LANDSCAPE APPROACHES TRAINING SERIES

Session 4: Freshwater Ecosystem Service Modeling

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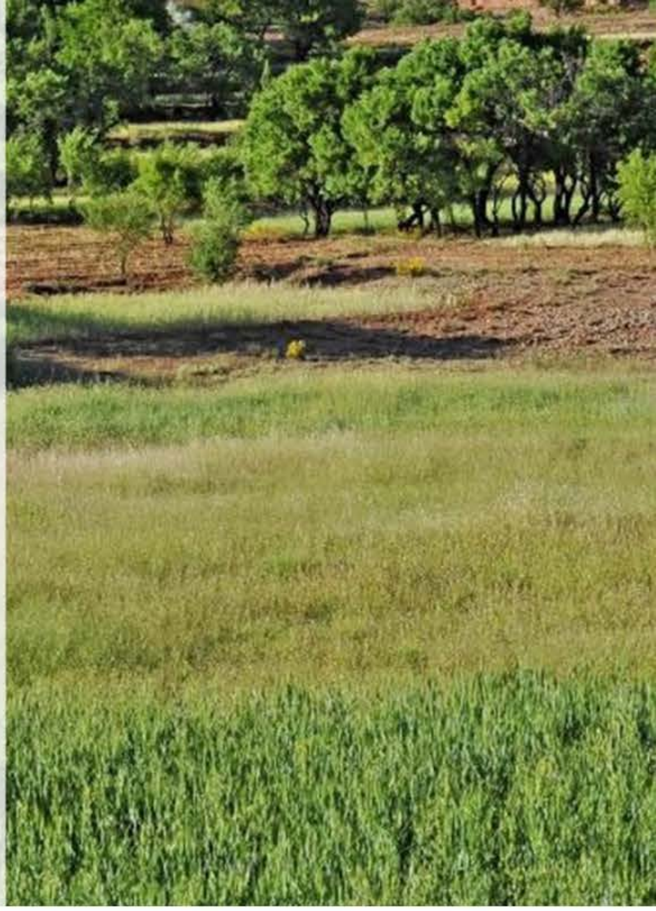
Environment, Natural Resources & Blue Economy

GPS Global Program on Sustainability



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Boris completed his PhD in Hydrology and MSc in Hydrology and Water Resources Management from Imperial College London, UK. Prior to that, he studied Civil Engineering at University of Cuenca, Ecuador. He is also the founder of the Institute for Applied Sustainability Research (IJASUR) in Ecuador, and scientific advisor for Forest Trends in the "Natural Infrastructure for Water Security" project. Boris has expertise in mountain hydrology, hydrological monitoring and ecosystem service management. In the last five years, he has published over 40 scientific articles and policy briefs, delivered more than 100 talks and conference presentations, seminars and webinars, and received 10 prizes and awards. Currently, he investigates how to combine ancient knowledge and nature-based solutions with conventional engineering options to solve problems related to national and global water security.

learning objectives

- Learn how to apply the InVEST Recreation model and interpret the results.

about our workshop

This session provides a conceptual understanding of freshwater modeling, with a deep dive into 3 models – Seasonal Water Yield (SWY), Sediment Delivery Ratio (SDR), Nutrient Delivery Ratio (NDR). The session also provides a step-by-step framework of the modeling practice, and considerations for selecting the best model. Along with discussing data points for each of the 3 models, the session also provides participants the space to consider key questions, limitations and applications for each of the models. Finally, there will be an analysis of how results can be used to inform decsion-making.

Keywords: InVEST Recreation Model, Seasonal Water Yield, Sediment Delivery Ratio, Nutrient Delivery Ratio, Freshwater Modeling

GPS Global Program on Sustainability

Freshwater Ecosystem Service Modeling

Exploring Landscape Assessments of Freshwater Ecosystems with National Scale Results for Zambia

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atuk

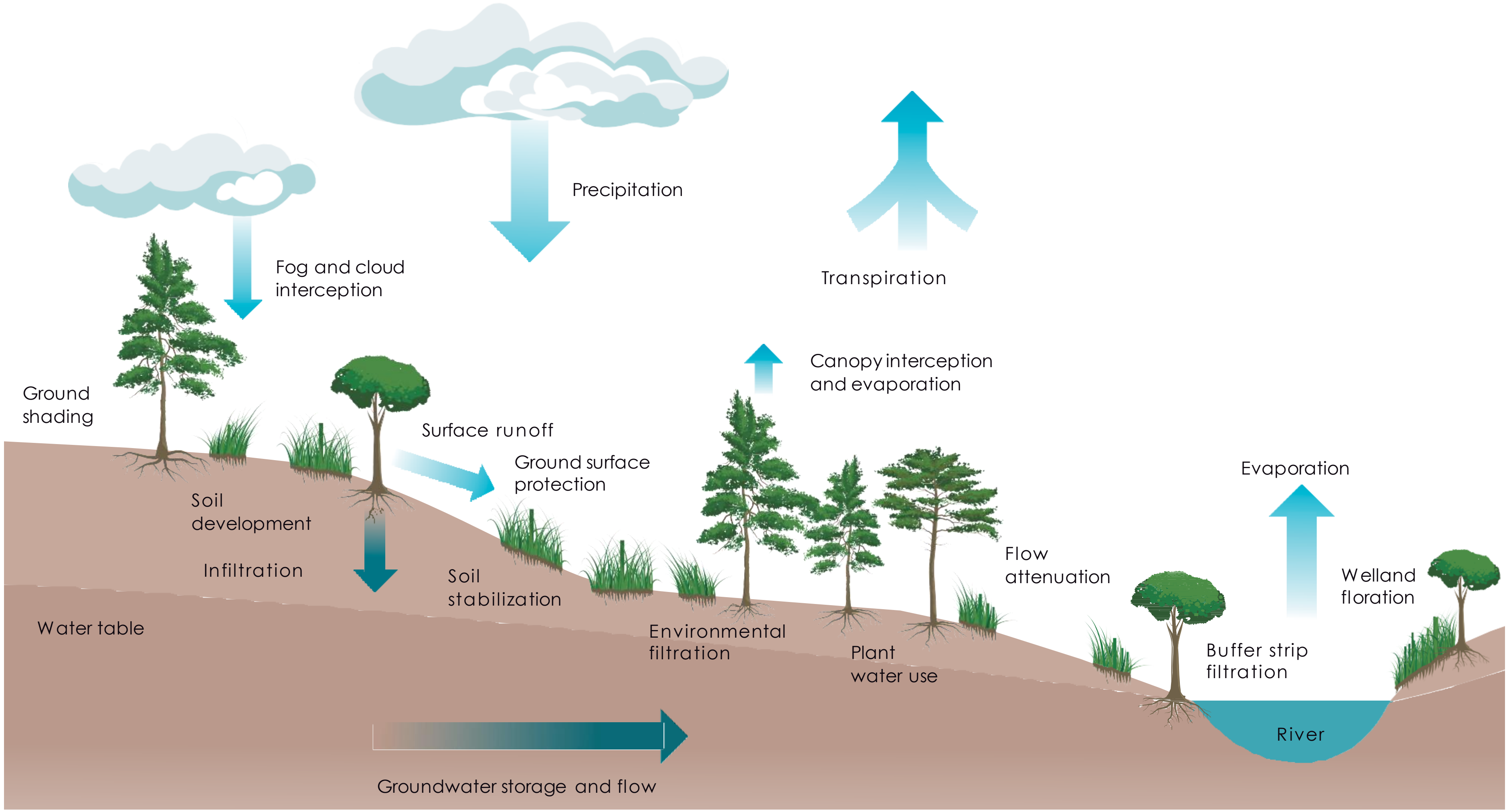
OBJECTIVES

- To provide conceptual basis on freshwater modelling: nutrients, sediments, water yield, initial examples.
- To strengthen the technical capacity around the use of freshwater modelling and understanding results to inform decisions and recommending policies.

CONTENT

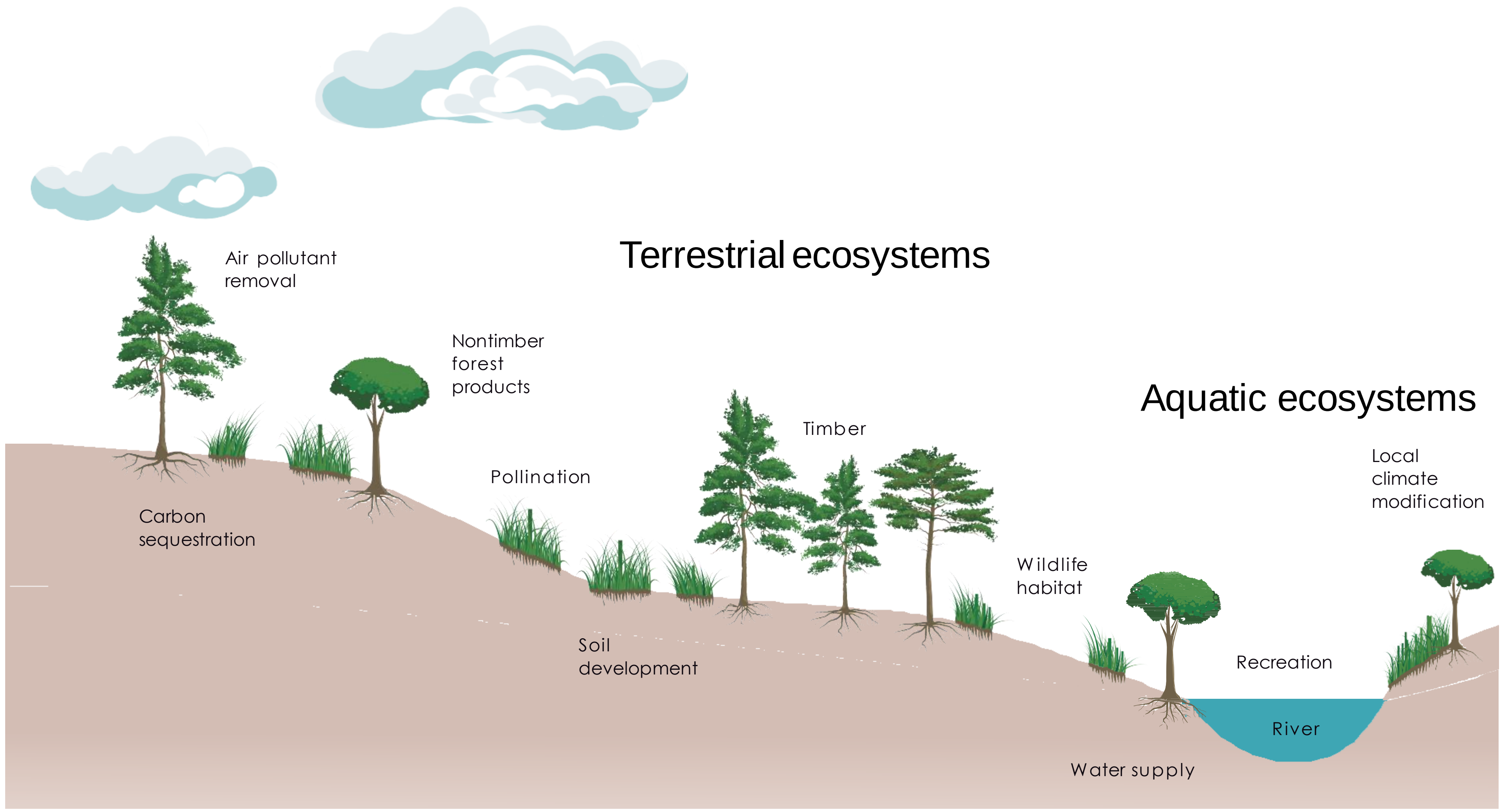
HYDROLOGICAL ECOSYSTEM SERVICES

HYDROLOGICAL CYCLE



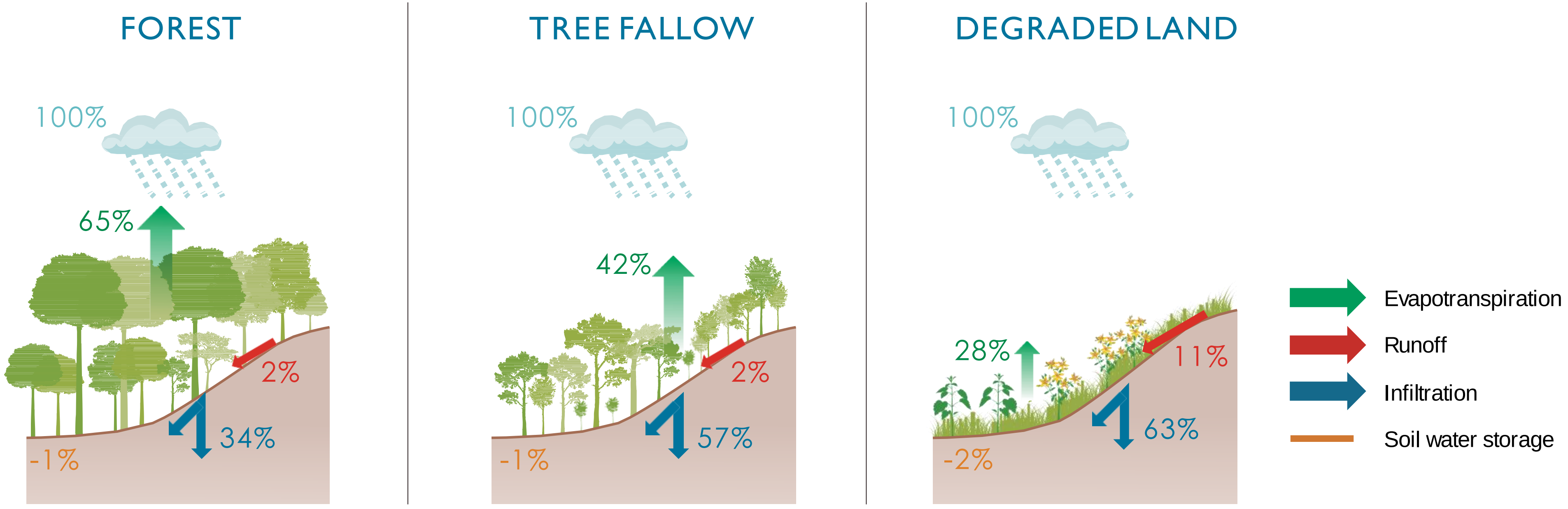
Brauman et al., 2007; Ochoa-Tocachi et al., 2022. Hydrological Modelling Guide for Natural Infrastructure.

HYDROLOGICAL ECOSYSTEM SERVICES



Brauman et al., 2007; Ochoa-Tocachi et al., 2022. Hydrological Modelling Guide for Natural Infrastructure.

Ecosystems do not create water; they move and modify flows.



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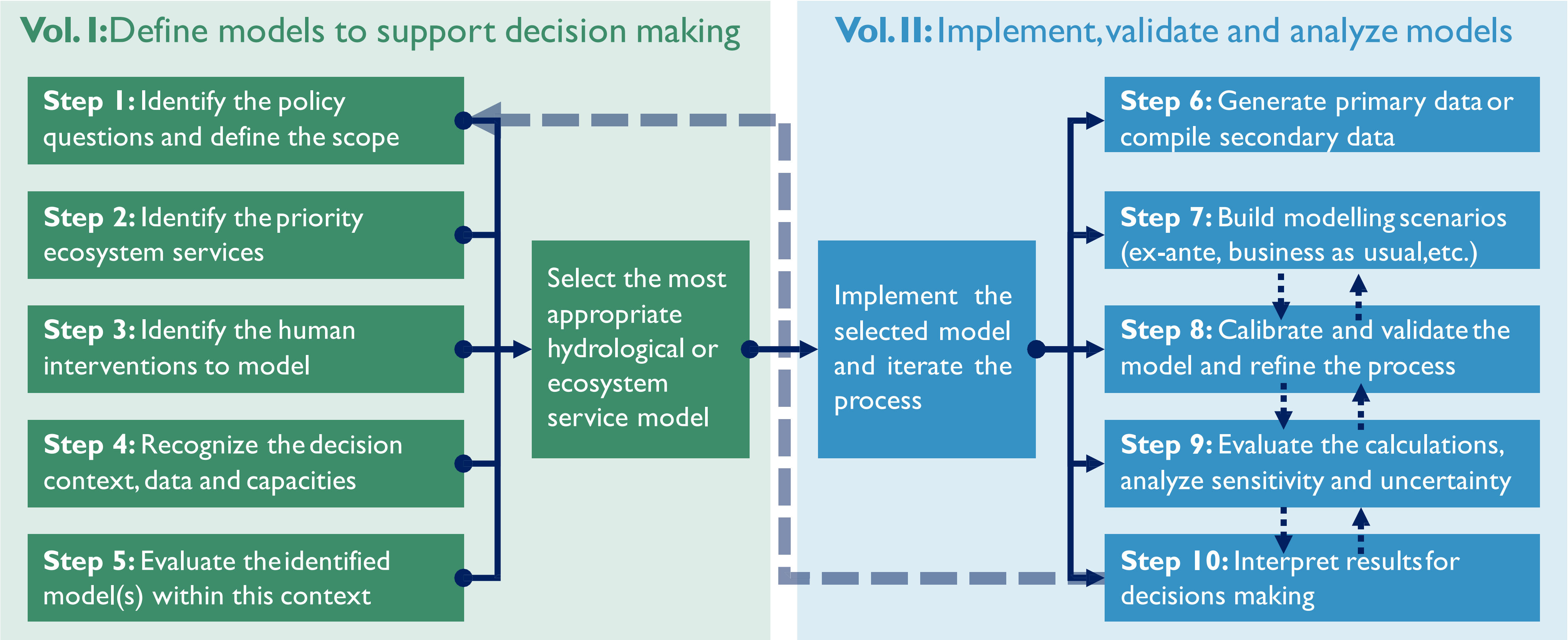
Van Meerveld et al., 2021; Ochoa-Tocachi et al., 2022. Hydrological Modelling Guide for Natural Infrastructure.

THE MODELLING PRACTICE



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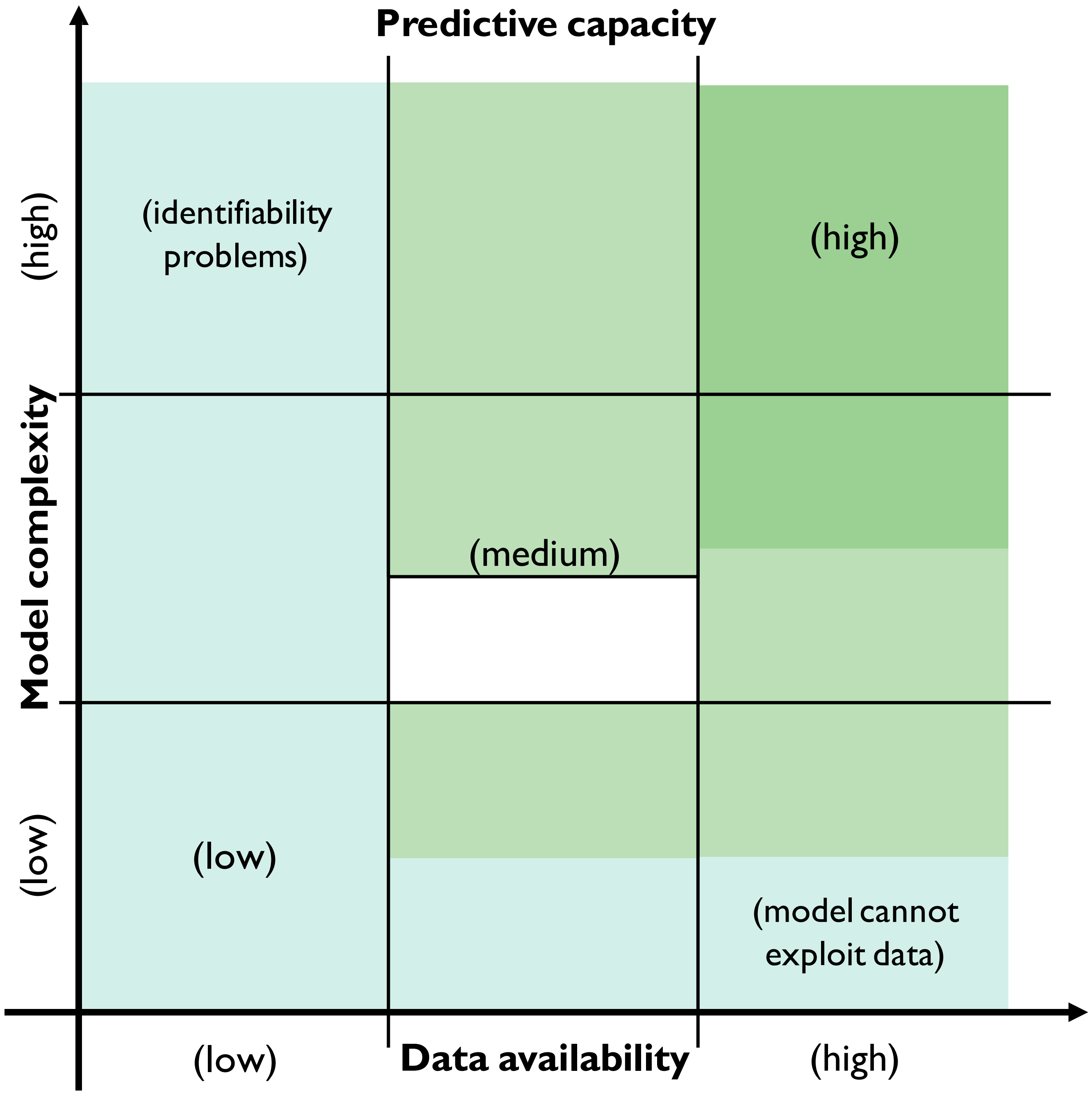
Bullock & Ding, 2018; Ochoa-Tocachi et al., 2022. Hydrological Modelling Guide for Natural Infrastructure.

DECISIONS AT HAND

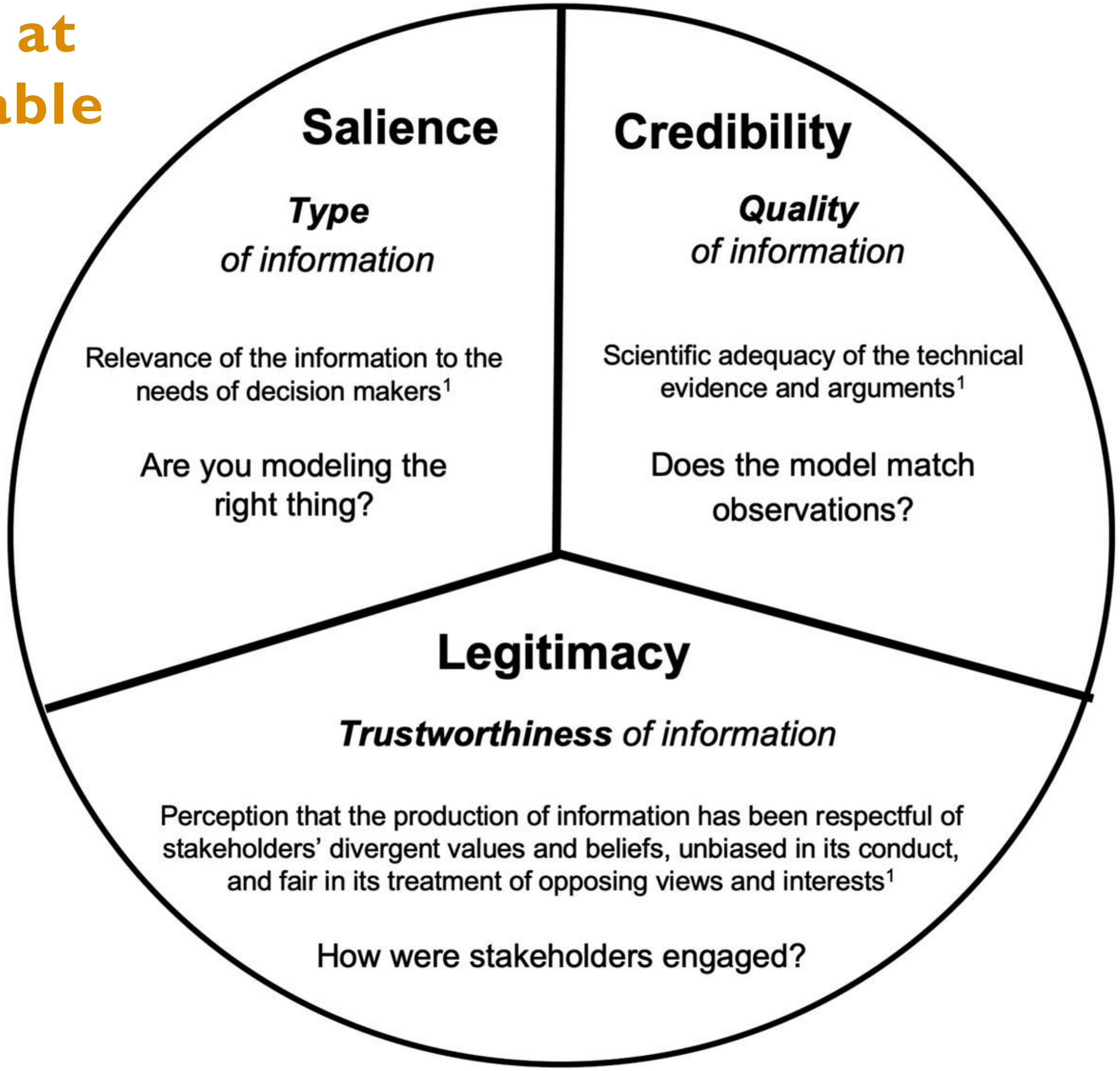
Why isn't the most complex model necessarily the best option?

- A complex model may not be the best option for an urgent decision in a data scarce context.
- Secondary data available in global databases for several variables that are needed can be used, but local data have been proved to generate most precise modelling estimates.
- Strengthening local staff technical capacity and knowledge must be considered as a very efficient way to improve results.



Grayson & Bloschl, 2000; Ochoa-Tocachi et al., 2022. Hydrological Modelling Guide for Natural Infrastructure.

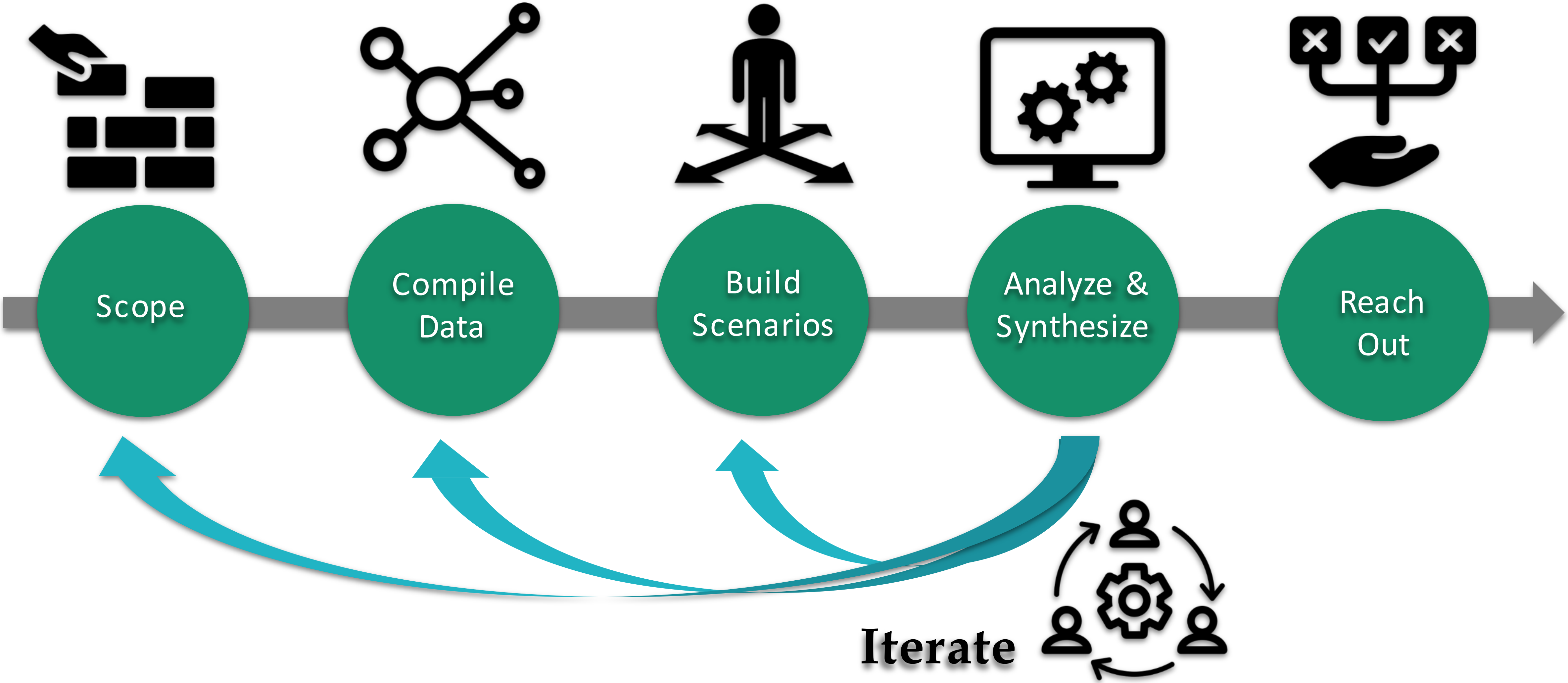
What do we need to look at when improving the available data and the results?



Cash et al., 2003; Brauman et al., 2021; Ochoa-Tocachi et al., 2022. Hydrological Modelling Guide for Natural Infrastructure.


Climate regulation
Food, fuel, fiber
Pollination
InVEST
integrated valuation of ecosystem services and tradeoffs
Clean water
Coastal protection
Spiritual Fulfilment

Assessment process



InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs): https://naturalcapitalproject.stanford.edu/software/invest

Changes in ecosystems →
Changes in ecosystem services

Seasonal water yield	Sediment delivery ratio	Nutrient delivery ratio
		

InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs): https://naturalcapitalproject.stanford.edu/software/invest

Seasonal Water Yield Model

Key questions

- How much water does the landscape produce?
- From where on the landscape does this water supply originate?
- How might land management or climate change affect these contributions?
- How are we contributing to SDG6 and its indicators?

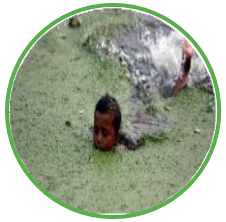
Decision contexts


Drinking water


Irrigation


Hydropower

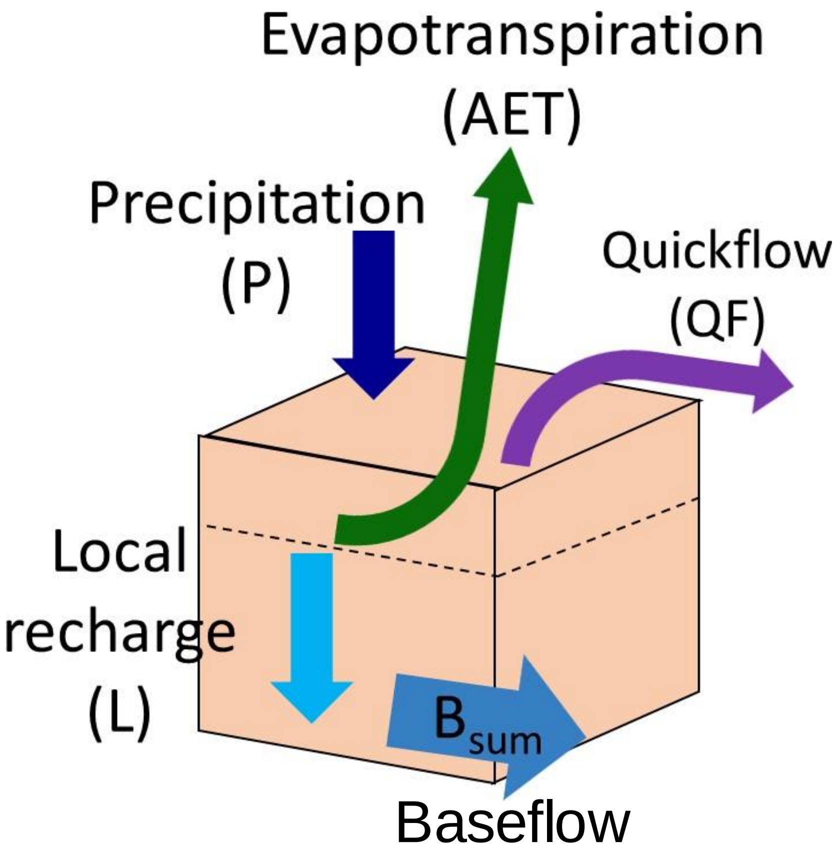

Flood risk reduction


Pollution dilution

InVEST Seasonal Water Yield: http://releases.naturalcapitalproject.org/invest-userguide/latest/seasonal_water_yield.html

SWY model

Modelled processes



Limitations

- Results are limited to a single year long-term monthly average quickflow and annual Baseflow.
- Baseflow is a relative index only, not absolute. It is one uniform value for the year.
- Uncertainty around flow routing (upslope contribution to AET).

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InVEST Seasonal Water Yield: http://releases.naturalcapitalproject.org/invest-userguide/latest/seasonal_water_yield.html

SWY model inputs

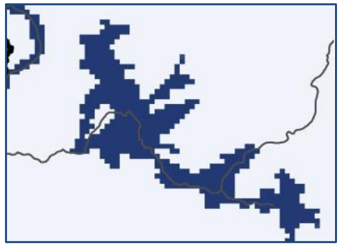
Watershed
Area of interest

Topography
DEM,
Threshold flow accumulation

Land Use/Land Cover
Curve numbers,
Evapotranspiration coefficients

Climate (monthly)
Precipitation,
evapotranspiration,
# of rain events

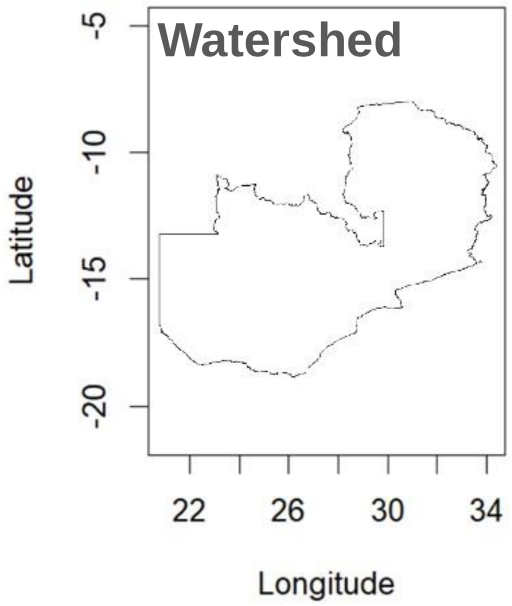
Soils
Hydrologic soil groups



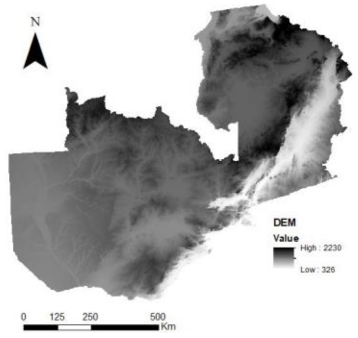
Optional
Climate zones,
recharge layer

InVEST Seasonal Water Yield: http://releases.naturalcapitalproject.org/invest-userguide/latest/seasonal_water_yield.html

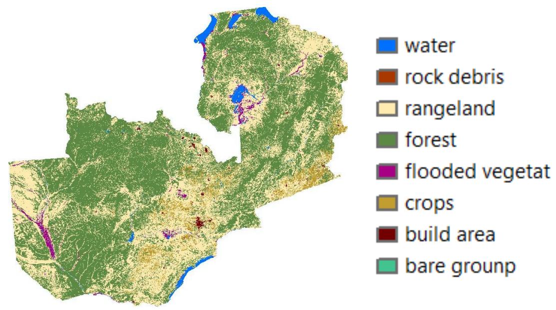
SWY model inputs



Topography

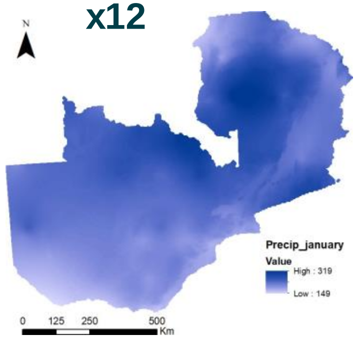


Land use / land cover



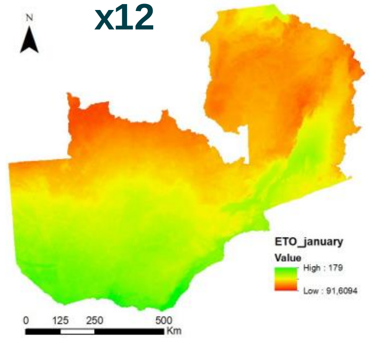
Monthly precipitation

x12

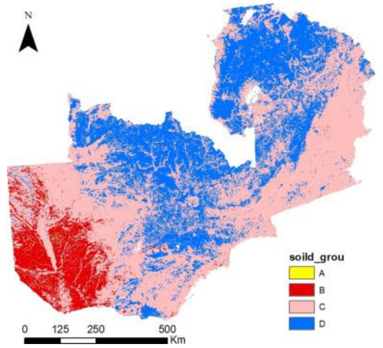


Monthly evapotranspiration

x12



Soil groups



Description
A: low runoff potential (>90% sand and <10% clay)
B: moderately low runoff potential (50-90% sand and 10-20% clay)
C: moderately high runoff potential (<50% sand and 20-40% clay)
D: high runoff potential (<50% sand and >40% clay)

SWY important calibration parameters

- **Kc:** crop water use factor by land cover type
- **Threshold flow accumulation** (TFA): The number of upslope cells that must flow into a cell before it is considered part of a sequence.
- **α:** temporal variability in the contribution of upslope available water to evapotranspiration on a pixel is a function of precipitation seasonality
- **β:** for a given amount of upslope recharge, the amount of water used by a pixel is a function of the storage capacity (local topography & soils)
- **γ:** fraction of pixel recharge that is available to downslope pixels is a function of soil properties and possibly topography

description	lucode	Kc_1	Kc_2	Kc_3	Kc_4	Kc_5	Kc_6	Kc_7	Kc_8	Kc_9	Kc_10	Kc_11	Kc_12	CN_A	CN_B	CN_C	CN_D
Urban	111	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	77	85	90	92
Pasture	231	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	49	69	79	84
Mosaic	241	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	55	71.5	80.5	85.5
Secondary Vegetation	323	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	30	51.5	67.5	75
Barren	333	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	77	86	91	94
Water	413	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1	1	1	1
Wetlands	512	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1	1	1	1
Crops	2211	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	43	65	76	82
Forest	31111	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	30	55	70	77
Grasslands	32112	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	49	69	79	84
Mangroves	600000	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	98	98	98	98
Seagrass	610000	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

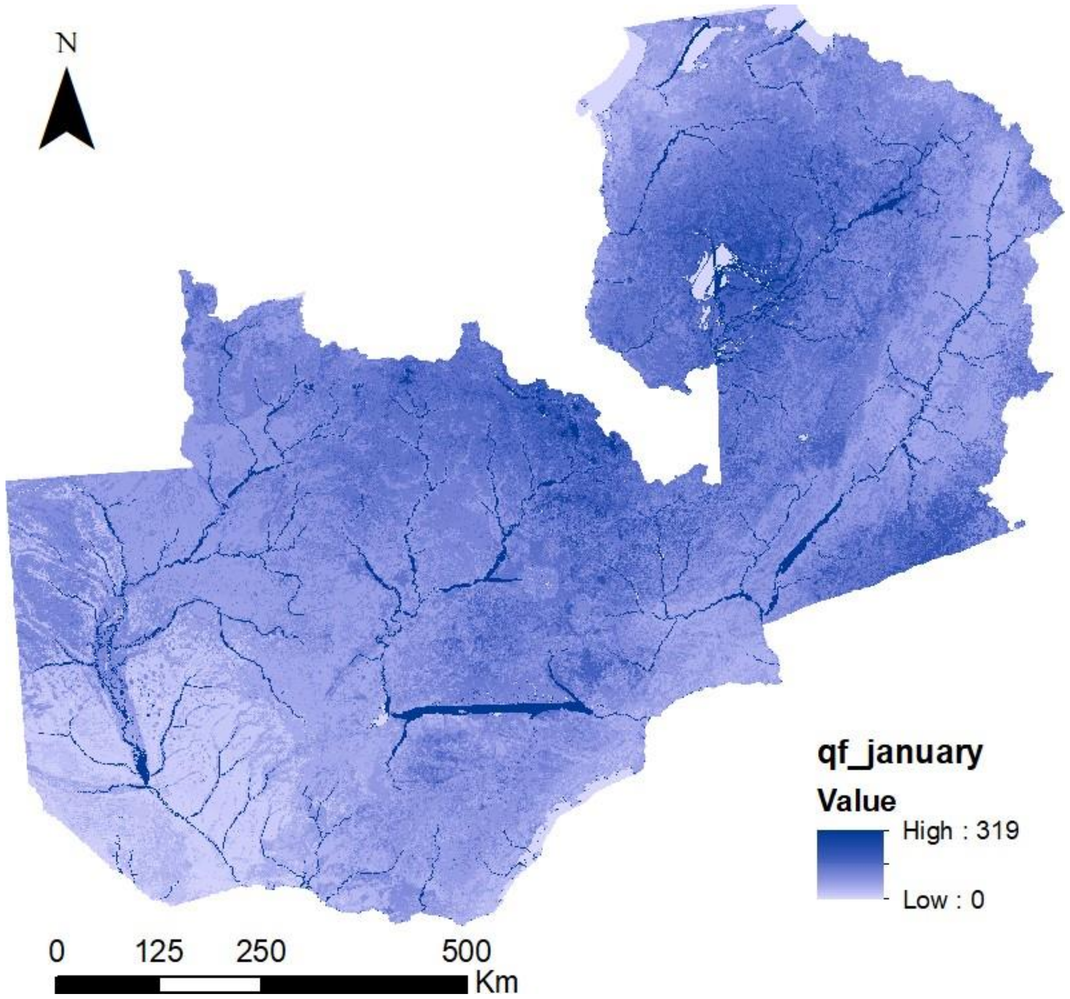
InVEST Seasonal Water Yield: http://releases.naturalcapitalproject.org/invest-userguide/latest/seasonal_water_yield.html

SWY model ou

- **Quick flow (mm)**

Water reaching streams during or shortly after rain events (direct runoff)

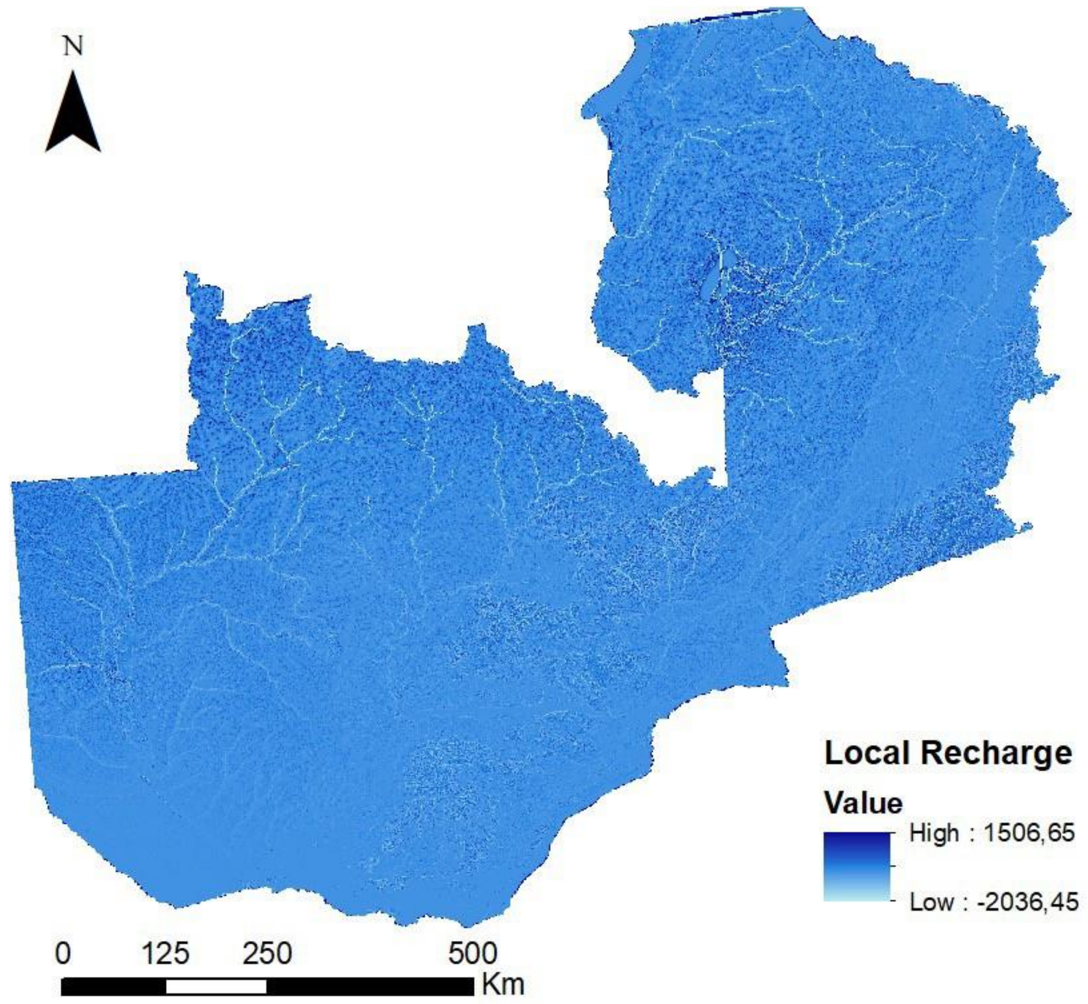
Annual and monthly averages



SWY model ou

- **Local recharge (mm)**

Annual average



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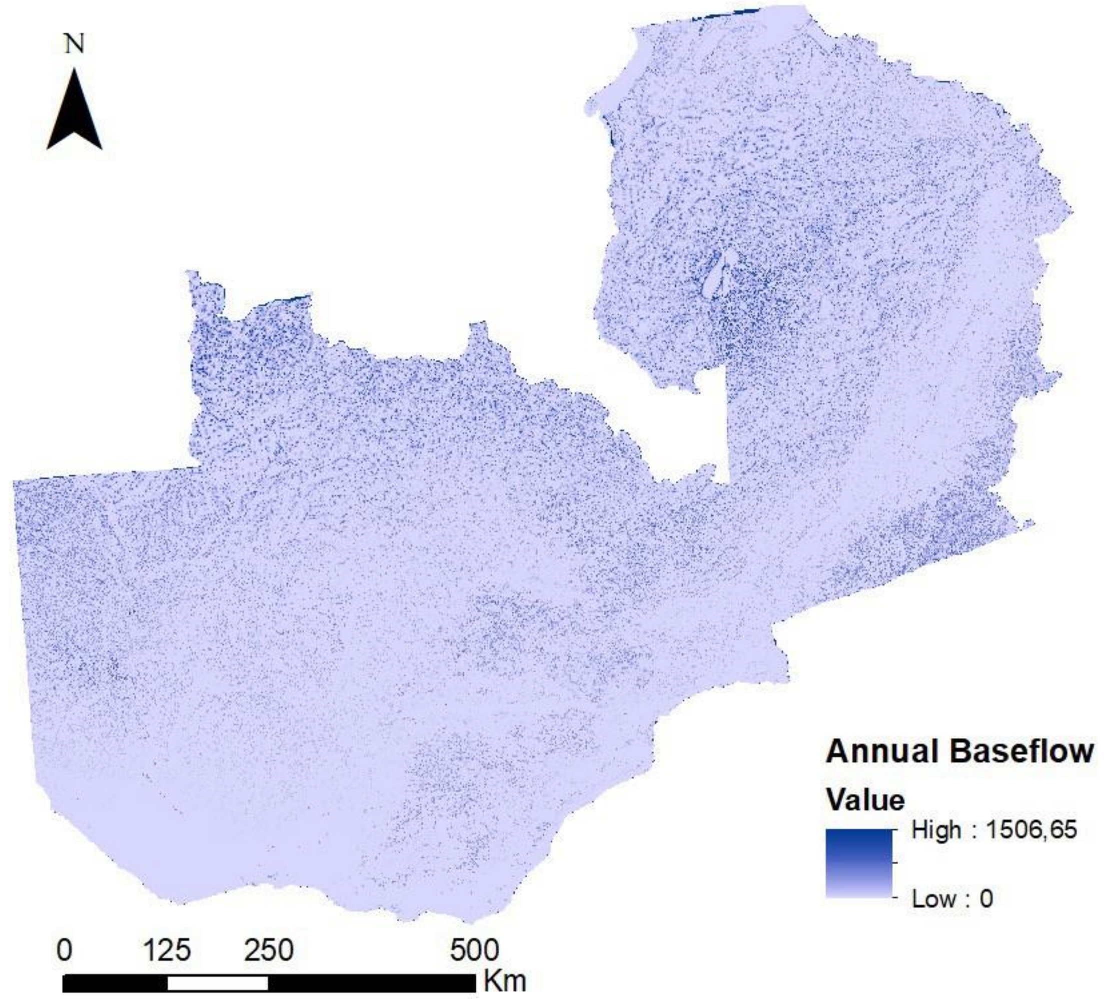
- **Baseflow (mm)**

Annual average
Water reaching streams later (between rain events; during dry season; residence times of months to years)

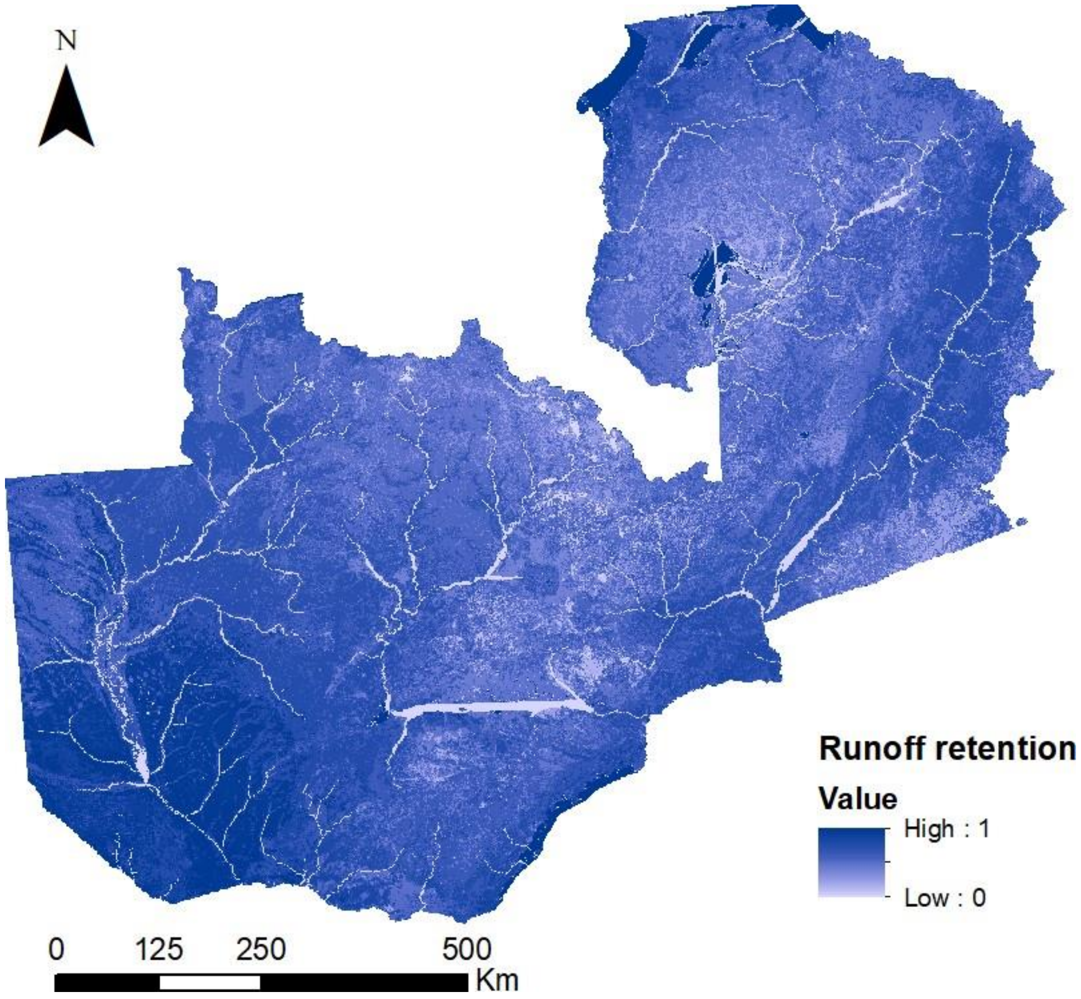


SWY model ou

- **Runoff Retention**

1 – (QF/Precipitation)

Annual and monthly averages



Potential applications

How does the water yield vary between dry years and wet years?

What is the impact of climate change on the water yield?

What is the forest/landscape restoration potential for water yield?

How to optimize the water yield use for production (food, electricity) with conservation?

What other applications **you see** for the seasonal water **yield** model?

Sediment Delivery Ratio Model

Key questions

- How is erosion as a natural process driven by topography, climate, vegetation, etc.?
- How does unsustainable land management increases erosion rates with impacts on food and water systems?
- How can erosion and sediment yield be controlled by human interventions on the landscape?

Decision contexts

Payments for watershed services programs

Global land use change impacts (agricultural expansion)

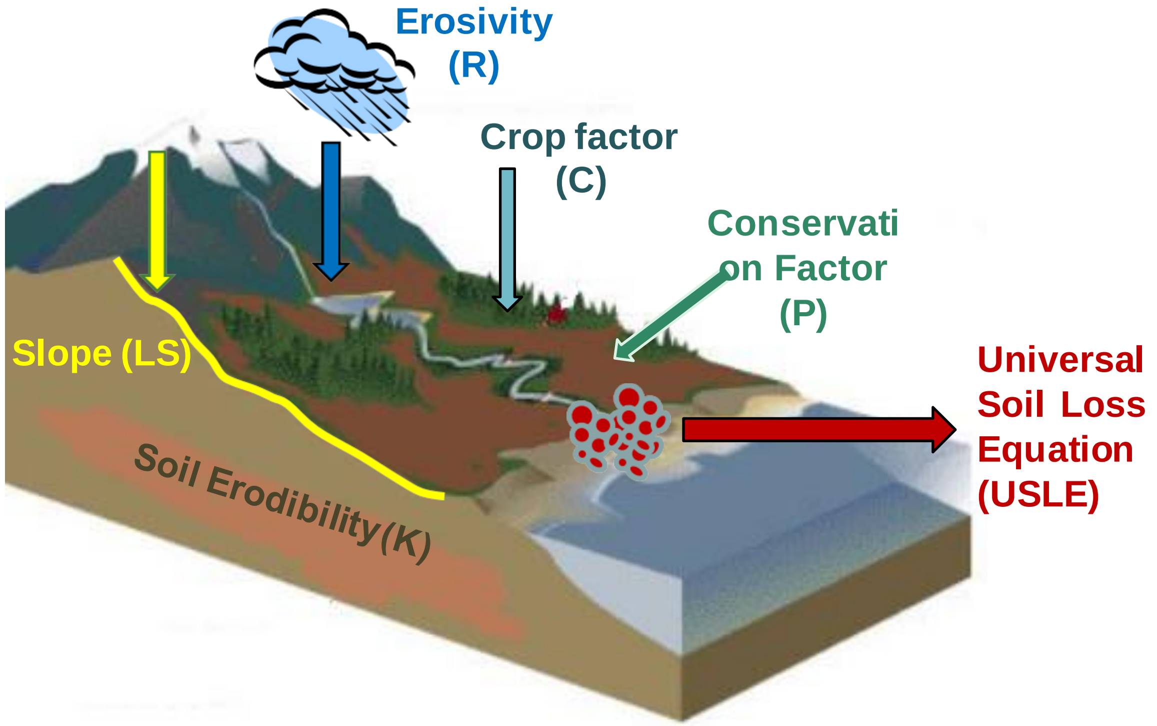
Impact assessment (infrastructure)

National accounting

InVEST Sediment Delivery Ratio: http://releases.naturalcapitalproject.org/invest-userguide/latest/sdr.html

SDR model

Modelled processes



Limitations

- Annual average values.
- 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 captured better).
- Valuation methods are highly contextual (e.g. treatment type, local regulations).

InVEST Sediment Delivery Ratio: http://releases.naturalcapitalproject.org/invest-userguide/latest/sdr.html

SDR model inputs

Climate

Rainfall erosivity

Watersheds

Main and sub-watersheds for point of interest

Soils

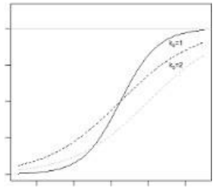
Soil erodibility

Topography

DEM, Threshold flow accumulation

Land Use/Land Cover

Crop factor and Practice factor

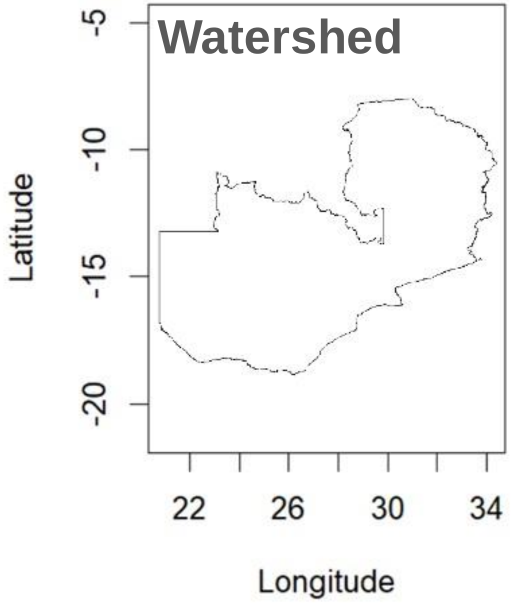


Calibration

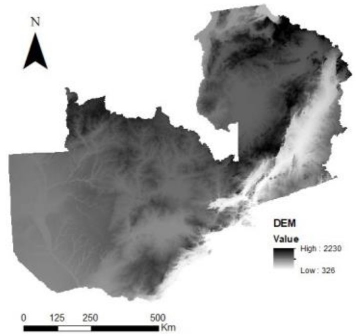
Connectivity/SDR

InVEST Sediment Delivery Ratio: http://releases.naturalcapitalproject.org/invest-userguide/latest/sdr.html

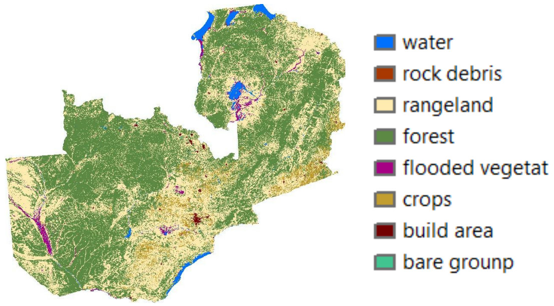
SDR model inputs



Topography

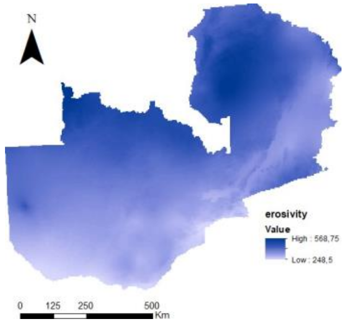


Land use / land cover

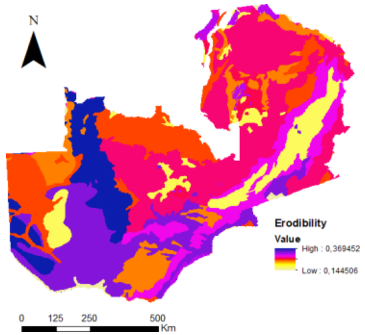


description	lucode	usle_c	usle_p
water	1	0	1
forest	2	0.025	1
flooded veget	4	0.2	1
crops	5	0.412	1
build area	7	0.99	1
bare ground	8	1	1
rock debris	10	0	1
rangeland	11	0.034	1

Rainfall erosivity



Soil erodibility



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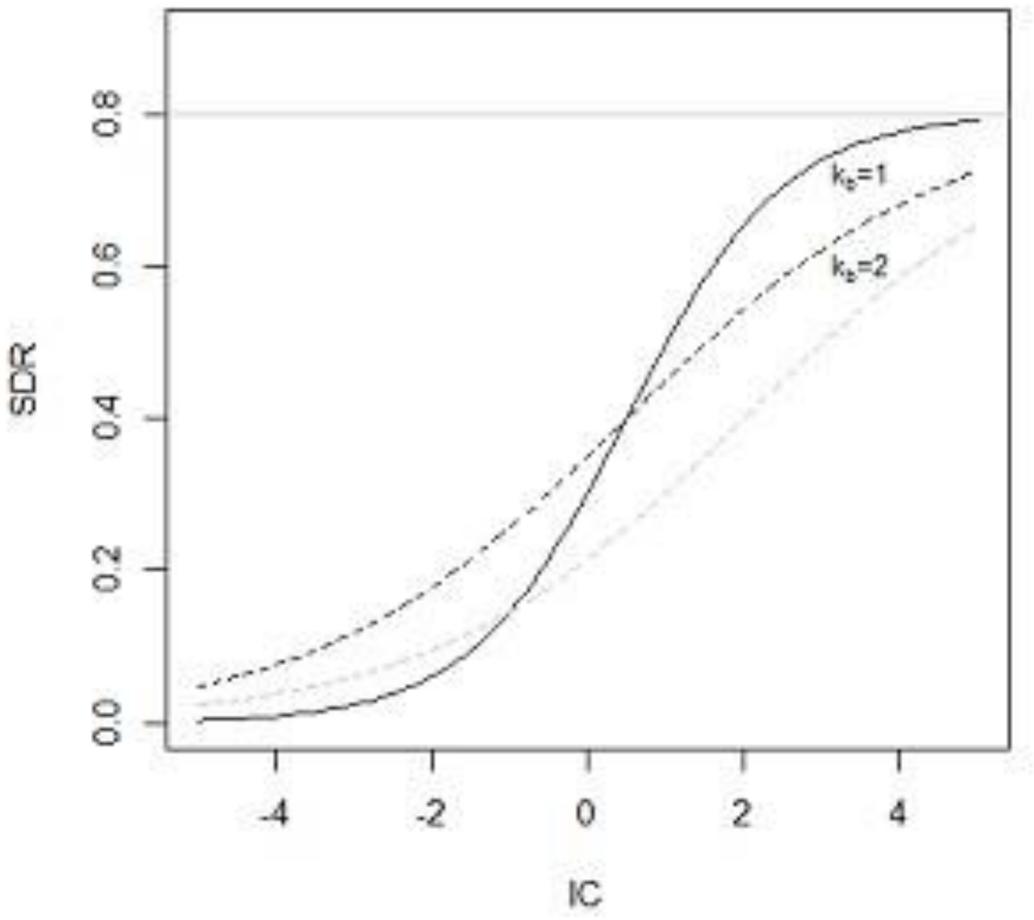
SDR important calibration parameters

- **Threshold flow accumulation**: The nu before it is considered part of a sequenc
- **Borselli k and IC0**: Determine the shap connectivity and sediment distribution ra
- **Max SDR value**: Maximum sediment d function of ground texture.
- **Max L value**: Maximum slope length.

Default Values

Threshold = 1000 ***Max SDR*** = 0,8 ***Max L* =** 122 - 333

k = 2 ***IC0* =** 0,5

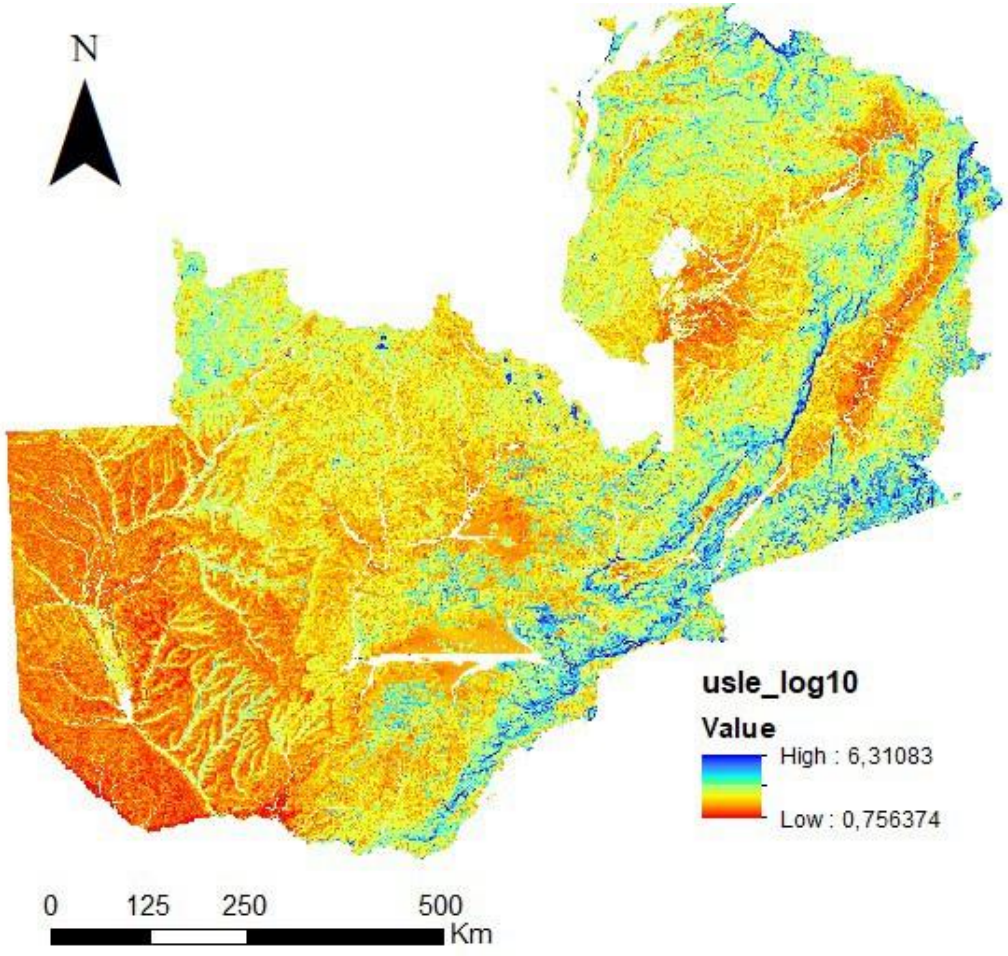


InVEST Sediment Delivery Ratio: http://releases.naturalcapitalproject.org/invest-userguide/latest/sdr.html

SDR model outputs

- **Potential soil loss (ton/yr)**

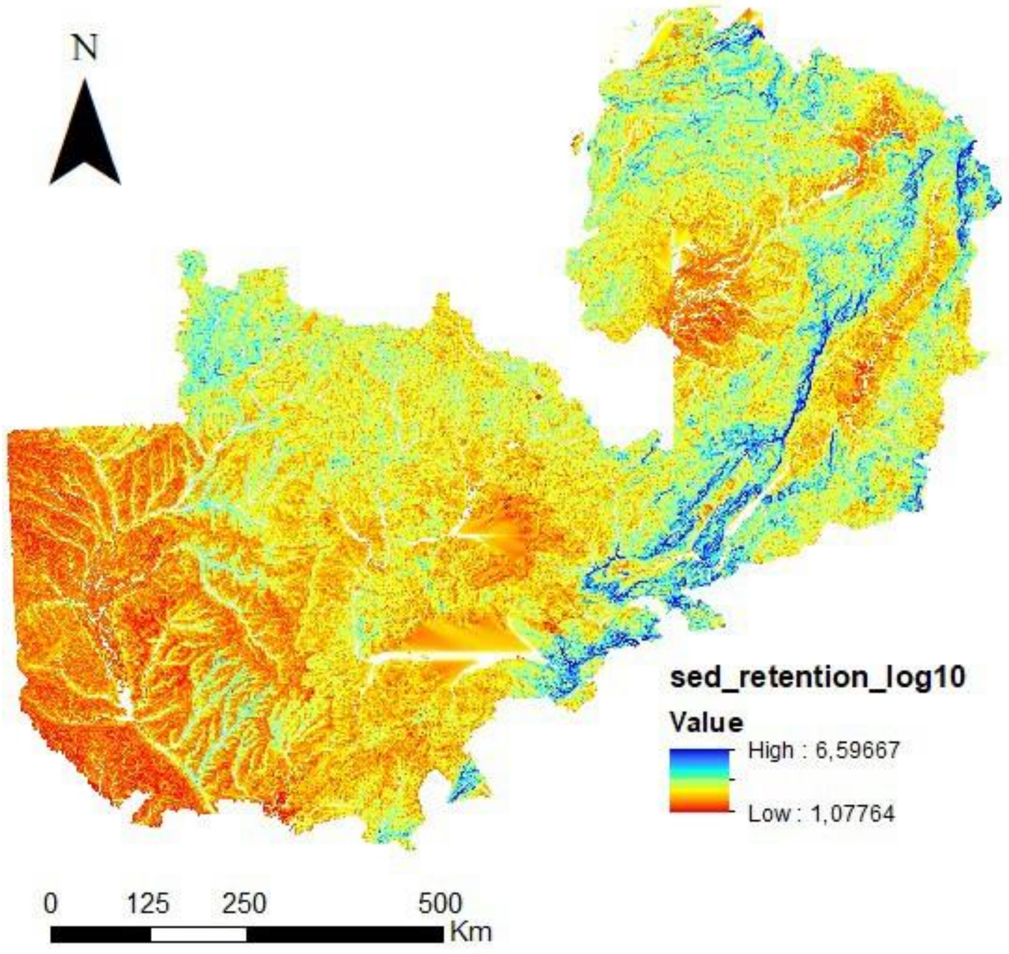
Results aggregated to watershed/sub-watersheds



SDR model outputs

- **Sediment export (ton/yr)**

Results aggregated to watershed/sub-watersheds

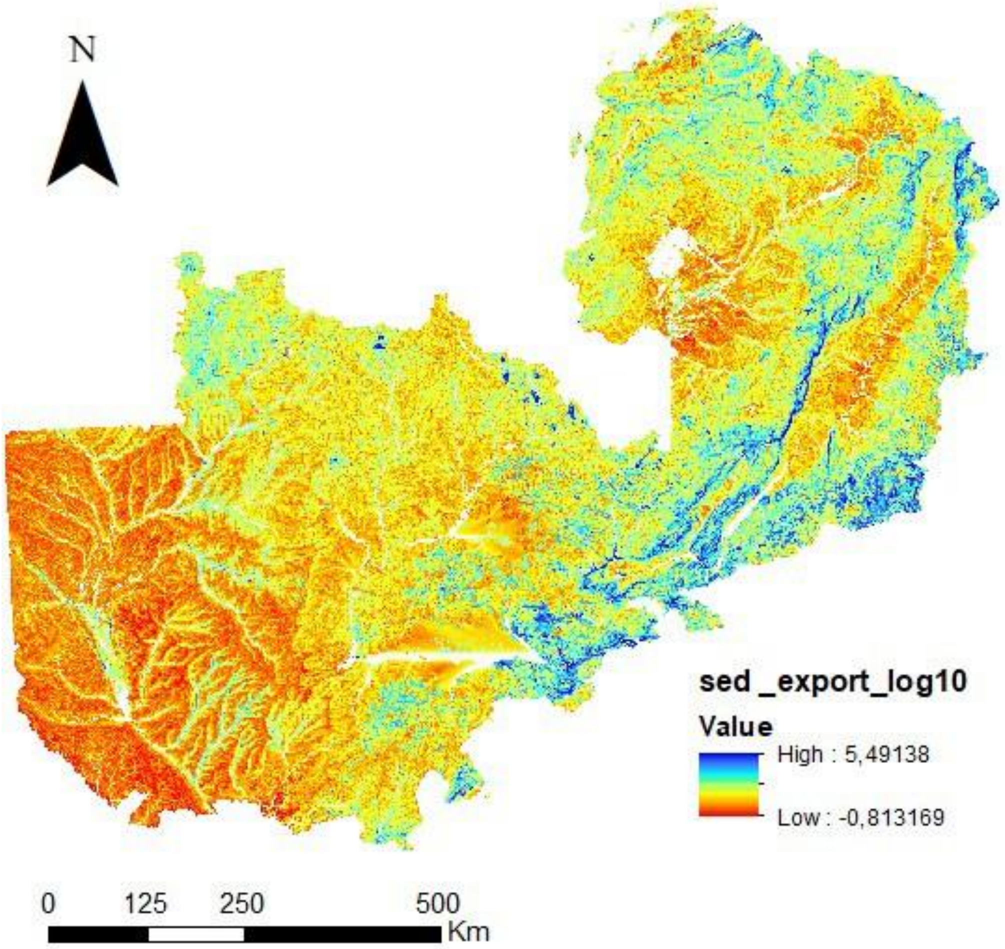


SDR model outputs

- **Sediment retention index**

Relative to bare ground

Results aggregated to watershed/sub-watersheds



Potential applications

Where are the most important sources of sediment production located?

How can different climate conditions determine erosion and sediment yield?

How human interventions and land planning can reduce erosion and sediment delivery?

What different alternative scenarios compare to decide future developmental pathways?

What other applications **you see** for the sediment retention model?

Nutrient Delivery Ratio Model

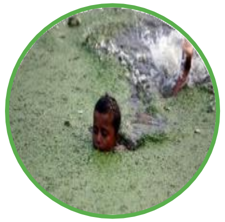
Key questions

- How much nutrient is produced on the landscape?
- Where is it produced?
- How does nutrient retention benefit people?

Decision contexts


Treatment plant


Drinking water


Pollution dilution


Stream health

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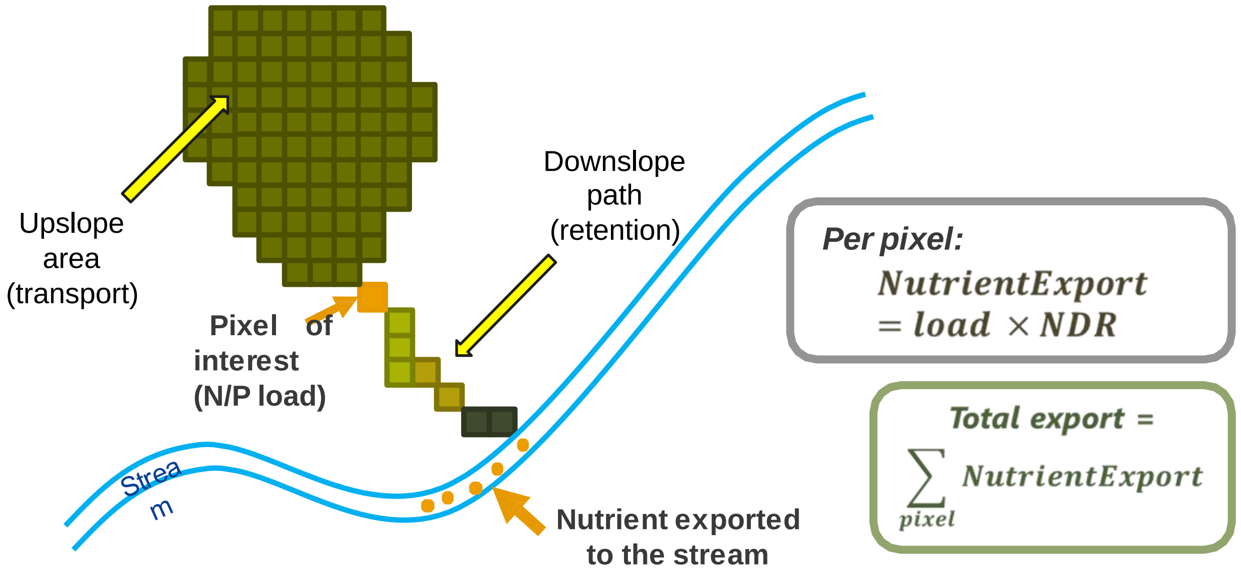
InVEST Nutrient Delivery Ratio: http://releases.naturalcapitalproject.org/invest-userguide/latest/ndr.html

NDR model

Modelled processes



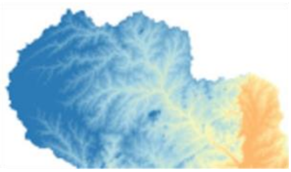
Limitations

- Non-point source.
- Simplified representation of nutrient transport, particularly subsurface.
- In-stream processes only, dam retention, etc. are not represented.
- Annual average values, not event-based.
- Requires calibration data to increase confidence in quantitative exports (relative differences are captured better).

InVEST Nutrient Delivery Ratio: http://releases.naturalcapitalproject.org/invest-userguide/latest/ndr.html

NDR model inputs

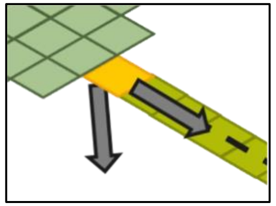
Climate
Precipitation
or quickflow



Topography
DEM, threshold flow
accumulation

Land Use/Land Cover
N/P load, efficiency,
retention length

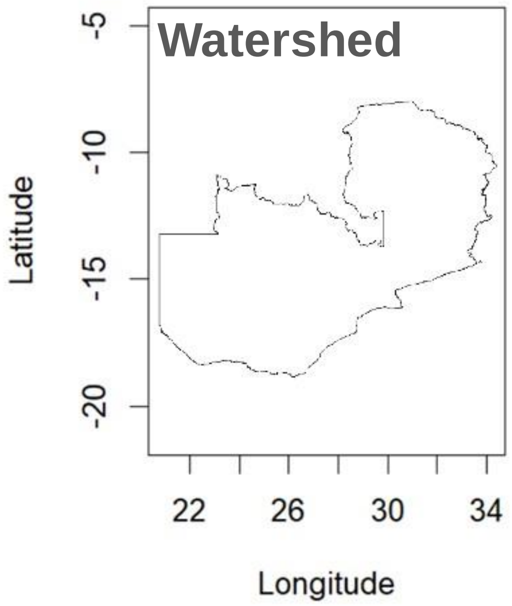
Watersheds
Serving point of
interest



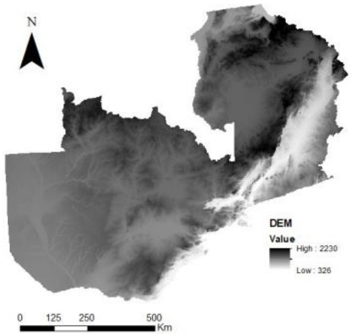
Optional
Information on
subsurface nutrients

InVEST Nutrient Delivery Ratio: http://releases.naturalcapitalproject.org/invest-userguide/latest/ndr.html

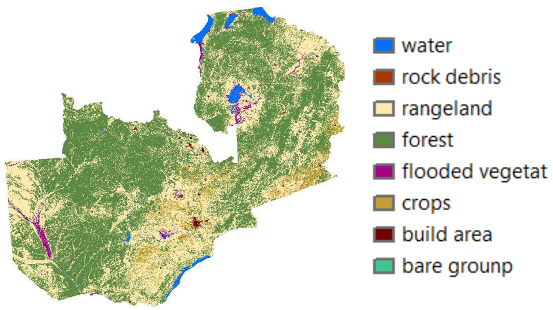
NDR model inputs



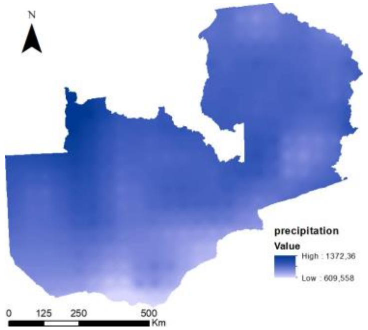
Topography



Land use / land cover

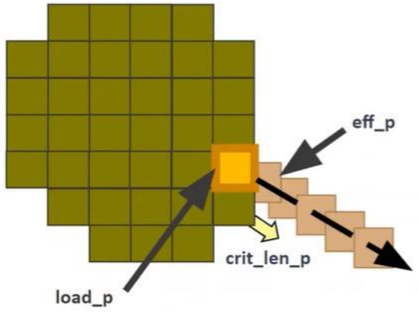


Annual precipitation



description	lucode	load_p	eff_p	crit_len_p
water	1	0	0.4	150
forest	2	2.1	0.67	150
flooded veget	4	1.5	0.65	150
crops	5	0.77	0.48	150
build area	7	0.6	0.26	150
bare ground	8	0.79	0.26	150
rock debris	10	0	0.3	150
rangeland	11	0.93	0.6	150

Biophysical table



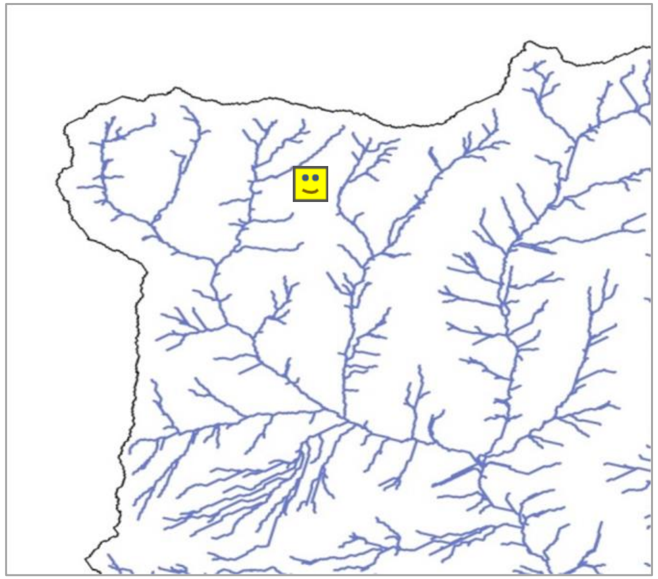
NDR important calibration parameters

- **Threshold flow accumulation**: The number of upslope cells that must flow into a cell before it is considered part of a sequence.
- **Borselli k**: Determine the shape of the relationship between hydrologic connectivity and nutrient supply ratio.

Default Values

Threshold = 1000 ***k***=2

TFA = 10,000 pixels



TFA = 100 pixels

InVEST Nutrient Delivery Ratio: http://releases.naturalcapitalproject.org/invest-userguide/latest/ndr.html

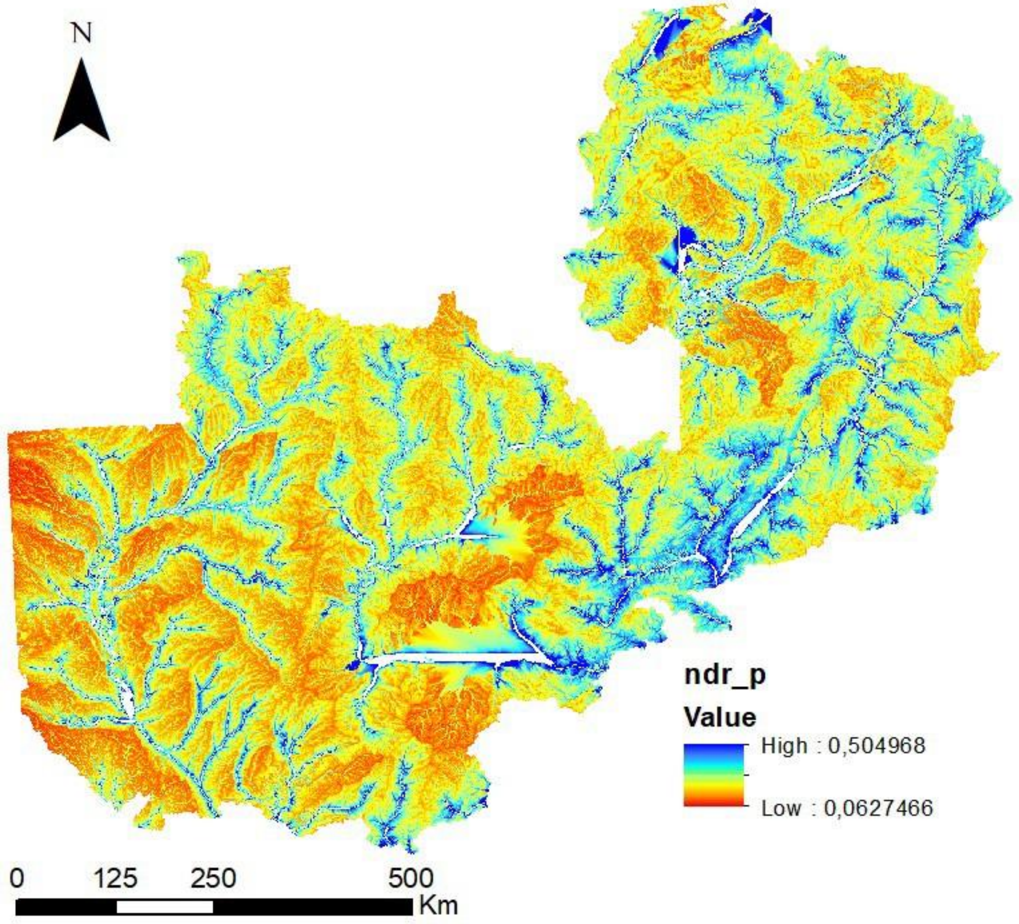
NDR model outputs

- **Nutrient discharge rate**

Shows the pattern of nutrient sources

Results aggregated to watershed/sub-watersheds

High-export areas could be targets for **restoration**.
Low-export areas could be targets for **conservation**.



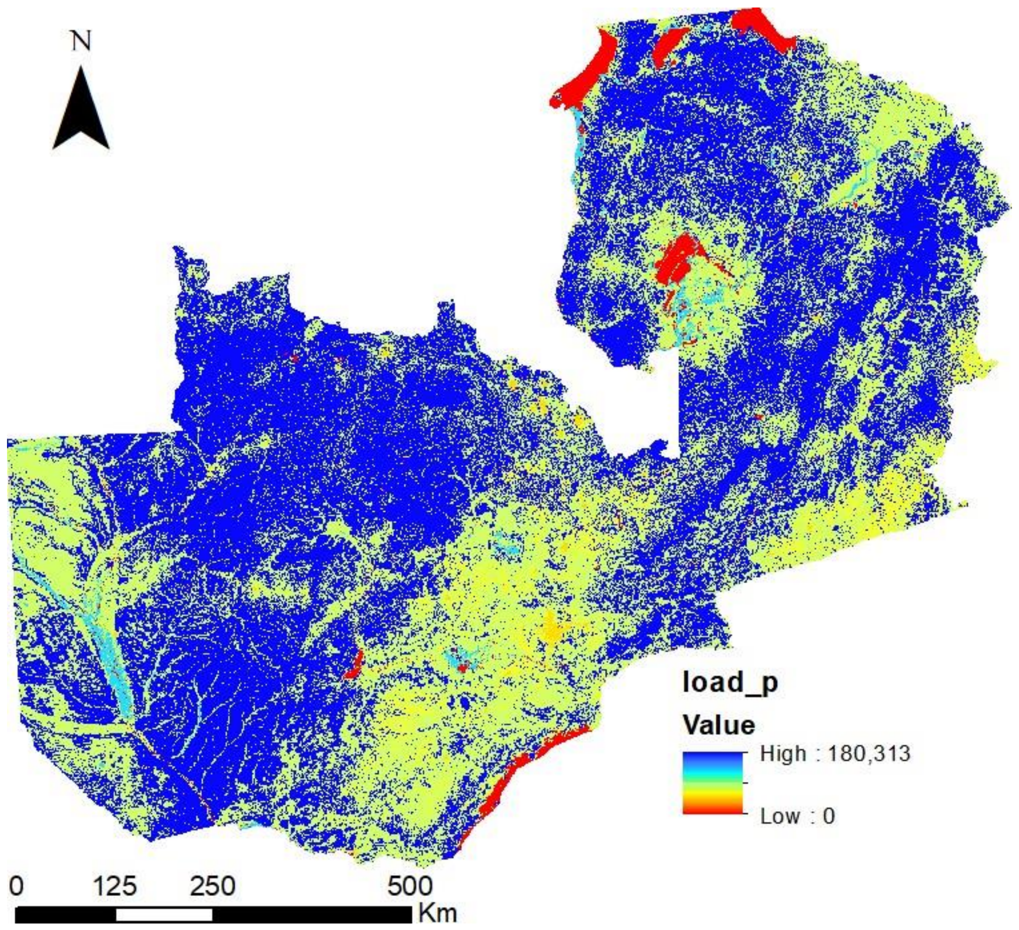
NDR model outputs

- **Load (kg/yr)**

Shows the pattern of nutrient sources

Results aggregated to watershed/sub-watersheds

High-export areas could be targets for **restoration**.
Low-export areas could be targets for **conservation**.

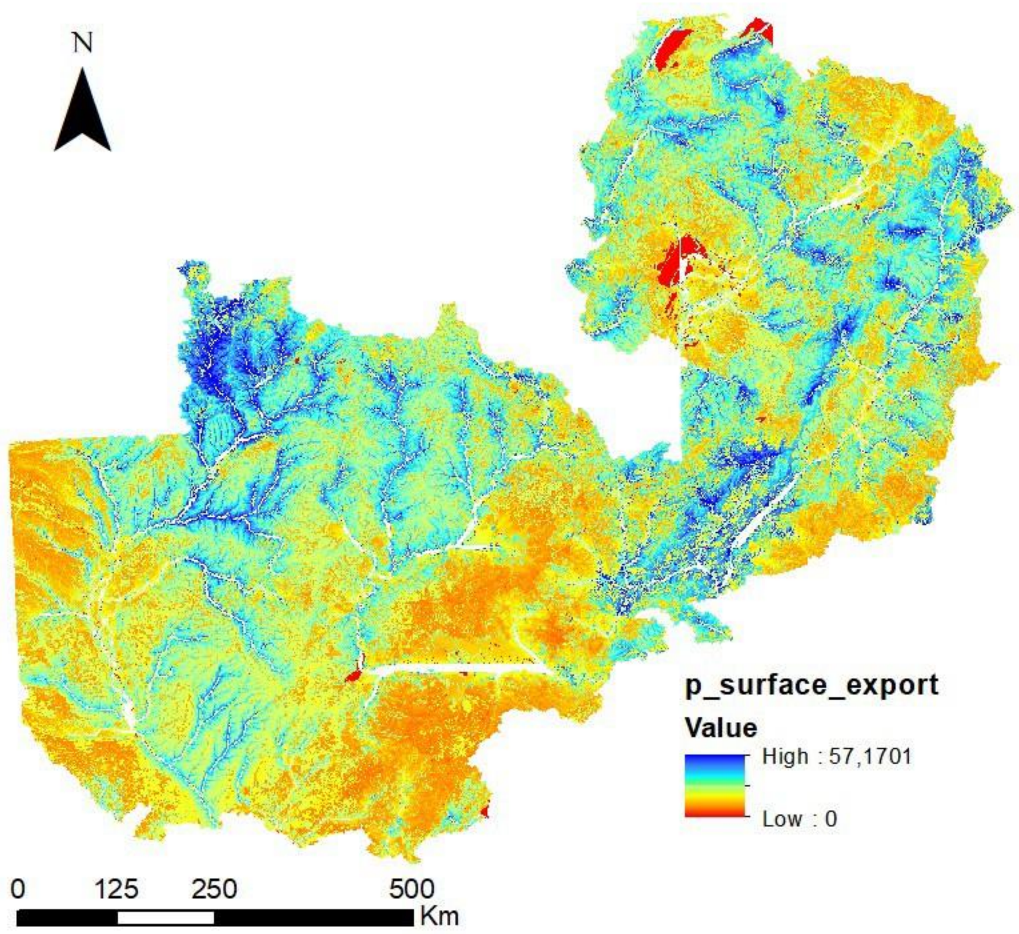


NDR model outputs

- **Nutrient export per pixel (kg/yr)**

Relative to bare ground

Results aggregated to watershed/sub-watersheds



Potential applications

Where are the most important sources of nutrient delivery located?

How can different climate conditions and seasonality determine nutrient delivery?

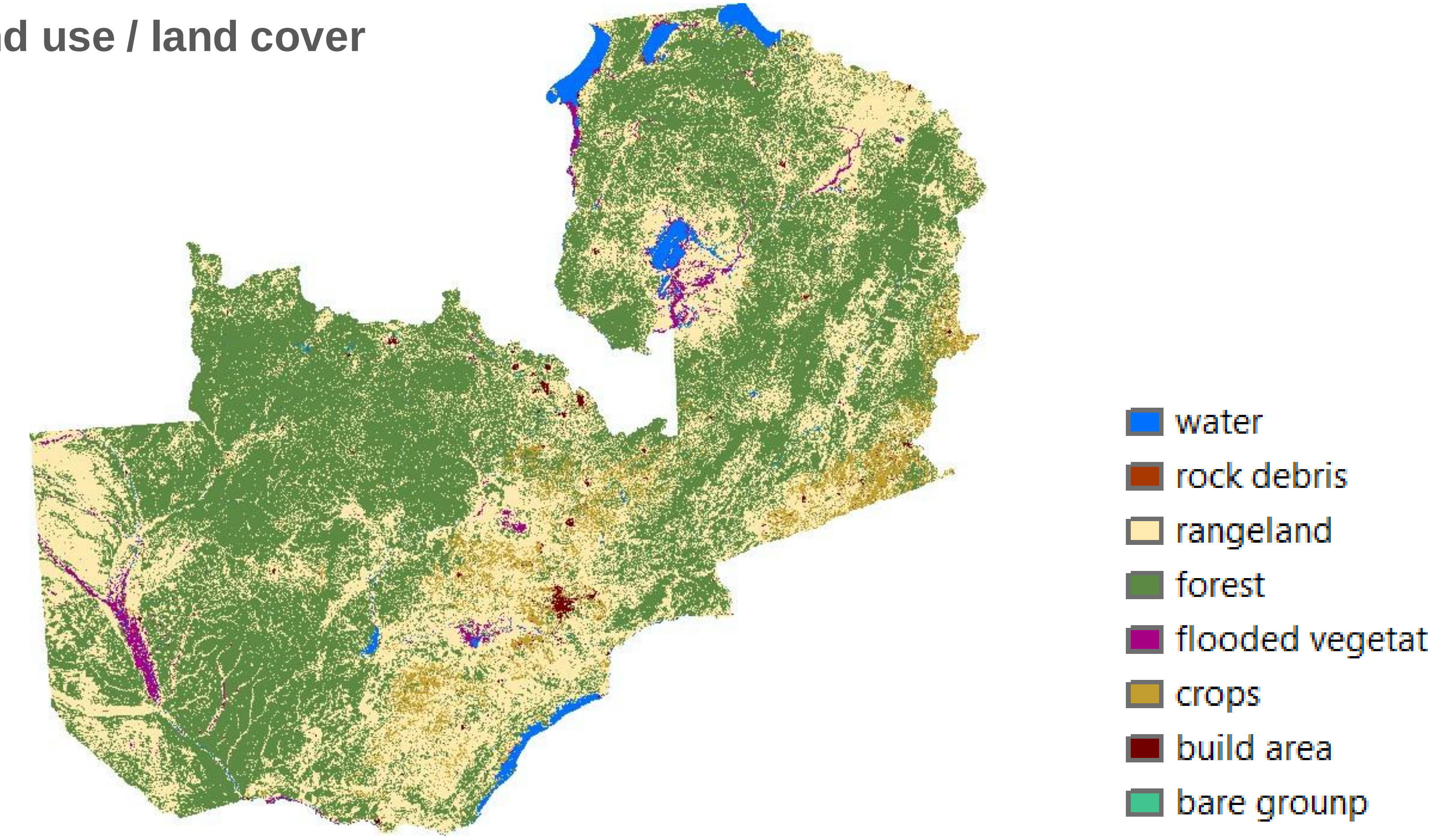
How human interventions and land planning can reduce nutrient delivery?

What different alternative scenarios compare to decide future developmental pathways?

What other applications you see for the nutrient retention model?

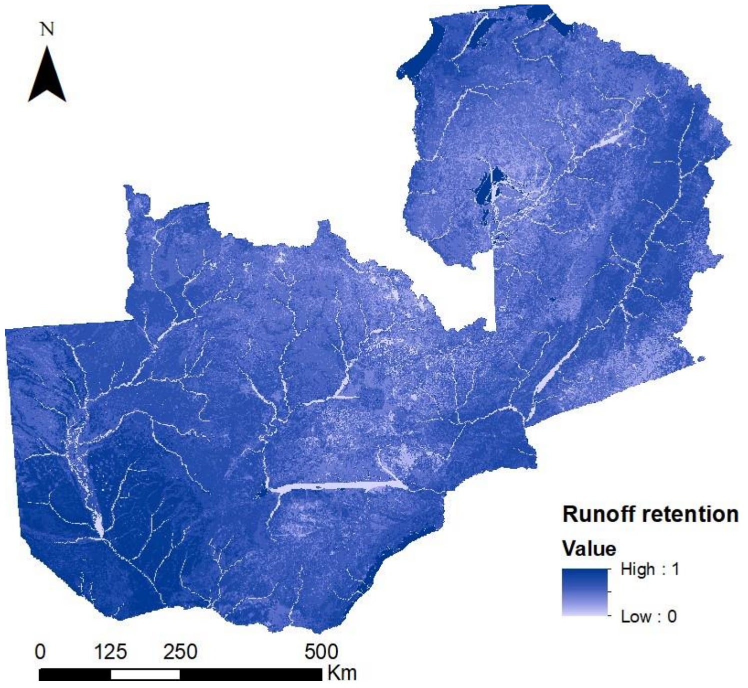
Integration of results for decision making

Land use / land cover

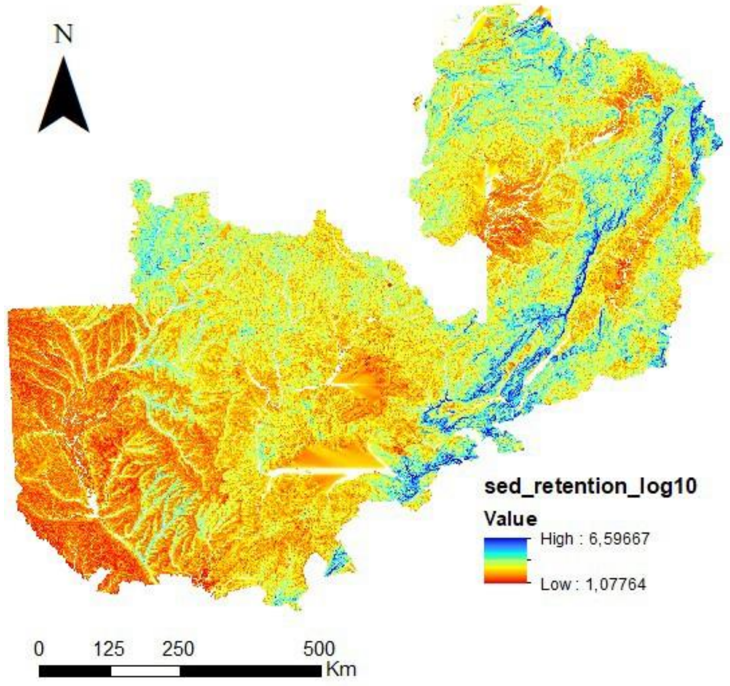


Integration of results for decision making

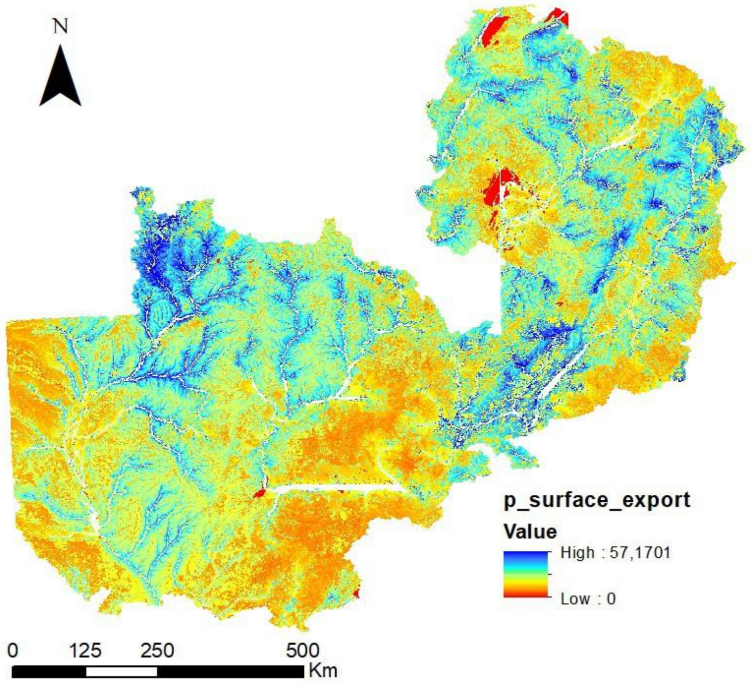
Seasonal water yield



Sediment delivery ratio



Nutrient delivery ratio



DATA GAPS

What do we need to focus on to improve the available information?

SWY input data

- **Watersheds:** InVEST's DelineateIt tool
- **DEM:** Shuttle Radar Topography Mission (SRTM)
- **LULC:** ESA Sentinel-2 (European Space Agency)
- **Precip:** WorldClim *and* Global Precipitation Measurement (NASA)
- **ET_0:** CGIAR Global Aridity Index and PET Climate Database
- **Soil Groups:** ONL-DAAC HYSOGs250m
- **Biophysical Table:** K_c: UN FAO Irrigation and Drainage paper 56, Chapter 6
  CN: USDA Urban Hydrology for Small Watersheds TR-55
- **Rain Events Table:** World Bank's Climate Data API

SDR input data

- **Watersheds:** InVEST's DelineateIt tool
- **DEM:** Shuttle Radar Topography Mission (SRTM)
- **LULC:** ESA Sentinel-2 (European Space Agency)
- **Soil erodibility (K):** Derived from the Harmonized World Soil Database (HWSD) and empirical equation:
  $K = 0.32 * \left(\frac{\%"\#\$\%}{\%"\&'()\%*\$\&+}\right)^{,\,..\,/}$ (Geleta, 2011)
- **Erosivity (R):** Derived from long term mean annual precipitation (WorldClim)and empirical equation:
  $R = 38.5 + 0.35 * Prc$ (Lee and Lee, 2000)
- **Biophysical Table:** USDA: Manual RUSLE (Renard et al., 1997)
- Application of the USLE in a Savannah environment: comparative experiences from East and West Africa (B.M. Mati and A. Veihe., 2008)
- Use of the universal soil loss equation to predict erosion in West (EJ Roose.,1976)

NDR input data

- **Watersheds:** InVEST's DelineateIt tool
- **DEM:** Shuttle Radar Topography Mission (SRTM)
- **LULC:** ESA Sentinel-2 (European Space Agency)
- **Precip:** WorldClim *and* Global Precipitation Measurement (NASA)
- **Biophysical Table:** load and efficiency: NatCap nutrient parameter database, local references for nutrient loadings and retention. link: efficiencies:https://naturalcapitalproject.stanford.edu/software/invest
- retention lengh: Mayer et al., 2007; Zhang et al.,2009

GPS Global Program on Sustainability

Thank you

Questions?

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