it saved all the results
  - Because we set our workspace to be the same as the where the Sample Data was, you should now see that folder.
  - But, it has new files added
  - Such as “tot_c_cur.tif”



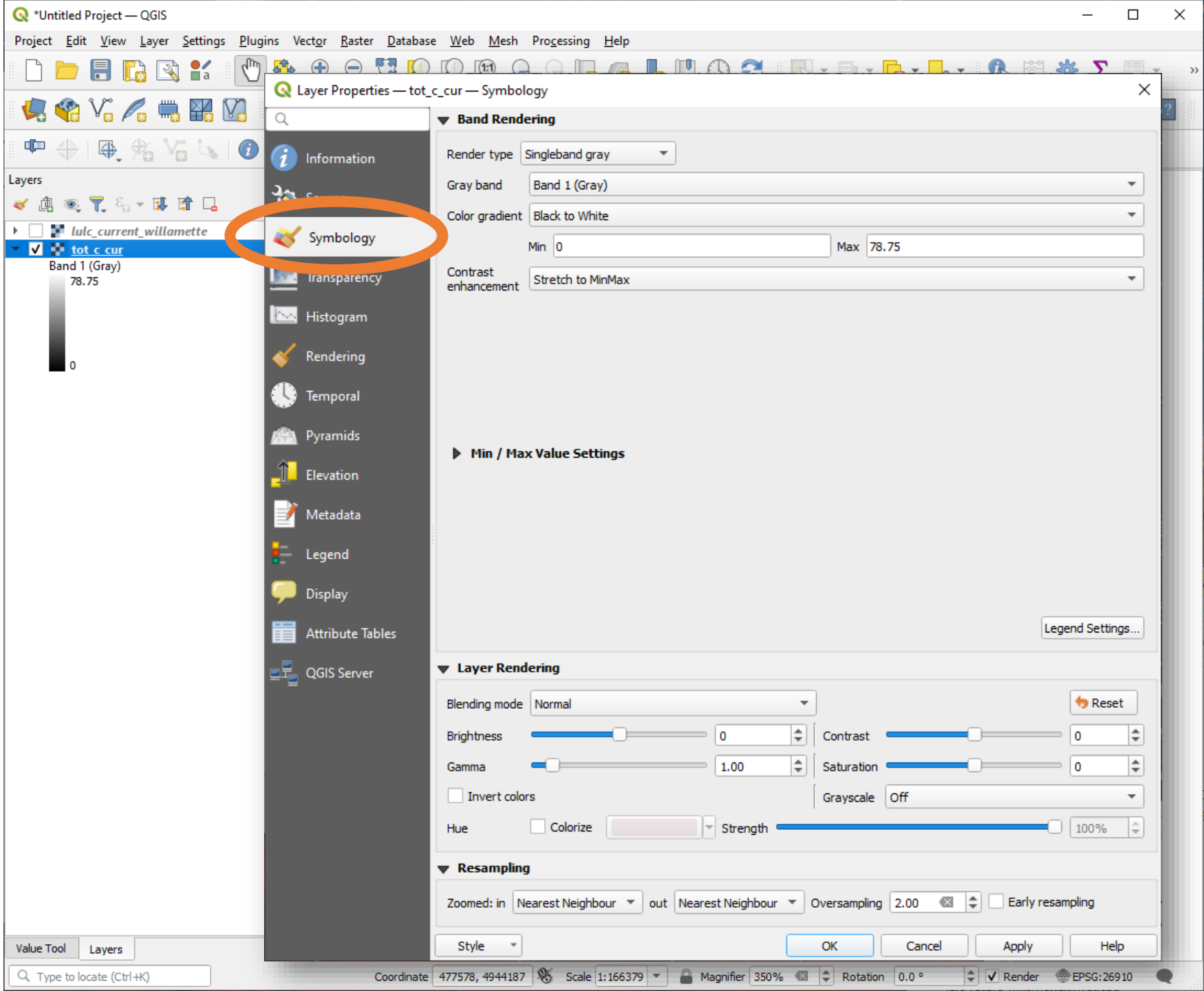
- Add “tot_c_cur.tif” to QGIS by dragging the file into QGIS.
- It will add it to the Layers tab.
- Depending on where you dropped the file, it might be hidden by the LULC map.
  - Scroll up in the Layers window and unselect anything above the new map.



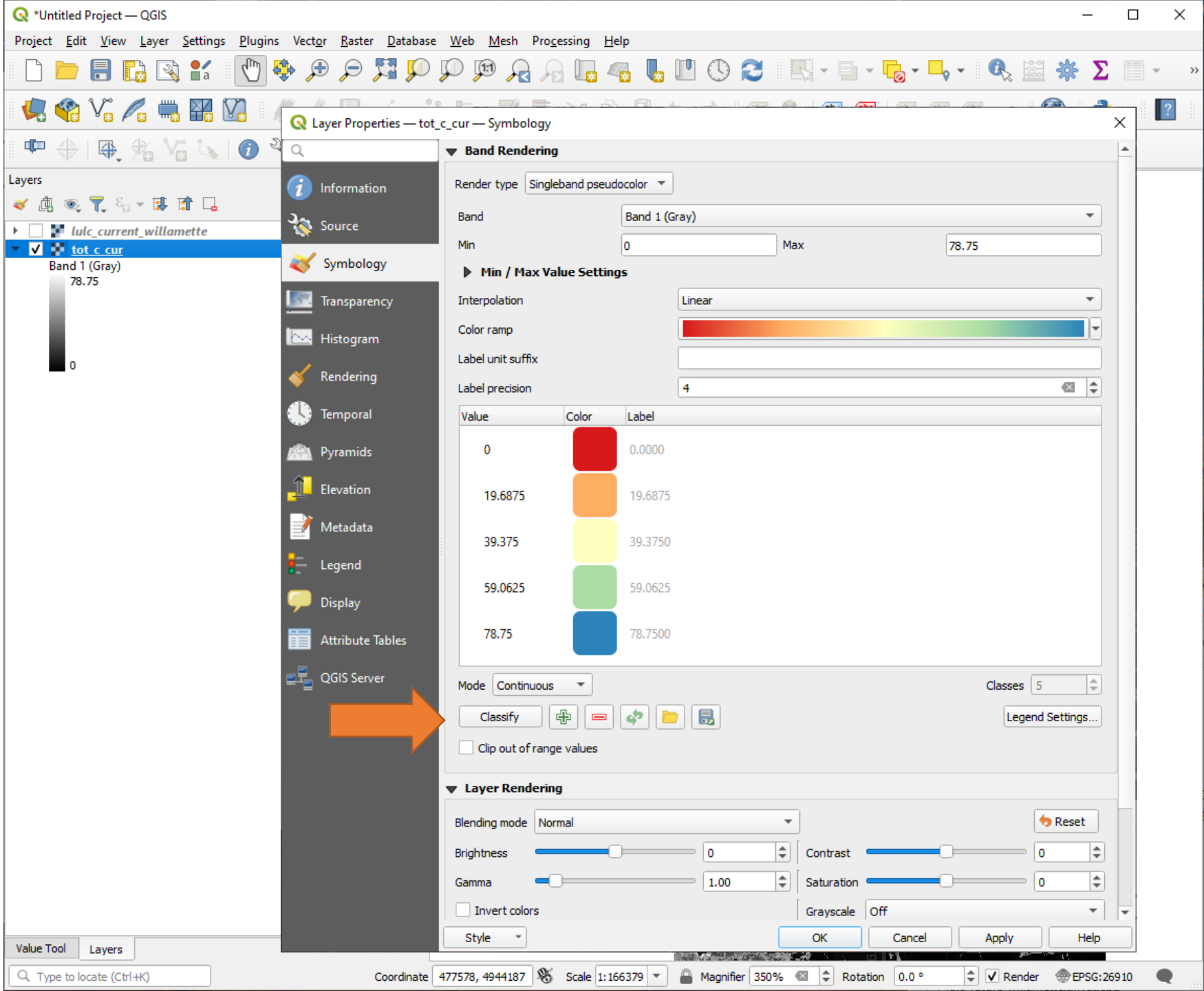
- Here I unselected the LULC layer and collapsed the legend so we could see the tot_c_cur layer.
- We get a slightly ugly map by default.
- Let's pretty-it-up.
  - Double click on the layer-name in the Layers window.



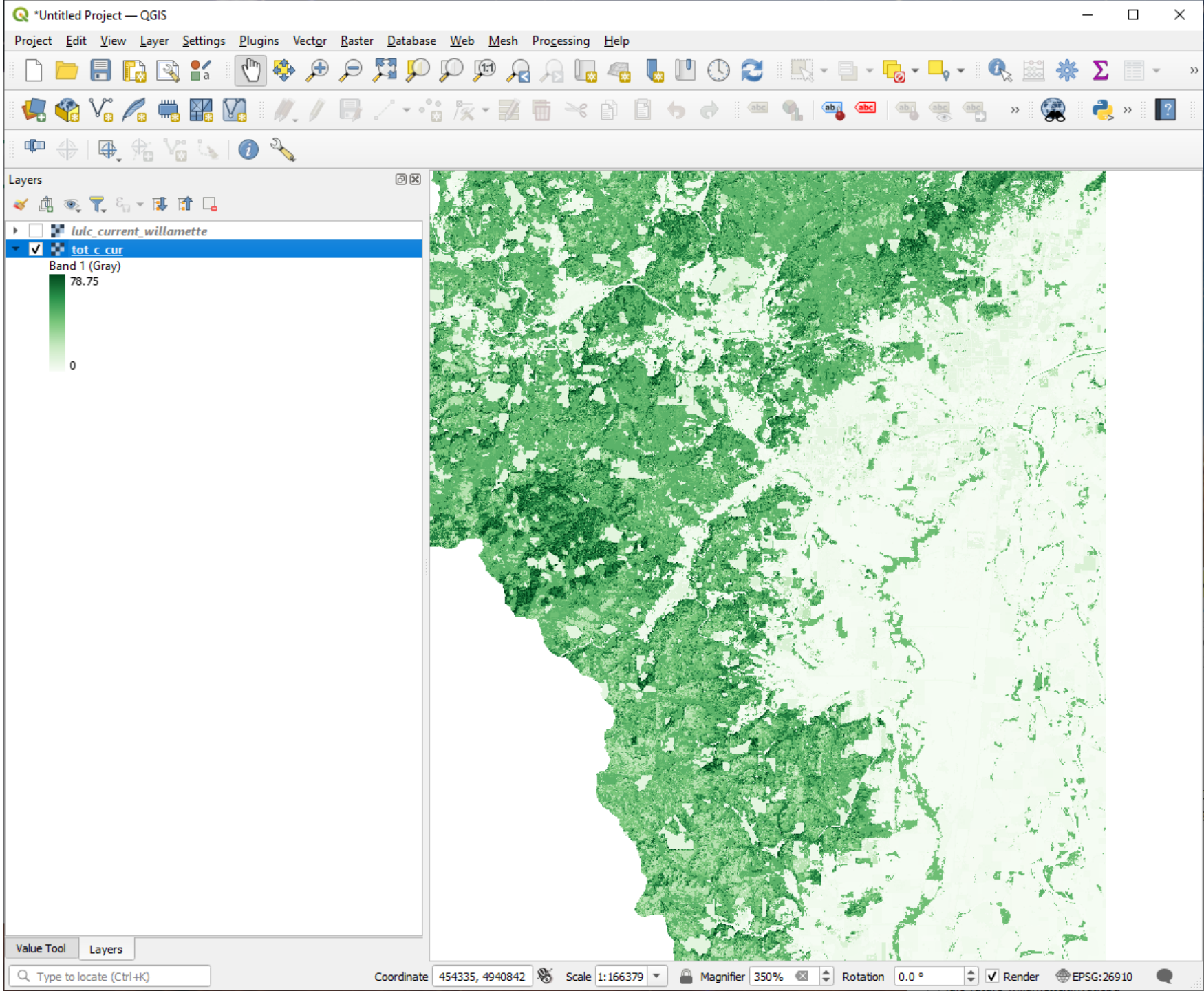
- Here I unselected the LULC layer and collapsed the legend so we could see the tot_c_cur layer.
- We get a slightly ugly map by default.
- Let's pretty-it-up.
  - Double click on the layer-name in the Layers window.
  - Then click the Symbology tab.



- For Render type, select Singleband psuedocolor.
- Press the Classify button.
- It will suggest some new colors and new break-points for the colorbar.
- More colorful, but still not pretty enough. Change the Color ramp option until you get something nice.
- Hit “Ok.”



- I chose green.
  - I like green.
- Now it is easier to interpret.
  - Discussion question: Based on carbon storage, where (roughly speaking) would it be most damaging to Climate Change to develop the land into agriculture? Why?



Exercise (and time for me to check that everyone's computer is setup correctly)

- Question 1: Rerun the Carbon model, but this time calculate carbon sequestration.
  - This will use lulc_future_willamette.tif
  - Assume the year for the current LULC map was 2023 and the future LULC was 2050.
  - Assume that the price of Carbon is $187 (based on the $51 per ton of Carbon Dioxide that the Biden administration uses).
  - Assume a discount rate of 0.03
  - Assume an Annual Price Change of 0
  - What is the total change in carbon between these time periods?
- Optional Question 2: Suppose that the future LULC map represents a policy of allowing logging in the area. Suppose that the value (net present value) of the timber is $50 million dollars. Use the information you've generated to make an argument that you could send to a legislator on whether or not this logging policy should be accepted.
- Hint: look for a report.html file that is generated in your Workspace directory.

What did we learn?

- InVEST is useful because we can **Quantify Tradeoffs.**
  - This is useful for policy makers to identify good policy.
- Important point: If we had not calculated the value of the carbon, the Cost-Benefit analysis would still have been run.
  - It just would have assigned a value of $0 to the lost carbon storage.

Extensions and improvements

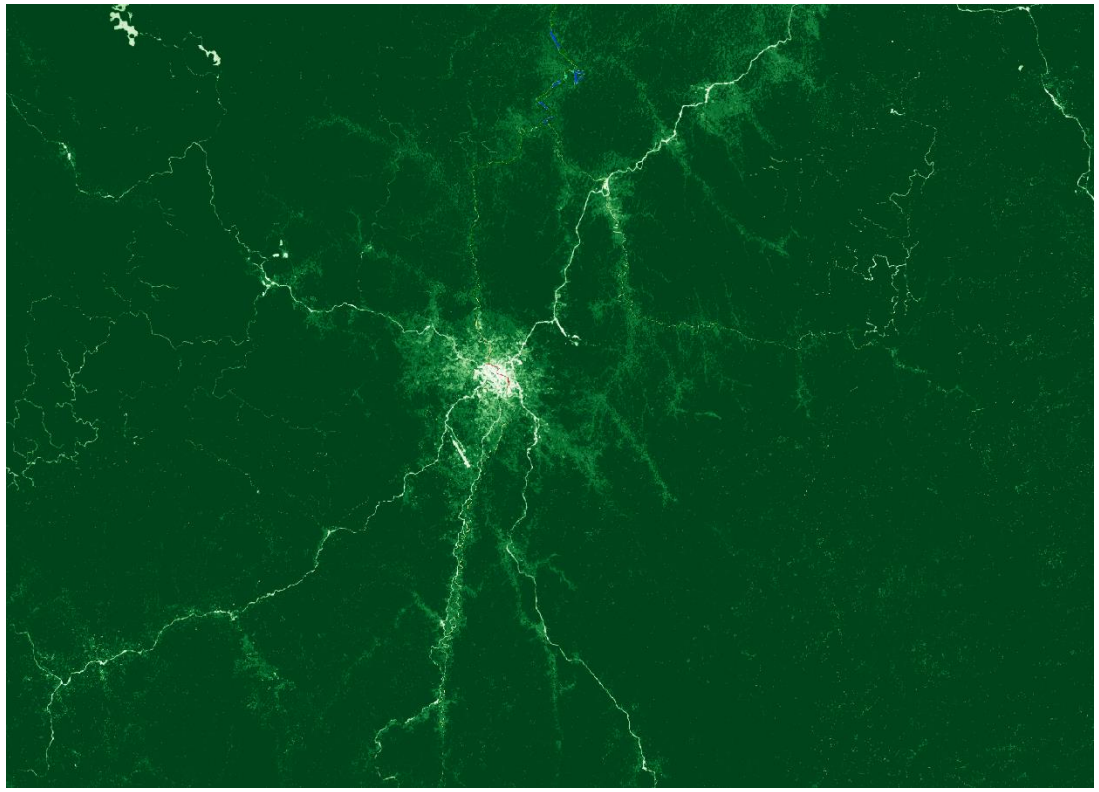
- The Edge-Effects Carbon model
- The carbon model from Global InVEST
- Machine-learning approaches to improve carbon estimates

Forest edge effects carbon model

- Accounts for forest carbon stock degradation due to the creation of forest edges.
- Extrapolates literature on the relationship between carbon storage and distance from forest edge to calculate edge effects in carbon storage
  - Combines these estimates with carbon inventory data to construct the overall carbon map.
- Identifies where there is “missing carbon”

Edge effects around a city

- Example of potential complexity in the carbon spatial relationship we could address:
  - There's an obvious ring of less carbon near the city. If those areas had the same LULC class as areas further out, there is a clear edge effect.
  - What parameters best predict this lower value in the intermediate ring?



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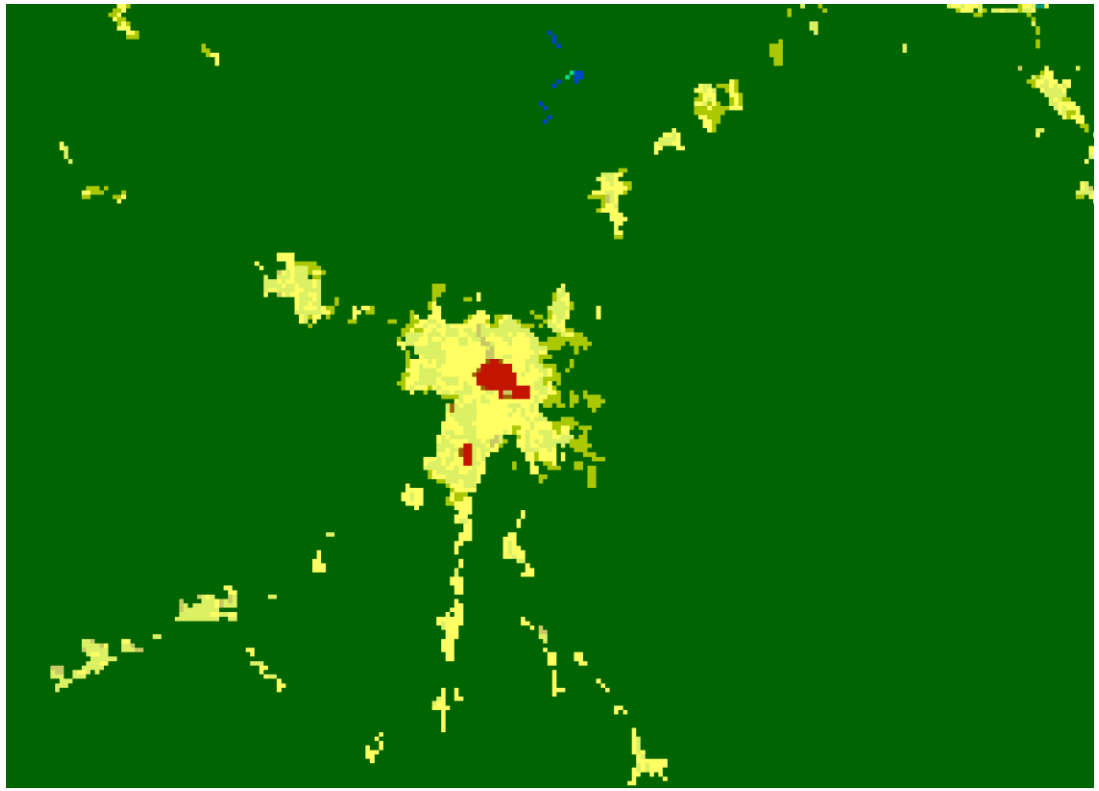
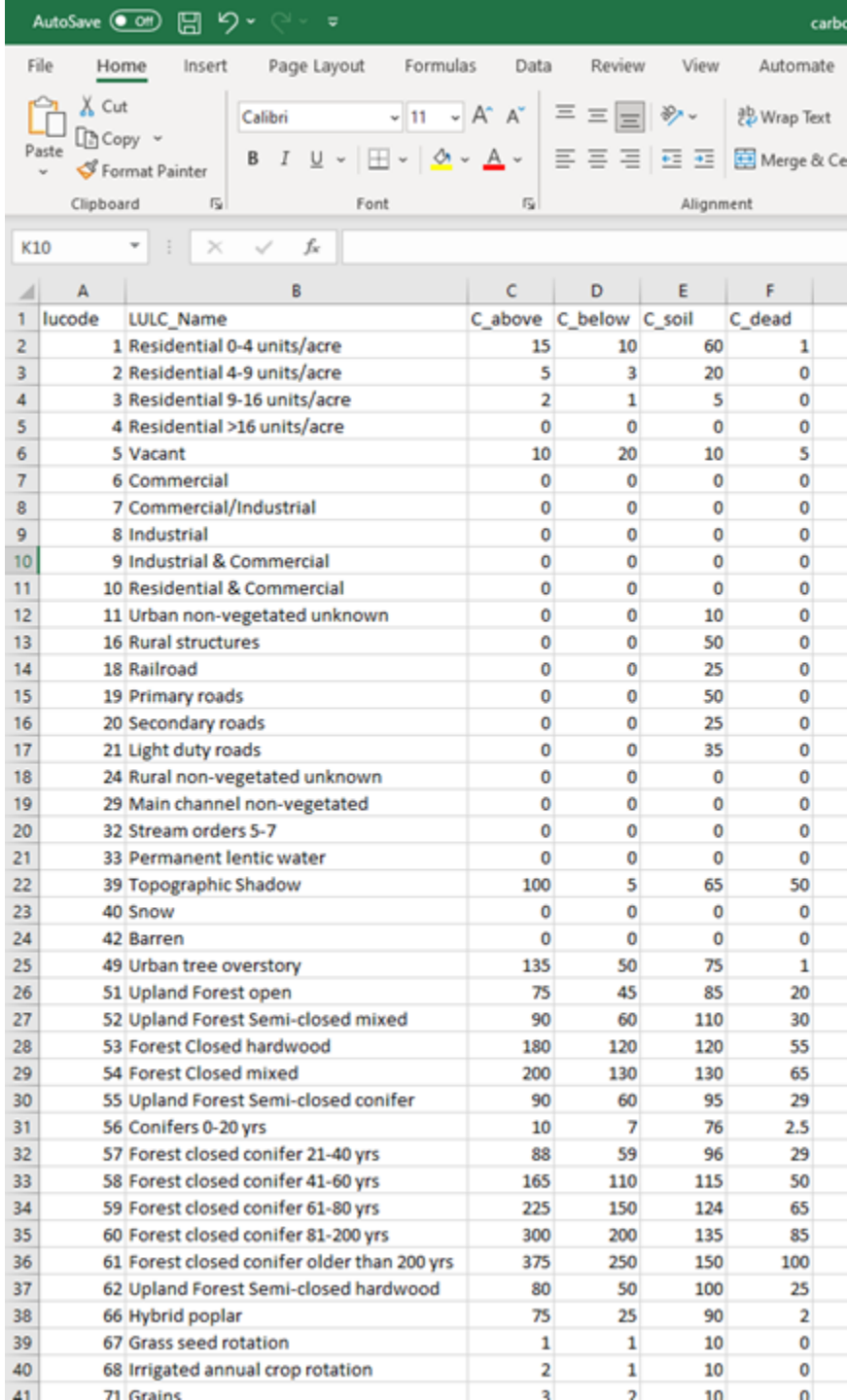


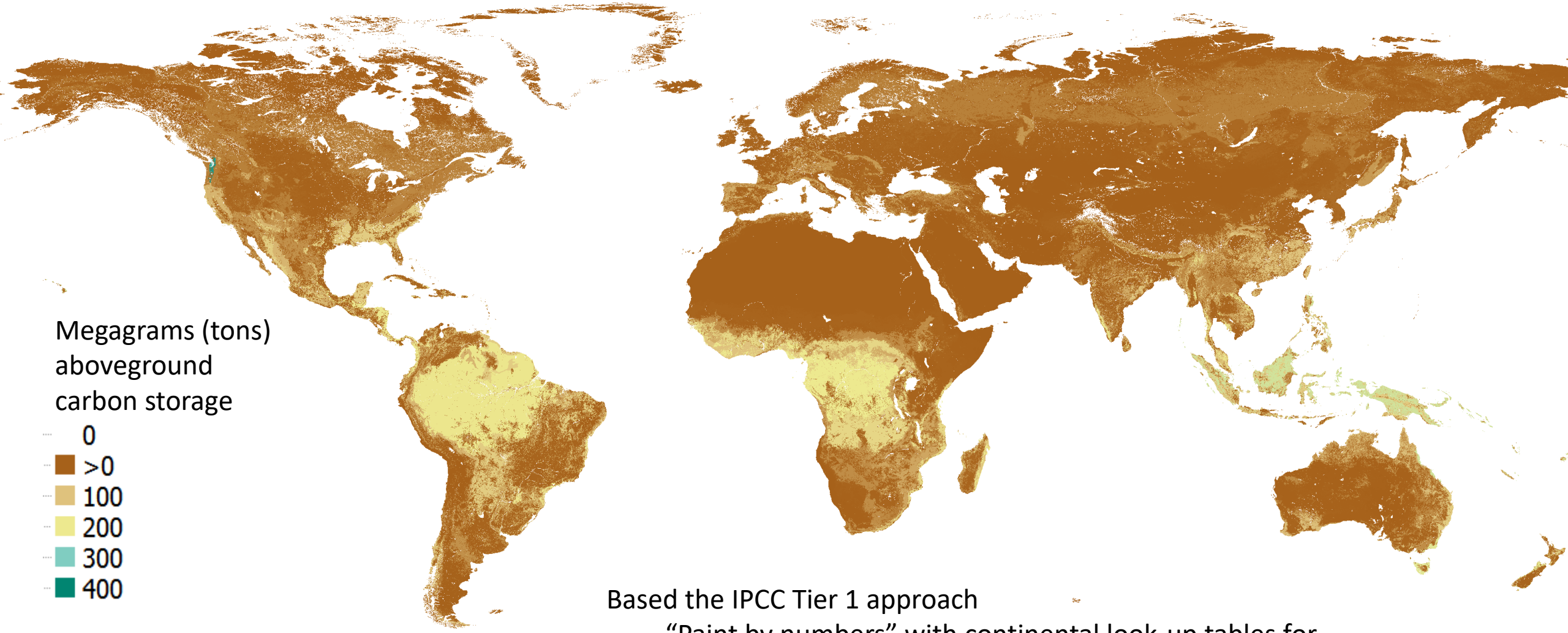
The “Global InVEST” carbon model

- The default carbon model is parameterized by a biophysical table.
  - Ideally drawn from local studies
  - Often falls back to the “IPCC Tier 1 carbon methodology” (Ruesch and Gibbs 2008)
    - This was a comprehensive review of the field studies that directly measured carbon
- The values in these tables are different in each ecofloristic regions, frontier forests, and continents
  - In reality, *most* areas would require 2 or more lookup tables
- The Global InVEST Carbon Model instead combines all of the different biophysical tables for all carbon zones and then recategorizes global LULC maps based on which zone they are in.



	A	B	C	D	E	F
1	lucode	LULC_Name	C_above	C_below	C_soil	C_dead
2	1	Residential 0-4 units/acre	15	10	60	1
3	2	Residential 4-9 units/acre	5	3	20	0
4	3	Residential 9-16 units/acre	2	1	5	0
5	4	Residential >16 units/acre	0	0	0	0
6	5	Vacant	10	20	10	5
7	6	Commercial	0	0	0	0
8	7	Commercial/Industrial	0	0	0	0
9	8	Industrial	0	0	0	0
10	9	Industrial & Commercial	0	0	0	0
11	10	Residential & Commercial	0	0	0	0
12	11	Urban non-vegetated unknown	0	0	10	0
13	16	Rural structures	0	0	50	0
14	18	Railroad	0	0	25	0
15	19	Primary roads	0	0	50	0
16	20	Secondary roads	0	0	25	0
17	21	Light duty roads	0	0	35	0
18	24	Rural non-vegetated unknown	0	0	0	0
19	29	Main channel non-vegetated	0	0	0	0
20	32	Stream orders 5-7	0	0	0	0
21	33	Permanent lentic water	0	0	0	0
22	39	Topographic Shadow	100	5	65	50
23	40	Snow	0	0	0	0
24	42	Barren	0	0	0	0
25	49	Urban tree overstory	135	50	75	1
26	51	Upland Forest open	75	45	85	20
27	52	Upland Forest Semi-closed mixed	90	60	110	30
28	53	Forest Closed hardwood	180	120	120	55
29	54	Forest Closed mixed	200	130	130	65
30	55	Upland Forest Semi-closed conifer	90	60	95	29
31	56	Conifers 0-20 yrs	10	7	76	2.5
32	57	Forest closed conifer 21-40 yrs	88	59	96	29
33	58	Forest closed conifer 41-60 yrs	165	110	115	50
34	59	Forest closed conifer 61-80 yrs	225	150	124	65
35	60	Forest closed conifer 81-200 yrs	300	200	135	85
36	61	Forest closed conifer older than 200 yrs	375	250	150	100
37	62	Upland Forest Semi-closed hardwood	80	50	100	25
38	66	Hybrid poplar	75	25	90	2
39	67	Grass seed rotation	1	1	10	0
40	68	Irrigated annual crop rotation	2	1	10	0
41	71	Grains	3	2	10	0

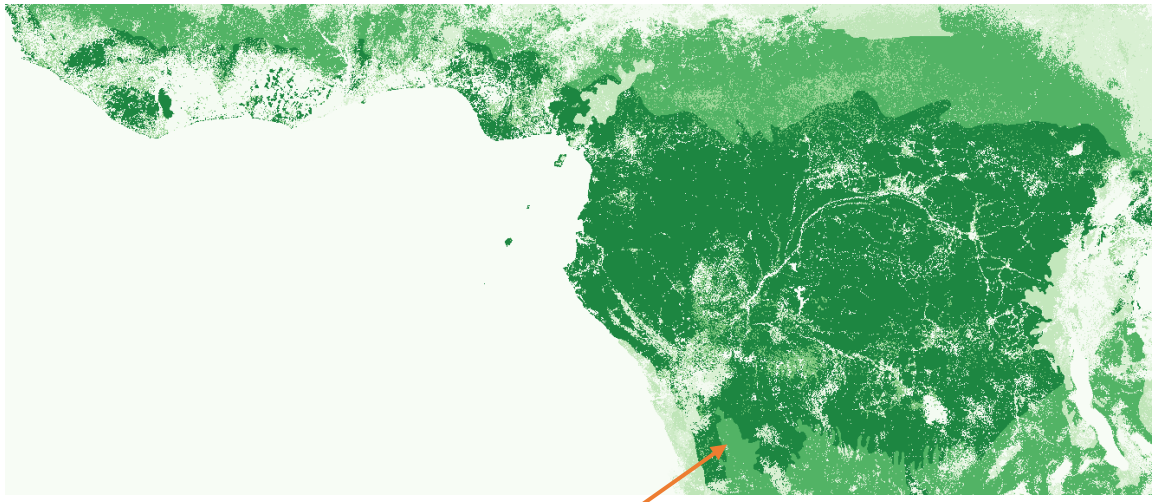
Ruesch and Gibbs 2008 (IPCC Tier 1)



Based the IPCC Tier 1 approach

"Paint by numbers" with continental look-up tables for different Land Use, Land Cover classes

InVEST Carbon Model is essentially a simplified version of the IPCC method



- Table values are heavily dependent on “Ecofloristic Zone”

First paper figure

- Lowest hanging fruit: creates projections that are accurate in aggregate
- SSE (Sum of Squared Errors) is about 3x higher in IPCC than Model 1