UN environment
United Nations Environment Programme

UN Environment
The Economics of Ecosystems and Biodiversity
Agriculture & Food

Part C: Modeling Food-System Scenarios

"I believe that the great part of miseries of mankind are brought upon them by false estimates they have made of the value of things." Benjamin Franklin, 1706-1790

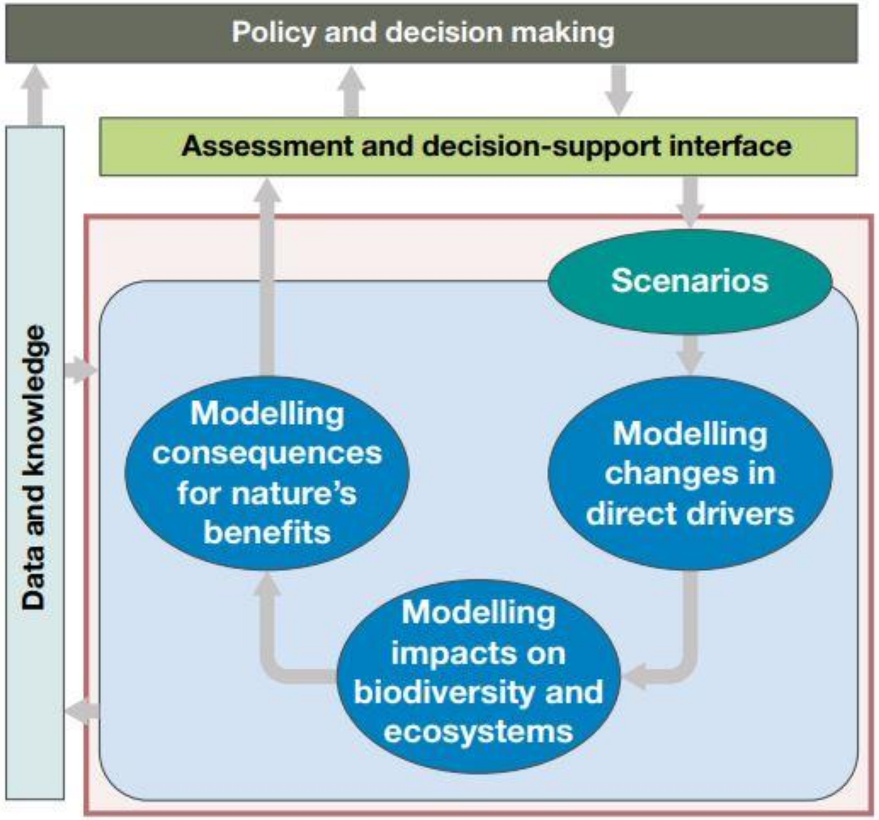
A composite satellite image reveals the scale of US cattle feedlots — and the pollution they cause.Credit: Mishka Henner

IPBES Scenarios and Models Report

"Scenarios and models play different, but highly complementary roles in informing and supporting policy and decision making. Scenarios are used to describe plausible futures for drivers of change, and options for altering the course of these drivers through policy and management interventions. Models then enable scenarios of change in drivers to be translated into expected consequences for nature and nature's benefits to people."

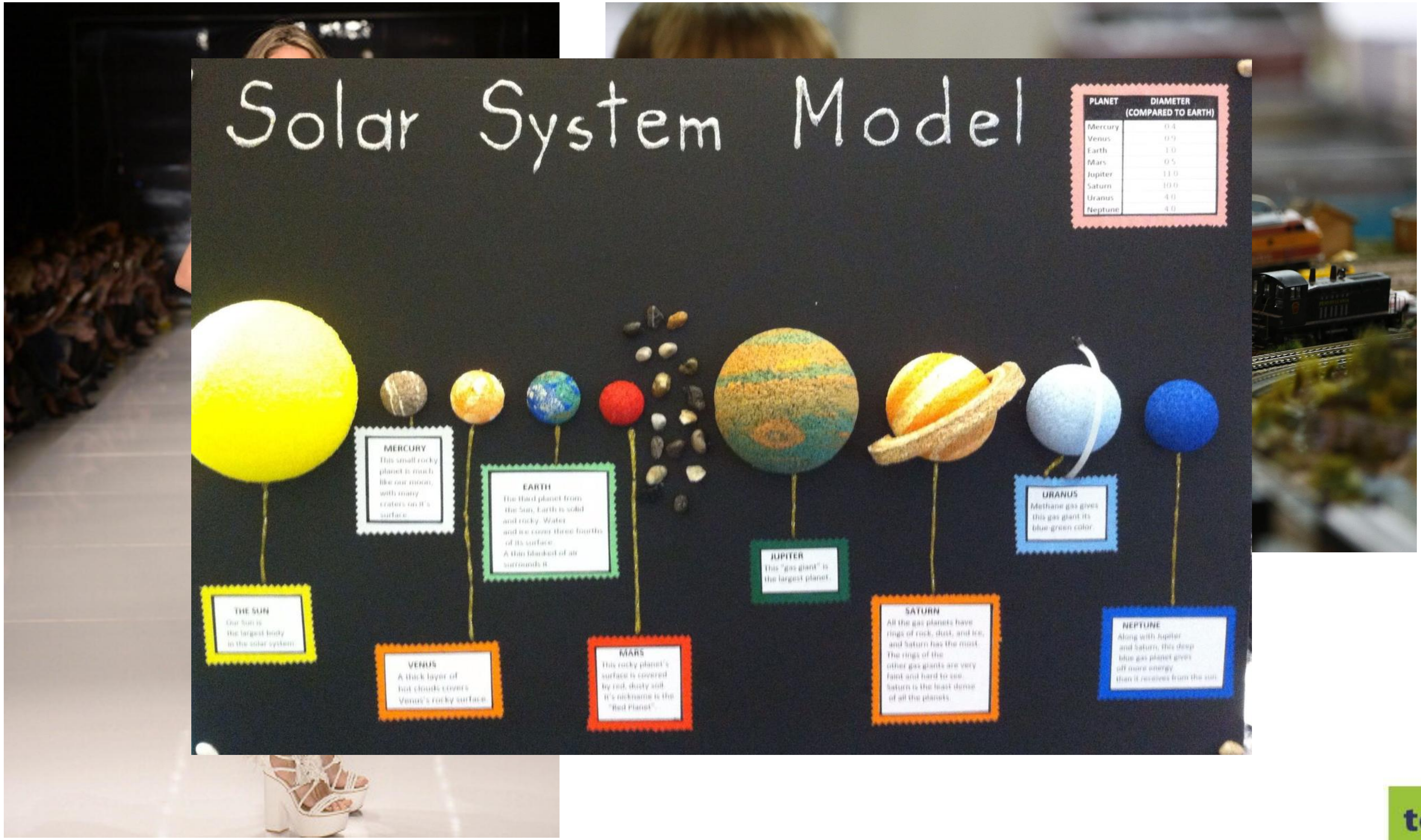
- Inter-governmental Science-policy Platform on Biodiversity and Ecosystem Services (IPBES), Assessment Report on Scenarios and Models of Biodiversity andEcosystem Services
- https://www.ipbes.net/assessment-reports/scenarios

Modeling Scenarios for Decision Making



- How would things be different if we get Scenario A vs Scenario B?
- What do we want to know?
  - What is human-nature relationship?
  - Magnitude of trade-offs?
  - Where do trade-offs occur?
  - Who will win or lose?

What is a model?



Modeling Scenarios for Decision Making

Predictive Models:

- Representation of cause –> effect relationship
- Predict what could or should happen
- Estimate differences between scenario A and B
- Replace experiments when experiments are impractical or impossible

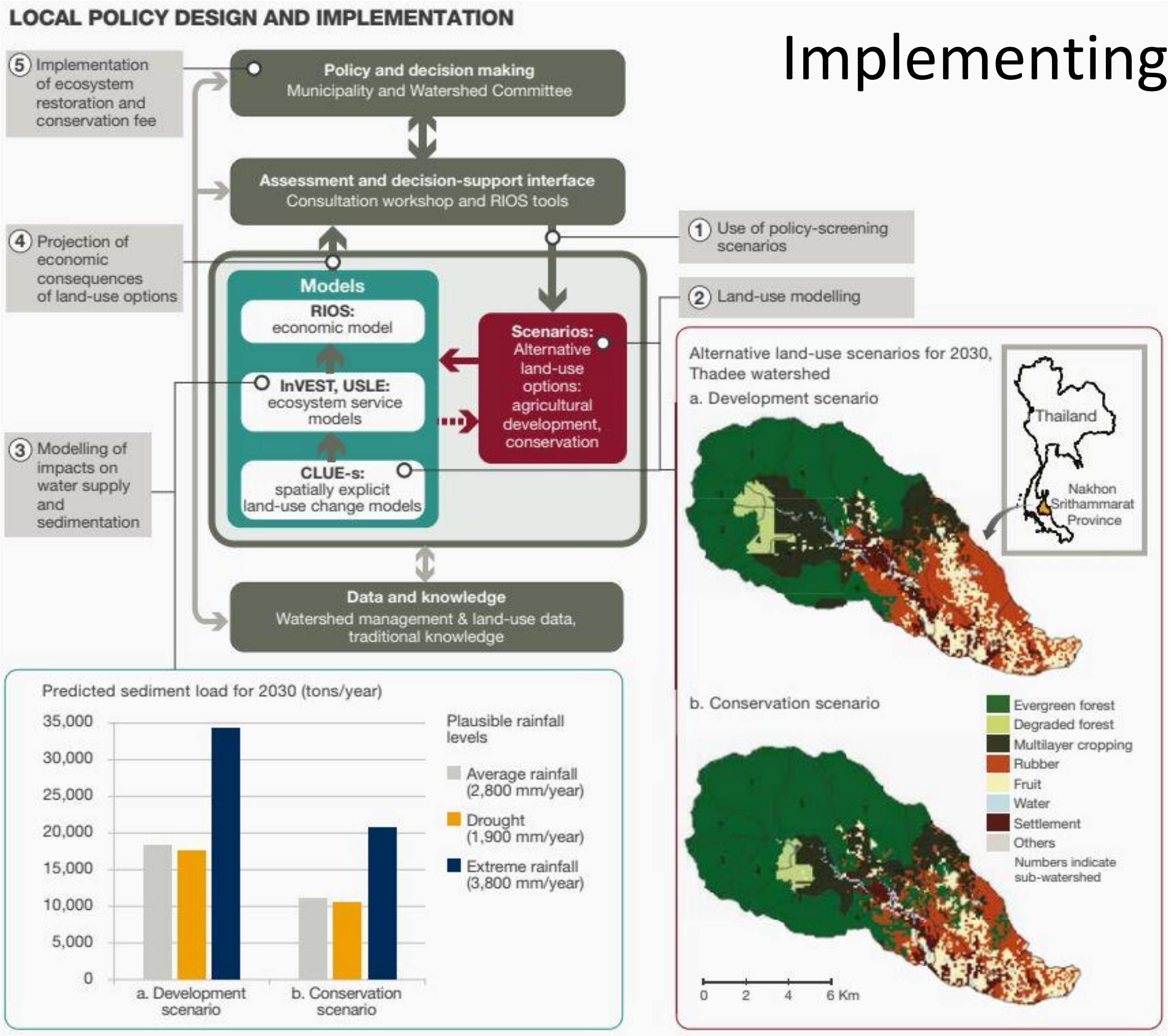
Types of predictive models

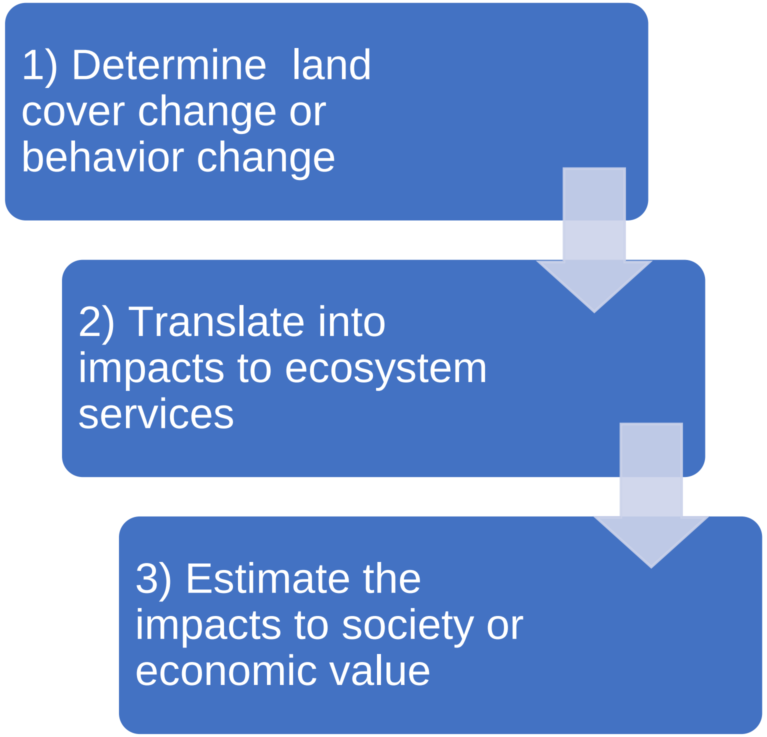
- **Expert-based** model: Prior knowledge or experience
- **Correlative** model: Analyze data trends
- **Process-based** model: Prior knowledge of relationships paired with data analysis

"All models are wrong, but some are useful."

- George Box (Statistician)

Implementing the AgriFood framework





teebweb.org

Drivers – Ecosystem Functions - Ecosystem Services

Services Category*	Ecosystem Structure/Functions	Ecosystem Services
Provisioning services	Productive agricultural land	Food, livelihoods
Regulating services	Mangroves absorbing impact of wind and waves	Shoreline protection, pollution treatment
Regulating services	Forests stabilizing sediment and retaining soil	Erosion control
Supporting services	Nutrient and pollution uptake by wetlands	Clean water
Cultural services	Diverse animals and plants	Education/Research/ Tourism
Cultural Services	Unique landscape of cultural, historical or spiritual meaning	Cultural, spiritual benefits

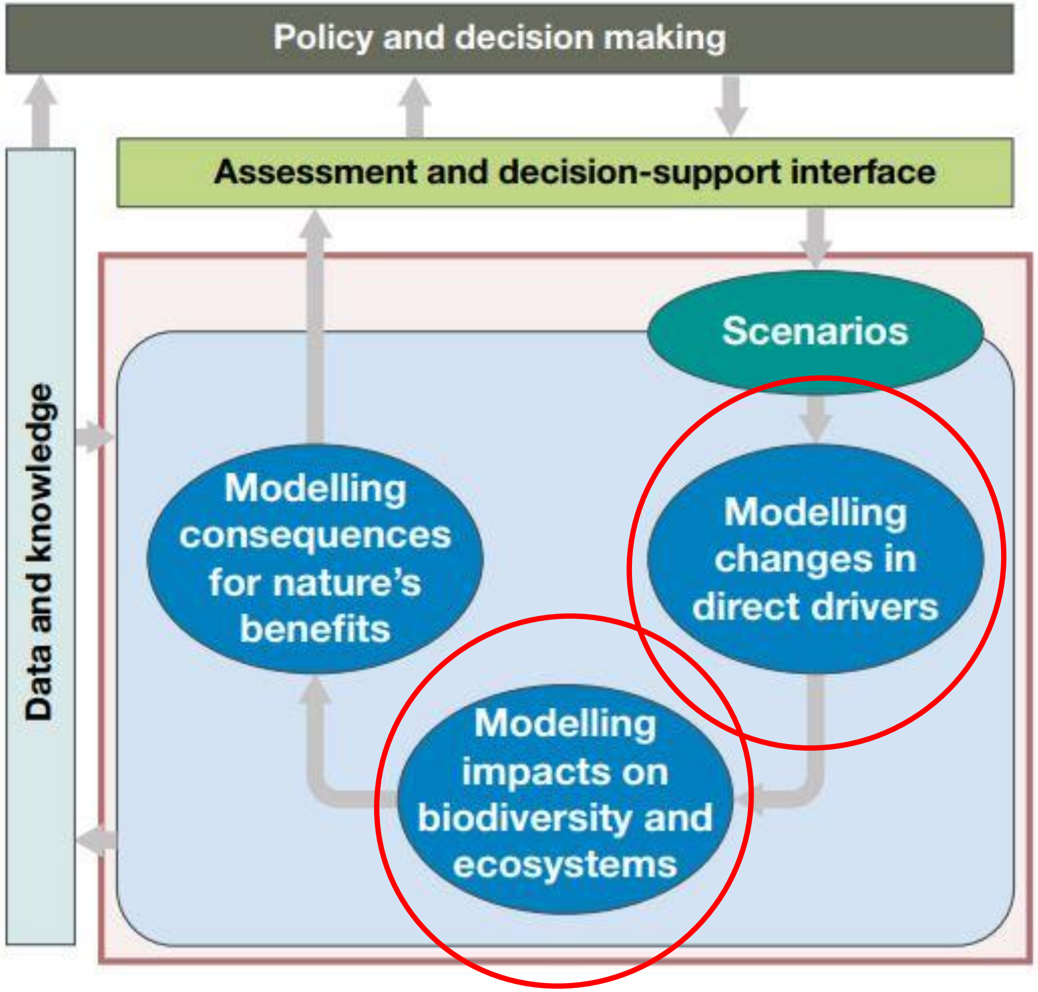
*Millennium Ecosystem Assessment (2005)

Models of infinite variety

TABLE 5.4
Summary of major ecosystem services model tools. Dynamic models are in orange, while snapshot models are in blue.

Tool	Model type	Scale in space, time	Ease of use	Community of practice	Flexibility	Reference
IMAGE	Process	Global, dynamic	Difficult	Small	Low	Stehfest *et al.*, 2014
EcoPath with EcoSim	Process	Region, dynamic	Medium	Large	High	Christensen et al., 2005
ARIES	Expert	Region, dynamic	Difficult	Small	High	Villa *et al.*, 2014
InVEST	Process and correlative	Region, static	Medium	Large	Medium	Sharp *et al.*, 2014
Co$ting nature	Correlative	Region, static	Easy-medium	Small	Medium	www.policysupport.org/costingnature
TESSA	Expert	Region, static	Easy	Small	Low	Peh *et al.*, 2014
Corporate ecosystem services review	Expert	Region, static	Easy	Small	Low	Hanson *et al.*, 2012
LUCI	Correlative	Region, static	Easy	Small	Medium	www.lucitools.org

Modeling Scenarios for Decision Making



- How would things be different if we get Scenario A vs Scenario B?

- Land use or behavior changes
- Changes to ecosystem function
- Changes to ecosystem services

Modeling AgriFood Systems: Biophysical Models

Biophysical modeling needs:

- “Drivers” (e.g. land use change, conservation area)
- Ecosystem process (e.g. Water infiltration or fish reproduction)
- Resource management, behavior (e.g. Soil management practices)

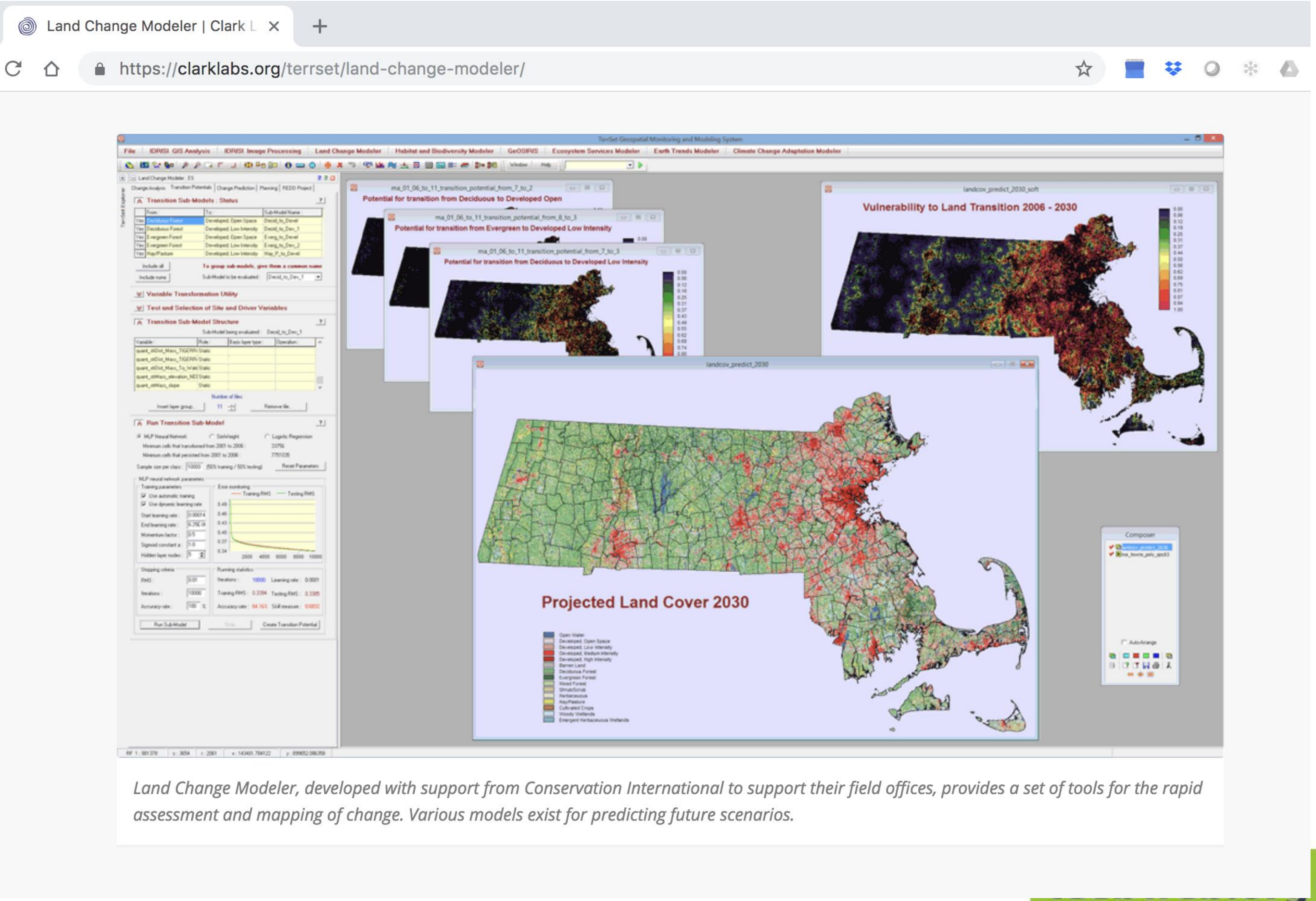
Some model examples:

- Land cover / land use scenarios (TerreSet, Marxan)
- Hydrology (SWAT)
- Soil Erosion (RUSLE)
- Carbon flux with land use practices (Daycent, Carbon Benefits Project)

Land cover change: TerreSet or Marxan

Land Change Modeler Features

- Quickly generate graphs and maps of land change
- Model land cover transition potentials that express the likelihood that land will transition
- Incorporate planning interventions, incentives and constraints.
- Conduct scenario mapping
- Validate the predicted land cover map
- Evaluate REDD conservation strategies with GHG emission impact accounting.



Hydrology: SWAT

Software | SWAT | Soil & Water

https://swat.tamu.edu/software/

SWAT Soil & Water Assessment Tool

Software Docs Workshops Conferences Publications Support Search

SWAT 2012

The SWAT model is a command line tool that uses text input and output files. See the other links on this page for interfaces and tools for SWAT 2012.

Download SWAT 2012 Executables

SWAT 2012 Interfaces

ArcSWAT
ArcGIS-ArcView extension for developing SWAT models

QSWAT
QGIS extension for developing SWAT models

SWAT Editor
Interface for editing SWAT inputs

SWAT-CUP
Sensitivity, calibration, validation, and uncertainty analysis

Output Analysis

SWAT Check
Helps to identify potential model input parameters issues

VIZSWAT
Visualization and analysis tool developed by Baird & Associates

SWAT Output Viewer
Alternative tool to quickly view and analyze SWAT outputs

Soil erosion: RUSLE

Revised Universal Soil Loss Equation

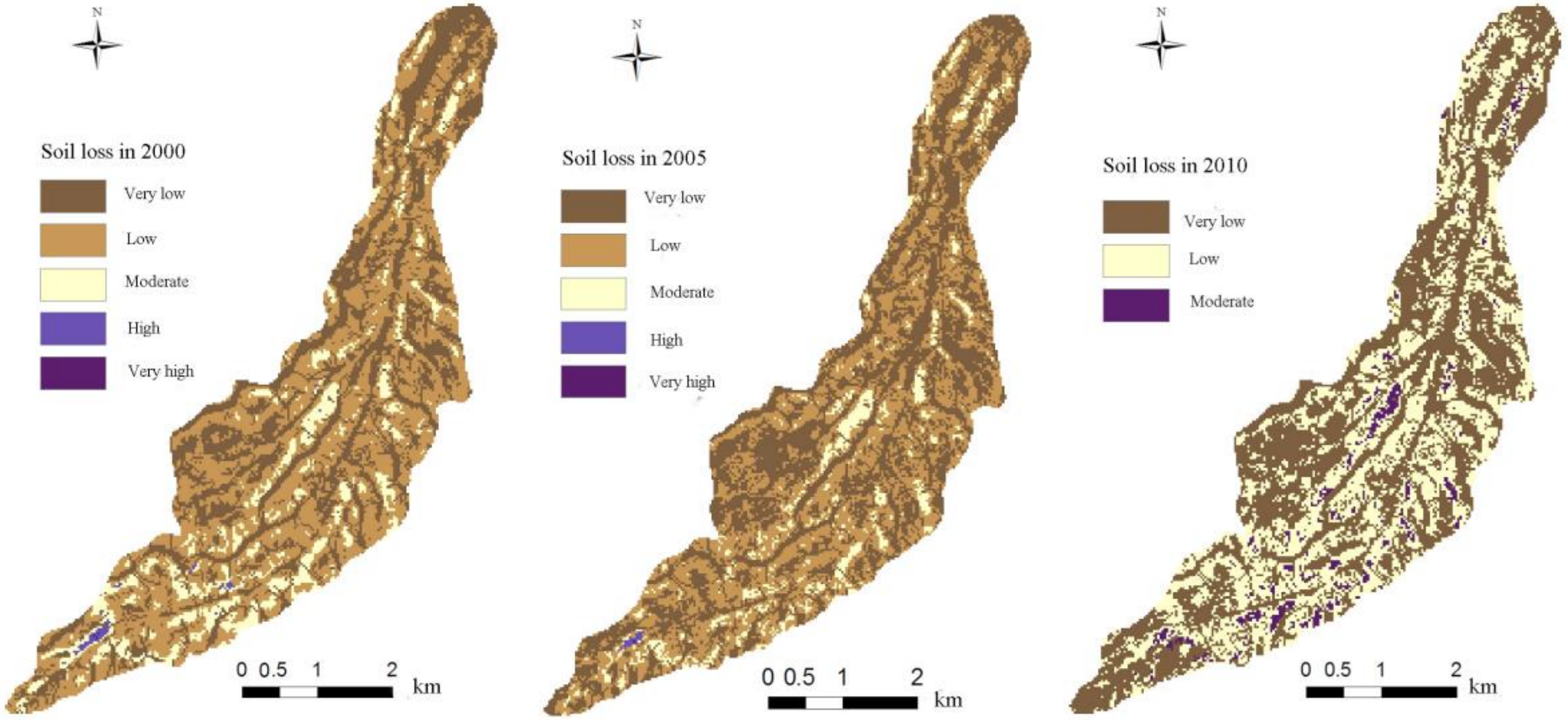


Figure 14. The spatial distribution of soil loss estimated using RUSLE for each of the study years.

Lei Wang et al 2018, PIAHS

Carbon flux: Daycent

- DAYCENT can simulate NPP, soil organic carbon, N2O emissions, and NO3 leaching has been tested with data from various native and managed systems (Del Grosso et al., 2001b; 2002; 2005).
- Model inputs: daily maximum/minimum air temperature and precipitation, surface soil texture class, and land cover/use data
- Model outputs: daily N-gas flux (N2O, NOx, N2), CO2 flux from heterotrophic soil respiration, soil organic C and N, NPP, H2O and NO3 leaching, and other ecosystem parameters.
- Can schedule management events daily, make crop germination a function of soil temperature and harvest date a function of accumulated growing degree days.

CHAPTER 14

DayCent Model Simulations for Estimating Soil Carbon Dynamics and Greenhouse Gas Fluxes from Agricultural Production Systems

Stephen J. Del Grosso[1], William J. Parton[2], Paul R. Adler[3], Sarah C. Davis[4], Cindy Keough[2], Ernest Marx[2]
[1]USDA, Agricultural Research Service, Fort Collins, CO
[2]Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO
[3]USDA, Agricultural Research Service, Pasture Systems and Watershed Management Research Unit, University Park, PA
[4]Energy Biosciences Institute, University of Illinois at Urbana-Champaign, Urbana, IL

CHAPTER OUTLINE

INTRODUCTION

Models are needed to quantify soil greenhouse gas (GHG) fluxes, NO_3 leaching, and other carbon and nutrient flows at regional and larger scales because it is not feasible to implement the required measurement intensity. Models currently used for this purpose range from simple spreadsheet calculators which assume that, for example, N_2O emissions are proportional to N inputs, to more complex models that represent the processes that control emissions. In this context, the Intergovernmental Panel on Climate Change defined three approaches for calculating GHG emissions (IPCC, 2006). Briefly, Tier 1 methods use default emission factors, Tier 2 methods use country- or region-specific factors, and Tier 3 methods use complex

Managing Agricultural Greenhouse Gases. DOI: 10.1016/B978-0-12-386897-8.00014-0
2012, Published by Elsevier Inc.

Modeling AgriFood Systems: Ecosystem Services

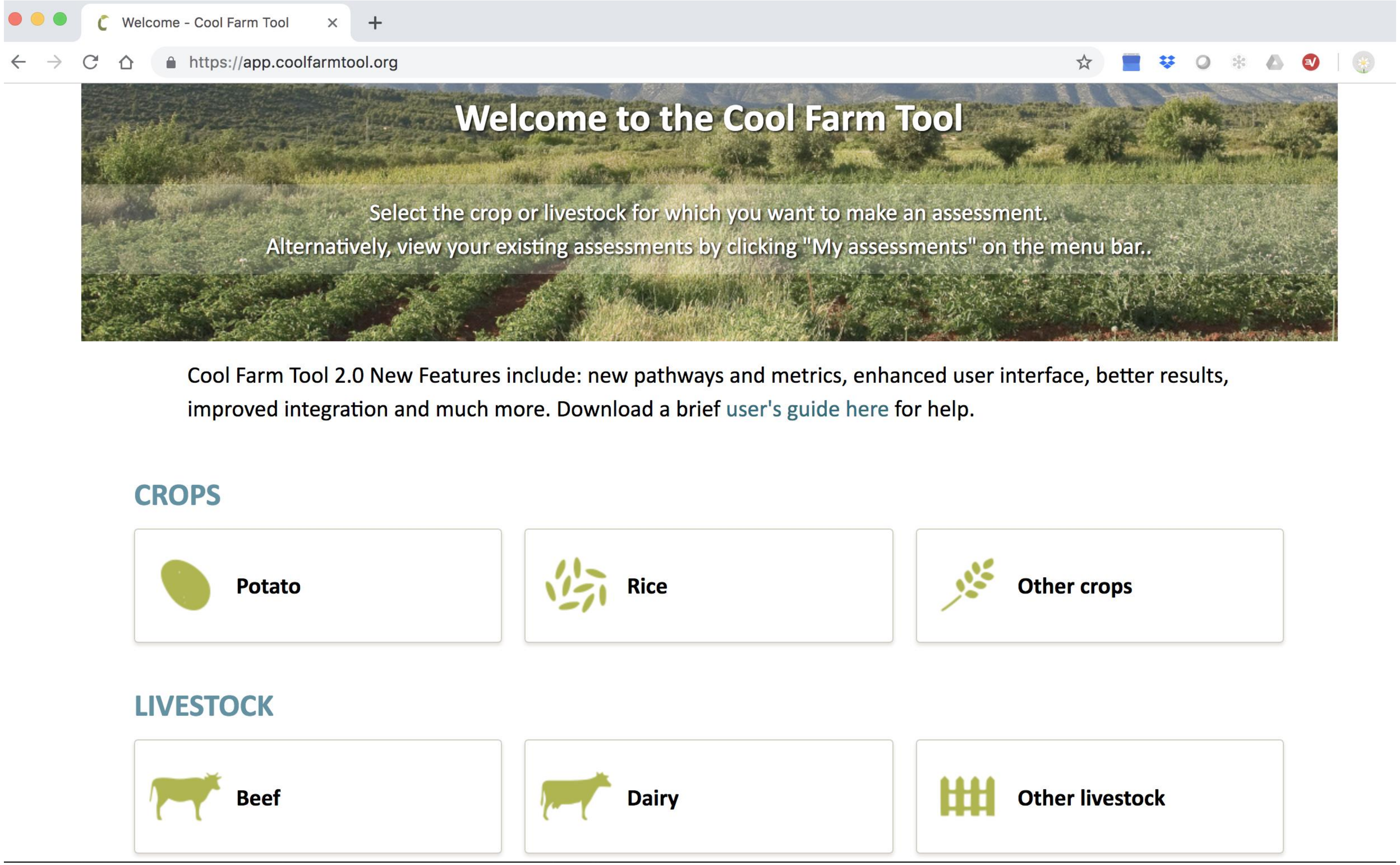
What are the impacts of behavior changes, drivers, or land use changes?

InVEST
integrated valuation of ecosystem services and tradeoffs

CFT
COOL FARM TOOL

Carbon Benefits Project

Ecosystem Services: Cool Farm



Ecosystem Services: Cool Farm

CA

DATA INPUTS

The data needed to calculate GHG emissions from crops is summarized here at-a-glance. Find detailed explanations for each item in the Data Inputs Guide. Drop down menus throughout the tool make data entry easier. Hover over the items with an asterisk "*" to see the kind of detail provided in drop down lists in the tool.

GENERAL INFO

- ☐ CROP
- ☐ YEAR
- ☐ HARVESTED YIELD
- ☐ YIELD TO MARKET

GROWING AREA

- ☐ CROP AREA*
- ☐ SOIL TEXTURE*
- ☐ SOIL ORGANIC MATTER*
- ☐ SOIL MOISTURE*
- ☐ SOIL DRAINAGE*
- ☐ SOIL PH*

FIELD TREATMENT

- ☐ FERTILISER APPLICATIONS*
- ☐ NUMBER OF PESTICIDE APPLICATIONS
- ☐ CROP RESIDUE MANAGEMENT*

MANAGEMENT
if applicable: above ground biomass

- ☐ LAND USE CHANGE*
- ☐ TILLAGE CHANGE*
- ☐ COVER CROP*

ENERGY & PROCESSING

- ☐ ENERGY USE*

OR

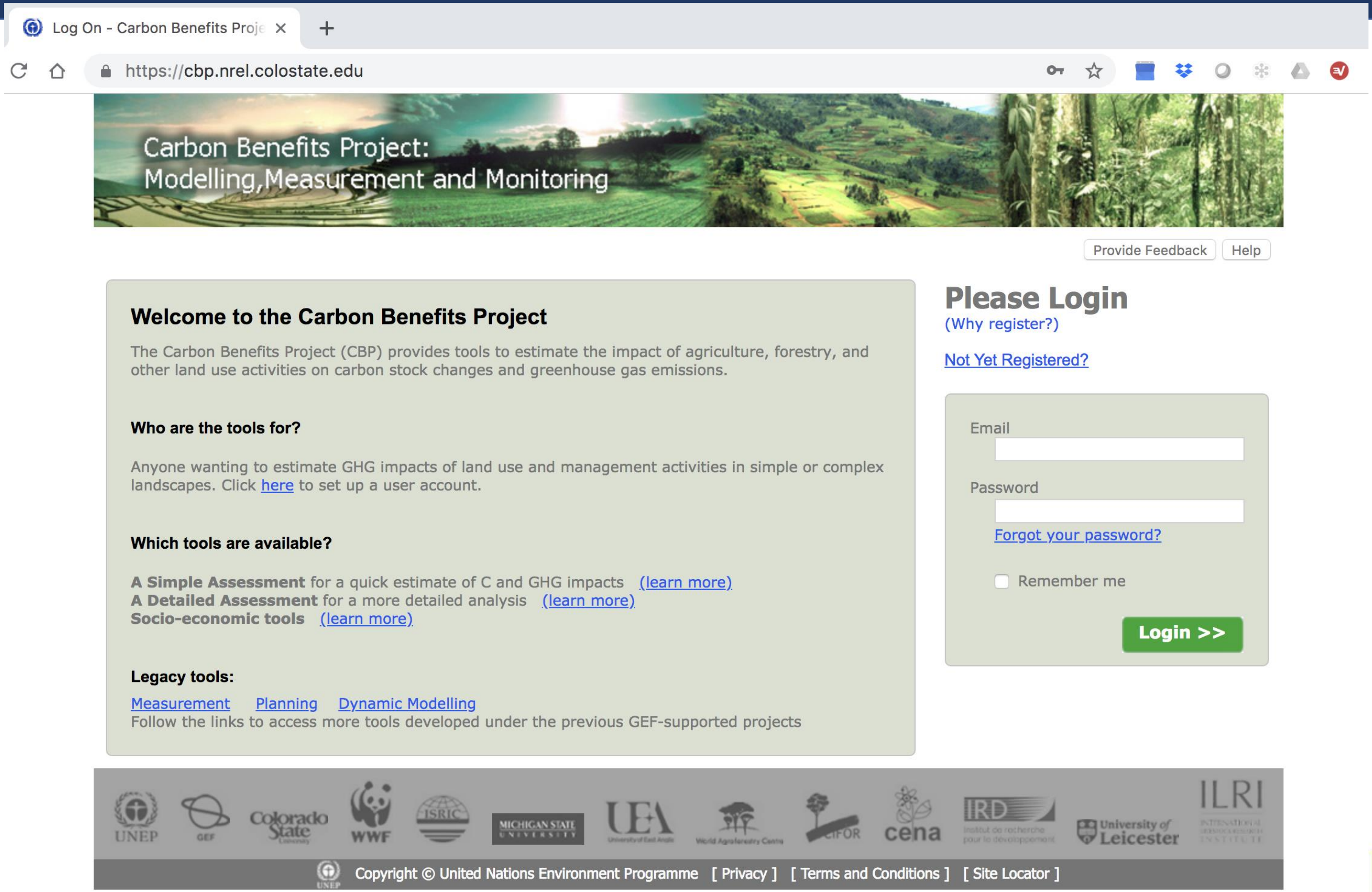
- ☐ HAVE THE TOOL CALCULATE ENERGY FOR YOU FROM: FIELD OPERATIONS, IRRIGATION, STORAGE, AND PROCESSING

TRANSPORT
(optional)

- ☐ TRANSPORT MODE*
- ☐ TRANSPORT WEIGHT
- ☐ TRANSPORT DISTANCE

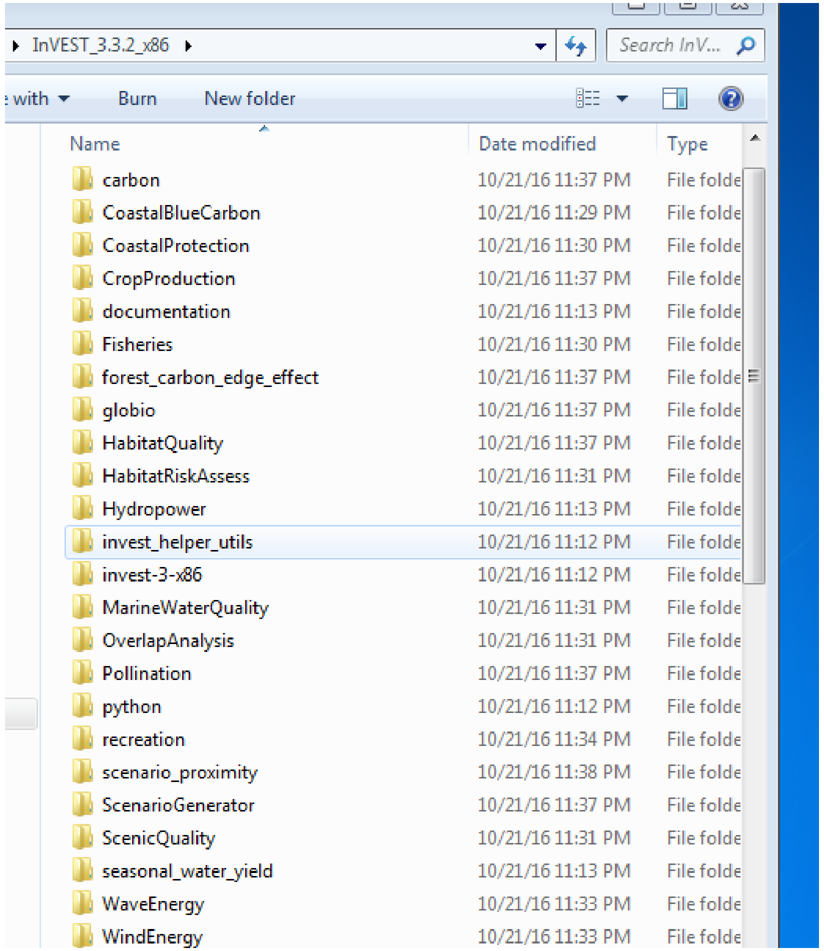
https://app.coolfarmtool.org/

Ecosystem Services: Carbon Benefits Project



teebweb.org

InVEST 3.6.0 (Free Download from Natural Capital Project!)



InVEST
integrated valuation of ecosystem services and tradeoffs

- InVEST has many, many ecosystem service models, in three categories
  - Direct benefit services
  - Proxy services
  - Supporting services
- Each ecosystem service is the output of a combination of unique ecosystem attributes
- Some model only biophysical production of landscape, some model economic value of ecosystem service

InVEST models – full list

Proxy Ecosystem Function: Final Ecosystem Service

- Carbon Storage and Sequestration: Climate Regulation
- Blue Carbon Storage and Sequestration: Climate Regulation
- Water Yield: Reservoir Hydropower Production
- Seasonal Water Yield
- Nutrient Retention: Water Purification
- Sediment Retention: Avoided Dredging and Water Purification
- Coastal Exposure and Vulnerability: Coastal Protection
- Unobstructed Views: Scenic Quality Provision

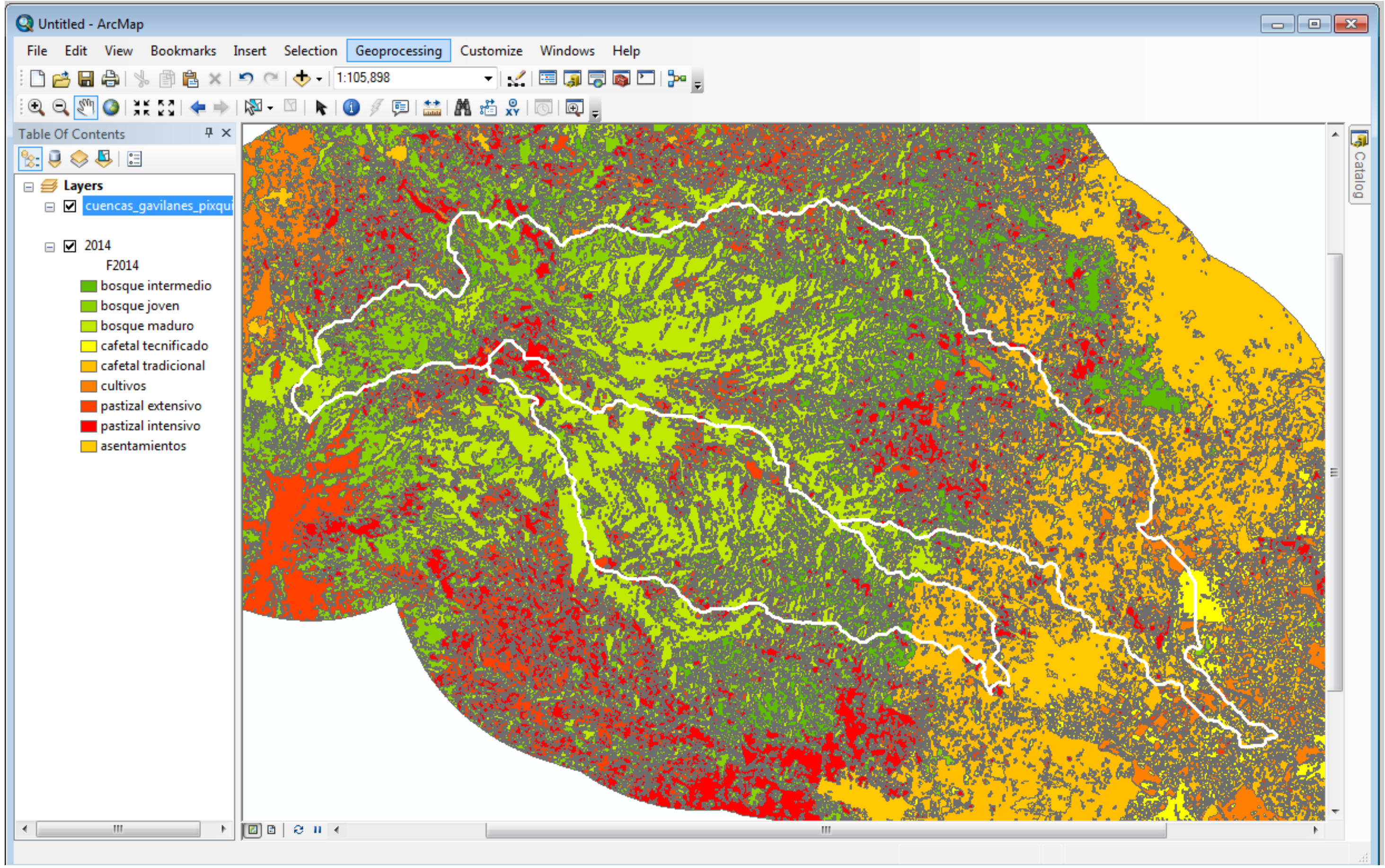
Direct Final Ecosystem Services

- Nature-based Recreation and Tourism
- Managed Timber Production
- Wave Energy Production
- Offshore Wind Energy Production
- Marine Finfish Aquacultural Production
- Marine Fisheries Production
- Crop Production

Supporting Ecosystem Services:

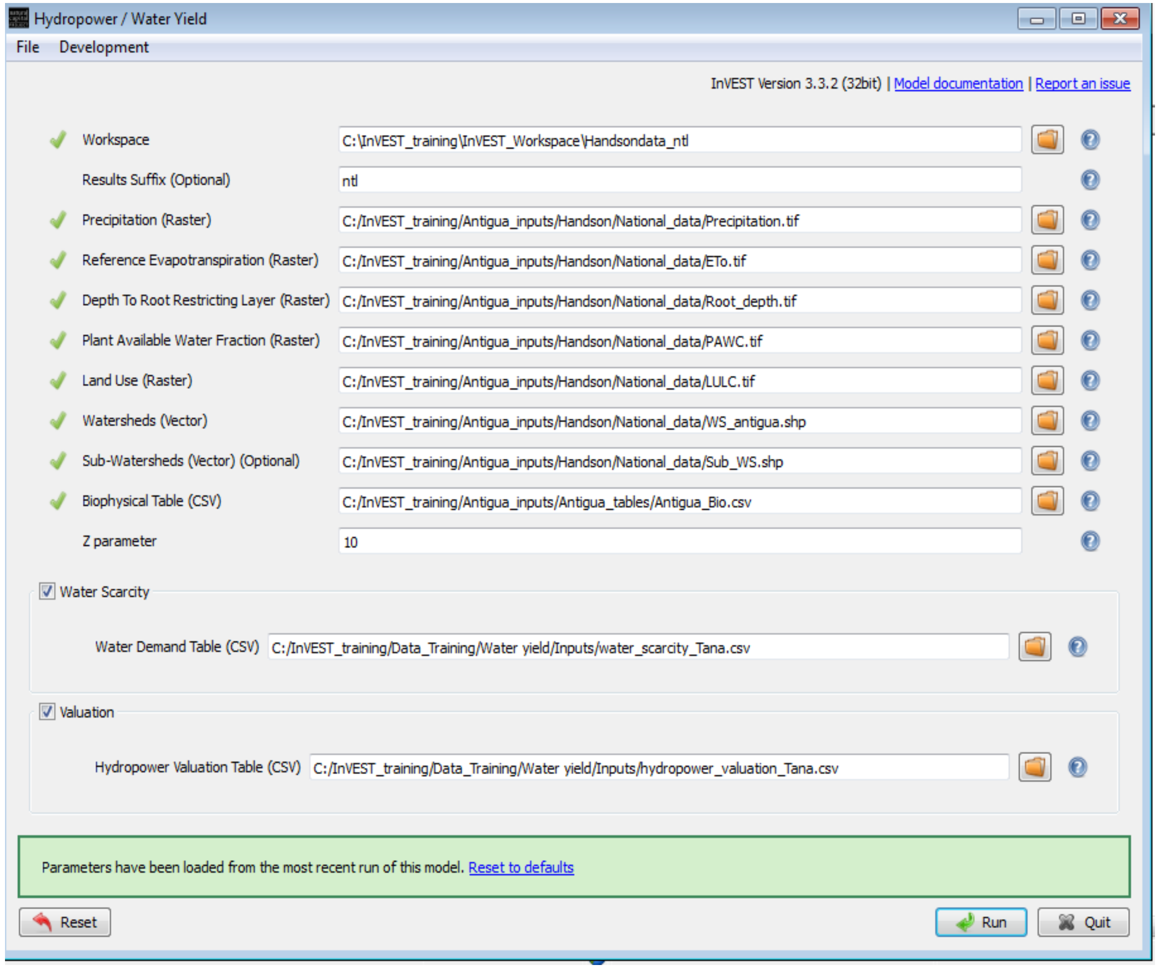
- Pollinator Abundance
- Habitat Risk Assessment
- Habitat Quality

Map "layers"? ArcGIS!



- Land cover
- Land contours (GEM)

Data inputs: Water Yield Model

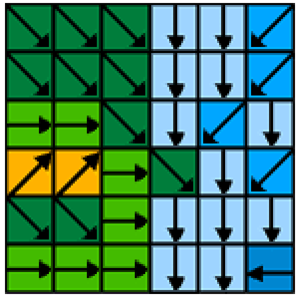


Data Inputs:

- Precipitation rates
- Evapotranspiration rates
- Land use
- Root depth
- Watershed boundaries
- Water Demands
- Hydropower value

Functionality: Pixels

- Attributes of each individual pixel combined with relationships between pixels to model paths for water and nutrient output



Flow direction

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

Flow accumulation

description	lucode	LULC_veg	root_depth	Kc	usle_c	usle_p	load_n	eff_n	crit_len_n	proportion_subsurface_n
Urban and paved roads	1	0	0	0.2	0.99	1	10	0.05	10	0
Bare soil and unpaved roads	2	0	500	0.15	1	1	1	0.05	10	0
Grass	3	1	2000	0.865	0.034	1	8	0.75	300	0
Shrub	4	1	2000	0.3	0.128	1	8	0.75	300	0
General agriculture	5	1	1000	1.1	0.412	1	10	0.5	300	0.5
Tea	6	1	1850	1.015	0.08135	1	10	0.5	300	0.5
Coffee	7	1	1600	1.055	0.4393	1	10	0.5	300	0.5
Mixed forest	8	1	3500	1.008	0.025	1	2.8	0.8	300	0

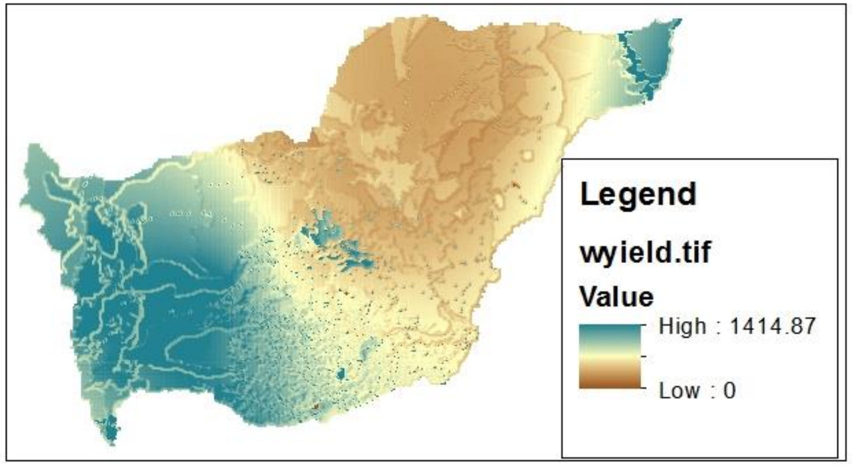
InVEST Outputs:

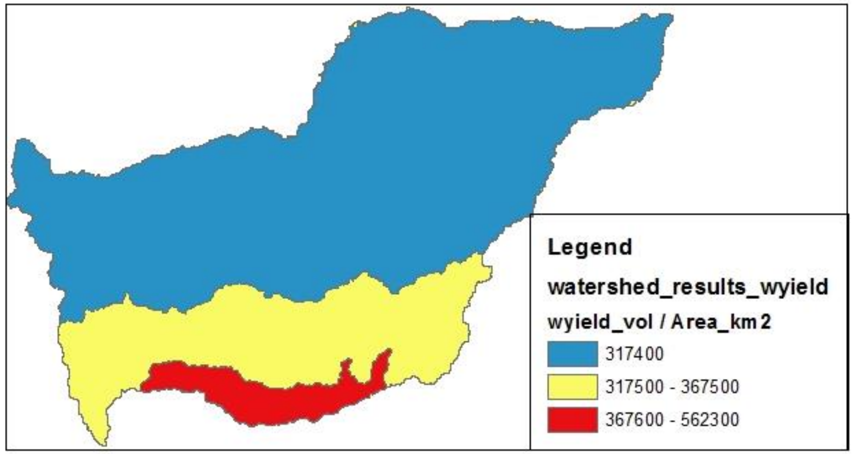
Raster and .dbf files

Example: Water Yield

ws_id	num_pixels	precip_mn	PET_mn	AET_mn	wyield_mn	wyield_vol
1	9104176.00	1089.20	1086.99	698.79	367.74	753299489.71
2	6448283.00	983.52	978.48	639.67	317.62	460820856.11
3	480454.00	1494.66	1500.11	932.59	561.80	60731325.92

- Output available by pixel, or by watershed





InVEST Summary

- Free software does heavy lifting to model ecosystem services spatially
- Requires many data layers;
- Model results are simple maps and tables, but should be interpreted carefully to understand numbers and distribution of ecosystem service benefits
- Does not distinguish well between STOCK of Natural Capital and FLOW of ecosystem services
- Outputs, particularly value outputs, are sensitive to assumptions and parameters (e.g. price per ton of CO2 for Carbon model)

Model Selection

Address the guiding questions below:

Q1
WHAT POLICY QUESTION DO WE WANT TO ADDRESS USING AN ECOSYSTEM SERVICE MODEL?

- Where should we allocate funds for restoration to get the most impact?
- If we invest in landscape restoration, will it help those in poverty?
- Would we save money in providing water services by restoring a certain wetland?

Q2
HOW CAN WE FRAME THIS QUESTION TO GET MEANINGFUL OUTPUTS FROM THE MODEL?

- Which are the most effective locations for land use change/ restoration to improve specific services (e.g., sediment retention or flood alleviation)?
- What are the economic benefits of landscape restoration for those who depend on the ecosystem services (e.g., fuelwood, forest products, grazing, water) for their livelihoods?
- What are the economic benefits of cleaner water created by restoring this wetland?

Q3
WHAT ECOSYSTEM SERVICES ARE IMPORTANT FOR OUR DECISION-MAKING AND WHAT IS THEIR GEOGRAPHIC SCALE?

- Carbon storage
- Water supply
- Water quality
- Crop pollination
- Agricultural production
- Erosion control
- Coastal protection
- Pest regulation
- Recreation and tourism
- At what scale will ecosystem services be modeled: sub-catchment, municipality level, country level, or beyond?

Q4
WHAT FORMATS (BIOPHYSICAL, ECONOMIC, MAPS) ARE NEEDED FROM THE MODEL OUTPUTS?

- Are biophysical or economic outputs needed?
- Are mapped outputs needed?

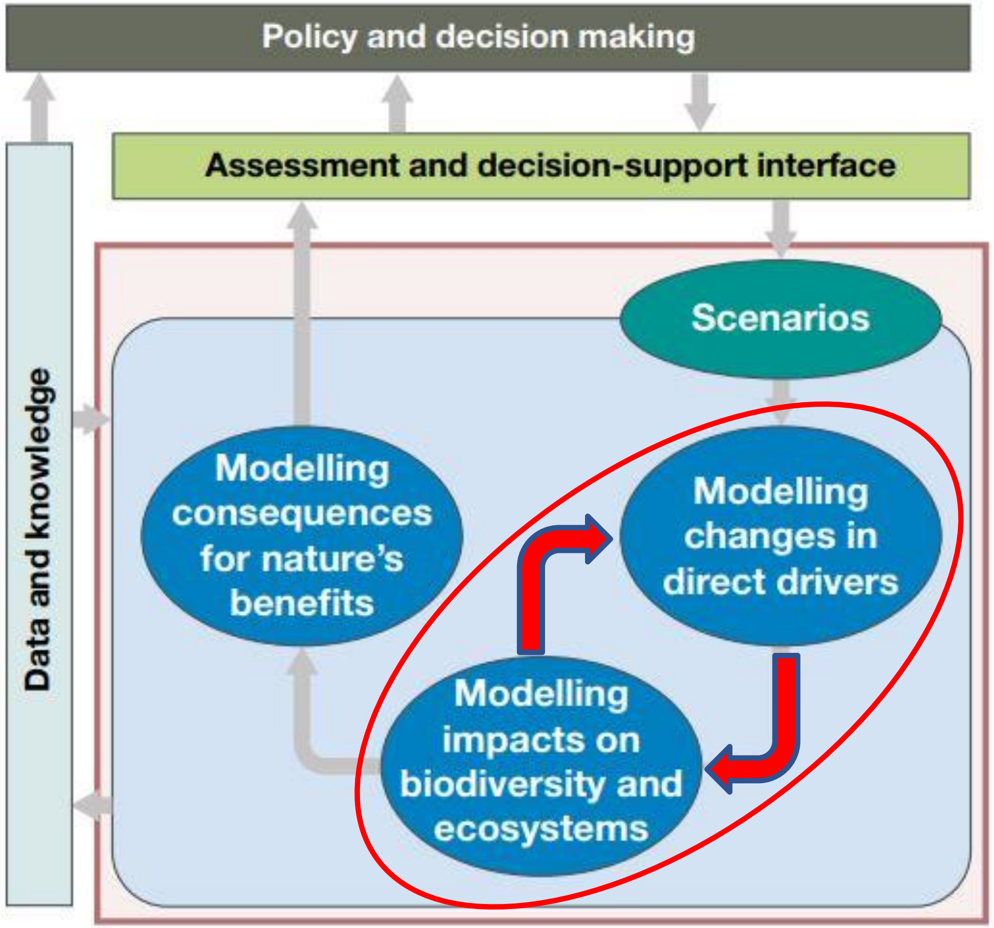
Q5
WHAT LEVEL OF ACCURACY IS NEEDED FOR THIS DECISION?

- Very accurate service estimates to represent the health of current ecosystems
- Very accurate service estimates for predicting future availability
- Moderately accurate estimates of the economic value of ecosystems
- Moderately accurate estimates of the most important locations for delivery of a service

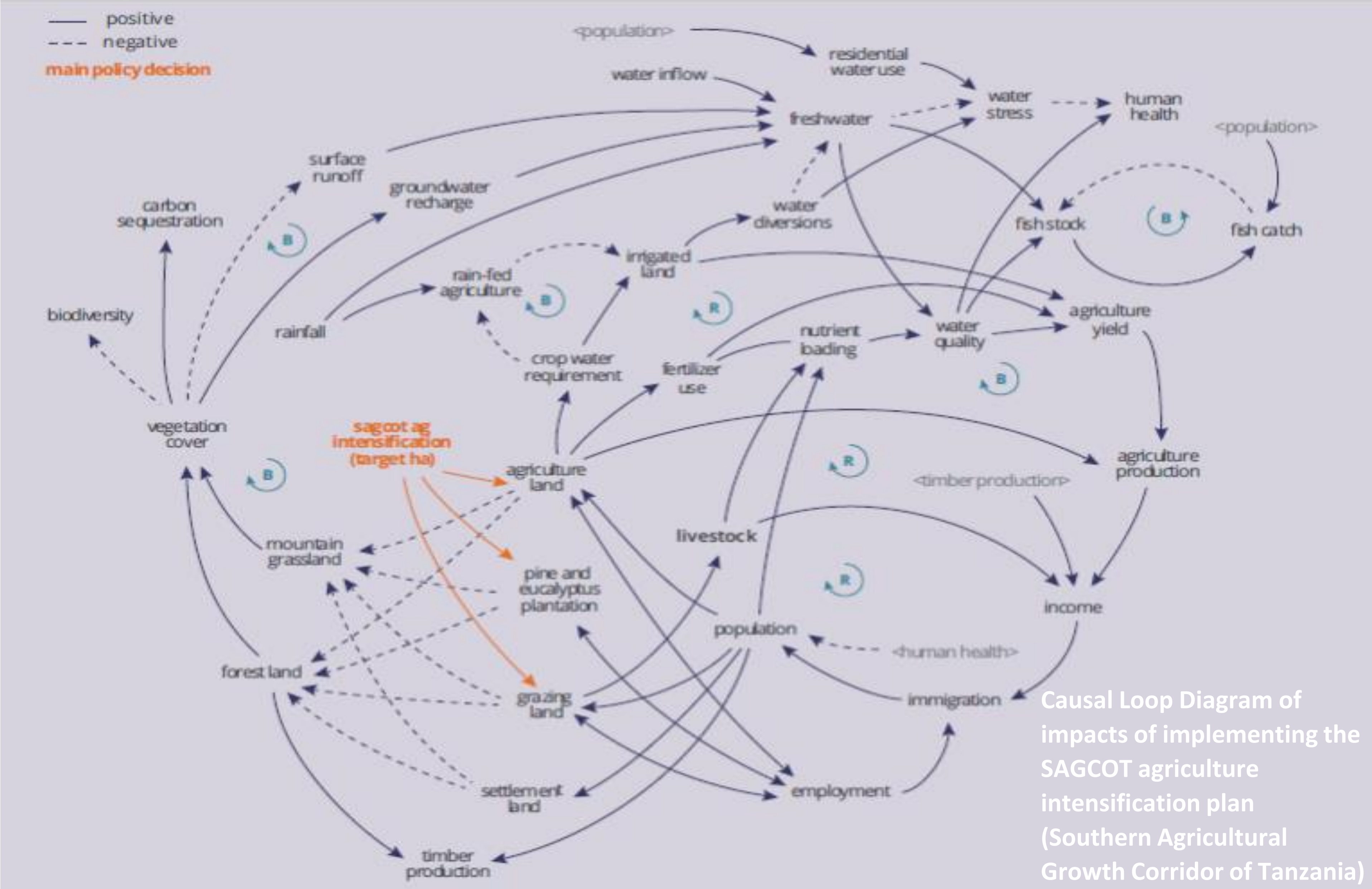
[WRI Guide for Selecting Ecosystem Services Models for Decision Making]()

Model Selection

- Models range from user-friendly apps to complex connections of algorithms programed in a statistical software
- What information do you need to make a decision or develop a policy?
- Is a simple cause -> effect model sufficient? Or do we need to know about ecosystem service?
- Do we need to include feedback loops ("system dynamics")?



TEEB Tanzania - getting the story straight about potential conflicting interests within the agriculture and natural resources sector

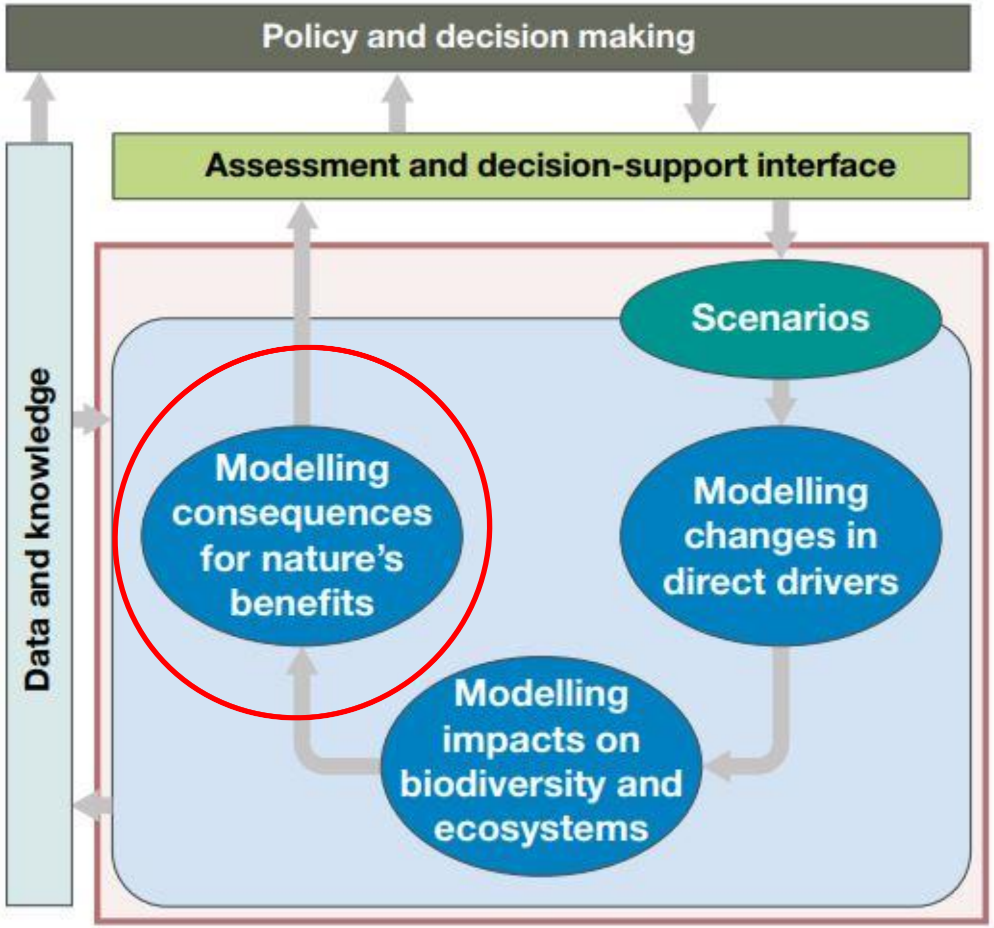


Causal Loop Diagram of impacts of implementing the SAGCOT agriculture intensification plan (Southern Agricultural Growth Corridor of Tanzania)

eebweb.org

Model Selection

- What information do you need to make a decision or develop a policy?
- Is a simple cause -> effect model sufficient? Do we need to know about ecosystem services? Or, do we need more?
- What are the IMPACTS to livelihoods and to the economy?



Is the economic value of natural resources important?

- How much do we benefit from natural ecosystems?
- What would be the benefits and costs of an activity that alters the environment (such as a new project, regulation or program)?
- What are the tradeoffs between resource protection, resource management, resource exploitation?
- How much money is it worth spending to protect an ecosystem?

Modeling AgriFood Systems: Valuation

Economic Impact Analysis

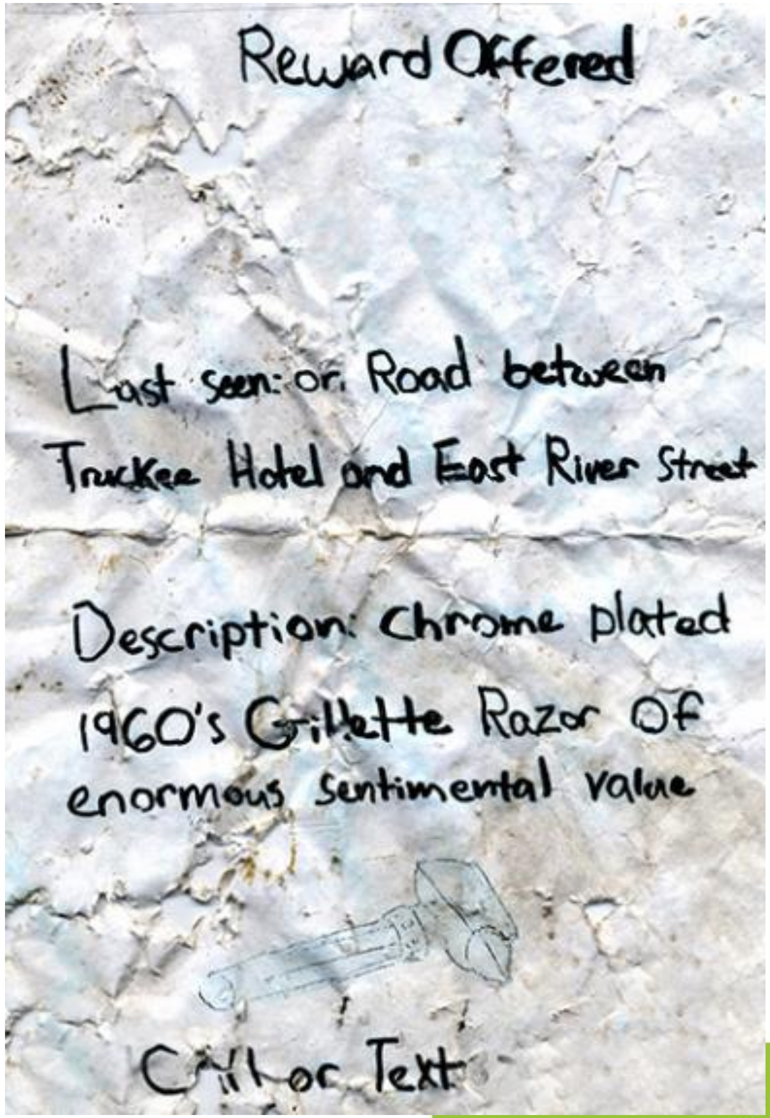
- Dollars spent or "Financial Value"
- Household livelihood impacts / Jobs
- National (macroeconomic) impacts

Valuation

- Net Benefit or "Worth"
- Willingness-to-Pay
- Market values
- Non-market values
- Benefits and Costs

Issues:

- Potential Value vs. Current Value
- Annual Value vs. Net Present Value



Can you measure ecosystem services in dollars?

teebweb.org

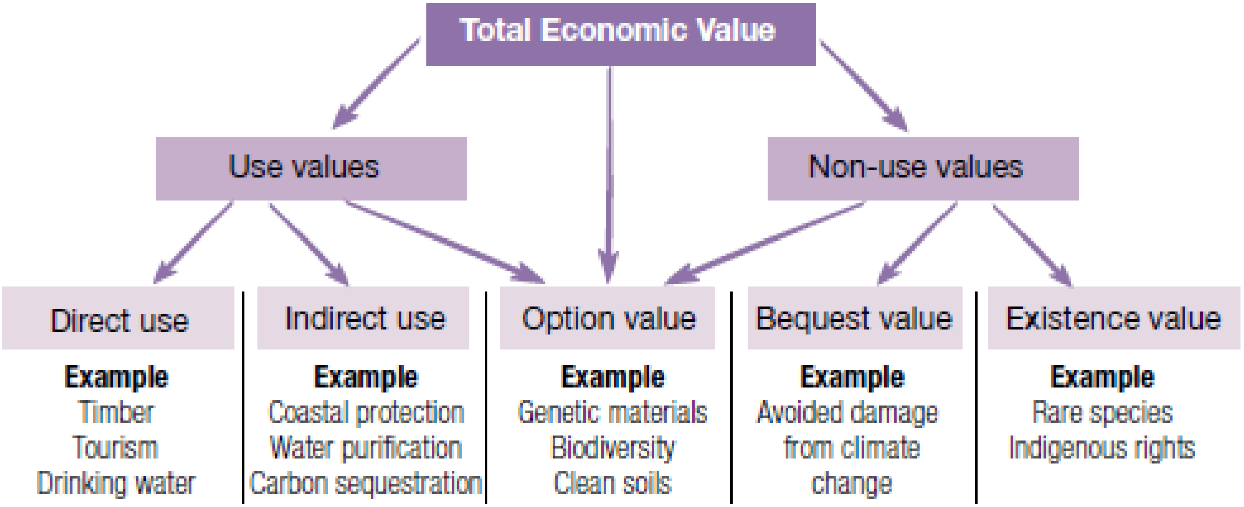
Economic Value ≠ Financial Value

Valuation does not PUT a price, it REVEALS or estimates two things:

i. How much nature contributes to our lives, livelihoods, jobs, businesses

ii. How much we pay, currently, for ecosystem benefits

- Economic ACTIVITY = money and jobs
- Economic VALUE = human benefits, well-being, happiness!



The Economics of Ecosystems & Biodiversity

USE VALUES

Direct values

Outputs that can be consumed or processed directly, such as fish, timber, fuel, non-timber forest products, medicines, wild foods, etc.

Indirect values

Ecological services, such as flood control, regulation of water flows and supplies, nutrient retention, climate regulation, etc.

NON-USE VALUES

Option values

Value placed on maintaining resources and landscapes for future possible direct/indirect uses, some of which may not be known now.

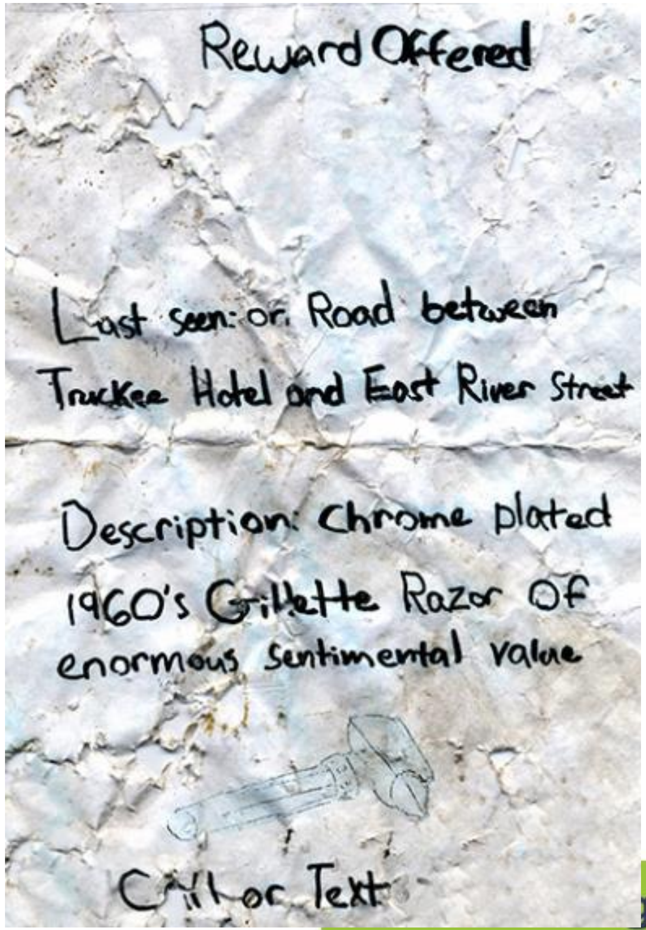
Existence values

Value of landscapes and specie, such as cultural, aesthetic, bequest significance just to exist.

How do you value the “priceless” gifts of nature?

Valuation models unique for each ecosystem service. Appropriate method depends upon the answers to these questions:

- Is the ecosystem bought and sold? (Direct market value)
- Is the ecosystem related to things that are bought and sold? (Indirect market value)
- What kind of data do we have? What can we collect?
- What kind of value do we want measure to? Price or Economic value? Current value or potential value?
- Who’s value? Business? Consumer or household? Community? Country? International value?



Economic valuation example:

Food value of artisanal maize farming in Mexico =

KG of crop harvested x Market price of market replacement – Time and input costs

- Replacement cost value represents BENEFITS, not dollars being spent

BUT, Total Economic Value also includes:

\+ Cultural value of growing maize

\+ Public benefit of greater genetic diversity of maize because of generations of small producers saving seeds

Economic valuation approaches:

- Replacement cost (Subsistence, value of pollination)
- Production function - How much does nature contribute to output? (Commercial ag)
- Avoided cost - What would be the costs if we didn’t have nature? (e.g. erosion or sedimentation)
- Revealed preferences (Tourism expenditures, or value of housing)
- Stated preferences

Thank you

Come and look for us at

teebweb.org

Chalet in mountain ecosystem in Switzerland, credit: Olivier