natural capital PROJECT

# SEDIMENT RETENTION MODEL

Hands-on training session

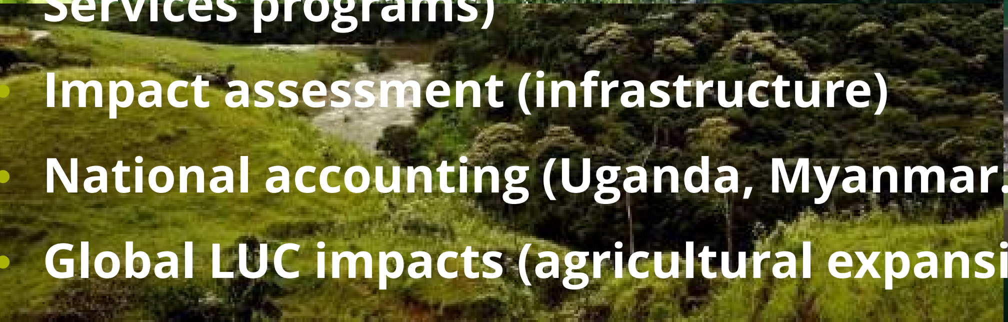
Perrine Hamel, Brad Eichelberger, Kim Falinski, Jesse Gourevitch

# OBJECTIVES

- Learn where and how the model can be applied
  - Typical decision contexts
  - Case study in Hawai'i
- Learn about the model theory
- Practice running the model and interpreting outputs (different scenarios)

# WHAT WE WON'T DO

- Go over your own data (please join Sandbox sessions!)
- Go into the details of valuation of the service

- Water Funds (Payment for Watershed Services programs)
- Impact assessment (infrastructure)
- National accounting (Uganda, Myanmar...)
- Global LUC impacts (agricultural expansion)

# TYPICAL DECISION CONTEXTS

- Water Funds (Payment for Watershed Services programs)
  - Where should we implement activities?
  - What is the return on investment?
- Global LUC impacts (agricultural expansion)
- National accounting (Uganda, Myanmar…)
- Impact assessment (infrastructure)

Services to downstream beneficiaries:
- health and well-being (water quality),
- economic returns (hydropower, water treatment plant)
- stream health (biological integrity)

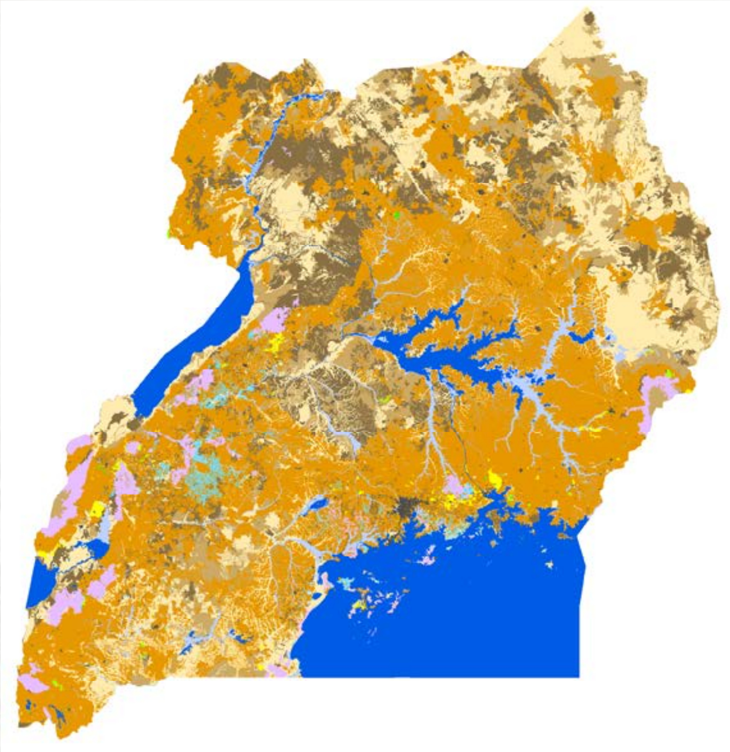
# IUCN: UGANDA

Improving investments in forest restoration to promote ecosystem service delivery

# DECISION CONTEXT

## ES PROVISION THROUGH FOREST LANDSCAPE RESTORATION





**Objectives:**

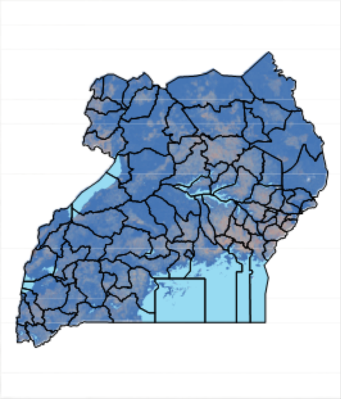
- Increase provision of multiple ecosystem services through forest landscape restoration

**Constraints:**

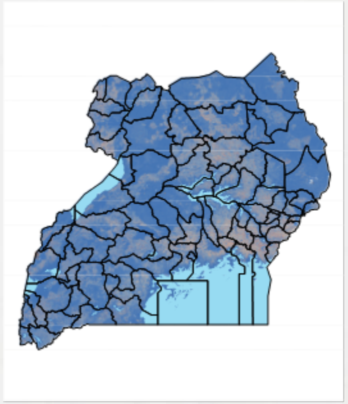
- Restore 2.5 million ha of degraded forest

# STEP 1: SCORE LANDSCAPE WITH SEDIMENT EXPORT

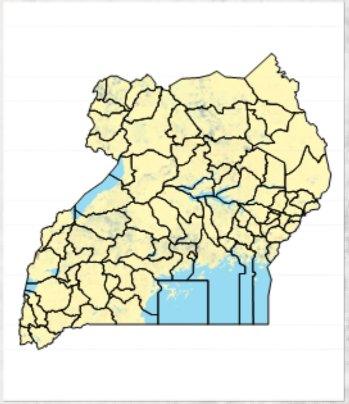
Sediment Export
Restored LC Scenario



Sediment Export
Current LC Scenario

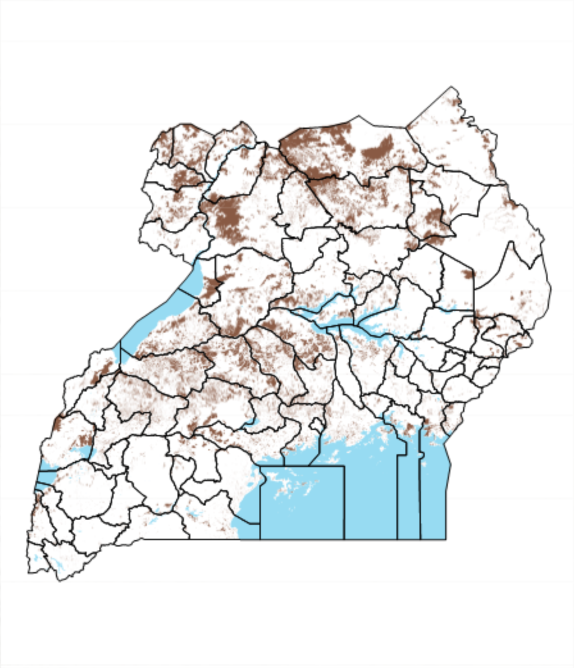


Reduction in
sediment export

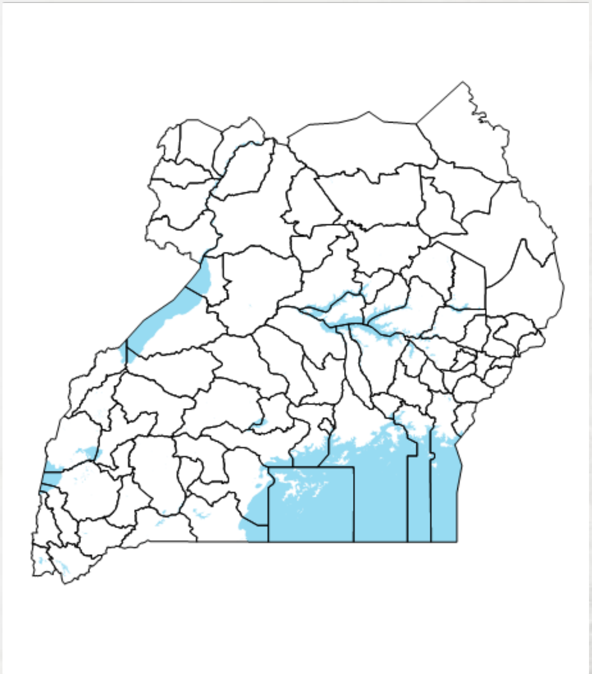


# STEP 2: DEFINE RESTORATION OPPORTUNITIES AND UNITS OF AGGREGATION

Parcels of degraded land

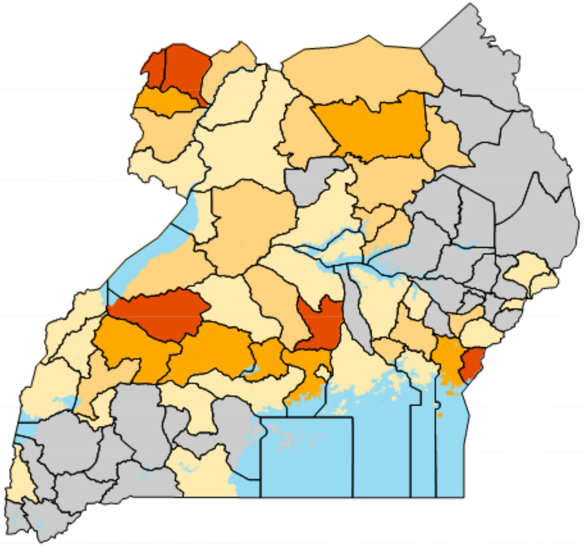


Districts



## STEP 3: SCORE DISTRICTS ACCORDING TO VALUE OF RESTORATION OPPORTUNITIES

Mean reduction in sediment export by district

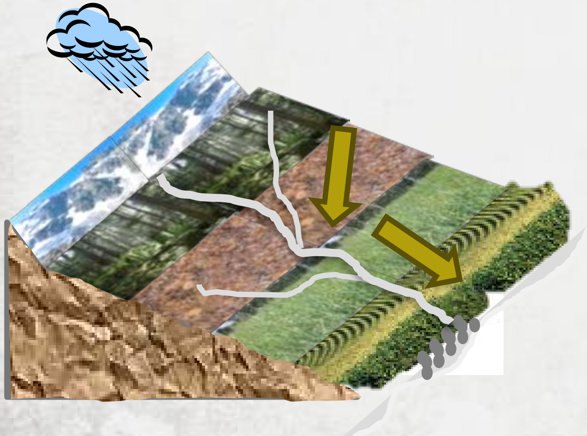


NEW OPTIMIZATION TOOL!

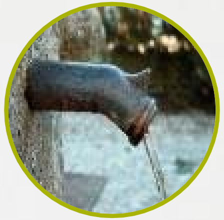
(A little bit of)

# MODEL THEORY

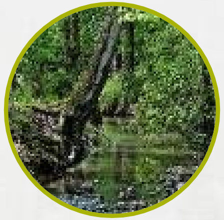
# MODEL OVERVIEW



Reservoir



Drinking water



Stream health

**AIM**

Understand the spatial patterns of sediment sources and transport to assess the value of sediment retention by natural landscapes

**Supply: Sediment retention** → **Service: Water purification** → **Value: avoided treatment/ dredging**



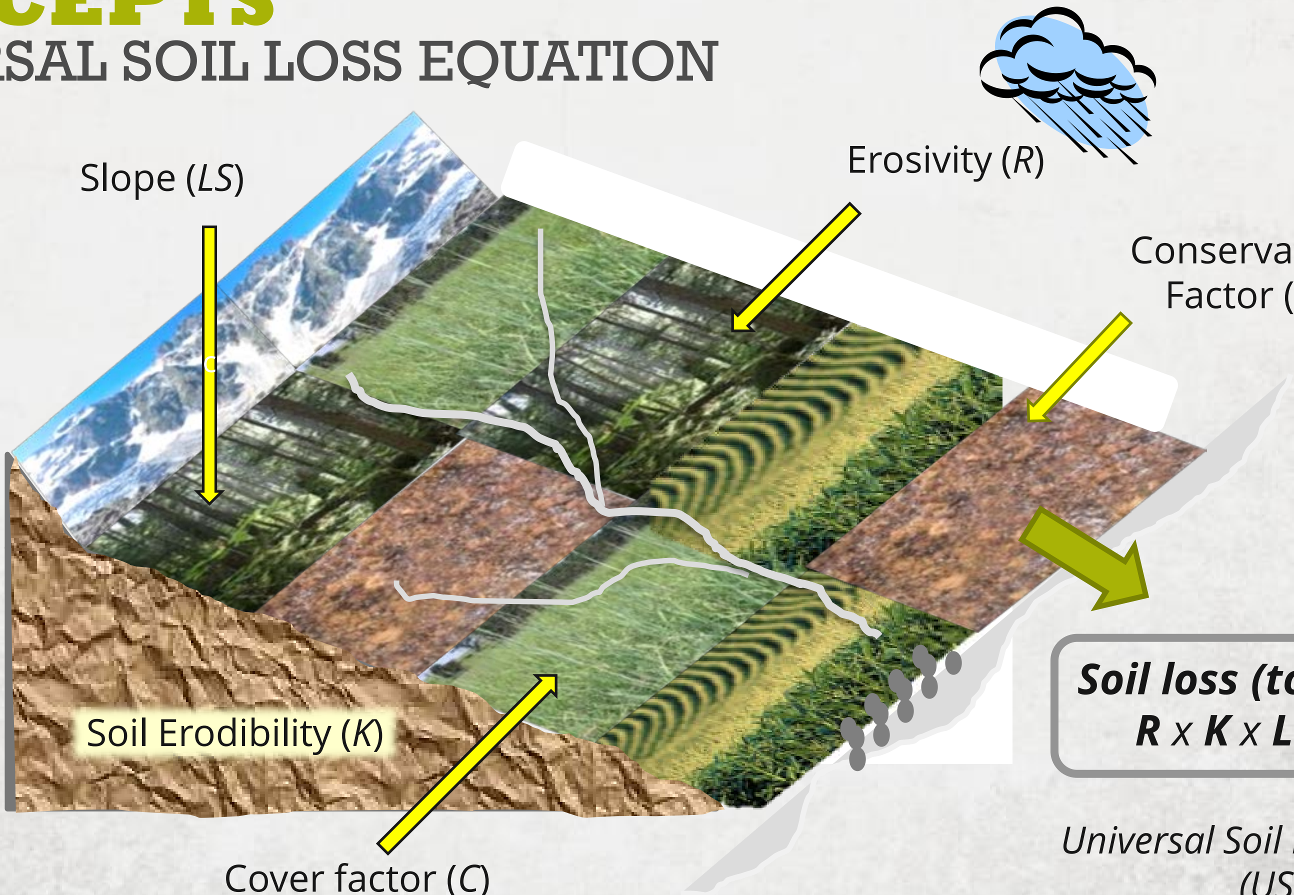
Photo credit: Creative Commons, pixabay.com

# MODEL OVERVIEW


**AIM**
Understand the spatial patterns of sediment sources and transport to assess the value of sediment retention by natural landscapes

Supply: Sediment retention → Service: Water purification → Value: avoided treatment/ dredging

# CONCEPTS
## UNIVERSAL SOIL LOSS EQUATION

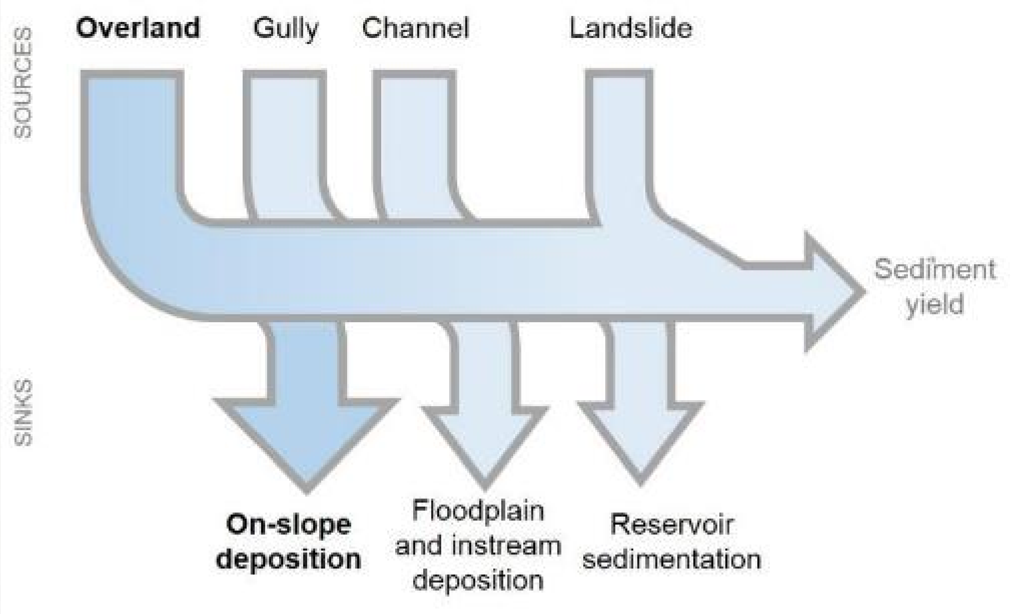



**Soil loss (ton/ha/yr)=**
**R** x **K** x **LS** x **C** x **P**

*Universal Soil Loss Equation (USLE)*

# CONCEPTS
## UNIVERSAL SOIL LOSS EQUATION

- Very popular method!
- BUT:
  - Only for **rill-inter-rill erosion**
  - Uncertainty in parameters:
    - **LS factor** for high slopes
    - **C,P factors**, etc.
- LOT of **literature**!



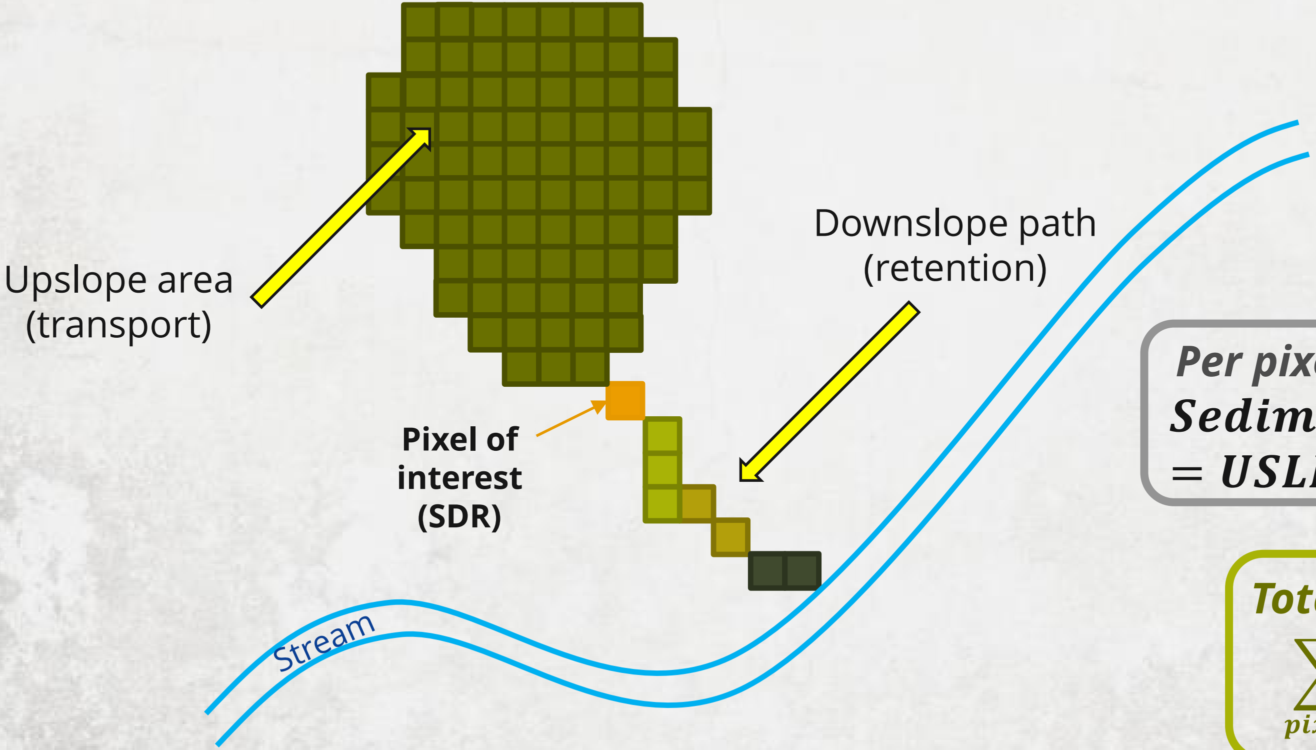
# CONCEPTS
## SOIL LOSS

- Soil **eroded** from a parcel
- Some of this soil is **deposited** and does not reach the stream

$$\boxed{\boldsymbol{SedimentExport = USLE \times SDR}}$$

Attenuation factor [0;1]

# CONCEPTS
## TRANSPORT/RETENTION




***Per pixel:***

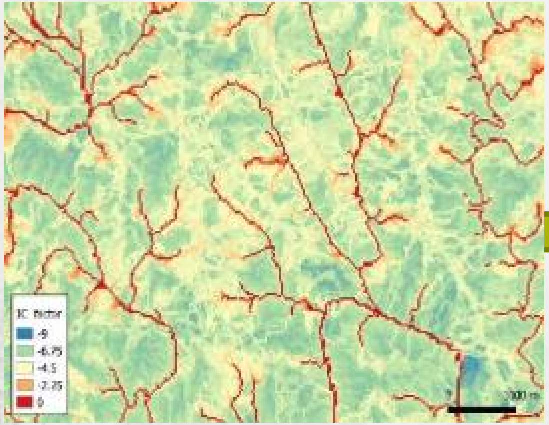
$$SedimentExport\ (ton/yr) = USLE \times SDR$$

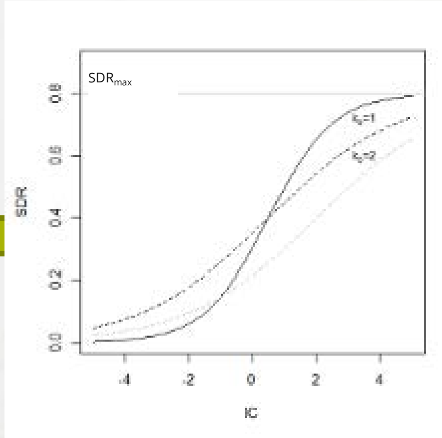
***Total export (ton/yr) =***

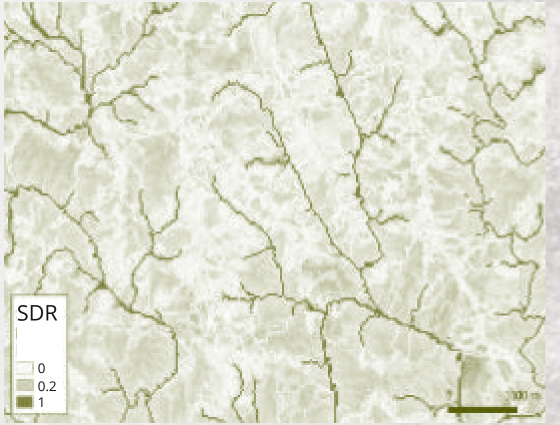
$$\sum_{pixel} SedimentExport$$

# CONCEPTS
## TRANSPORT/RETENTION

$$SDR_i = \frac{SDR_{max}}{1 + \exp\left(\frac{IC_0 - IC_i}{k}\right)}$$



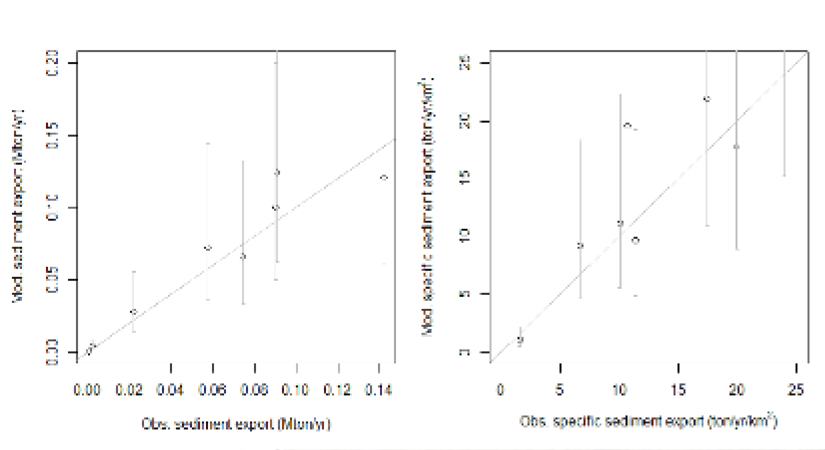



- Calibration parameters:
  - $k_b$, $IC_0$
  - $SDR_{max}$

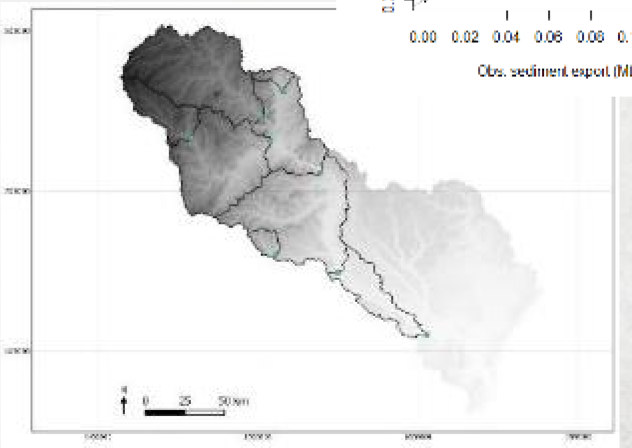
# MODEL TESTING

- Sensitivity analyses
- If observed data is available:
  - Model calibration
  - Testing of model performance for predicting land use change (need several gauges)




(Hamel et al., in review)

- Eg. Cape Fear basin



# CONCEPTS
## VALUATION

- Very context-specific!
- Two main options:
  - Replacement and avoided cost approaches
  - Contingent valuation (Willingness to pay)

# CONCEPTS
## VALUATION

- Very context-specific!
- Two main options:
  - Replacement and avoided cost approaches


**ASSUMES that MITIGATION OPTIONS ARE WORTHWHILE!**

plant

Recover the lost storage capacity

# CONCEPTS
## VALUATION

- Very context-specific!
- Two main options:
  - Replacement and avoided cost approaches



$ Service

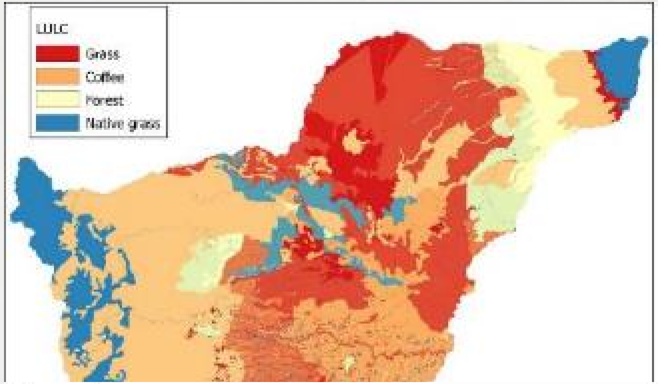
Net present value: $$NPV = \sum_{t=0}^{n} \frac{C}{(1+r)^t}$$

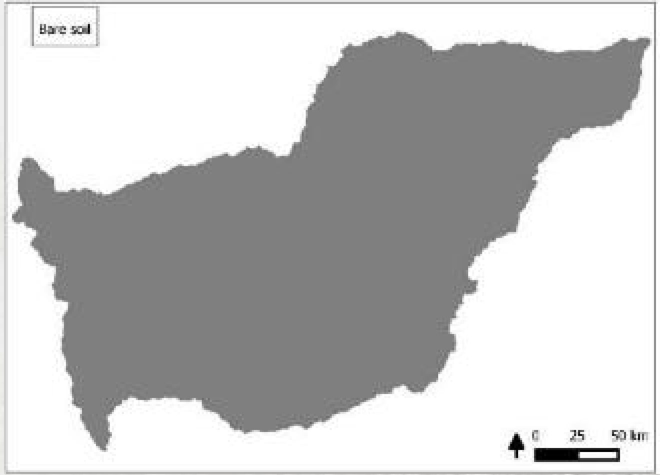
Cash inflow

Discount rate

# CONCEPTS
## VALUATION

- Very context-specific!
- Two main options:
  - Replacement and avoided cost approaches
  - Contingent valuation (Willingness to pay)
- In InVEST: retention is calculated using a reference scenario of **bare soil**
  - $Retention = Export_{bare\_soil} - Export_{current\_land\_use}$



In practice

# MODEL INPUTS/OUTPUTS

# MODEL INPUTS

## Climate

Rainfall erosivity

## Soils

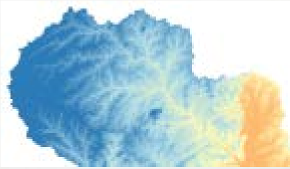
Soil erodibility

## Land Use/Land Cover

Crop factor and Practice factor (retention attenuation)

## Watersheds

Main and sub-watersheds for point of interest



## Topography

DEM, Threshold flow accumulation


## Economic

Dredging cost, treatment cost



Photo credit: Creative Commons, pixabay.com; Tracey Saxby, Integration and Application Network

# MODEL INPUTS
## DATA SOURCES



**References in User Guide!**

### Climate
Rainfall erosivity

→ Erosivity maps! (USGS)
Rain gauges (relationships between precipitation and erosivity in the literature

### Soils
Soil erodibility

→ Harmonized World Soil Database
SOTER
SSURGO (US)

### Land Use/Land Cover
Crop factor and Practice factor (retention attenuation)

→ MODIS (NASA)
Global Land Cover Facility
NLCD (US-EPA)



Photo credit: Creative Commons, pixabay.com; Tracey Saxby, Integration and Application Network

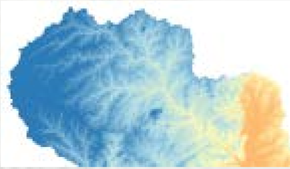
# MODEL INPUTS
## DATA SOURCES

**References in User Guide!**

### Watersheds

Main and sub-watersheds for point of interest

→ From Basin Management Agencies
HydroSHED (WWF)
DEM (with ArcHydro)



### Topography

DEM, Threshold flow accumulation

→ HydroSHED (WWF)
ASTER (NASA)

$$

### Economic

Dredging cost, treatment cost

→ Water treatment plant or reservoir manager!



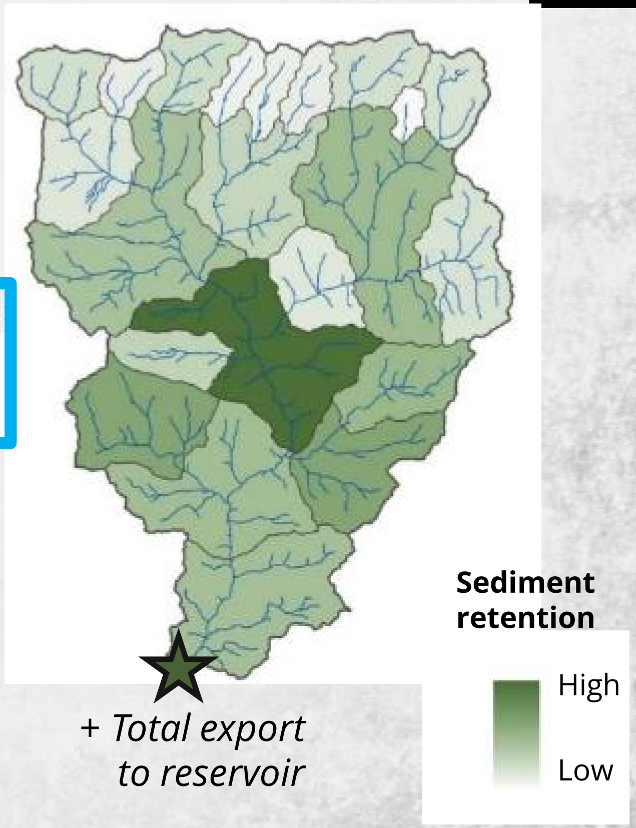
Photo credit: Creative Commons, pixabay.com; Tracey Saxby, Integration and Application Network

# MODEL OUTPUTS
## MAIN OUTPUT FOLDER

- Shapefile with attribute table (for each subwatershed):

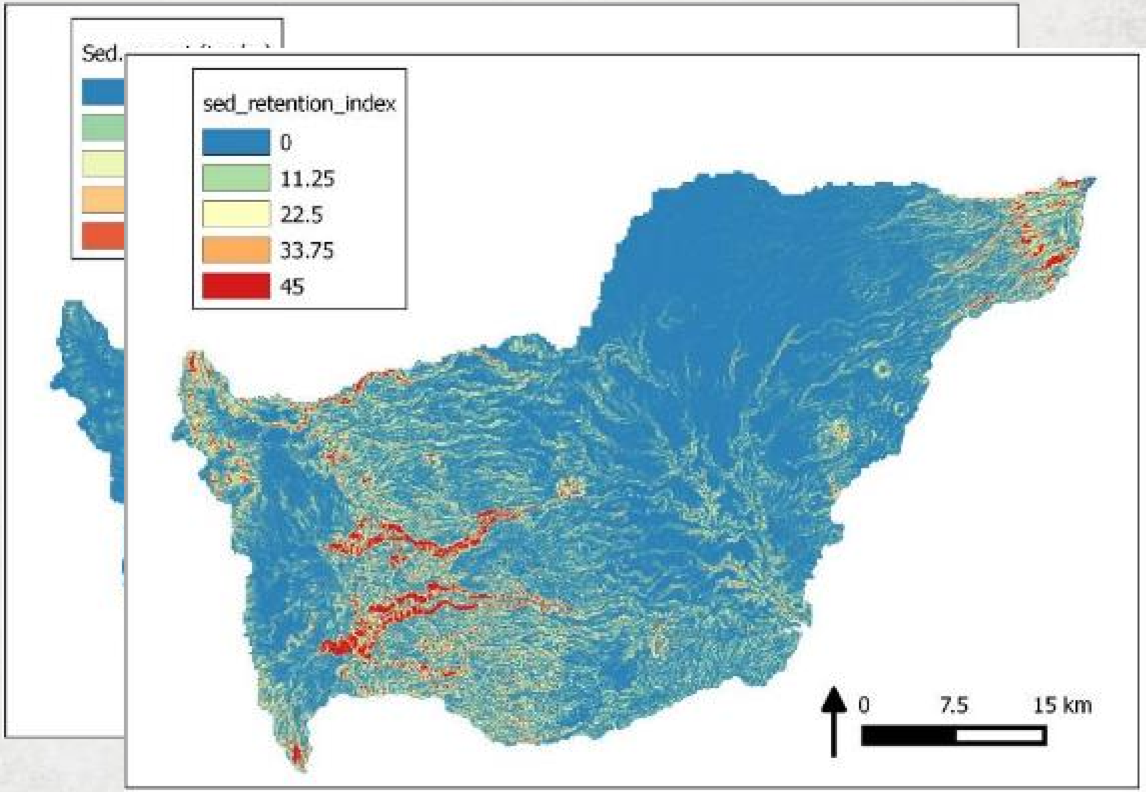
| Name | ws_id | subws_id | Area_km2 | sed_retent | sed_export | usle_tot |
|---|---|---|---|---|---|---|
| Sagana | 1 | 1 | 2050 | 168555021.39... | 8949835.8121... | 100331790.84... |
| Up_hydro | 2 | 2 | 1452 | 98877762.077... | 4606155.1569... | 52748729.642... |
| Gura | 3 | 3 | 108 | 12718757.728... | 514065.29002... | 6769660.2423... |

  - Sediment export (ton/yr)
  - Sediment retention (ton/yr)
    - $Retention = Export_{bare\_soil} - Export_{current\_land\_use}$
  - Soil loss (USLE) (ton/yr)



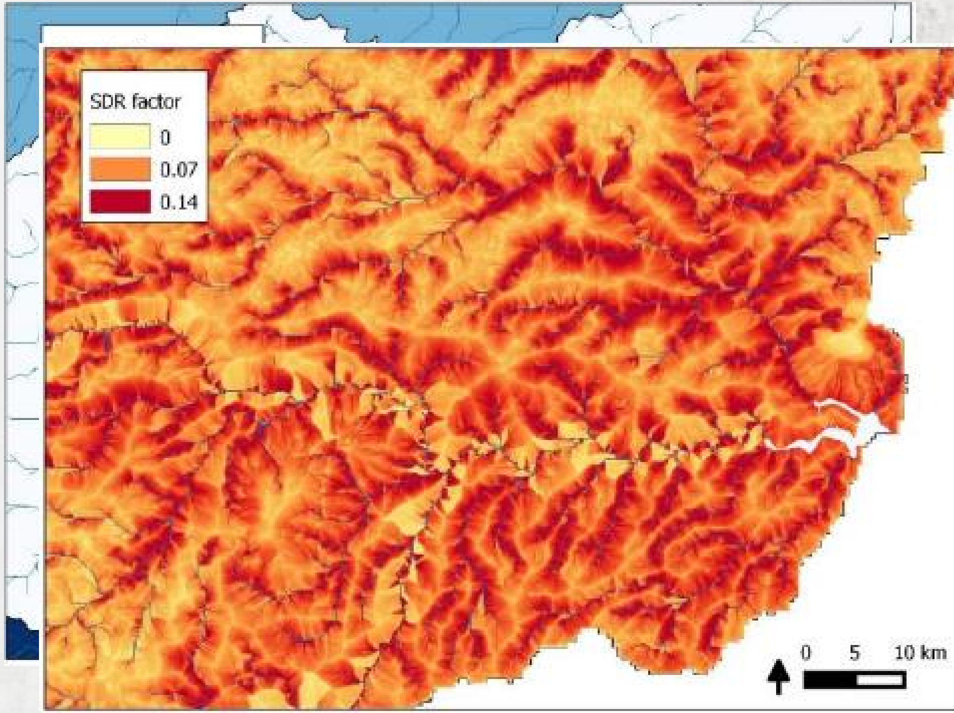
# MODEL OUTPUTS
## MAIN OUTPUT FOLDER

- Rasters:
  - Sediment export (ton/pixel)
  - USLE (ton/pixel)
  - Sediment retention **index**



# MODEL OUTPUTS
## 'INTERMEDIATE' OUTPUT FOLDER

- Stream maps
- SDR factor [0;1]
- All layers used to calculate SDR ($D_{up}$, $D_{dw}$, IC factor,…)



# LIMITATIONS

- Considers only **one type of erosion** (sheetwash/rill): no consideration of gully erosion, landslides, etc.
- Requires calibration data to increase confidence in quantitative exports (relative differences are better captured)
- Valuation methods are highly contextual (e.g. treatment type, local regulations)

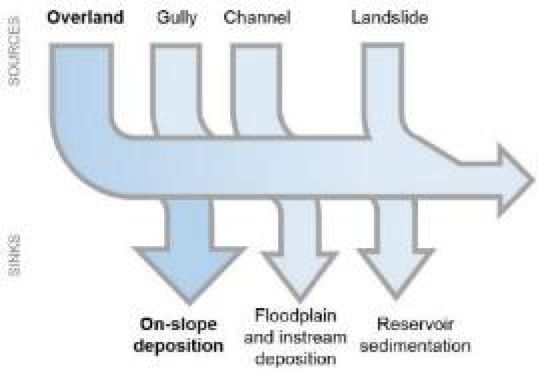




Photo credit : Alain Hamel

# QUESTIONS?

Application of the sediment model in details

# CASE STUDY IN HAWAI'I

# HOW MUCH SEDIMENT GETS TO THE REEF?

**Kim Falinski, University of Hawaii at Manoa**

Kirsten Oleson, Tova Callender, Hla Htun (UH Manoa, Ridge to Reef)

Crow White, Clara Rowe (CalPoly, Yale)

Joey Lecky, Lisa Wedding, Kim Selkoe (UH Manoa, Stanford)

Dec 2014

Maui shoreline showing nearshore sediment plumes resulting from run-off from pineapple fields after a Kona rainstorm. Photo: USGS, 2004.

# Motivating question

What land management actions best regulate sediment and nutrient ecosystem service delivery to coral reefs?

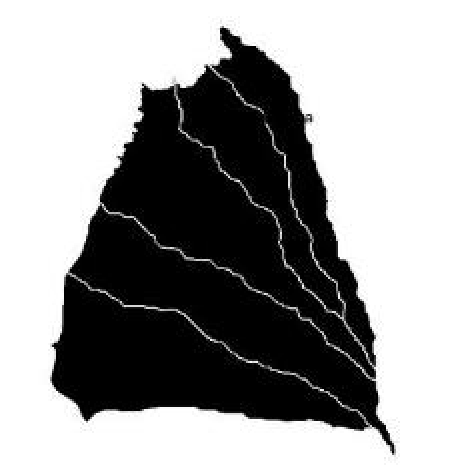
Photo: NOAA

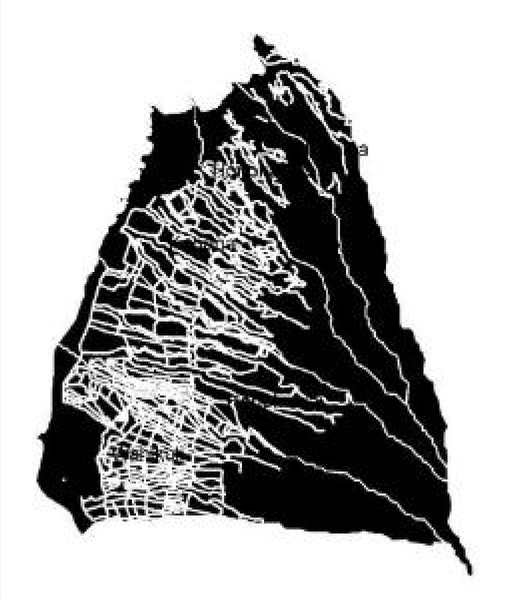
# MAIN HAWAIIAN ISLANDS

# APPLICATION OF INVEST TOWARDS DECISION ON MULTIPLE SCALES

Main Hawaiian Islands

Watershed scale (24,000 acres)





Best management practices (4m)

# APPLICATION OF INVEST TOWARDS DECISION ON MULTIPLE SCALES

Centuries

Decades

Storms?

Star Journal, Biz journal, Maui County

# APPLYING INVEST

1. How will changing agricultural land use over centuries affect sediment retention ecosystem services?
   – How can we identify hotspots on the landscape that will allow for multiple benefits?
2. Where is the best place to implement one specific BMP – road rehabilitation?
3. How important is sediment in defining coral reef ecosystem regime? Is sediment a tipping point?

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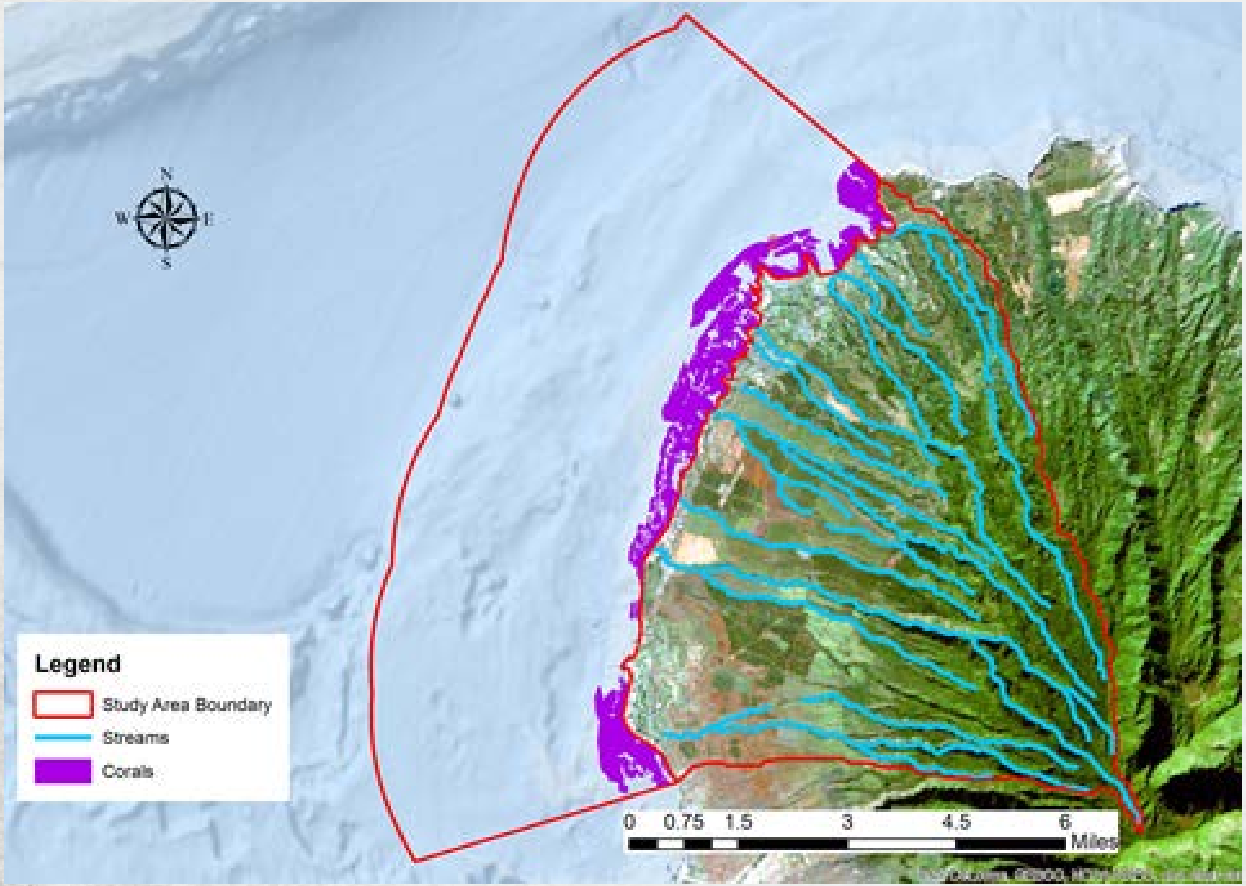



# WEST MAUI

**Annual Rainfall:**
**54 to 776 cm**

**Elevation Range:**
**0 to 1717 m**

**Small watersheds:**
**< 5 km²**

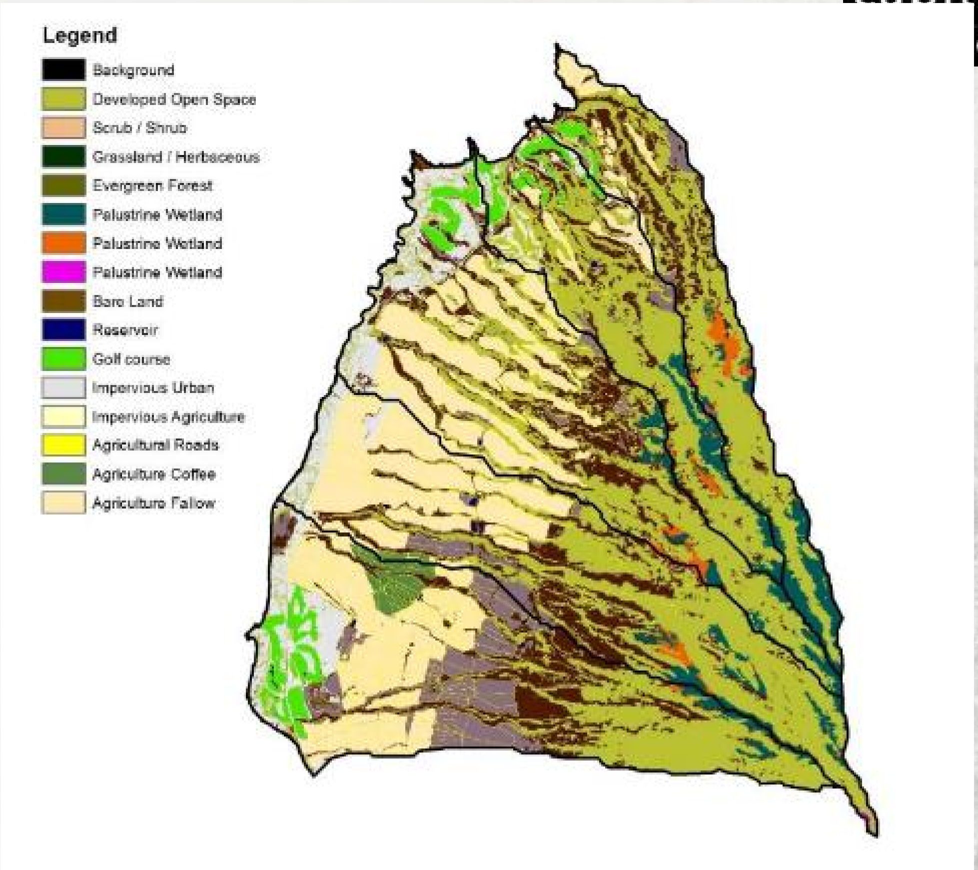
# STUDY SITE: WEST MAUI

# Five Priority Watersheds

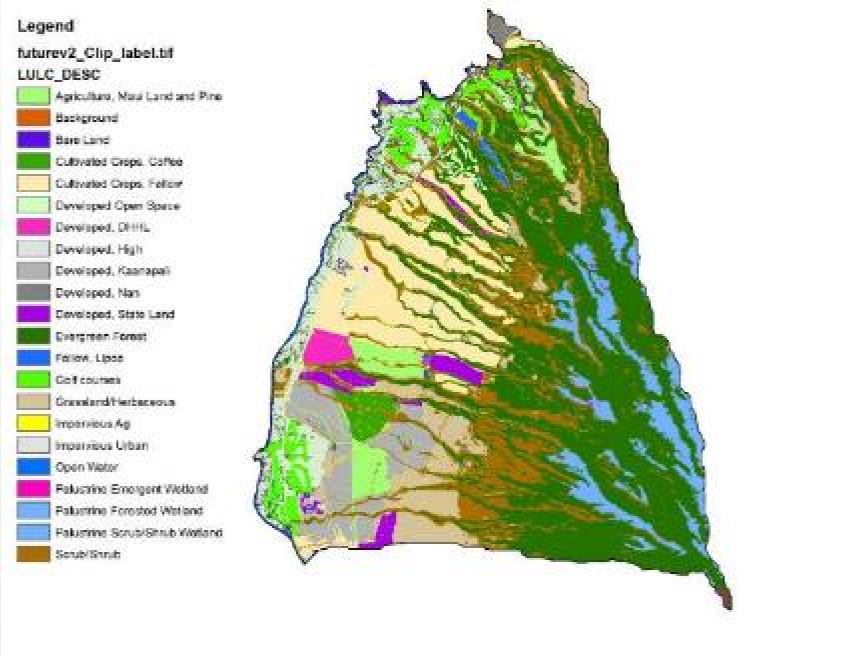
If you add 7,000 new homes, what happen
(does anything happen) to sediment expor

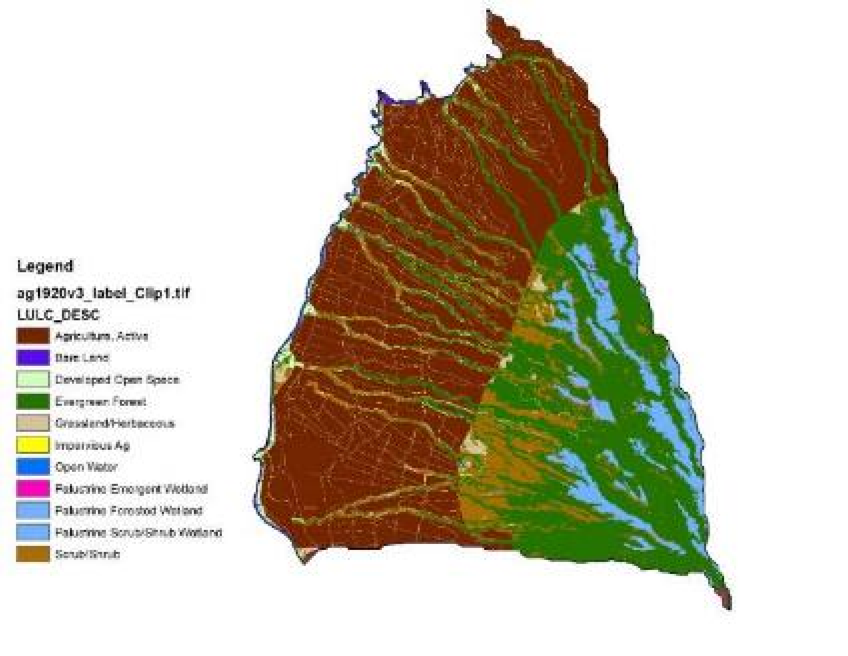
# APPROACH

- ✓ Develop past and future scenarios
- ✓ Parameterize InVEST sediment delivery based on existing data
- ✓ Quantify ecosystem service change
- ✓ Identify hotspots and win-win locations in the watersheds



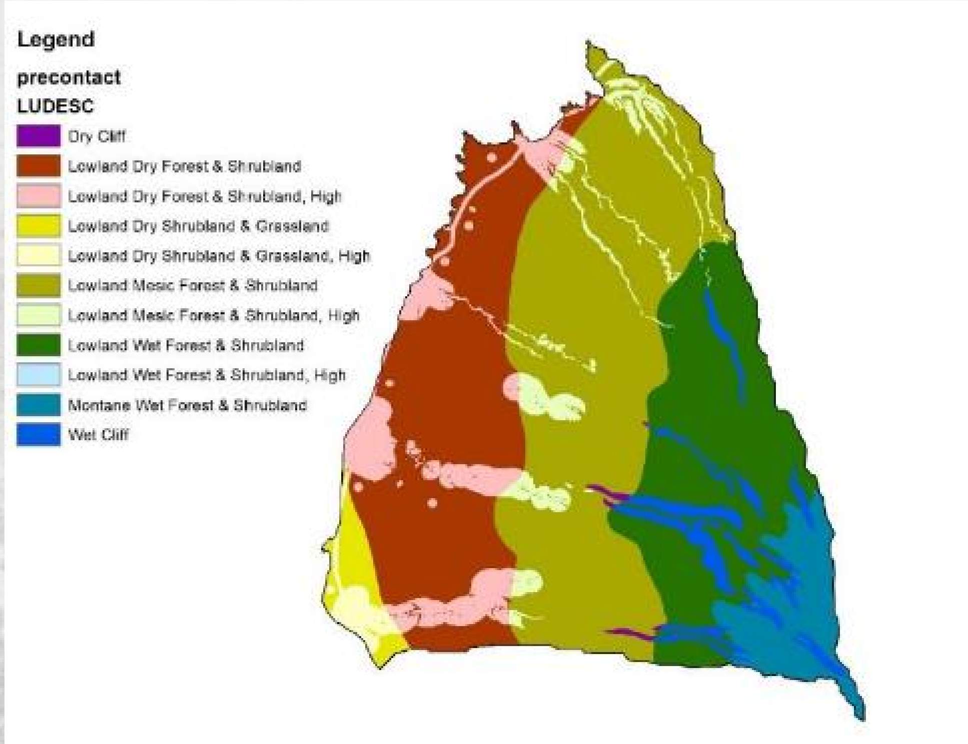

Current (2010)




Future Development (2030)

Agriculture (1920)




- Creation of a pre-European contact map involved combining:
  - Pre-contact ecosystems
  - Early human footprint
  - Understanding of where agriculture was physically possible
  - Archival photos, stories, chants, documentation

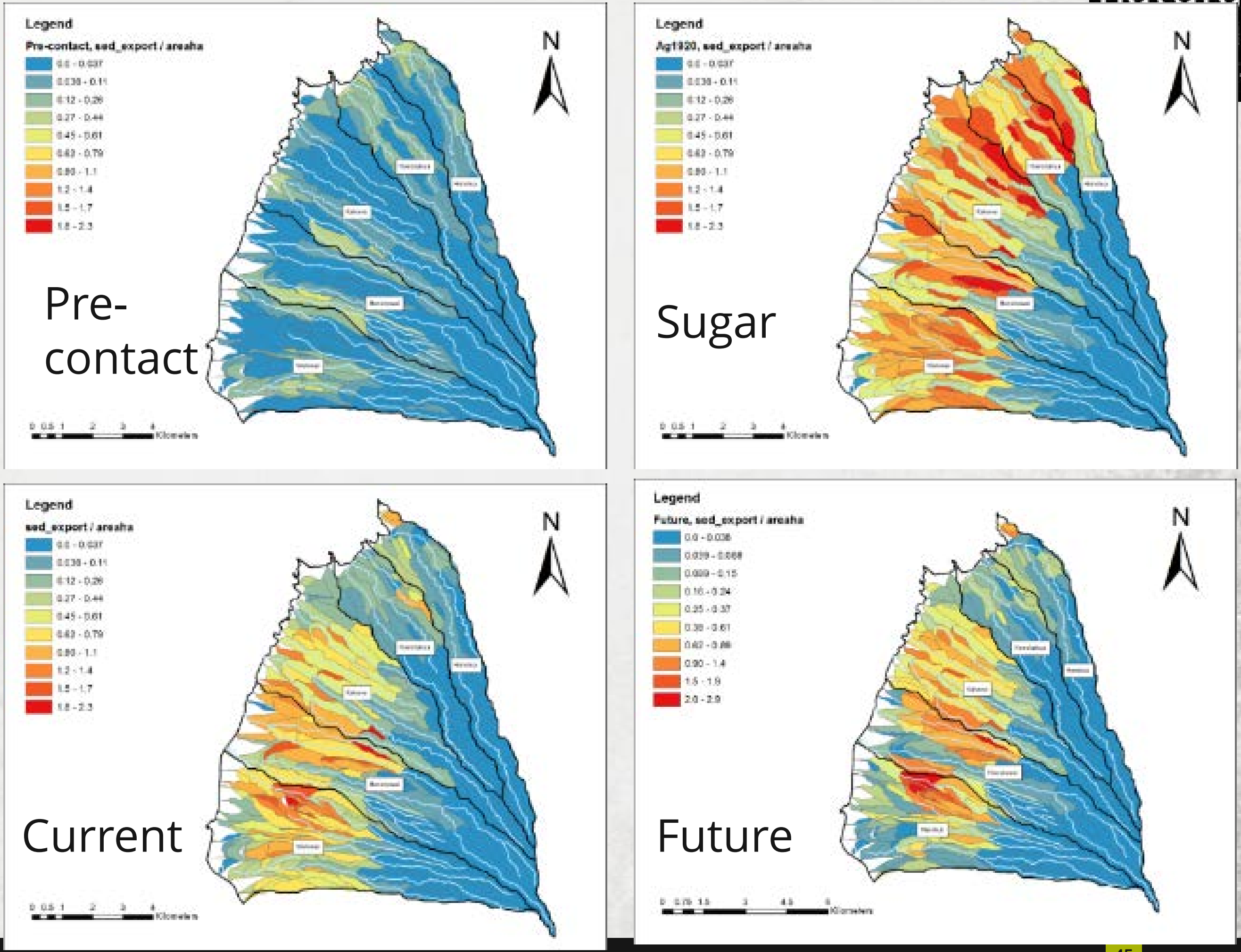
# SEDIMENT

1778 →

1920 →

2010 →

2030



# CHALLENGES

- How to account for ditches in the system?
  - Irrigation ditches move water far from the watersheds where rain falls
- How to account for uncertainty in the model in years that are in the future, past?
- Many of the sediments that exist today are legacy sediments remaining from previous erosion. Is there a way to account for this?
- Soil erodibility (K factor) not recently updated.

Honolua Stream

# APPLYING INVEST

1. How will changing agricultural land use over centuries affect sediment retention ecosystem services?
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3. How important is sediment in defining coral reef ecosystem regime? Is sediment a tipping point?

# FINE SCALE: ROAD REHABILITATION

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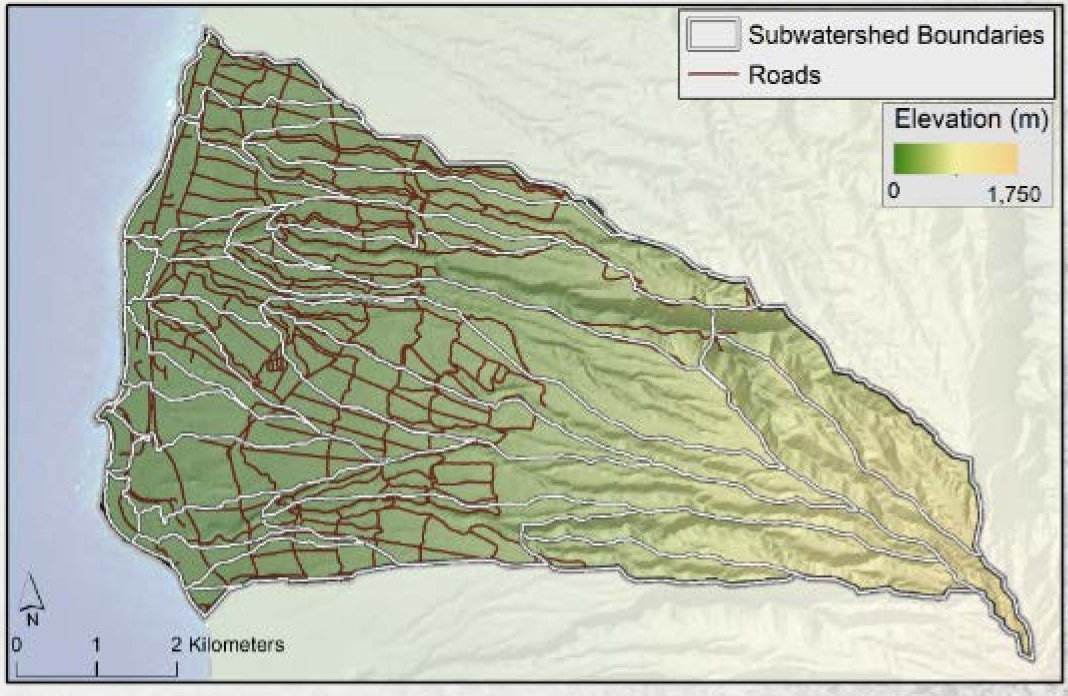
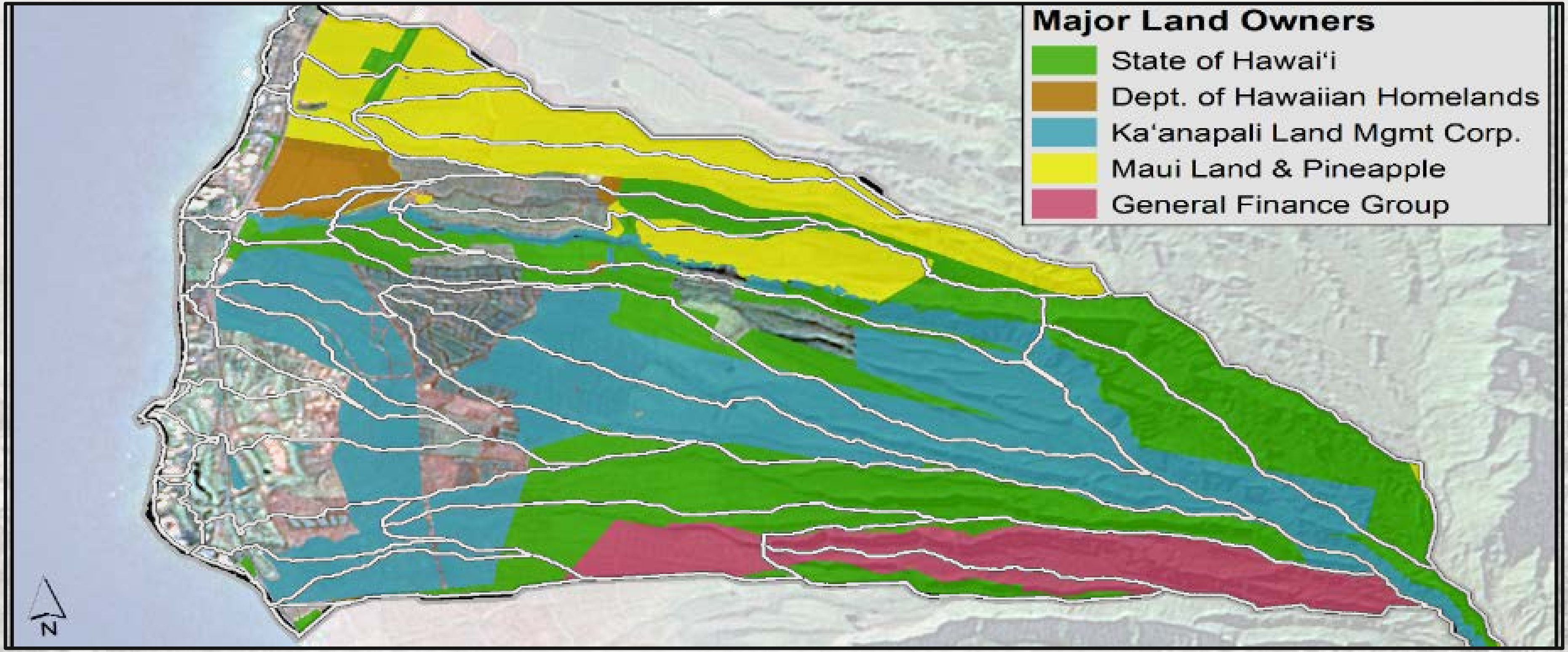
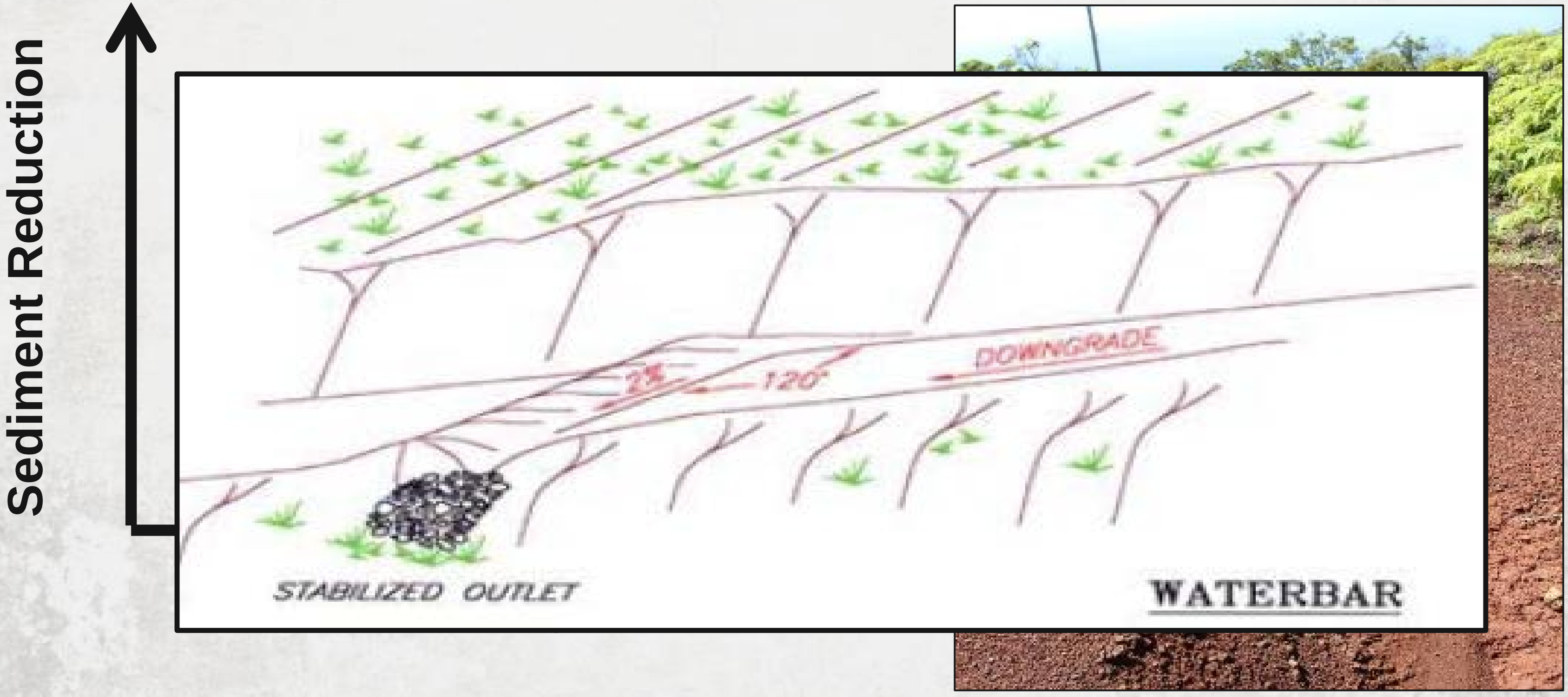
The problem:
Roads and trails are considered a possible sediment source



# MAJOR LAND OWNERS

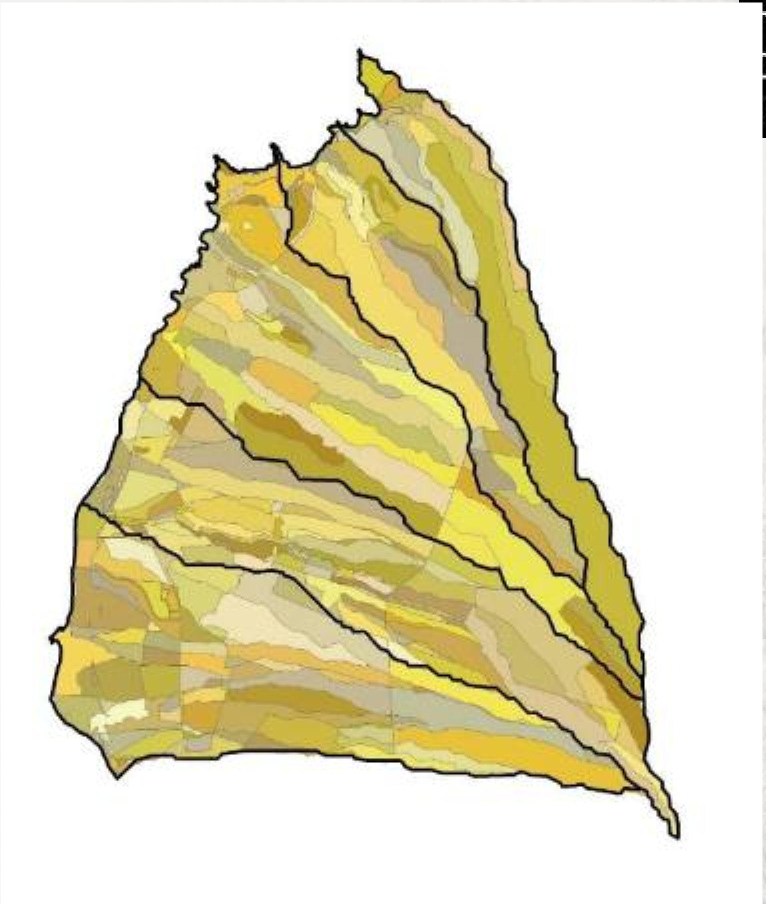


# Trade-off: Sediment Reduction and Management Costs



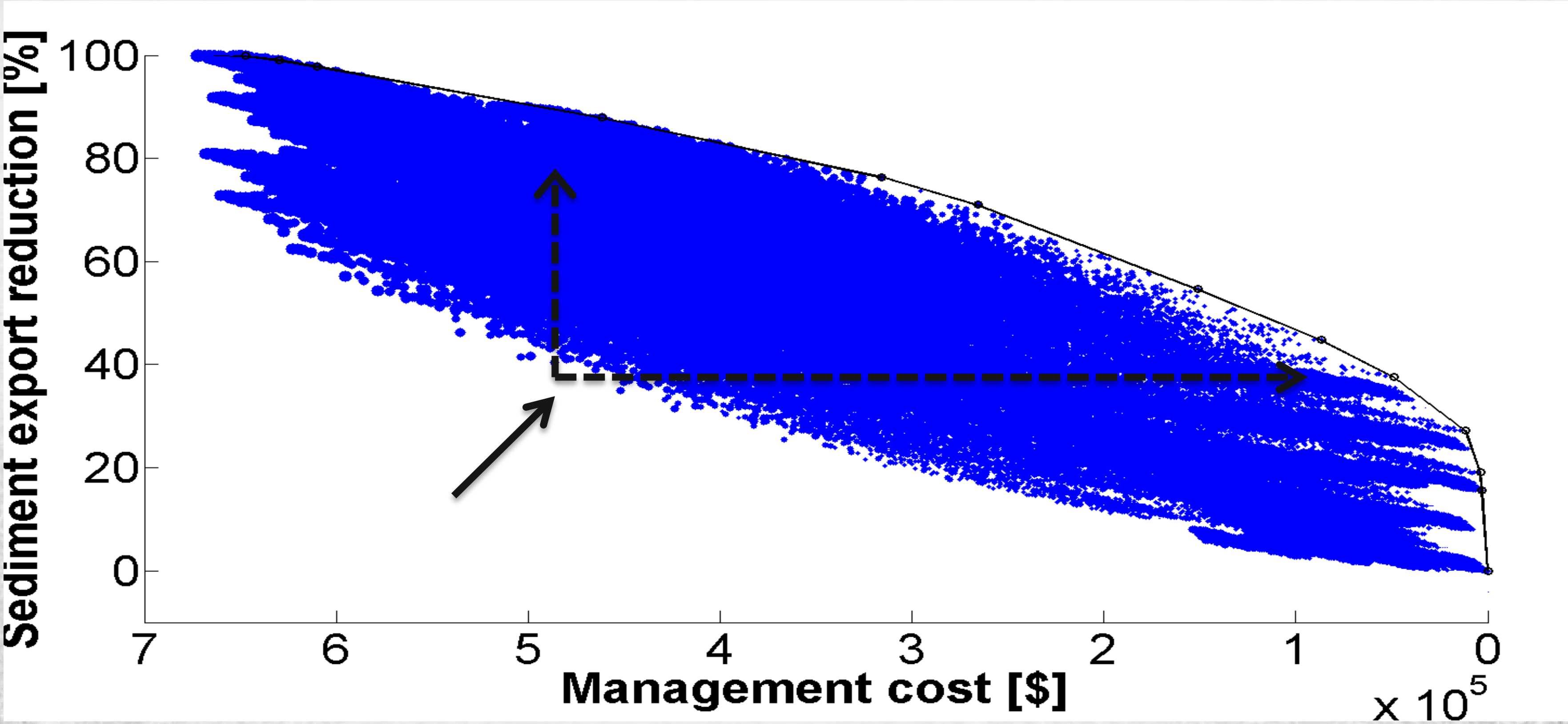
# APPROACH

- Create decision units
  - Hydrologic subwatersheds
  - Land use classification (Urban, Agriculture, Conservation)
  - Major land owner
- Run InVEST Sediment Delivery Model for Fixed and Not Fixed scenarios
- Analyze the effect of each road on total sediment budget alone or in combination (~$10^6$ scenarios !)

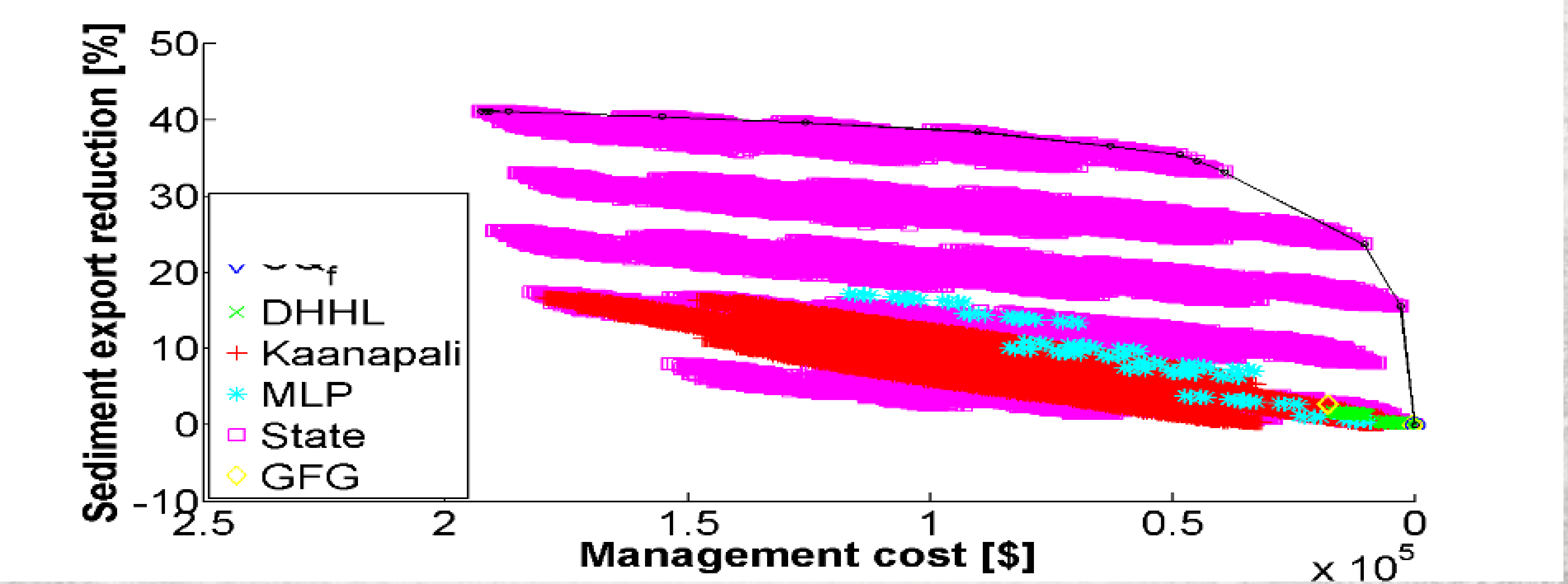


Hydro - Management units

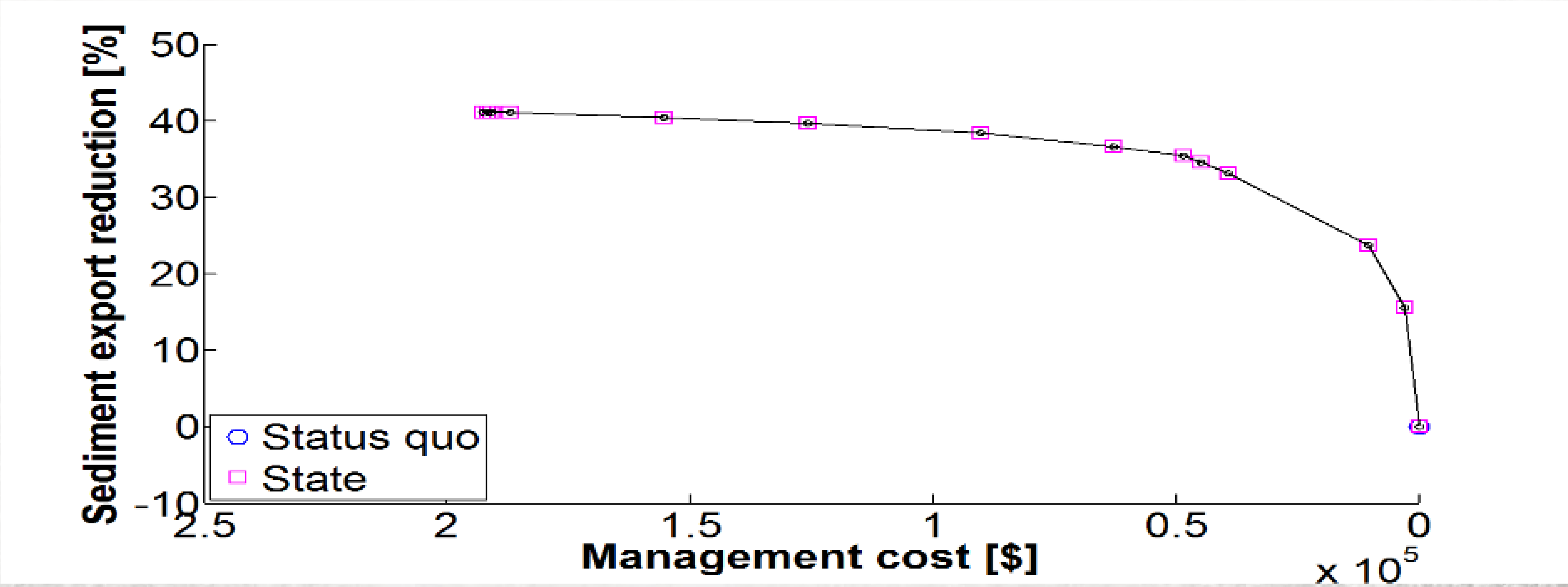
# MANAGEMENT OPTIONS FOR SEDIMENT



# SEDIMENT REDUCTION BY LAND OWNER: EFFICIENCY FRONTIER



# Sedimen Reduction by Land Owner: Efficiency Frontier



# Management Scenario 3

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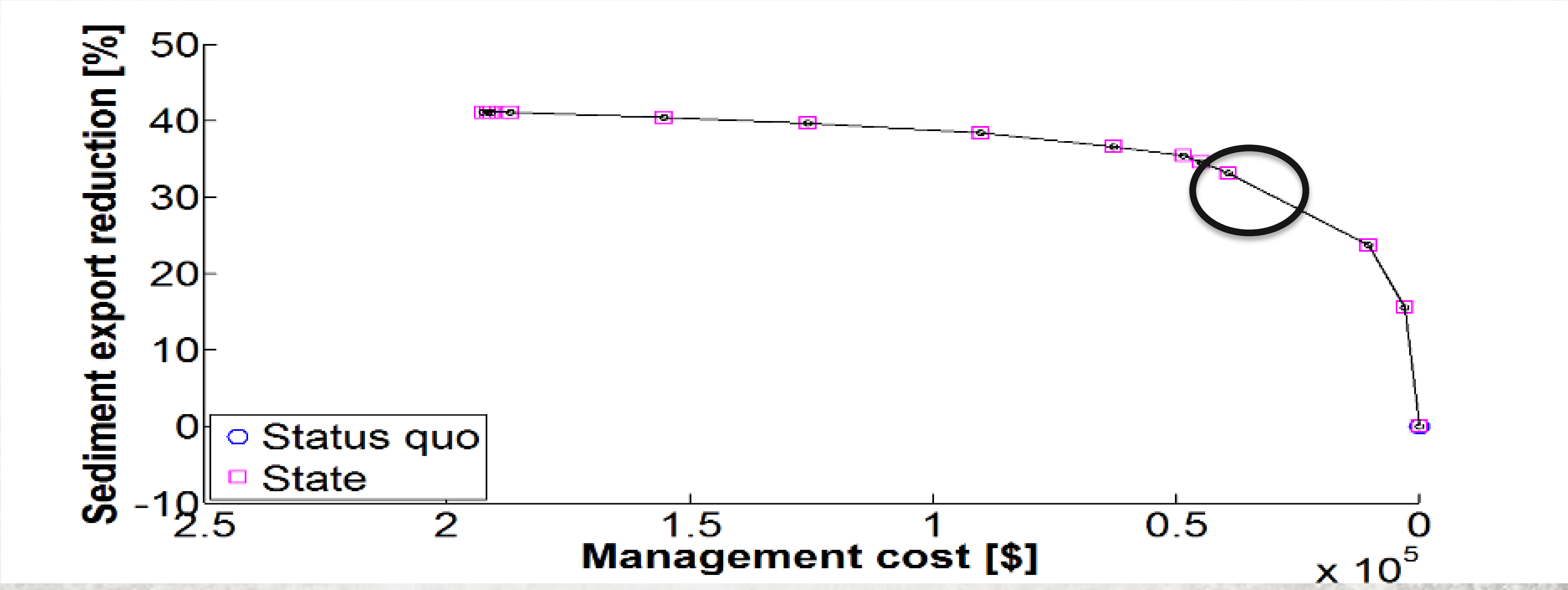
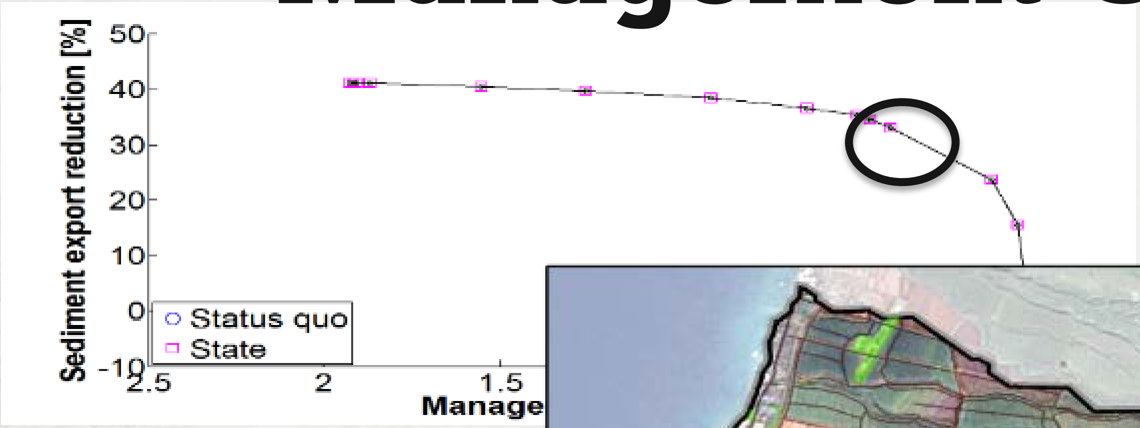
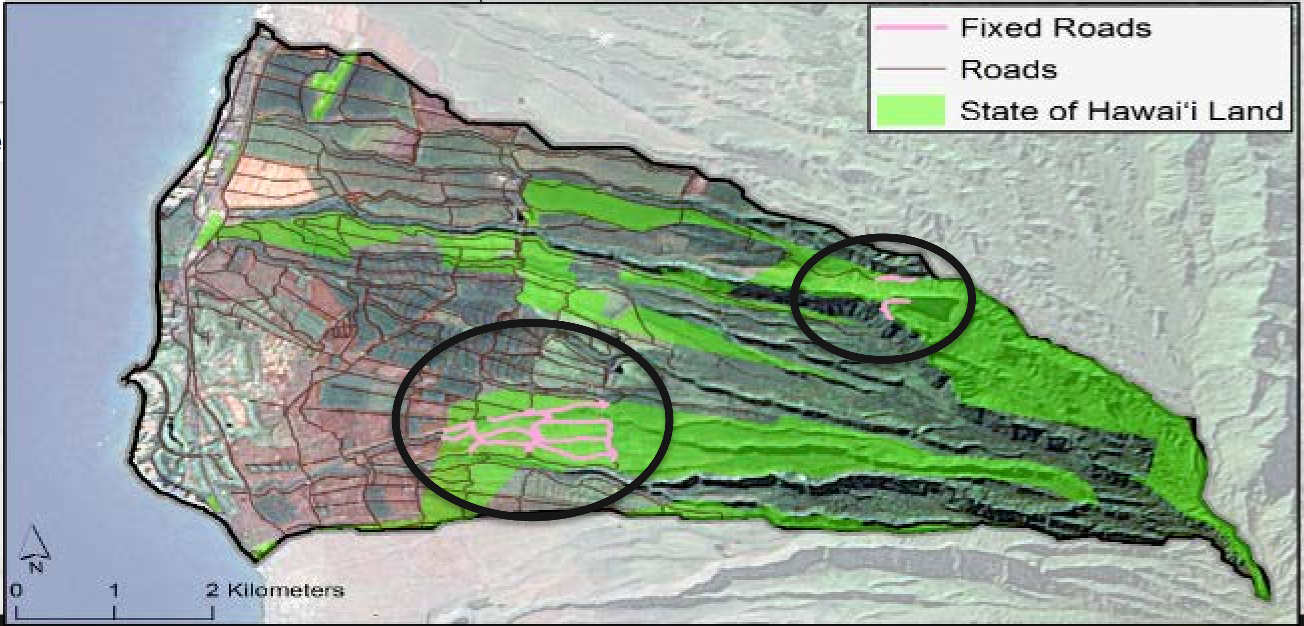


# Management Option 3



# MOVING BEYOND HI STATE ROADS

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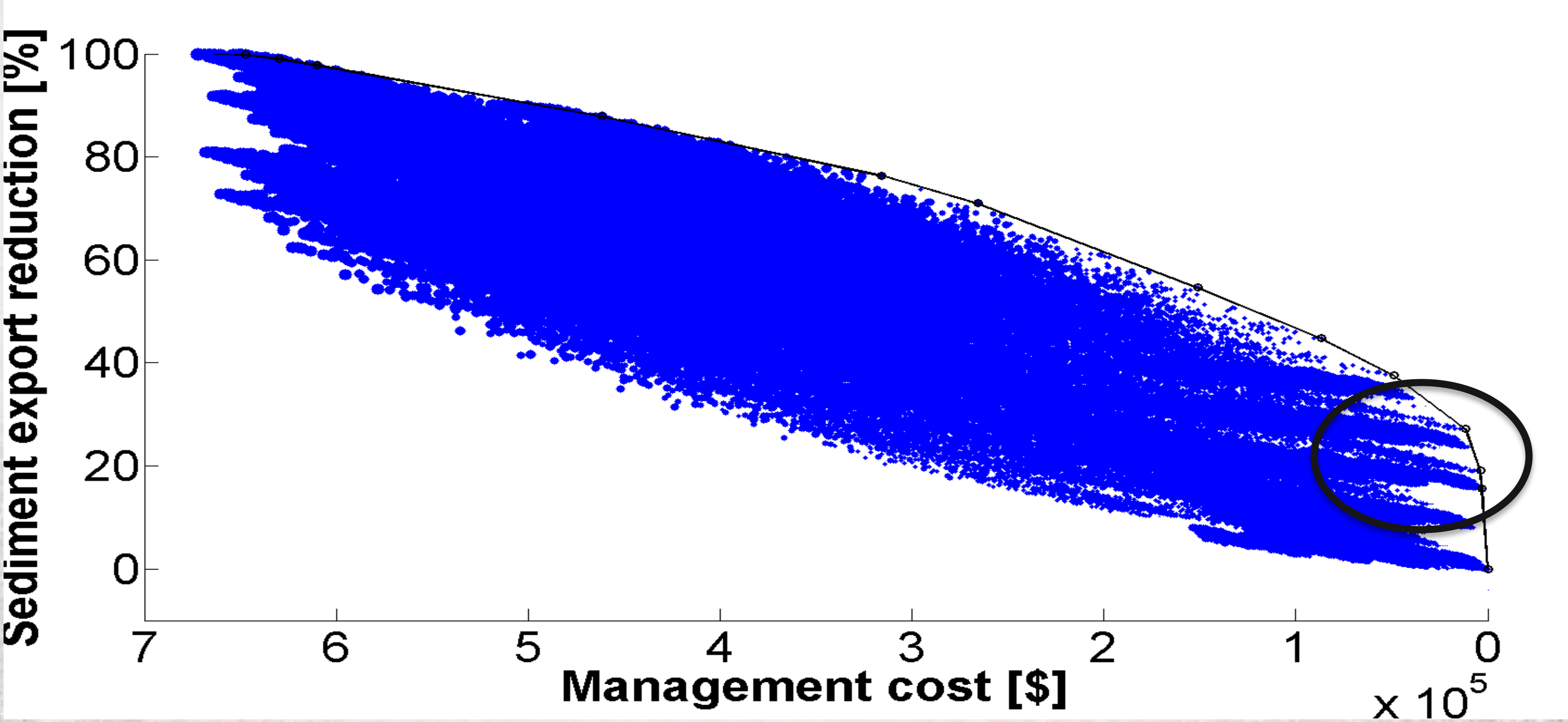

# CHALLENGES

- Rough approximation for "fixing" a BMP
- The method closely relies on predicting WHERE on the landscape (+- 5m) there are roads
- Need to build data sets – in this case World View 2 vision used to map roads

# APPLYING INVEST

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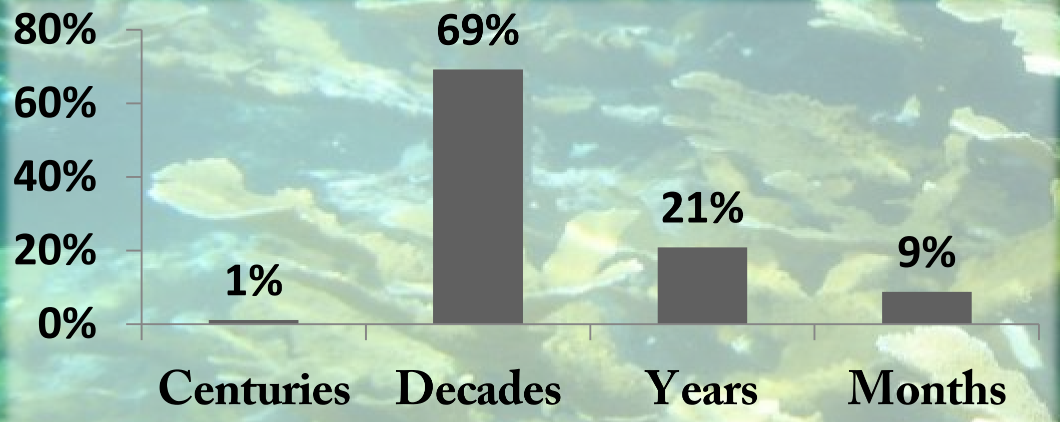
1. How will changing agricultural land use over centuries affect sediment retention ecosystem services?
   – How can we identify hotspots on the landscape that will allow for multiple benefits?
2. Where is the best place to implement one specific BMP – road rehabilitation?
3. How important is sediment in defining coral reef ecosystem regime? Is sediment a tipping point?

# Although recovery may be possible, ecosystems that have crossed a threshold tend to remain in an altered condition for decades

Which stressors are responsible for coral reef regime shift? → Island wide sediment and nutrient export maps

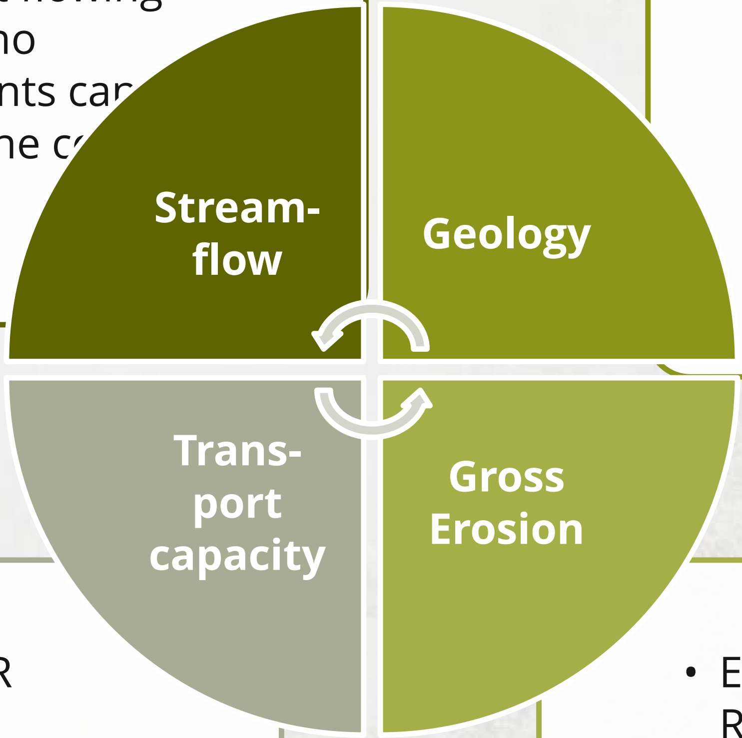



Credit: Ocean Tipping Points

# IS IT POSSIBLE TO HAVE SEDIMENT EXPORT EVERY-WHERE?

- Without flowing water, no sediments car get to the c

- •Newly formed lava rock not yet weathered enough to have movable sediment




- SDR

- E = R*K*LS

# COMBINING LAND USE AND GEOLOGY

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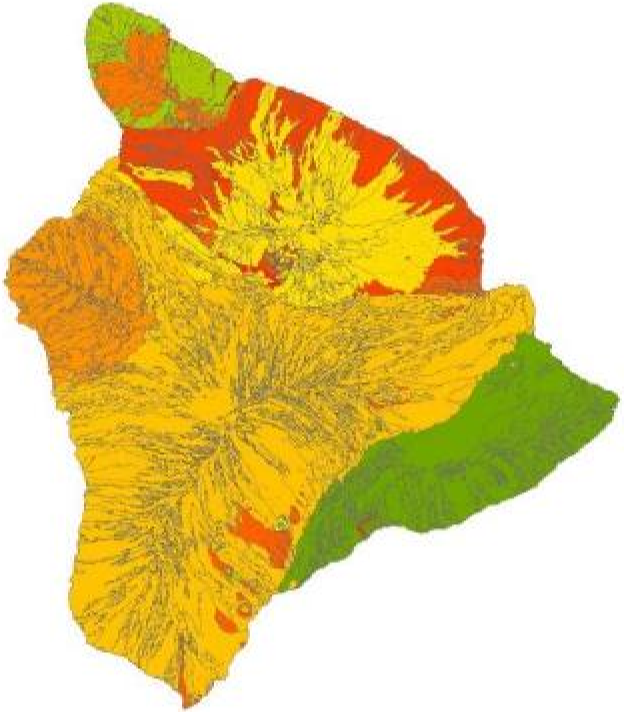
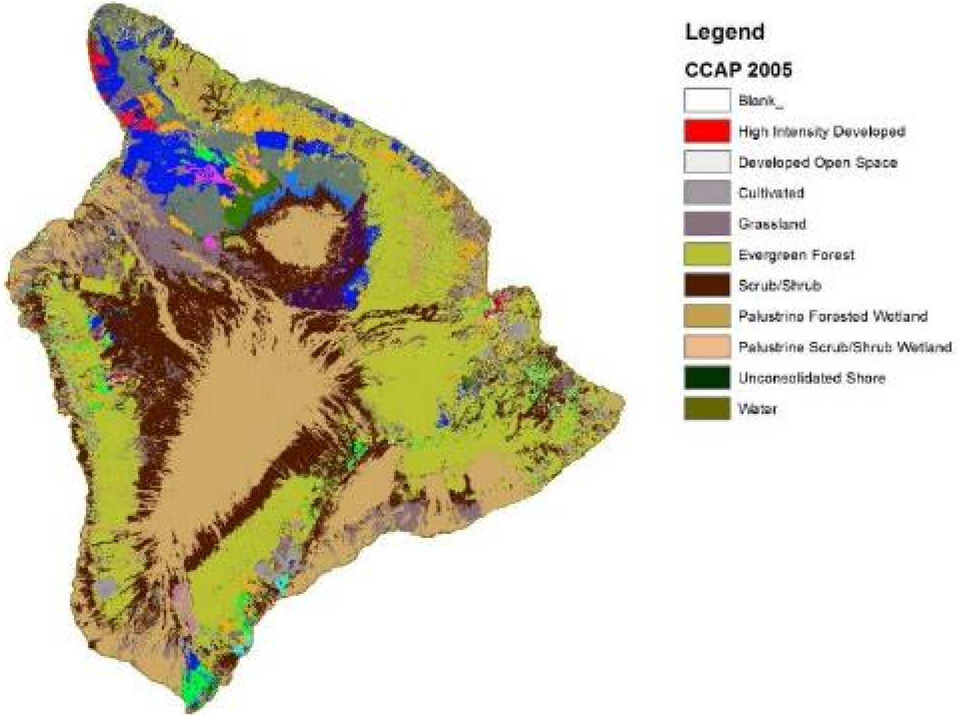
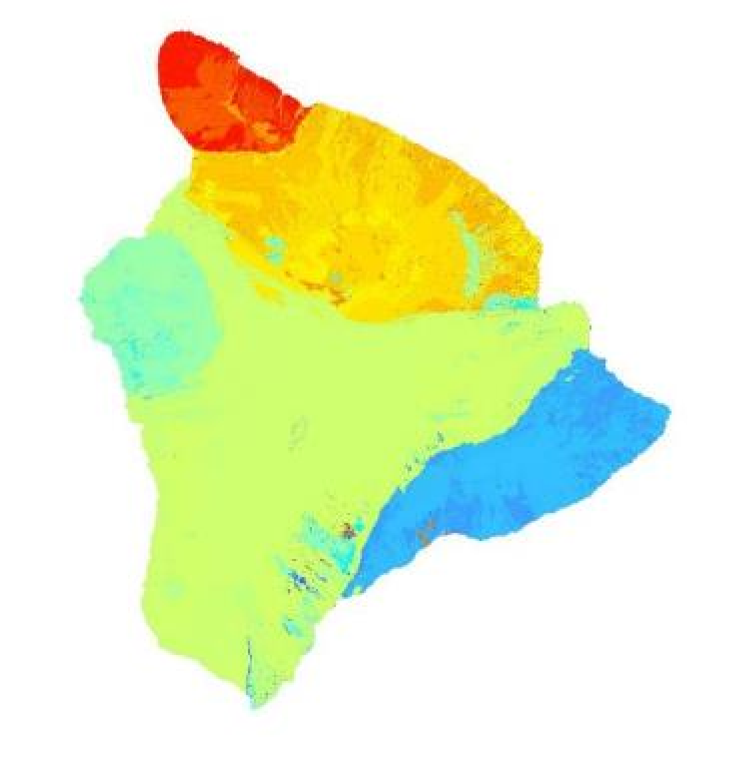




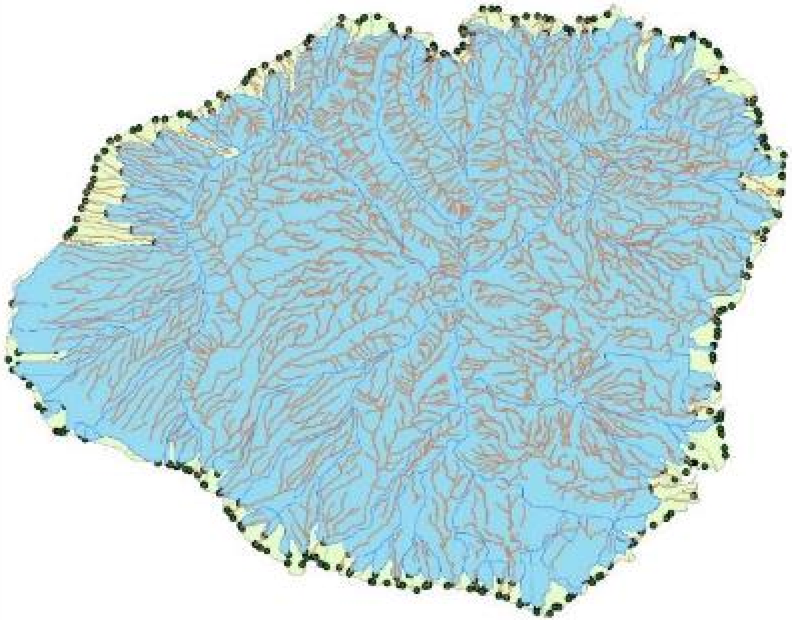

Hawaii Island

# COMBINING LAND USE AND GEOLOGY

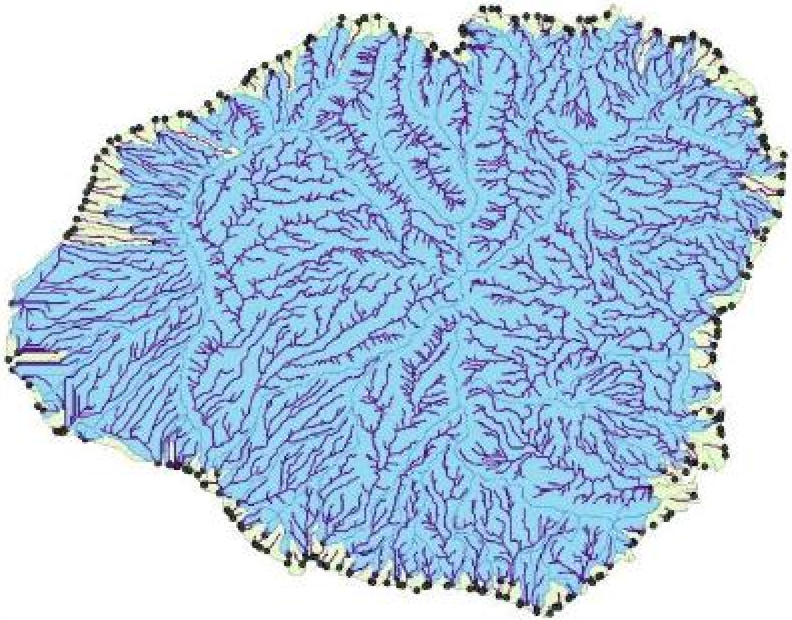


- 197 land uses classes created
- C-factor regulated by terrain type

# HOW DENSE IS MY STREAM NETWORK

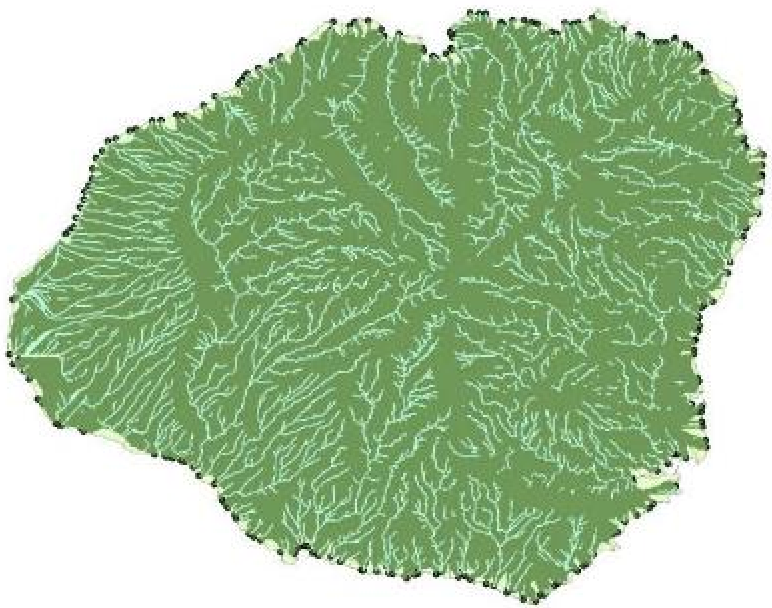


DAR mapped streams



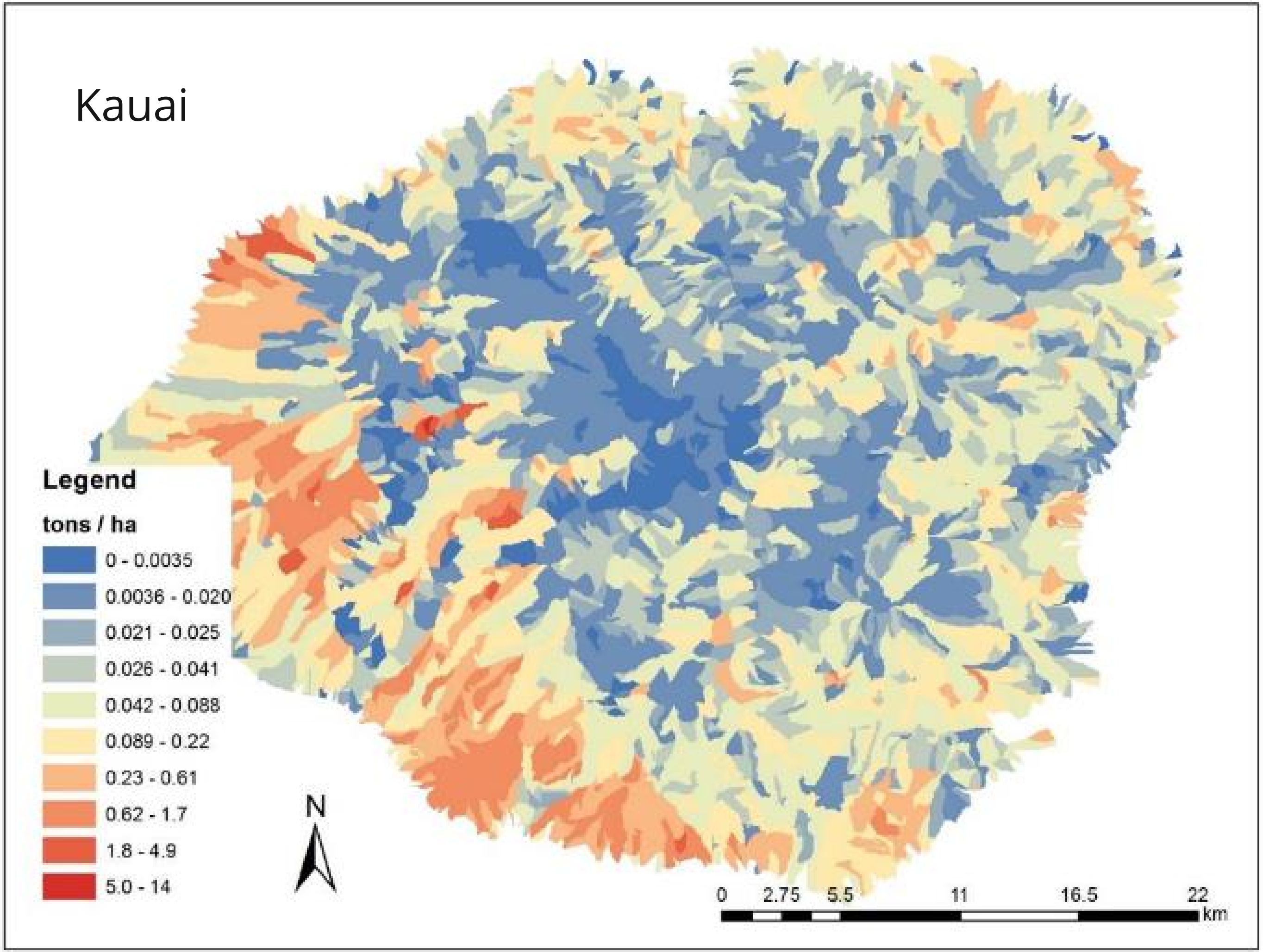
Arc Hydro predicted streams

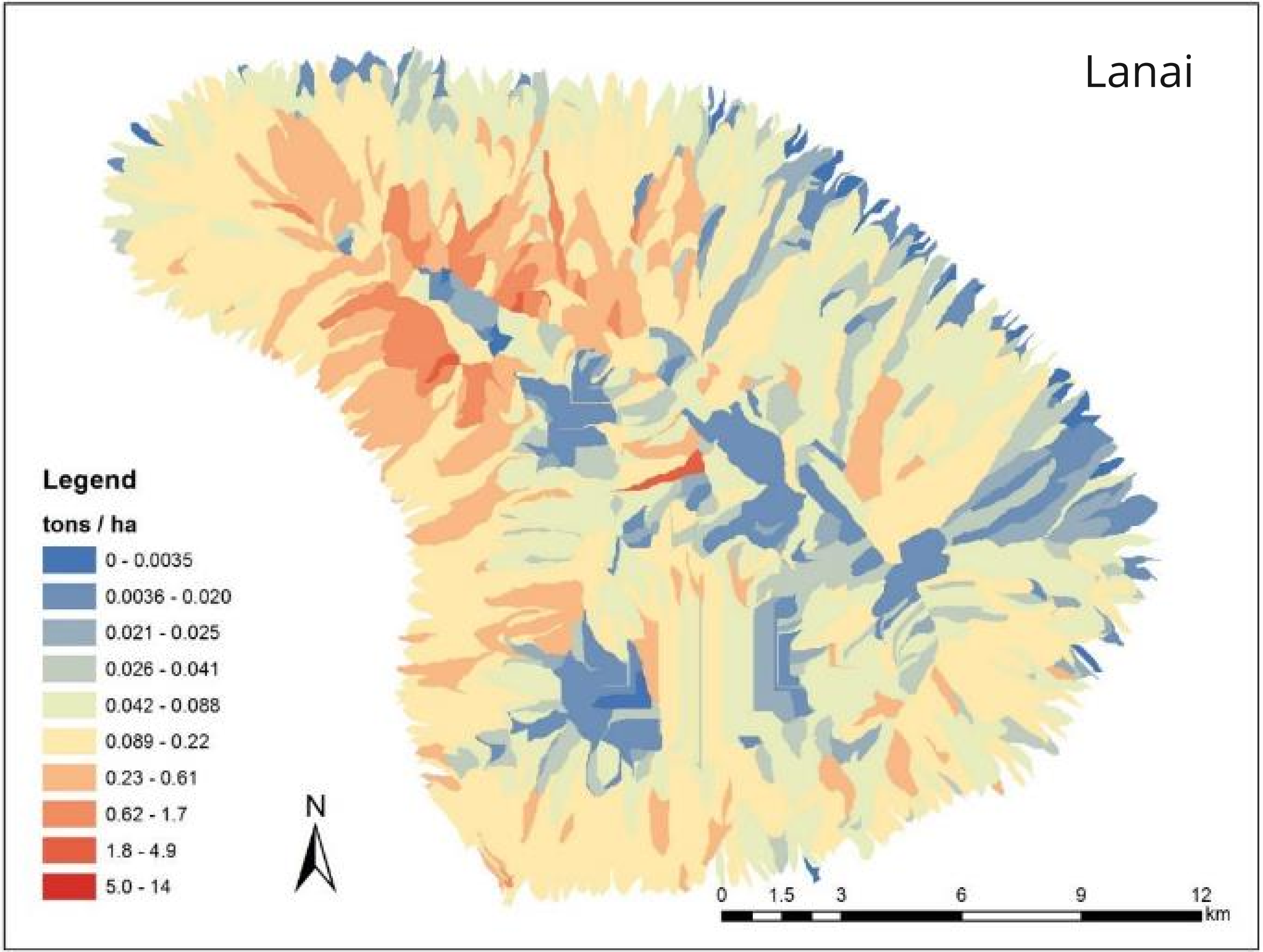
# DELINEATING STREAMS IN INVEST



InVEST stream density

- Stream density, in part, controls how much sediment is exported


Kauai
Legend
tons / ha
0 - 0.0035
0.0036 - 0.020
0.021 - 0.025
0.026 - 0.041
0.042 - 0.088
0.089 - 0.22
0.23 - 0.61
0.62 - 1.7
1.8 - 4.9
5.0 - 14
N
0 2.75 5.5 11 16.5 22
km


Lanai
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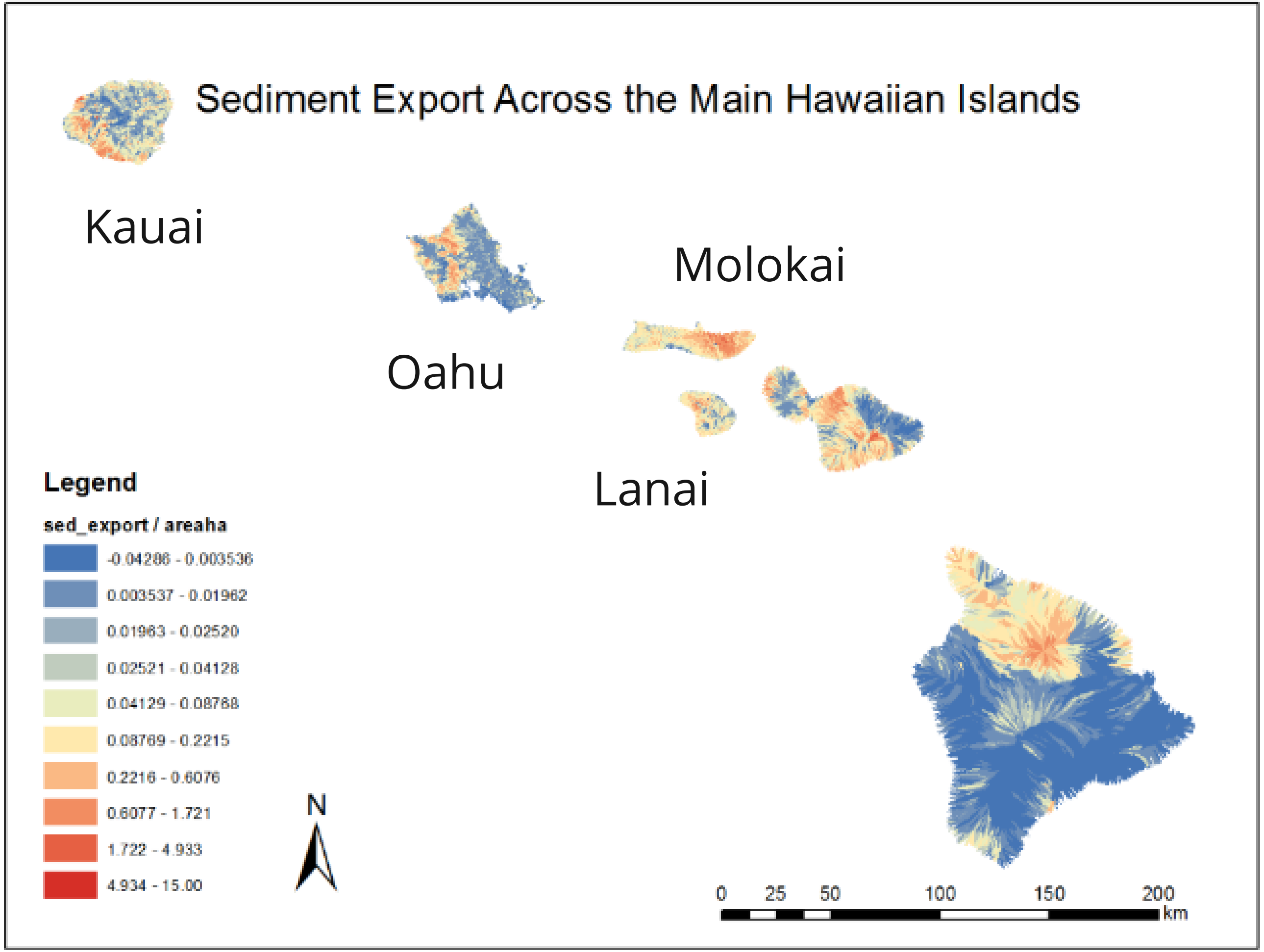
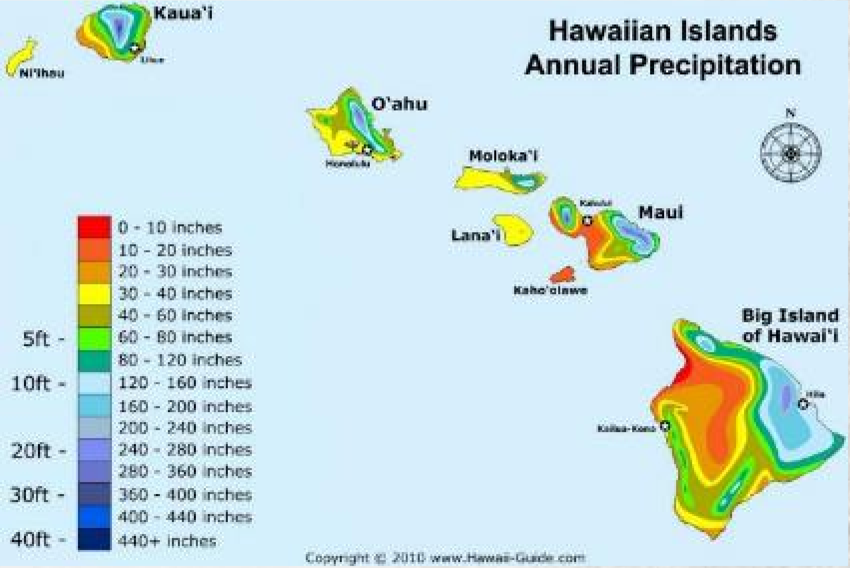
0 - 0.0035
0.0036 - 0.020
0.021 - 0.025
0.026 - 0.041
0.042 - 0.088
0.089 - 0.22
0.23 - 0.61
0.62 - 1.7
1.8 - 4.9
5.0 - 14
N
0
1.5
3
6
9
12
km


Sediment Export Across the Main Hawaiian Islands
Kauai
Oahu
Molokai
Lanai
Legend
sed_export / areaha
-0.04286 - 0.003536
0.003537 - 0.01962
0.01963 - 0.02520
0.02521 - 0.04128
0.04129 - 0.08768
0.08769 - 0.2215
0.2216 - 0.6076
0.6077 - 1.721
1.722 - 4.933
4.934 - 15.00
N
0 25 50 100 150 200
km

# CHALLENGES

- Stream flow accumulation not constant
- Have not yet considered how to include the transport piece – how will the sediment get to the stream



# CHALLENGES

## CALIBRATION – A 2-PART PROBLEM

Spatial + Temporal

- Erosion pins?
- Long-term weathering

- USGS recently started monitoring sediment on Oahu, missing continuous sediment monitoring on neighbor islan

# ONGOING DEVELOPMENT

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**Calibration**

- Calibration and validation of InVEST against other models (SWAT, GSSHA, N-SPECT) and budgeting techniques

**Integration**

- Integration with coastal water quality models

**Transfer**

- Continuing to work with decision makers to identify decisions that would benefit from this modeling

# Acknowledgements

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# HANDS-ON EXCERCISE

## Tana Water Fund

# OBJECTIVES

- Run the model and visualize outputs
- Explain the effect of the model calibration
- Compare model predictions under land use change or climate change scenarios
- Conduct a simple sediment retention valuat

**InVEST workshop:**
**Sediment delivery and retention model**

Increases in sediment yield are observed in many rivers of the world, having impacts on water quality and reservoir management. This exercise illustrates how the InVEST sediment model can provide a rapid assessment of where and how much natural landscapes can retain sediment inland.

After the session, participants should be able to:

- Run the model and visualize outputs
- Explain the effect of the model calibration
- Compare model predictions under land use change or climate change scenarios
- Conduct a simple sediment retention valuation

**Background**

The Tana River basin supplies water for irrigation and domestic use that benefits millions of Kenyans. Major water users, including rural communities, the Nairobi water utility, and a hydropower company are establishing a Water Fund that will secure the provision of key water services. To design the program and better target soil-retention interventions, it is crucial to understand the location and magnitude of the sediment retention service.

**Tasks**

1. Assess the retention service for the baseline scenario
2. Calibrate the model
3. Assess the retention service for the activities scenario
4. Assess the retention service for a climate change scenario
5. [Optional] Provide a valuation to the retention service

***Reminder:** Refer to the user guide for technical terms and input data (see link in the user interface)*

**Step-by-step**

*Task 1: Retention service for the baseline scenario*

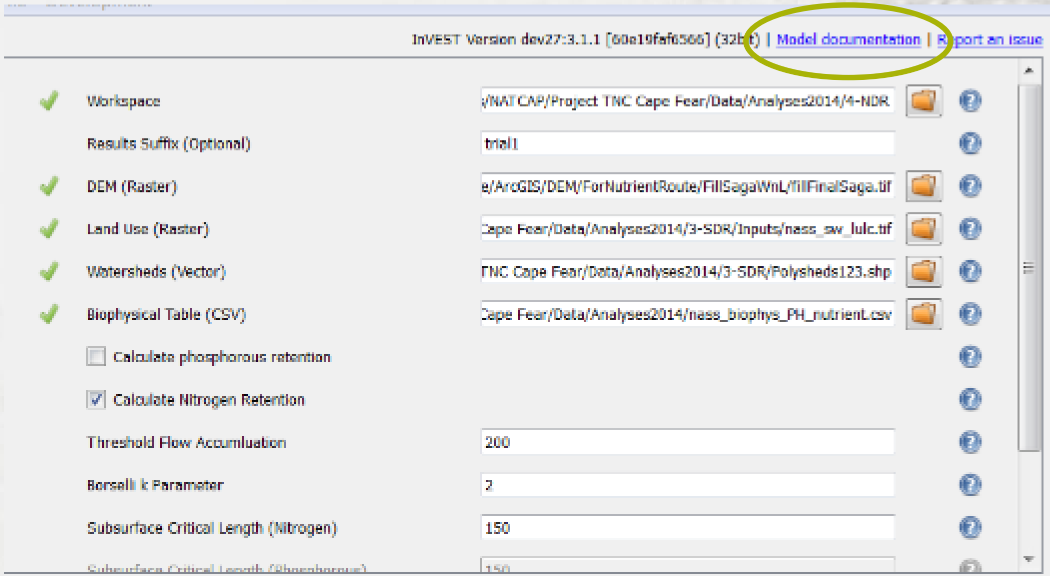
- Select your working folder and suffix (e.g. 'baseline')
- Input data for the baseline scenario (all data in 'inputs' folder)

# CONTEXT
## TANA WATER FUND

- First Water Fund in Africa (started in 2011)
- Project led by The Nature Conservancy
- Objective: to restore and protect the condition of the Upper Tana River and improve Nairobi's water security.
- Business case study in the Upper Tana Watershed (11,000 $km^2$)
  - Services of interest: water supply, sediment retention
  - Key beneficiaries: rural communities, the Nairobi water utility, and a hydropower company

# HANDS ON EXERCISE
## TIPS

- Online User's guide: naturalcapitalproject.com > InVEST > Online User's guide
- Run the models while answering questions
- Drag and drop inputs in User Interface!



# HANDS ON EXERCISE
## TANA WATER FUND

*Task 1: Retention service for the baseline scenario*

- Select your working folder and suffix (e.g. 'baseline')
- Input data for the baseline scenario (all data in 'Inputs' folder)
- Leave the values of other parameters as defaults (TFA, $k_b$, $IC_0$, $SDR_{max}$)
- Run model (~5-10min) and open results in a GIS software: *watershed_outputs_SUFFIX.shp*, and *sed_export_SUFFIX.tif*

| |
|---|
| Which subwatershed has the highest sediment export and retention? Per unit area?<br>Within a subwatershed, which areas contribute the most to the sediment export? |

*Task 2: Model calibration*

Based on previous studies, the expected total sediment yield for the baseline scenario is ~3.7Mt/yr. In this question, we calibrate the model by changing the $k_b$ parameter.

- Re-run the model with $k_b$=1.3 (*don't forget to change the suffix or results will be overwritten*)

| |
|---|
| How sensitive the model was to a change in the $k_b$ parameter?<br>Did the spatial pattern of sediment export/retention change? What are the implications in terms of uncertainty?<br>Optional: analyze the sensitivity of the model to other parameters. |

# HANDS ON EXERCISE
## TANA WATER FUND

*Task 3: Climate change scenario*

A (hypothetical) climate change scenario forecasts an increase in precipitation intensity in the upper areas.

- Run the (calibrated) model with the new climate layer ("erosivity_s_CCscenario.tif")

| |
|---|
| How did the hypothetical climate change scenario impact the results?<br>How would a spatially-constant increase in precipitation intensity impact the results? |

*Task 4: Land management scenario (Gura)*

A land use/land cover scenario for the watershed was developed with the RIOS model. It includes 5 land management activities (e.g. riparian management, terracing, agroforestry, reforestation, grass strips), which were sited based on their efficiency, cost, and stakeholder preferences.

- Run the (calibrated) model with the new land use land cover map for the Gura subwatershed (i.e. new LULC, Watershed, and biophysical table in "Gura" folder)

| |
|---|
| How did sediment export and retention change? How did the potential soil loss (USLE) change?<br>How would you communicate the difference between two scenarios? |