Presentation given the TransLinks workshop:

Modeling and Managing Watersheds

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Modeling and Management

Watershed Workshop: Universal Soil Loss Equation and InVEST

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Outline

- Universal Soil Loss Equation Overview
- InVEST Version 2.0

Excessive Erosion

- Consequences
  - Loss of organic matter and nutrients which reduces fertility of land
  - Degrades soil structure, reduces water holding capacity, which causes increased runoff of water and soil
  - Increased sediment in rivers, streams, and oceans
    - Kills certain aquatic species and prevents others from reproducing
    - Decreases water quality for people

Universal Soil Loss Equation

$$A = R * K * LS * C * P$$

A: Average annual soil loss (Tons/ha*yr)
R : Rainfall and runoff erositivity
K: Soil erodibility
LS: Slope length-gradient factor
C: Crop and management Factor
P: Support practice factor

USLE

- Universal Soil Loss Equation
  - Developed at National Runoff and Soil Loss Data Center in 1954 by Science and Education Administration
  - More than 10,000 plot-years runoff and soil loss data from 49 federal research projects throughout the United States

USLE

- Universal Soil Loss Equation
  - Developed to allows users to predict the average rate of soil erosion for certain crop system, management techniques, and control practices on a site basis
    - Designed to model sheet and rill erosion
    - Does not predict deposition, sediment yield from gully, streambank, and streambed erosion
    - Compare the rates predicted by the model to soil loss tolerances for the site leads to erosion management plans

USLE: DATA REQUIREMENT

- Digital Elevation Model
  - Calculate slope for length slope gradient factor
- Rainfall Erosivity
  - Precipitation
- Soil Erodibility
  - Soils data
- Landuse Landcover
  - Crop and management factor for each landuse type
  - Support practice factor for each landuse type

USLE: Slope Length Gradient Factor

- Digital Elevation Model (DEM)
  - Needed to calculate slope
  - Input in WCS/USFS Project
    - ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer
    - Resolution: 30 meters x 30 meters

USLE: R Factor

- Rainfall Erosivity (R)
  - Requirements
    - Raster representing rainfall intensity
    - SI Units: MJ*mm / ha*h*yr
  - Input in WCS/USFS Project
    - Calculated using Renard and Freimund (1994) Fournier Index Method
    - US Customary Unit:
      - Hundreds of foot * tonf * inch/acre * h *yr
    - Convert to SI multiply by 17.02

$$\text{R–factor} = (0.07397\,F^{1.847})/17.2 \quad \text{when } F < 55\text{ mm}$$

$$\text{R–factor} = (95.77-6.081*F+0.4770*F^2)\,/17.2 \quad \text{when } F >= 55\text{ mm}$$

$$F = \frac{\sum_{i=1}^{12} P^2_i}{\sum_{i=1}^{12} p_i}$$

Where, P_i is monthly precipitation (mm/month) and F is modified Fournier coefficient

USLE: K Factor

- Soil Erodibility (K)
  - Requirements
    - GIS raster representing ability of soil to move by rainfall and runoff
    - SI Units: T*ha*h / ha*MJ*mm
  - Input in WCS/USFS Project
    - Calculated using Wischmeier and Smith (1978)
    - Soils should be average over the profile
    - Harmonized World Soil Database (HWSD) Version 1.1
      - Spatial Resolution: 1 km x 1 km
      - Database contains
        - » Genera l info of soil units
        - » Information on phases
        - » Physical and chemical properties for topsoil (0-30 cm) and subsoil (30-100 cm)

USLE: K Factor

- Soil Erodibility (K)

$$= 27.66 * m^{1.14} * 10^{-8} *(12 - a) + (0.0043 * (b - 2)) + (0.0033 * (c - 3))$$

- m = (silt% + very fine sand%) * (100 – clay%)
- a = organic matter %
- b = structure code: 1-4
  - 1: very structured or particulate; 2: fairly structured; 3:slightly structured ; 4: solid
- c= profile permeability code: 1-6
  - 1: rapid; 2: moderate to rapid; 3: moderate; 4: moderate to slow; 5: slow; 6: very slow

USLE: K Factor

- Soil Erodibility (K)
  - Organic Matter (OM)
    - HWSD provided percent organic carbon
    - OM = Organic Carbon * 1.724
  - Soil Permeability Code
    - Permeability is the ability of soil to allow fluids to pass through it.
    - No information on permeability is provided in HWSD
    - Information was provided on soil texture
    - Correlations between soil texture and infiltration rates

USLE: K Factor

City of Knoxville, TN
BMP Manual, May 2003

Table ST-03-1
Typical infiltration Rates from USDA Soil Texture

	USDA Soil Texture	Typical Water Capacity (inches per inch of soil)	Typical Infiltration Rate (inches per hour)	Hydrologic Soil Group
*	Sand	0.35	8.27	A
**	Loamy sand	0.31	2.41	A
**	Sandy loam	0.25	1.02	B
**	Loam	0.19	0.52	B
	Silt loam	0.17	0.27	C
	Sandy clay loam	0.14	0.17	C
	Clay loam	0.14	0.09	D
	Silty clay loam	0.11	0.06	D
	Sandy clay	0.09	0.05	D
	Silty clay	0.09	0.04	D
	Clay	0.08	0.02	D

* - Suitable for infiltration with typical 6' to 8' separation from seasonal high groundwater
** - Suitable for infiltration with at least 3' separation from seasonal high groundwater

Same as Permeability Class

USDA NRCS, Soil Quality Test Kit Guide
July, 2001

Table 3. Infiltration rates and classes.

Infiltration rate (minutes per inch)	Infiltration rate (inches per hour)	Infiltration class
< 3	> 20	Very rapid
3 to 10	6 to 20	Rapid
10 to 30	2 to 6	Moderately rapid
30 to 100	0.6 to 2	Moderate
100 to 300	0.2 to 0.6	Moderately slow
300 to 1,000	0.06 to 0.2	Slow
1,000 to 40,000	0.0015 to 0.06	Very slow
> 40,000	< 0.0015	Impermeable

USLE: C and P Factor

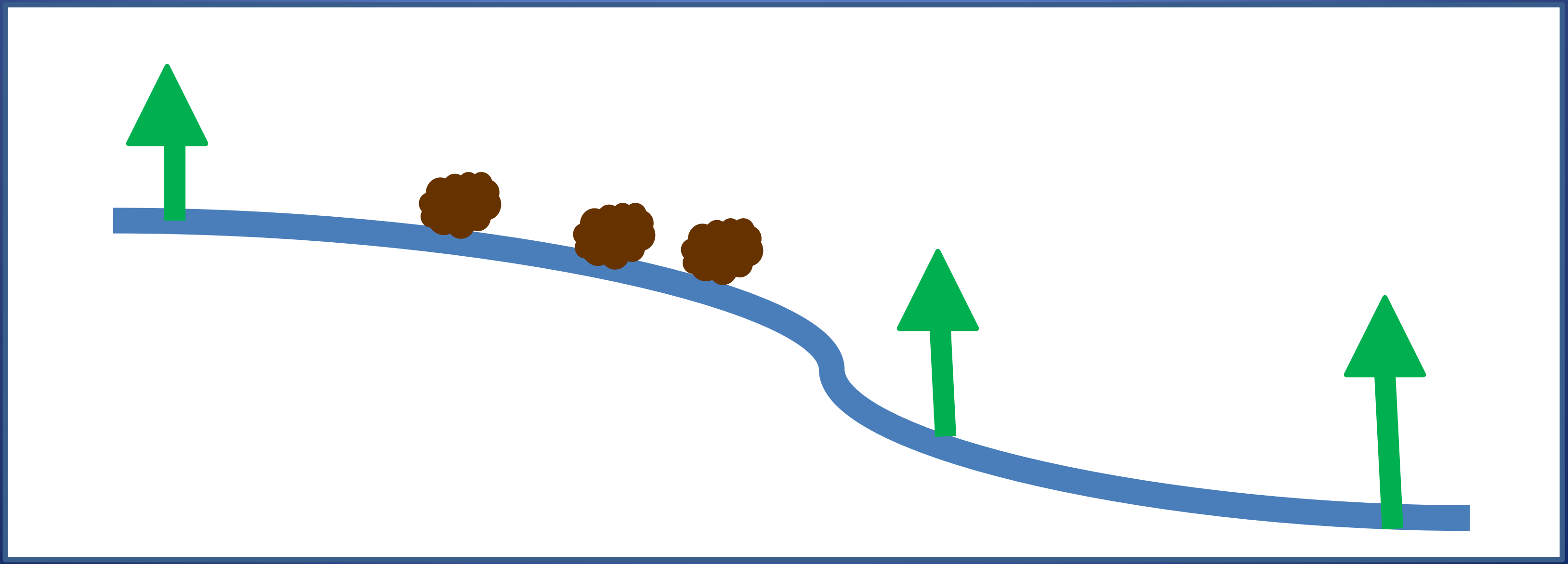
- (C) Cover and management factor
  - The ratio of soil loss from land with a specified type and amount of cover to the corresponding loss from a clean tilled continuous fallow site. Fallow site has value 1, any ground cover reduces C factor and soil loss on the site.
- (P) Support practice factor
  - It reflects the effects of practices that will reduce the amount and rate of the water runoff thus reducing the amount of erosion. Only used in row cropped landuse all other landuse given a value of 1.

USLE: C and P Factor

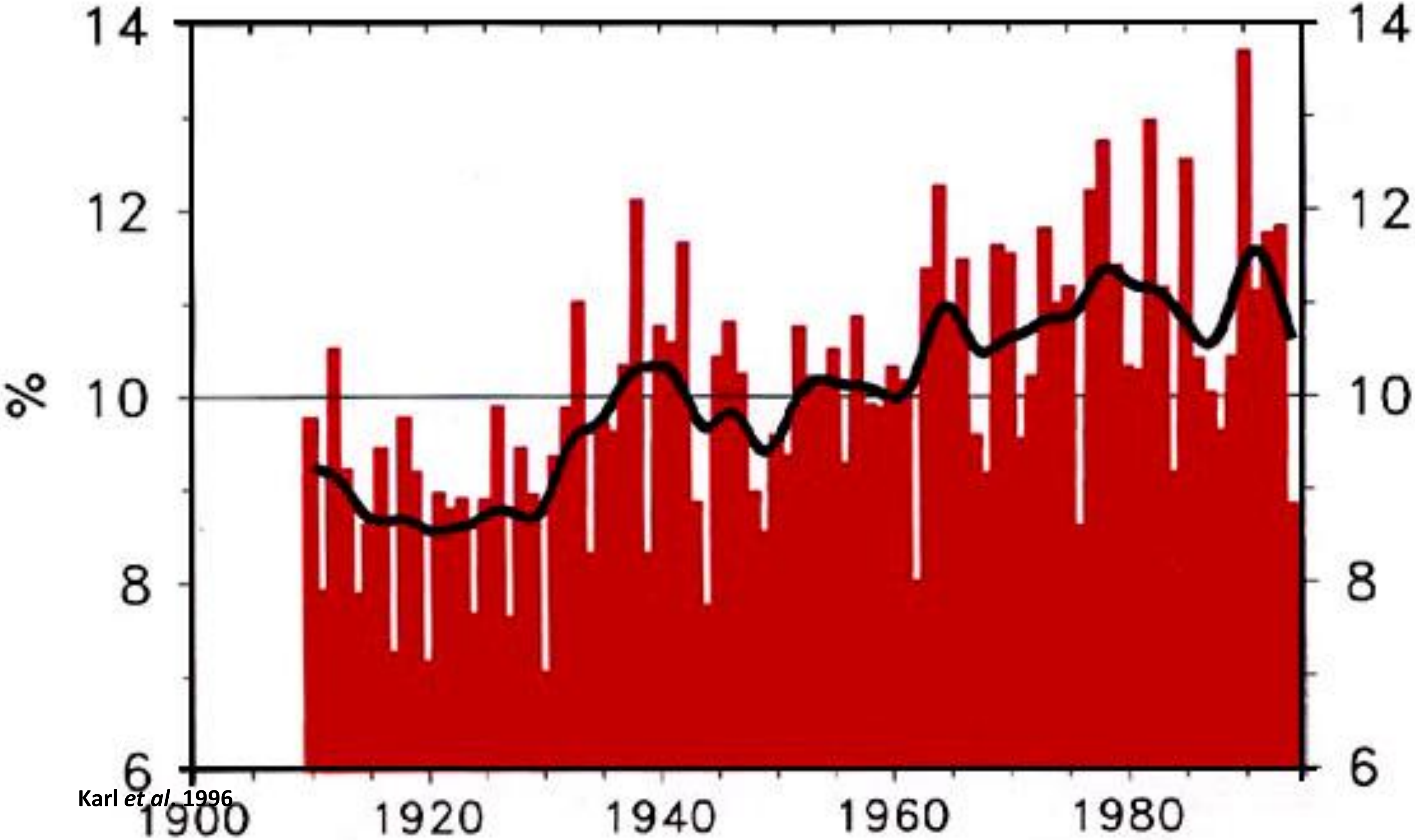
- Landuse /Landcover
  - Needed for C and P Factor
  - Input in WCS/USFS Project
    - European Space Agency Globcover Dataset
    - Year 2009
    - Resolution: 300 meters x 300 meters
    - 22 landuse classes

InVEST : Sediment Retention

- Role of vegetation
  - Keeps sediment from eroding
- Vegetation Retention Efficiency

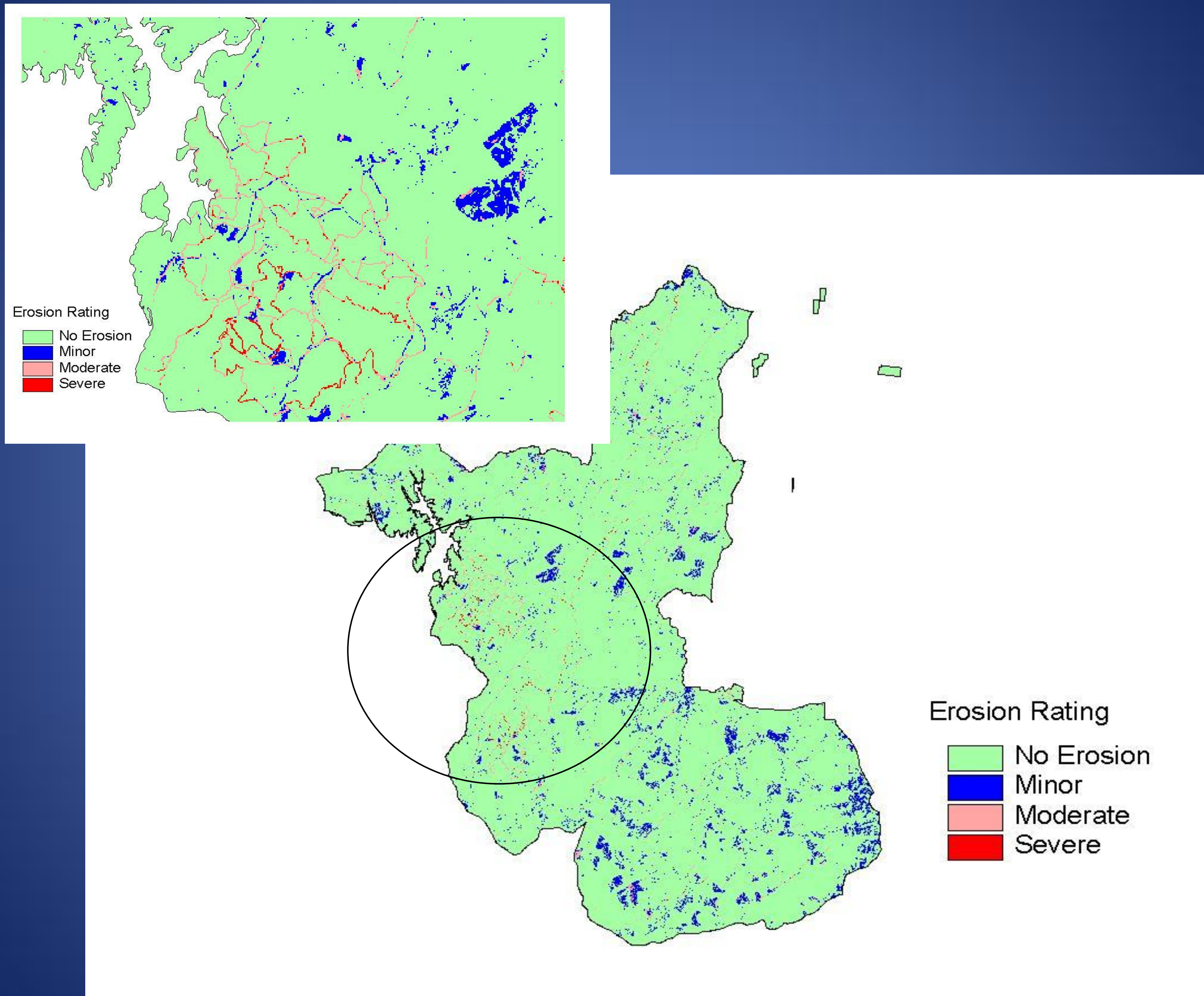


Percent of the continental USA with a much above normal proportion of total annual precipitation from 1-day extreme events (more than 2 inches or 50.8mm)

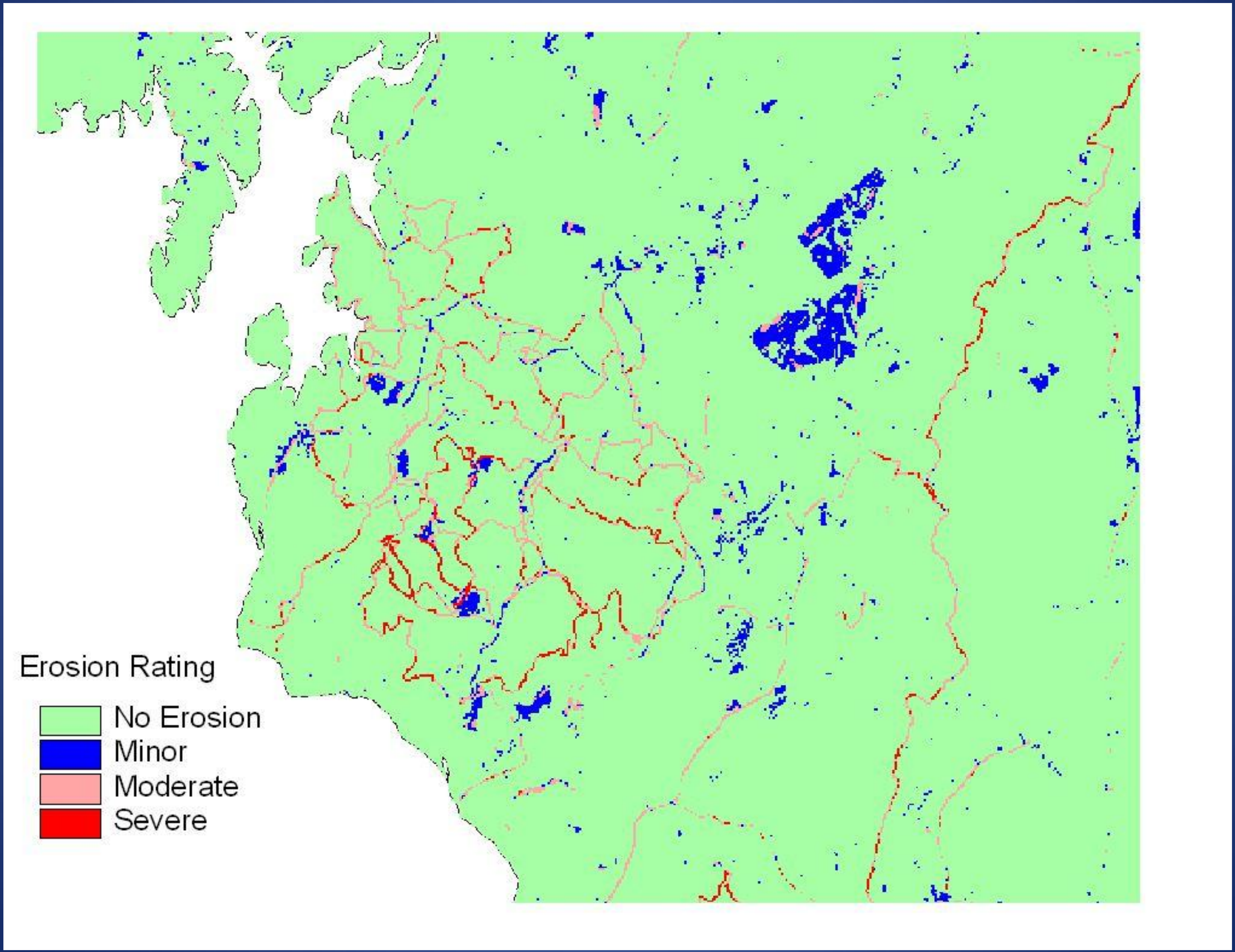


Karl *et al.* 1996

Uwharrie National Forest Current Soil Erosion Map



Areas of Soil Erosion By 2030 On UNF



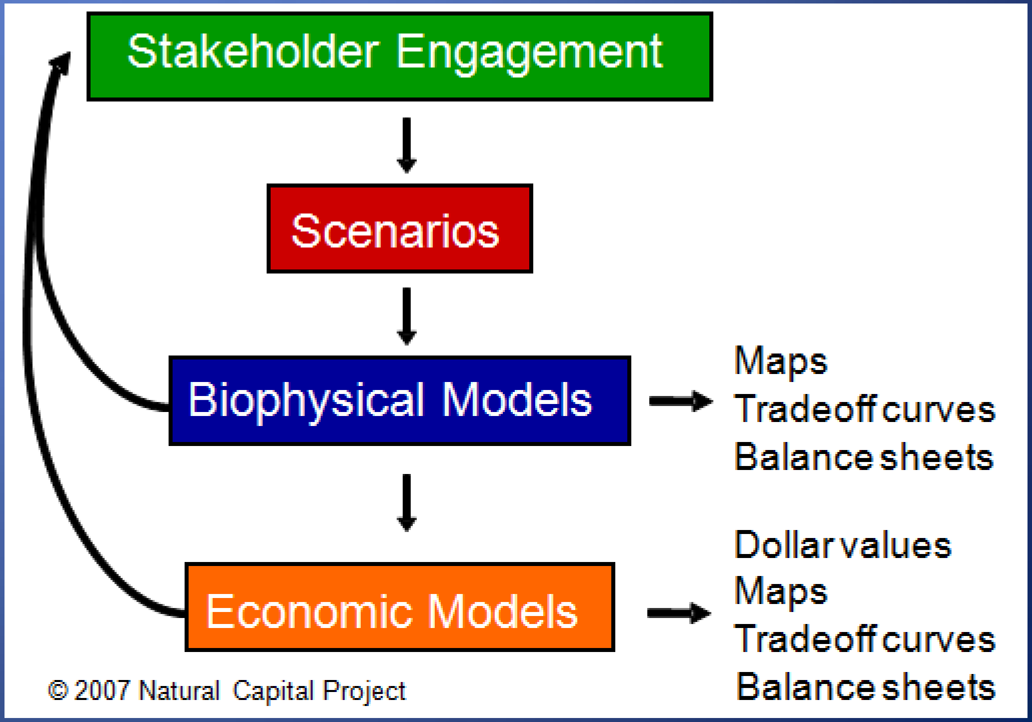
INVEST VERSION 2.0 OVERVIEW

Model

- InVEST: Integrated Valuation of Ecosystem Services and Tradeoffs
  - Partners:
    - Stanford University's Woods Institute for the Environment,
    - University of Minnesota's Institute of the Environment
    - The Nature Conservancy
    - World Wildlife Fund

InVEST 2.0

- Process and Results
  - Biophysical Models
    - Quantifies the amount of the ecosystem service (i.e. amount of sediment loss in tons)
  - Economic Models
    - Estimates the value for that ecosystem service (i.e. dollar cost of removing the sediment)



InVest 2.0

- Design
  - Tiered approach
- Toolbox
  - ESRI ArcGIS ArcToolBox environment
  - 11 models
  - More in development

TIER 1 Models	TIER 2 Models	TIER 3 Models
Simplest models; ignore certain real processes	Incorporate more real processes	Most complex; dynamic, process-based models
Least data required	More data required	Most data required
Annual average time step, no temporal dynamics	Daily to monthly time step, some temporal dynamics	Daily to monthly time step, temporal dynamics with feedbacks and thresholds
Appropriate spatial extent ranges from sub-watershed to global	Appropriate spatial extent ranges from parcel to global	Appropriate spatial extent ranges from parcel to global
Low precision estimates best for identifying areas of high & low ecosystem service production	More precise estimates of ecosystem service delivery	More precise estimates of ecosystem service delivery
No ecosystem service interactions	Some ecosystem service interactions	Sophisticated ecosystem service interactions with feedbacks and thresholds
Produce either absolute values or relative indices	Produce absolute values	Produce absolute values

Tallis et al., 2010

InVest 2.0

- Software Requirement
  - ARCGIS 9.3 (service pack 1 or 2)
  - ArcInfo level license
  - Spatial Analyst extension installed & activated
  - Python 2.5 or higher
  - Tool runs as scripts in ArcToolbox

InVEST 2.0 Models

- Wave Energy Model
- Coastal Vulnerability Model
- Marine Fish Aquaculture
- Aesthetic Quality
- Biodiversity: Habitat Quality & Rarity
- Carbon Storage and Sequestration
- Reservoir Hydropower Production
- Water Purification: Nutrient Retention
- Sediment Retention Model
- Managed Timber Production Model
- Crop Pollination

InVest 2.0

- Sediment Retention Model
  - What it does:
    - “Calculates the average annual soil loss from subwatershed
    - Determines how much soil will arrive at a certain point
    - Estimates the ability of each parcel to retain sediment
    - Assess the cost of removing accumulated sediment on an annual basis”

Tallis et al., 2010

InVest 2.0

- Sediment Retention Model
  - How it does it:
    - Universal Soil Loss Equation
    - Sediment Retention
    - Sediment Services
      - Avoided Sedimentation of Reservoirs
      - Water Quality
    - Sediment Valuation

DATA REQUIREMENT

- Digital Elevation Model
- Rainfall Erosivity
- Soil Erodibility
- Landuse Landcover
- Watersheds
- Subwatersheds
- Biophysical Table
- Threshold Flow Accumulation
- Slope Threshold
- Sediment Threshold Table
- Sediment Valuation Table (optional)

DATA REQUIREMENTS

- Watershed/Subwatersheds
  - Requirements
    - Polygon shapefile
    - Each watershed /subwatershed must have a unique id (integer)
    - Columns with names ws_id and subws_id must appear in attribute table and contain the unique id number.
    - Maximum extent of a watershed/subwatershed is 4000x4000 cells.
  - Input in WCS/USFS Project
    - Delineated from ASTER DEM using ArcGIS hydro tools
    - Rwanda: wshed, 21; subws,295
    - Tanzania: 400
    - Zambia: 266

DATA REQUIREMENTS

- Biophysical Table
  - Requirements
    - dbf or mdb table with the following columns:
    - lucode: a unique number representing each landcover class (integer)
    - LULC_desc: a description of the landcover class
    - usle_c: cover and management factor x 1000
    - usle_p: practice factor X 1000
    - sedret_eff: sediment retention value. A percent between 0-100
  - Input in WCS/USFS Project
    - Referred to literature to obtain values for c and p
    - Referred to invest manual to obtain values for sediment retention

DATA REQUIREMENTS

- Threshold Flow Accumulation
  - This number determines how many cells must flow into a cell before it is considered a stream.
  - Can compare known stream layer to v-stream raster created by this threshold
    - Requirement: integer number
    - Value used: 1000(default) and 6500
- Slope threshold
  - This number represents the slope at which terracing becomes necessary .
    - Requirement: integer number
    - Value used: 75

DATA REQUIREMENTS

- Sediment Threshold Table
  - Requirements (optional)
    - dbf or mdb table with the following columns:
    - ws_id: watershed unique id
    - dr_time: remaining lifetime for the reservoir of interest. (integer)
    - dr_deadvol: Volume of water below turbine than can not be released by gravity. Sediment can collect here. Number in cubic meters
    - wq_annload: Allowed annual sediment loading in metric tons, a number set by water quality standards.
  - Input in WCS/USFS Project
    - Dredging or Water quality option
    - Referred to literature to obtain values or used sample values from invest manual

DATA REQUIREMENTS

- Sediment Valuation Table (optional)
  - Requirements
    - dbf or mdb table with the following columns:
    - ws_id: watershed unique id
    - dr_cost: cost of sediment dredging in currency/cubic meter removed
    - dr_time: remaining lifetime for the reservoir of interest. (integer)
    - dr_deadvol: Volume of water below turbine than can not be released by gravity. Sediment can collect here. Number in cubic meters
    - dr_disc: rate of discount over time span, used in net present value calculations
    - wq_cost: cost of removing sediment for water quality or treating water in currency/cubic meter removed
    - wq_time: same as dr_time
    - Wq_disc: rate of discount over time span.

DEMO