Presentation given the TransLinks workshop:

Modeling and Managing Watersheds

September 13-16, 2011

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Umubano Hotel, Boulevard de l'umuganda

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MODELING ECOSYSTEM SERVICES WITH ARIES

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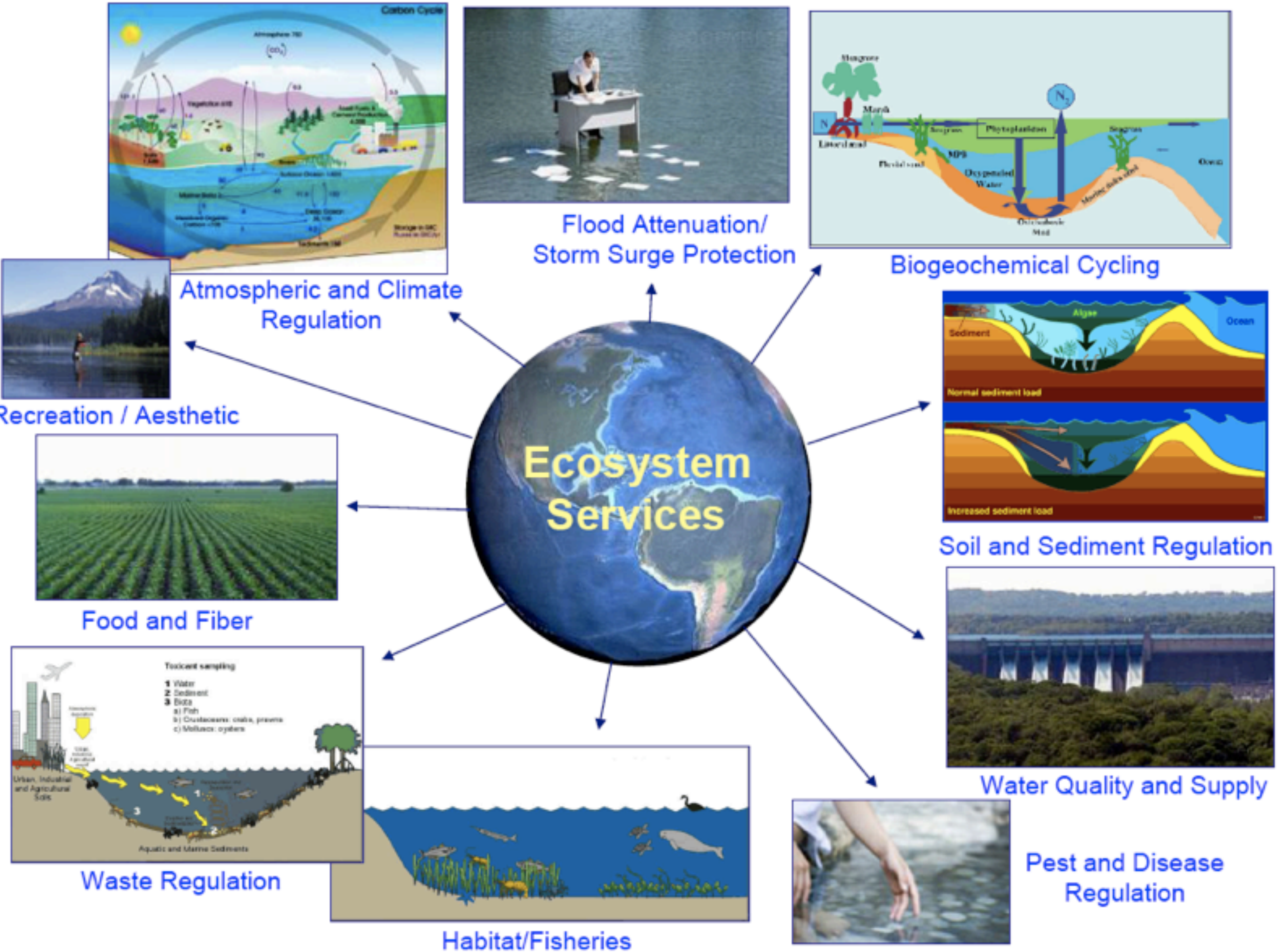
www.uvm.edu/giee www.ariesonline.org


Ecosystem Services
Atmospheric and Climate Regulation
Carbon Cycle
Flood Attenuation/ Storm Surge Protection
Biogeochemical Cycling
Phytoplankton
Soil and Sediment Regulation
Algae
Sediment
Ocean
Normal sediment load
Increased sediment load
Water Quality and Supply
Pest and Disease Regulation
Habitat/Fisheries
Waste Regulation
Toxicant sampling
1 Water
2 Sediment
3 Biota
a) Fish
b) Crustaceans: crabs, prawns
c) Molluscs: oysters
Urban, Industrial and Agricultural Soils
Aquatic and Marine Sediments
Food and Fiber
Recreation / Aesthetic

Role of Modeling

1. Scoping Models

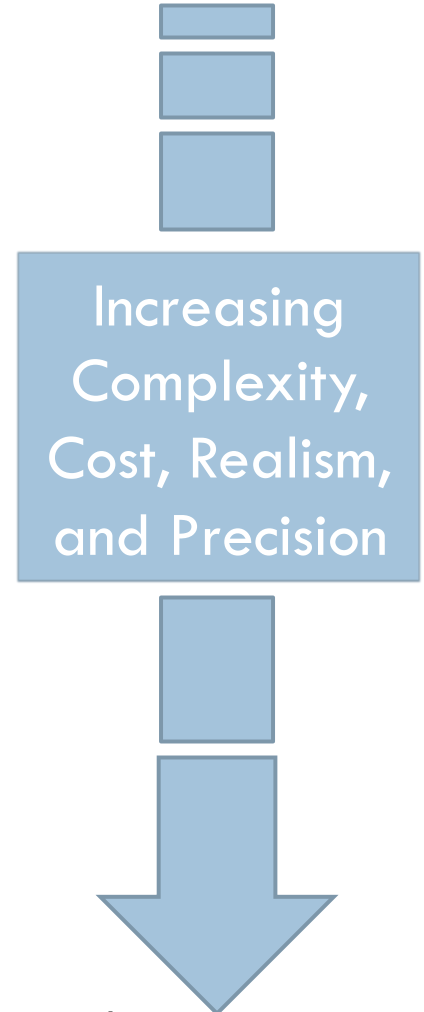
   High generality, low resolution, broad participation by all stakeholder groups.

2. Research Models

   More detailed and realistic attempts to replicate the dynamics of a particular system of interest, with emphasis on calibration and testing.

3. Management Models

   Medium to high resolution. Emphasis on producing future management scenarios. Can be exercising #1 or #2, or require further elaboration to apply management questions.



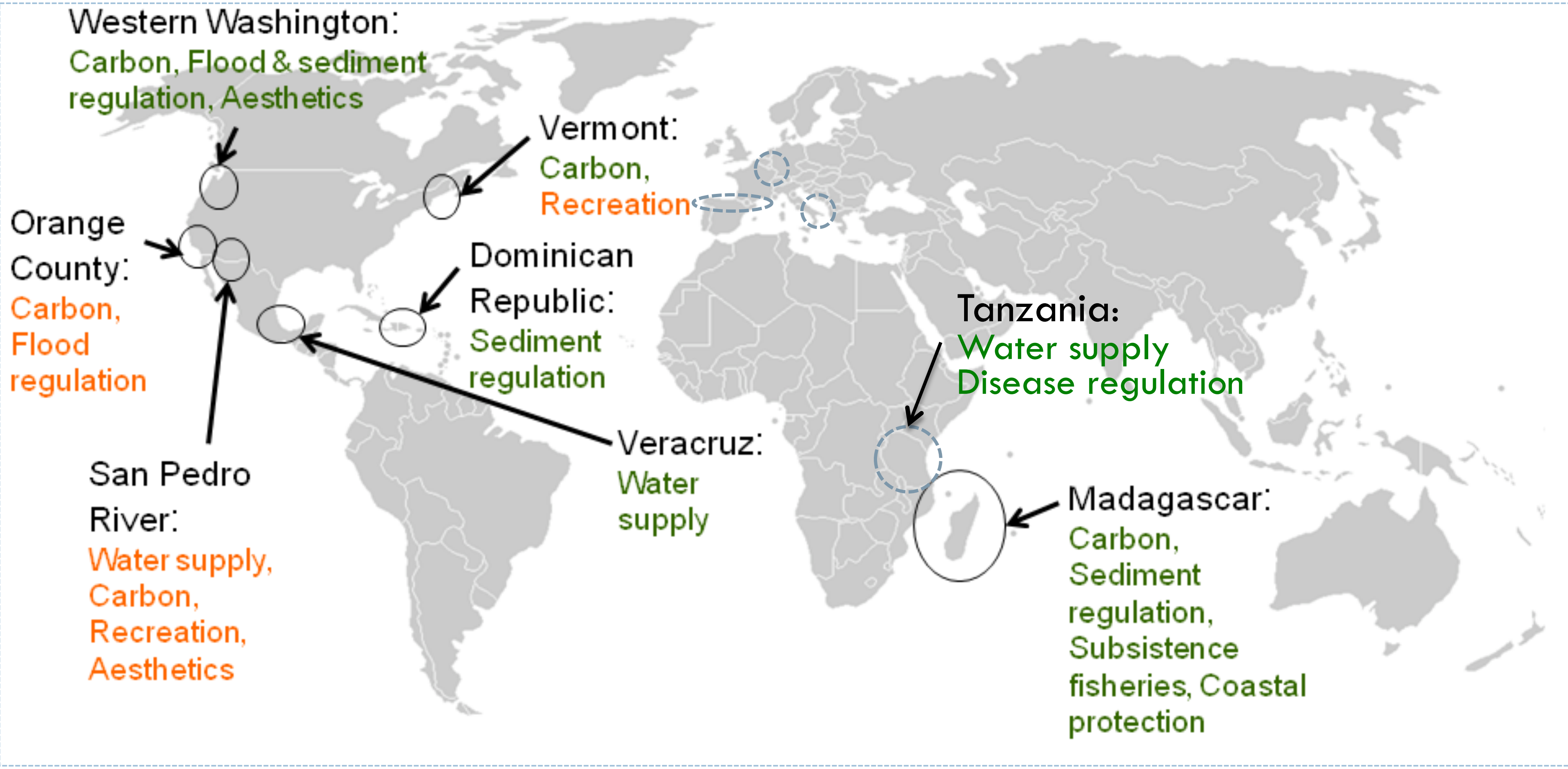
Source: Costanza, R. and M. Ruth, "Using Dynamic Modeling to Scope Environmental Problems and Build Consensus," *Environmental Management* 22: 183-195, 1998.

ARIES: A Brief Overview

***AR**tificial **I**ntelligence for **E**cosystem **S**ervices*

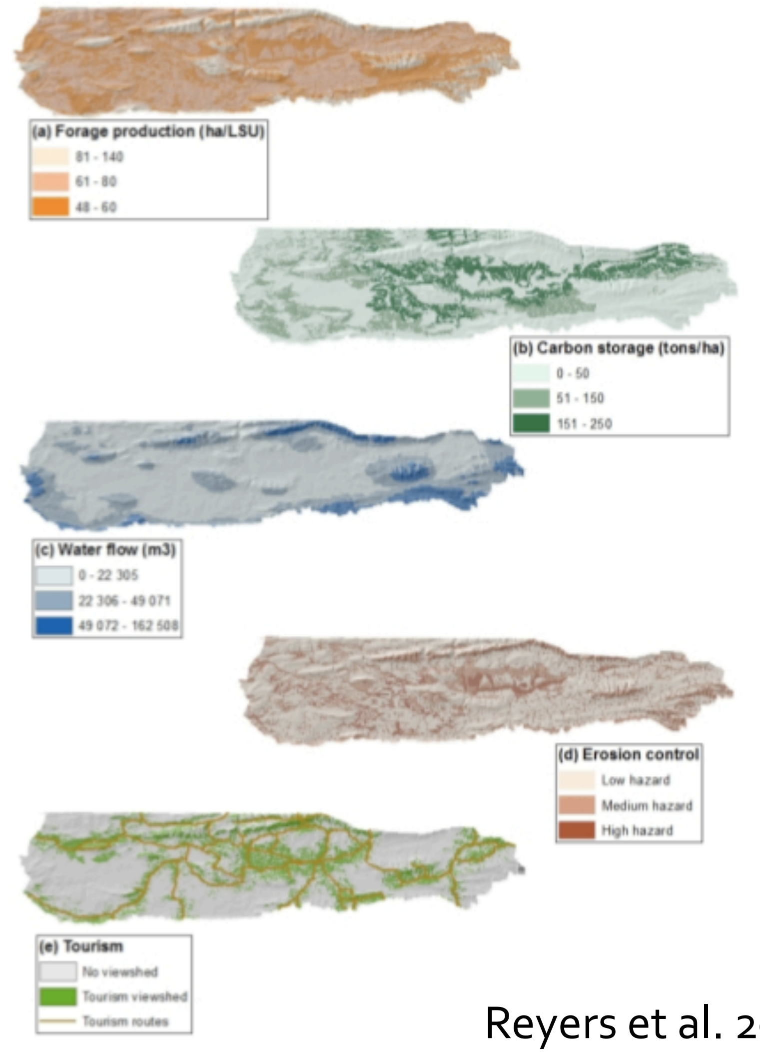
- **Assessment** toolkit for ecosystem services (ES) and their values
- Not a single model, but an **intelligent system** that customizes models to user goals.
- A mapping process for ecosystem service **provision**, **use**, and **flow**.
- Includes both **deterministic** and **probabilistic** models to inform decision-makers of likelihood of possible outcomes.
- **Web-based**, customizable for specific user groups, geographic areas and policy goals.
- Target **audience** includes researchers, governmental decision makers and policy makers, corporate environment and sustainability offices.

Case Study Sites



ES Assessment: State of practice

GIS database



Soil erosion = f (rainfall, soil depth, soil texture, slope, vegetation type)

Reyers et al. 2009

ARIES ES modeling elements

1. Areas of provision of ES and biodiversity

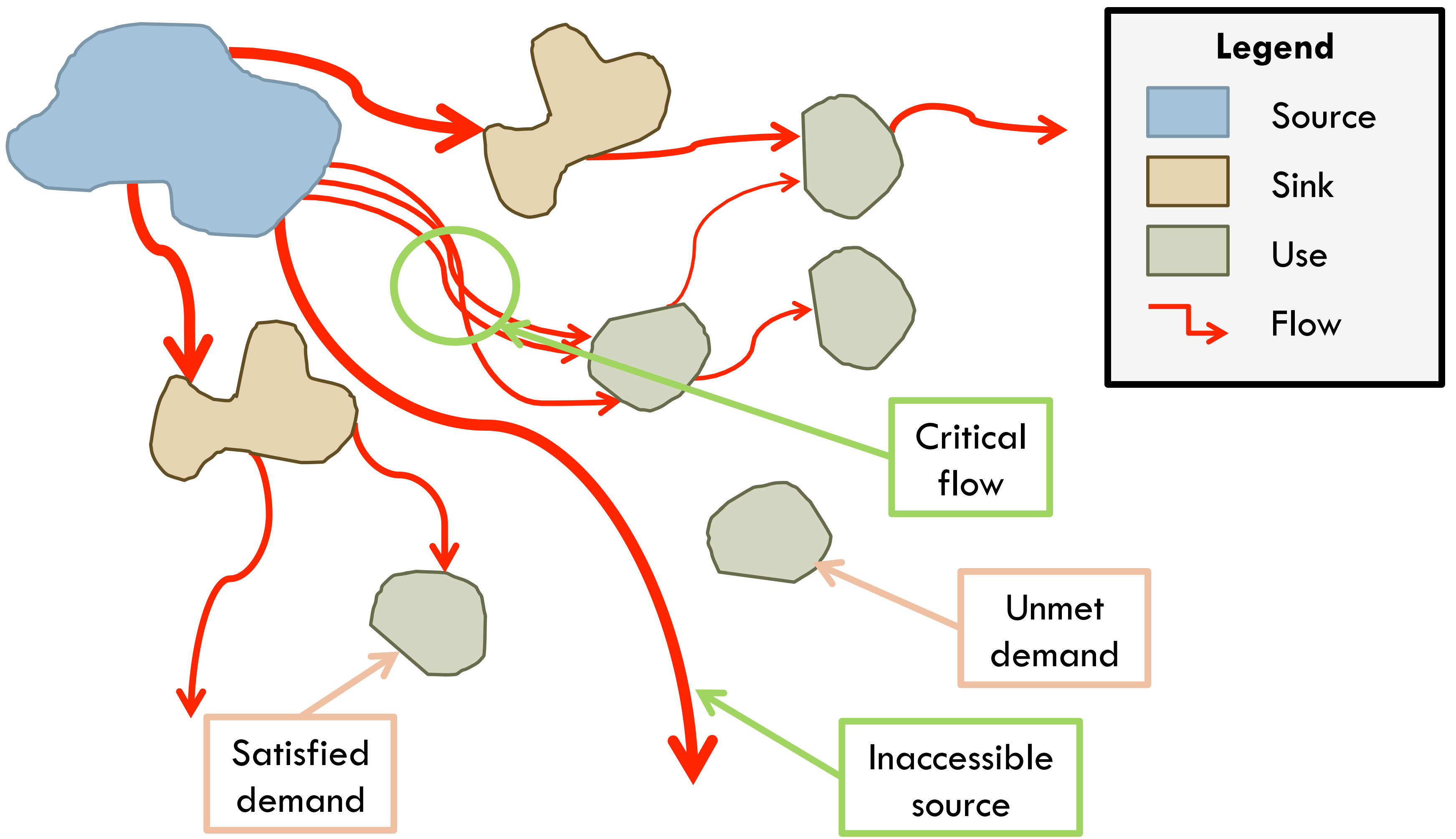
3. Flow paths between provision and use ares

2. Areas of use of ES & biodiversity where beneficiaries are located

Provision Sheds

Benefit Sheds

Ecosystem Service Flows



Enabling technology:

The integrated modeling platform

Multi-scale variability (context)

SPATIAL
Vector vs. raster, projections, resolutions

TEMPORAL
Continuous vs. discrete, regular vs. irregular

STRUCTURAL
Aggregation, choice of variables

Multi-representation

Deterministic
.
Probabilistic

Classifications
Measurements
Rankings
Currencies
Binary

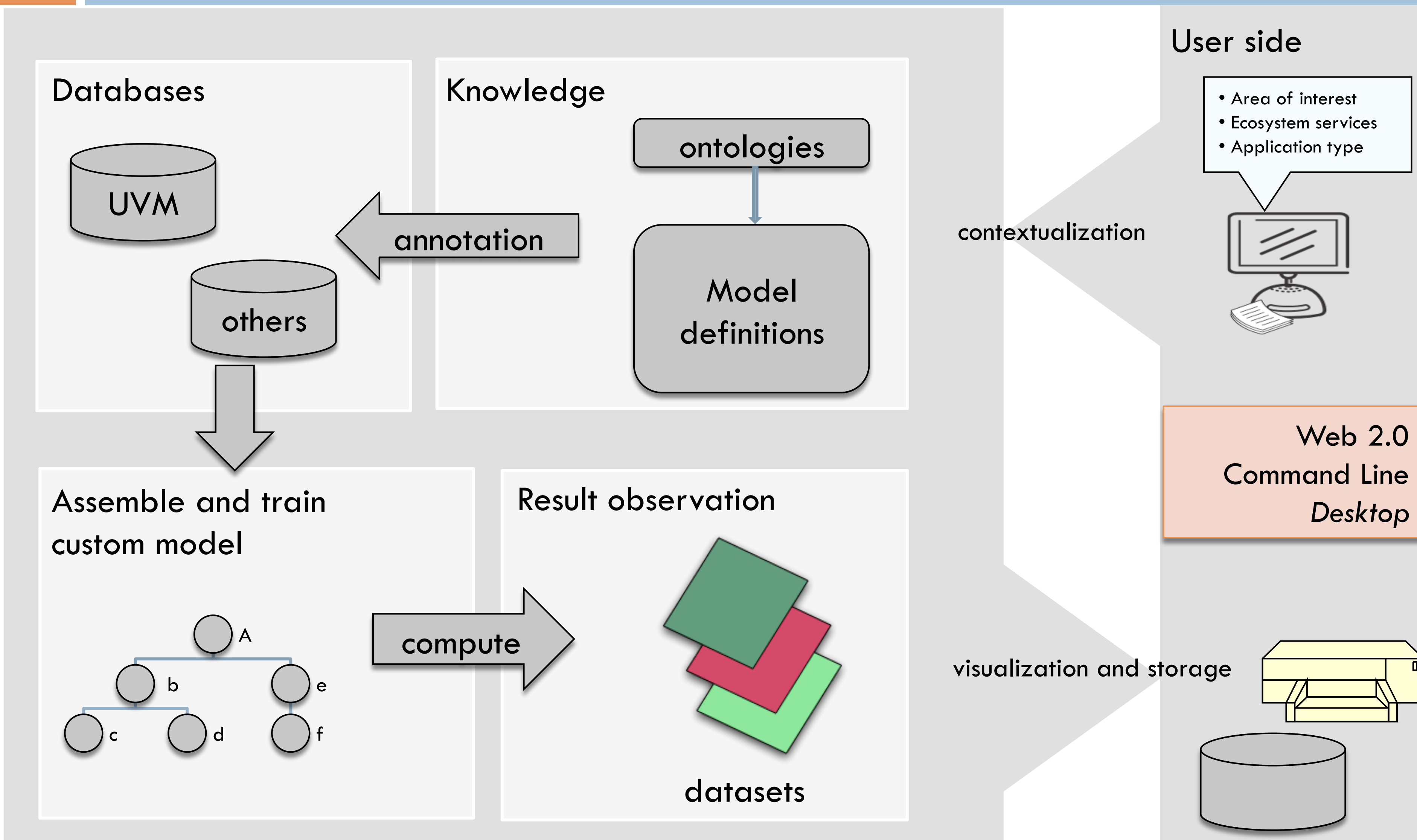
Multi-paradigm

- Agent-based
- DDE, process-based
- Bayesian networks
- Static (GIS)
- • • •

Explicit Semantics

Semantically annotated data & models -> True Modularity, Substitutability
Content mediation and propagation -> Automatic Scaling & Matching

Session workflow



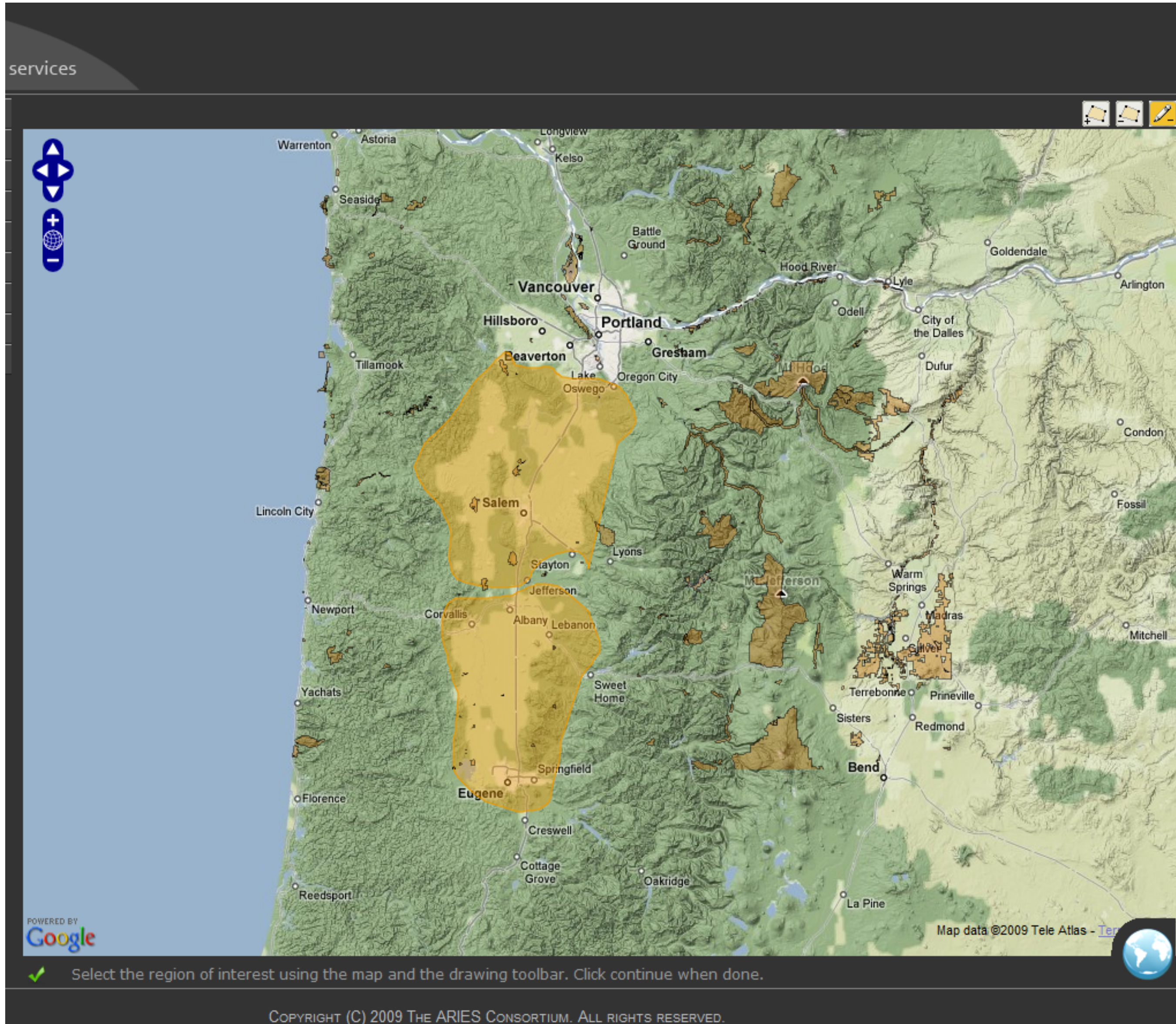
ARIES: a web-based ES analysis tool

Interface through **web browser**

Probabilistic models carry & report uncertainty estimates, work in regions with incomplete data

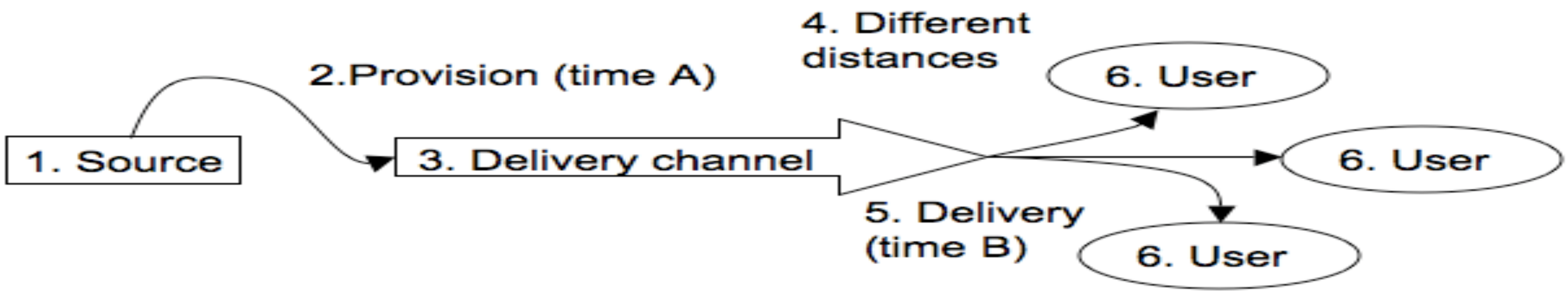
Accounts for **spatial flows of ecosystem services** from provision to beneficiaries

Modeling system designed to interface with existing ecological process models



The ARIES Modeling Process

1. Collect spatial data
2. Identify beneficiaries
3. Identify carriers (matter, energy, or information)
4. Develop Bayesian models for source, sink, and use
5. Develop flow models to move services between ecosystems and people



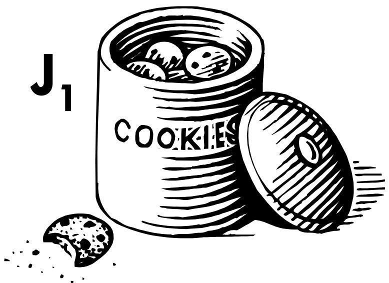
Ruhl et al. 2007

1. Collecting spatial data

- GIS data for as many components as possible to map source, sink, and use
  - Raster or Vector
- Local data where possible, otherwise global
- Where no data exists, use **Bayesian prior probabilities** or base assumptions on training data from a similar contextual setting where full dataset exists

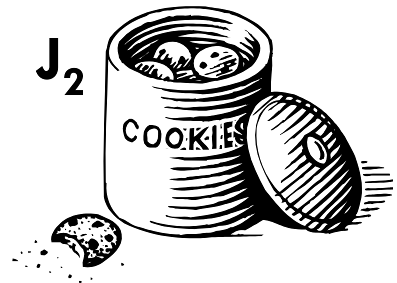
Bayesian Inference

J_1



10 chocolate chip
30 plain cookies

J_2



20 chocolate chip
20 plain cookies

Experiment Steve picks a jar at random, and then a cookie at random.
The cookie is plain.
What's the probability that Steve picked from jar #1?

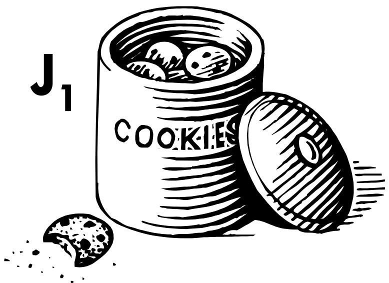
Prior Probabilities $P(J_1) = P(J_2) = 0.5$

Event E = observation of plain cookie

Conditional Probabilities
$P(E|J_1) = 30/40 = 0.75$
$P(E|J_2) = 20/40 = 0.50$

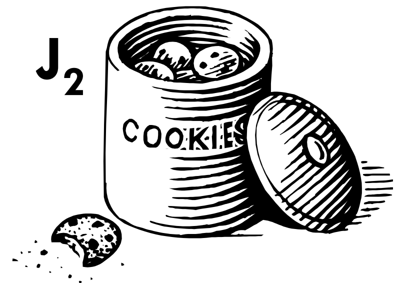
Bayesian Inference

J_1



10 chocolate chip
30 plain cookies

J_2



20 chocolate chip
20 plain cookies

Experiment Steve picks a jar at random, and then a cookie a random.
The cookie is plain.
What's the probability that Steve picked from jar #1?

Bayes Theorem

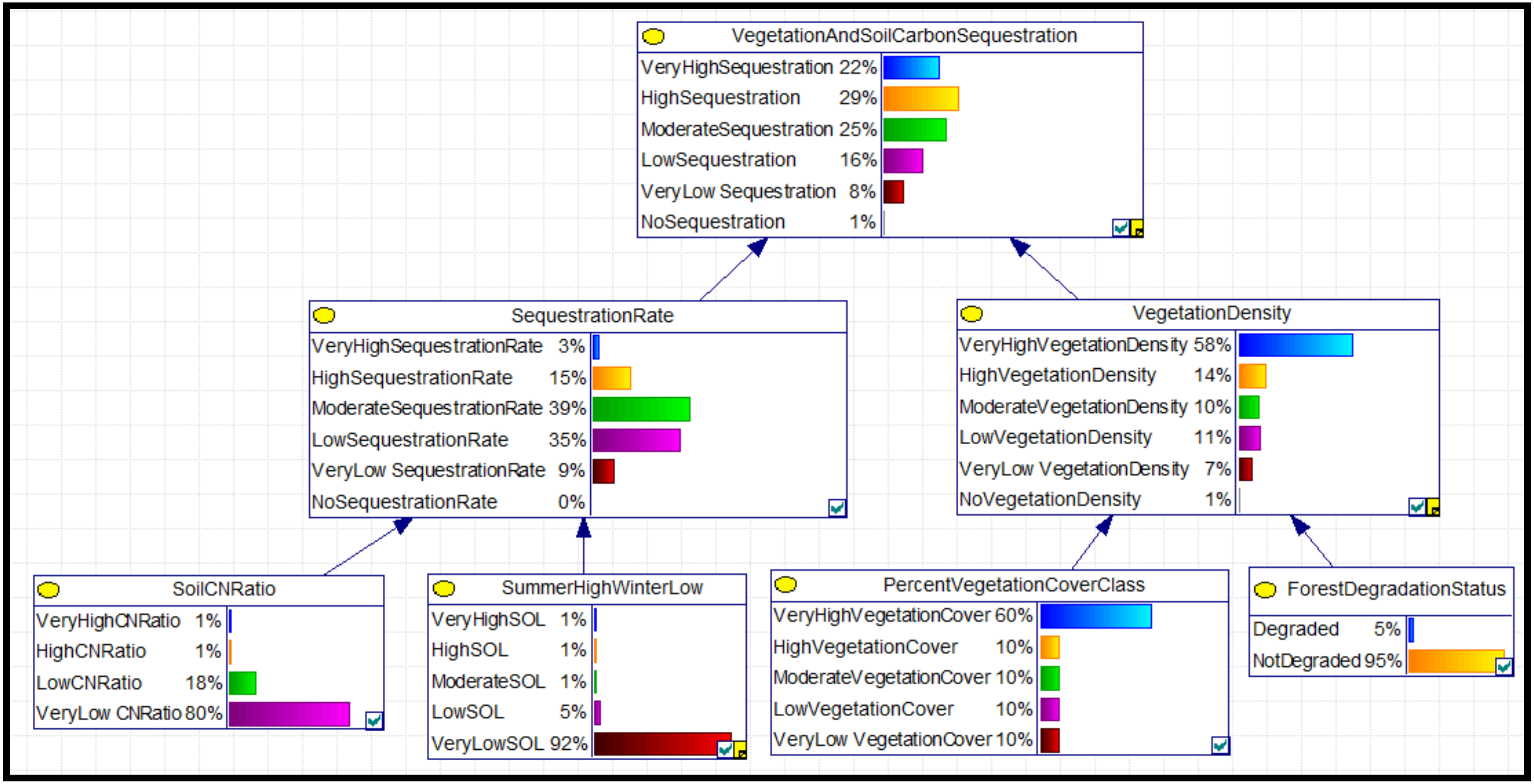
$$P(J_1|E) = \frac{P(E|J_1)\,P(J_1)}{P(E|J_1)\,P(J_1) + P(E|J_2)\,P(J_2)}$$

Posterior Probability

$$P(J_1|E) = \frac{0.75 \times 0.5}{0.75 \times 0.5 + 0.5 \times 0.5} = 0.6$$

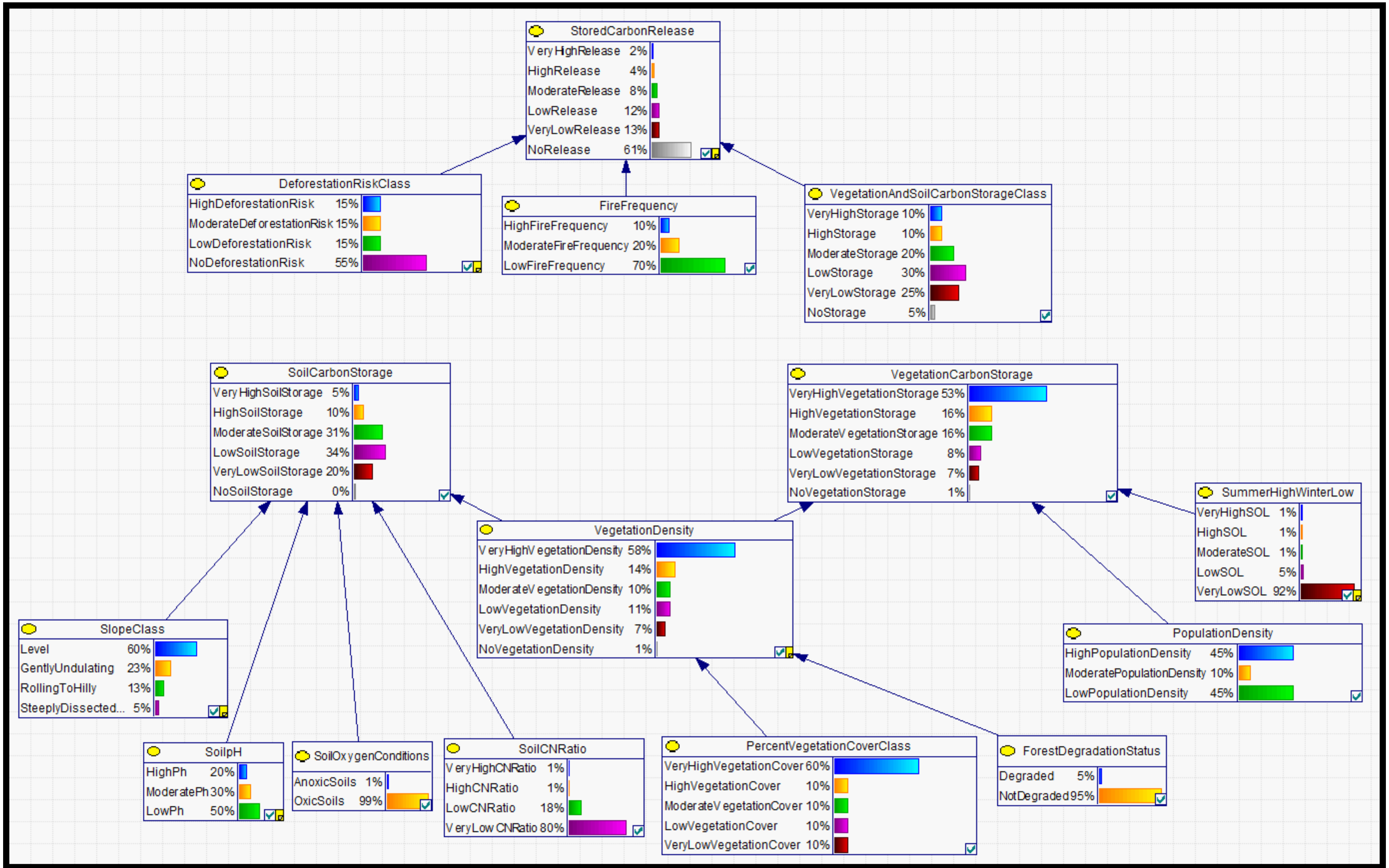
Example: Carbon Sequestration

Carbon Source and Sink Models as Bayesian Networks



Example: Carbon Sequestration

Carbon Source and Sink Models as Bayesian Networks



Example: Carbon Sequestration

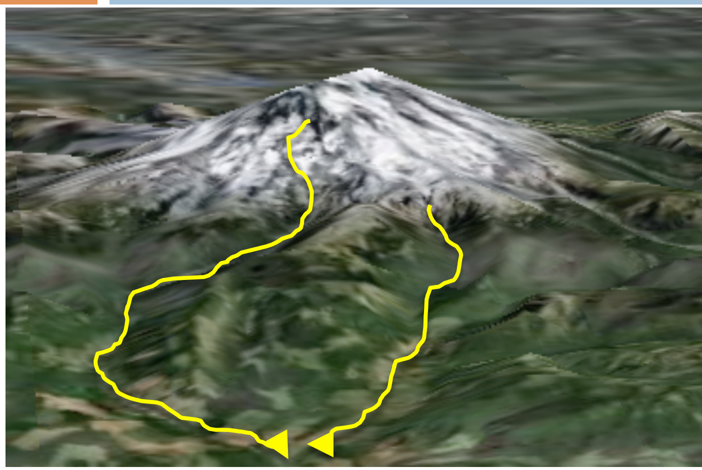
Carbon *Use* Model as GIS Database

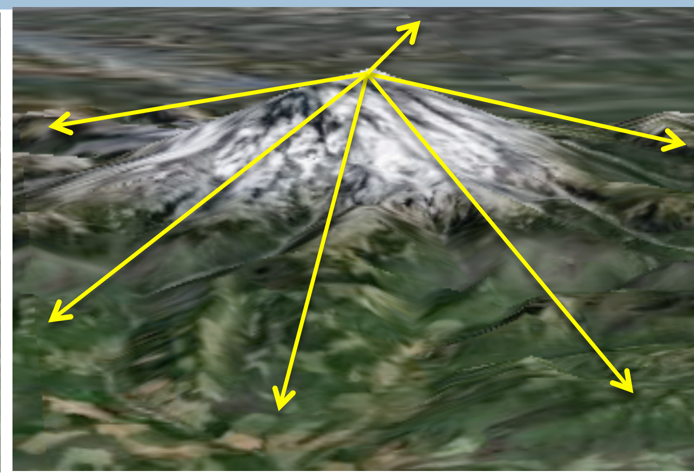
Layer	Source	Extent	Resolution	Year
GHG emissions	VULCAN Project	USA	10 x 10 km	2002
Per capita emissions	EIA	Global	Non-spatial	2006
Population density	LANDSCAN	Global	30 arc-second	2006

2. Identifying beneficiaries

Ecosystem Services	General Beneficiary Class	Specific Beneficiary Group
Carbon sequestration & storage	Groups vulnerable to climate change	Coastal populations, snowmelt dependent populations, farmers, etc.
	Users of atmospheric CO_2 absorption	Greenhouse gas emitters
Aesthetic value	Scenic views	Homeowners with scenic views
	Proximity to open space	Homeowners near open space
Soil retention	Non-eroded systems	Farmers on erodible land
	Areas benefiting from sedimentation	Some floodplain farmers
	Non-sedimented systems	Some farmers, fishermen, hydro utilities, etc.
Disturbance regulation	Flood protection	Floodplain residents, farmers, public & private property owners
	Storm surge protection	Same groups as above
	Mudslide/avalanche protection	Same groups as above
Provision of adult salmon	Cultural icon	Native Americans, watershed residents, U.S. citizens
	Food source	Native Americans, subsistence fishermen, consumers
	Recreational amenity	Recreational fishermen, wildlife watchers

3. Identifying ES carriers

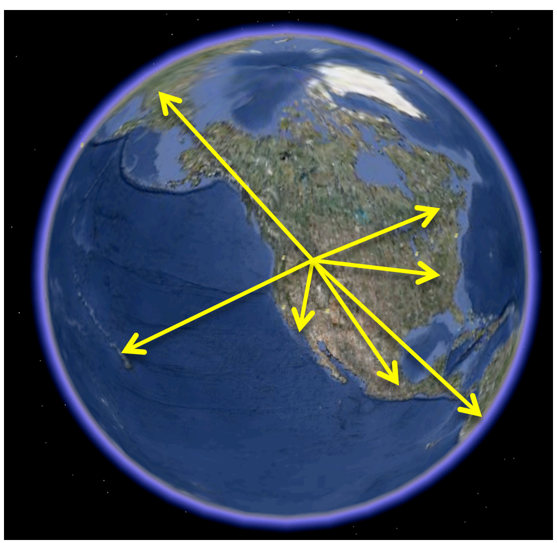




Hydrologic services

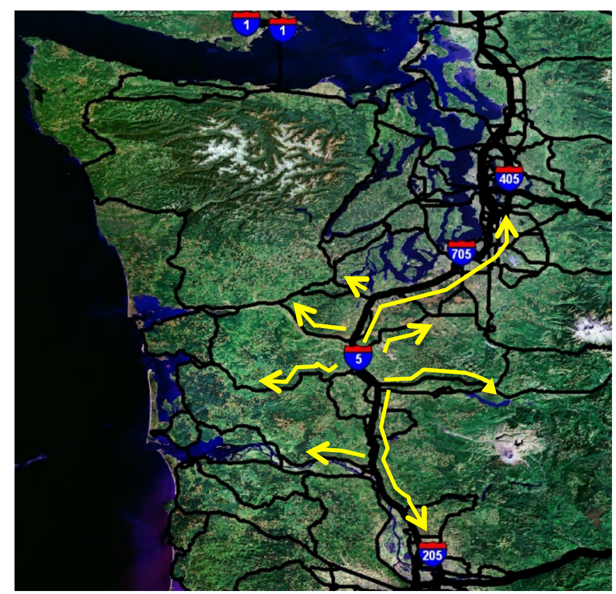
Aesthetic viewsheds

Recreation, flood regulation, many ecosystem goods



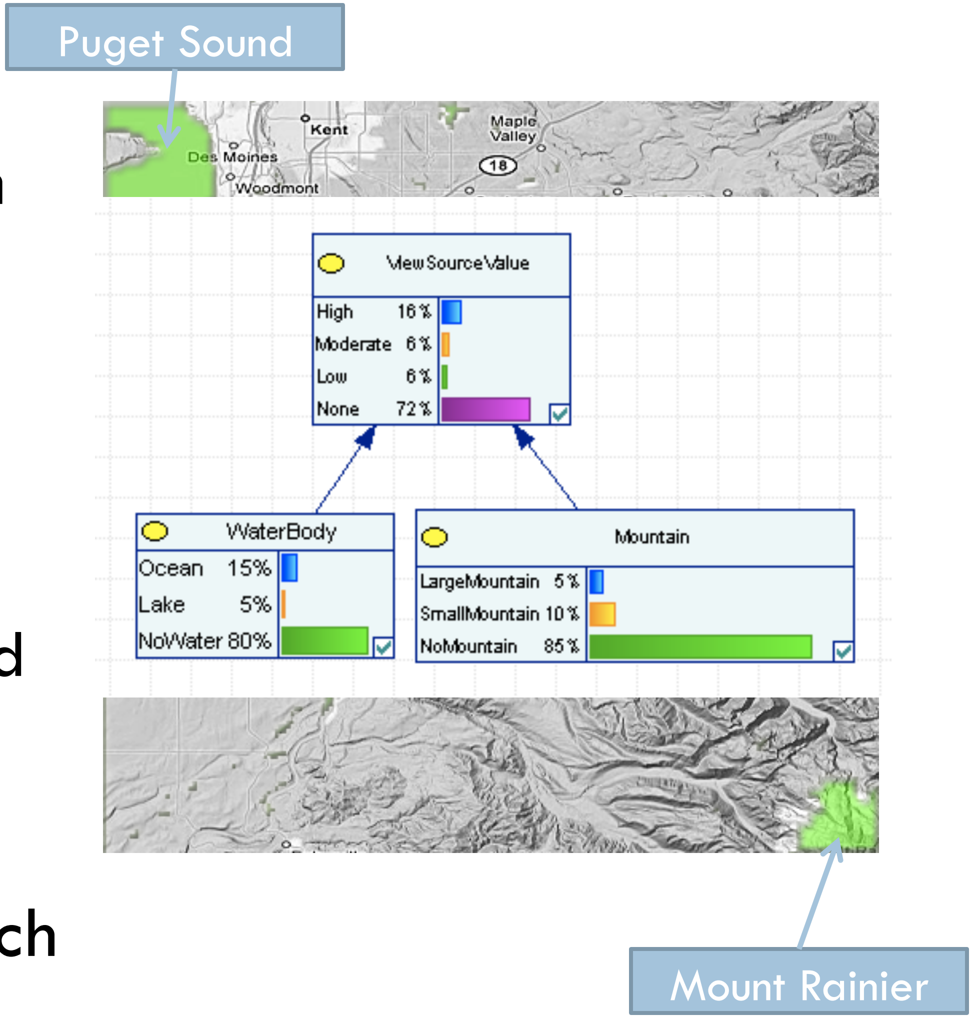
Carbon sequestration, some cultural values

Recreation, aesthetic proximity, some cultural services



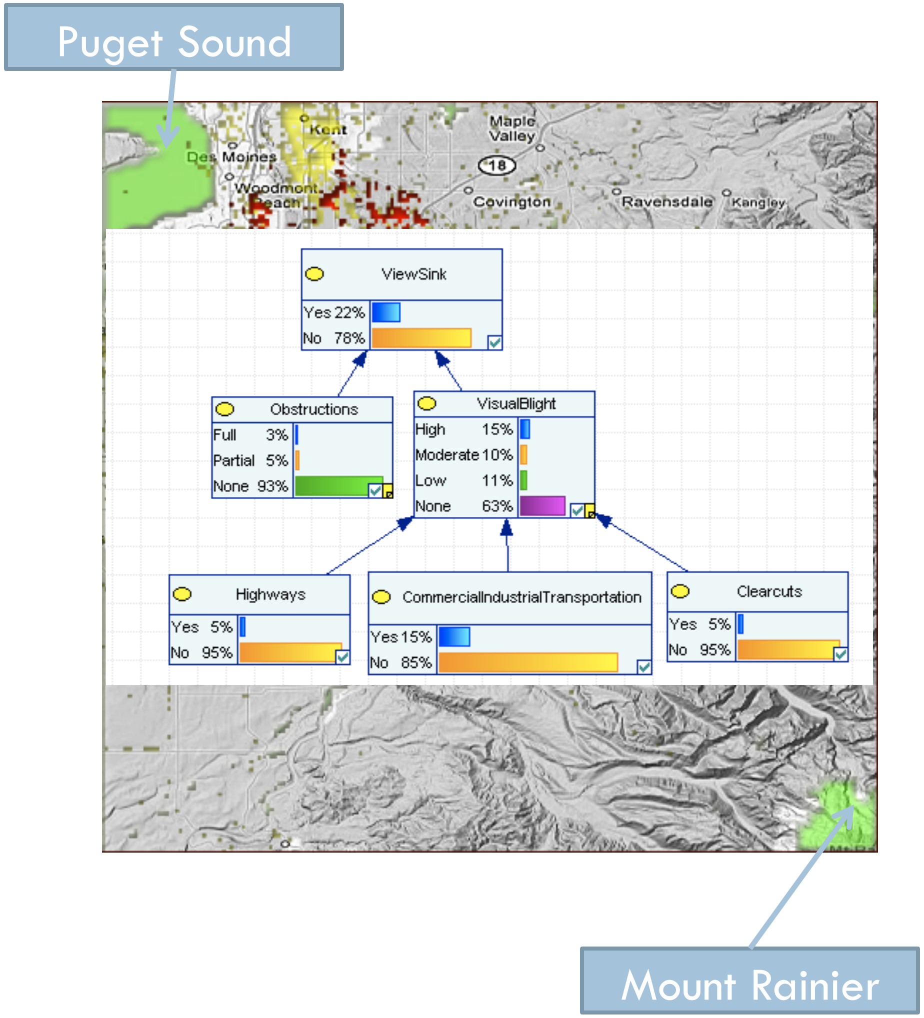
4. Modeling ES sources

- "Production function" of important ecological contributors to ES provision
- For entire model or inputs:
  - Use existing ecological models & their outputs
  - If no good models exist, build ad hoc models based on expert knowledge
- How much of a given benefit is produced for each landscape district?



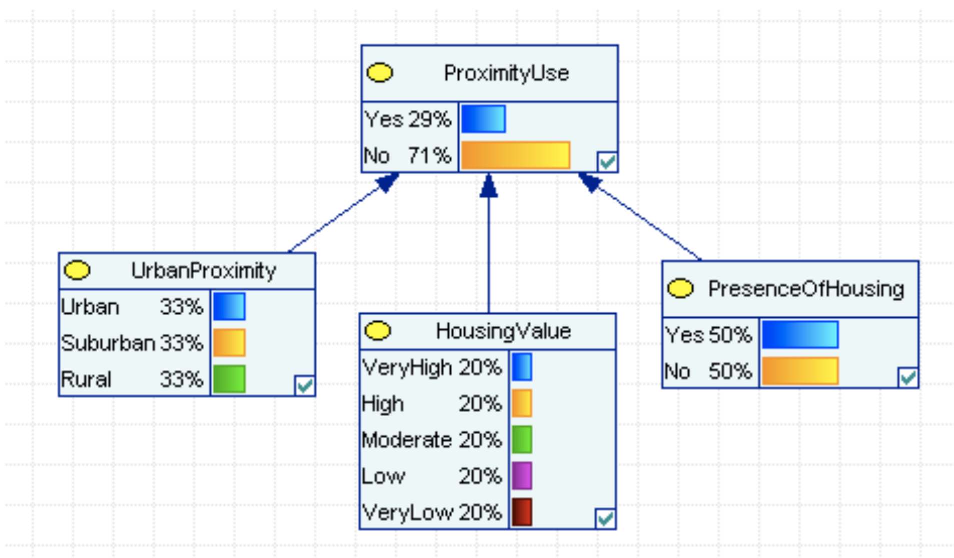
4. Modeling ES sinks

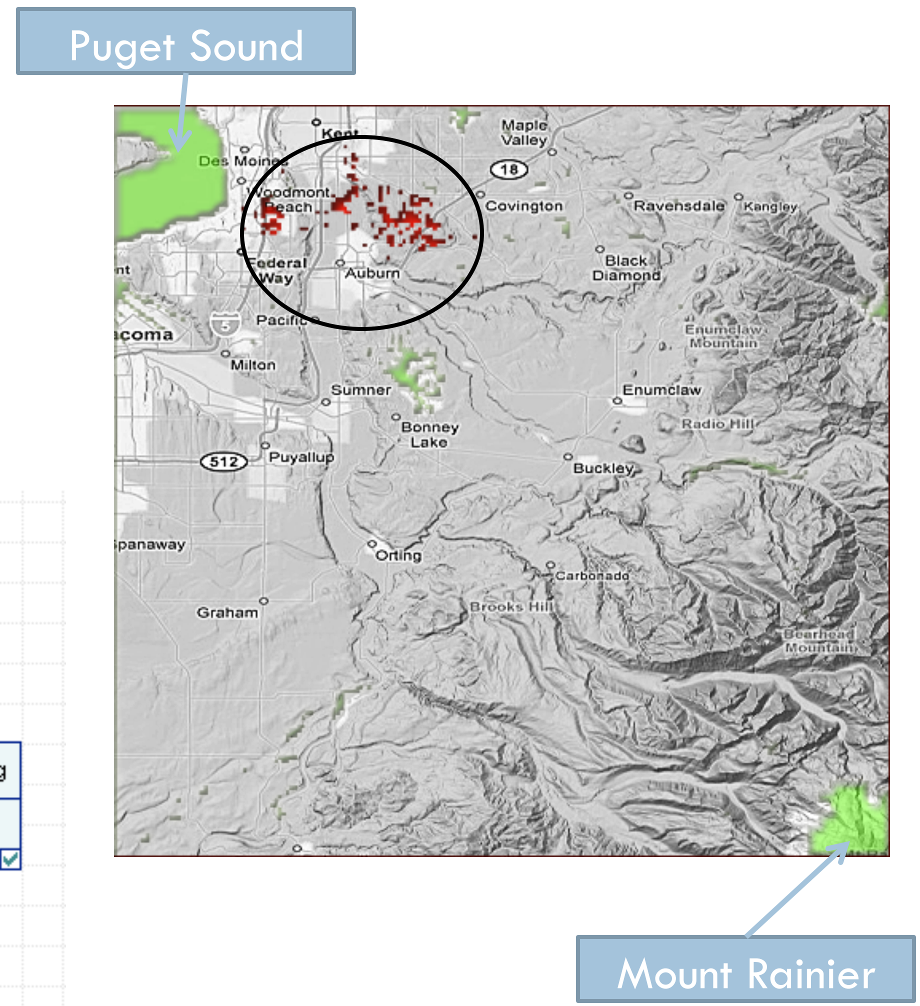
- Depending on the service, sinks could be beneficial / detrimental:
  - Absorption of flood water, nutrients (+)
  - Visual blight reducing the quality of views (-)



4. Modeling ES uses

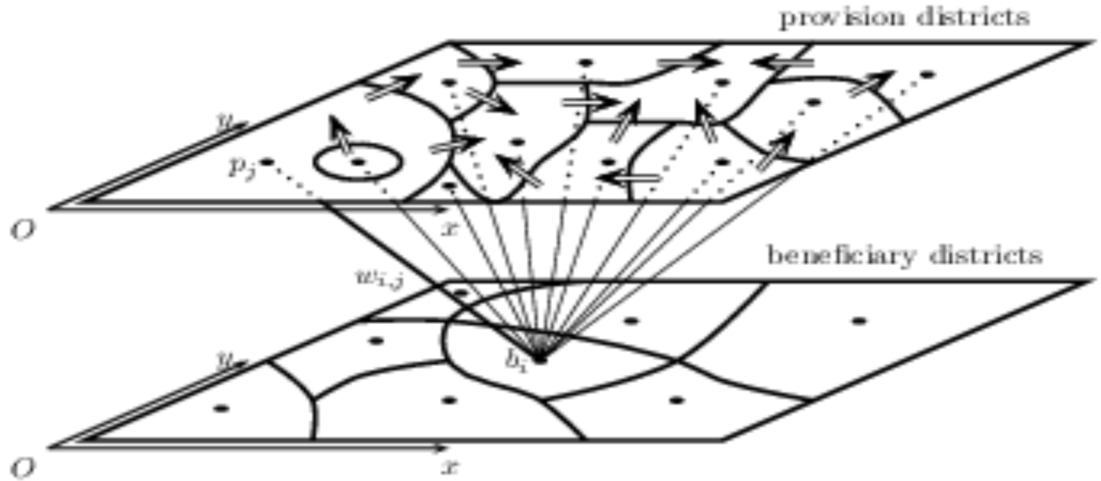
- Similar process to modeling ES provision
  - How do we locate (potential) users of ES on the landscape?





5. Modeling ES flows

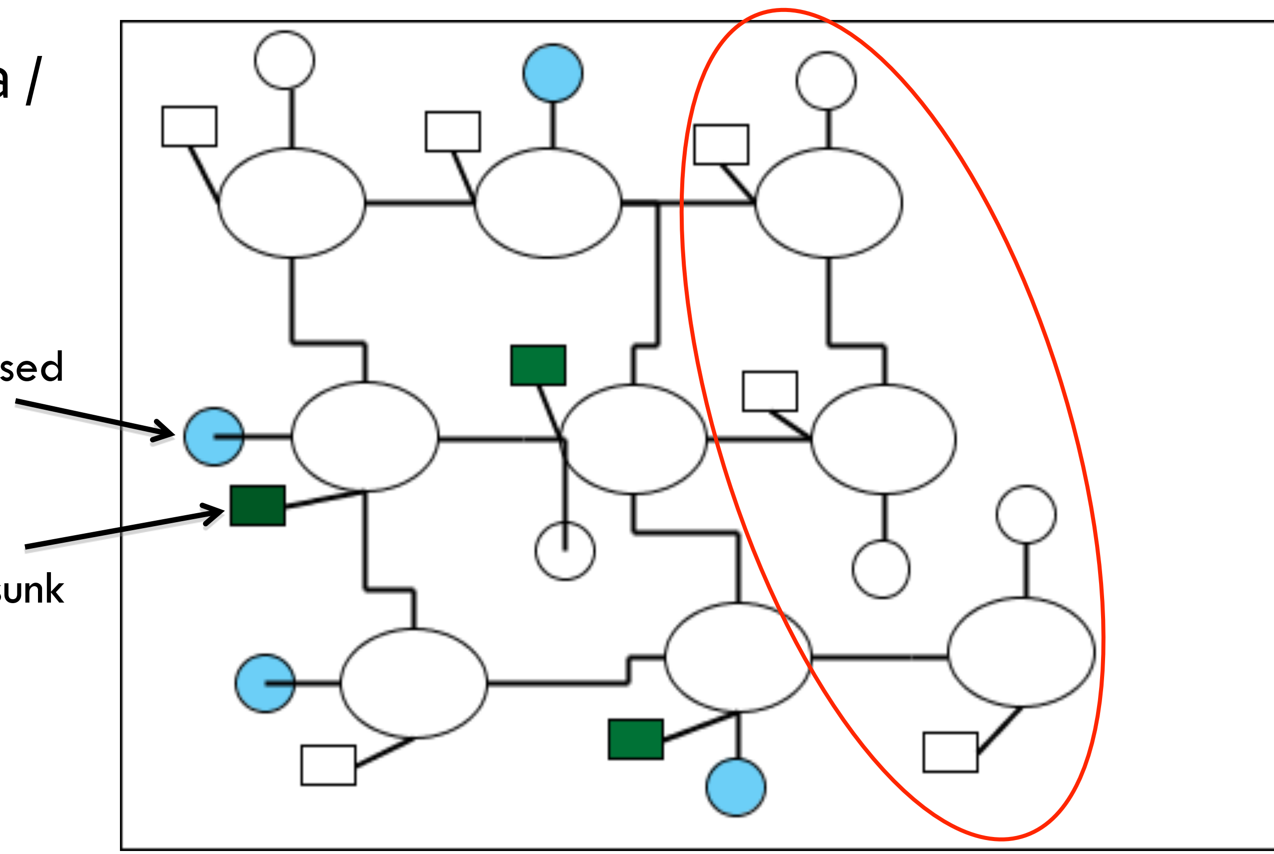
Service flows will accrue at use locations on the landscape



Note: Beneficiary regions may be of different scale than provisioning

5. Modeling ES flows

- Agent-based
- Initial condition informed by data / priors
- Each location contains:
  - Source distribution
  - Sink and use rates & capacities
  - Sink cache
  - Use cache
  - Carrier cache

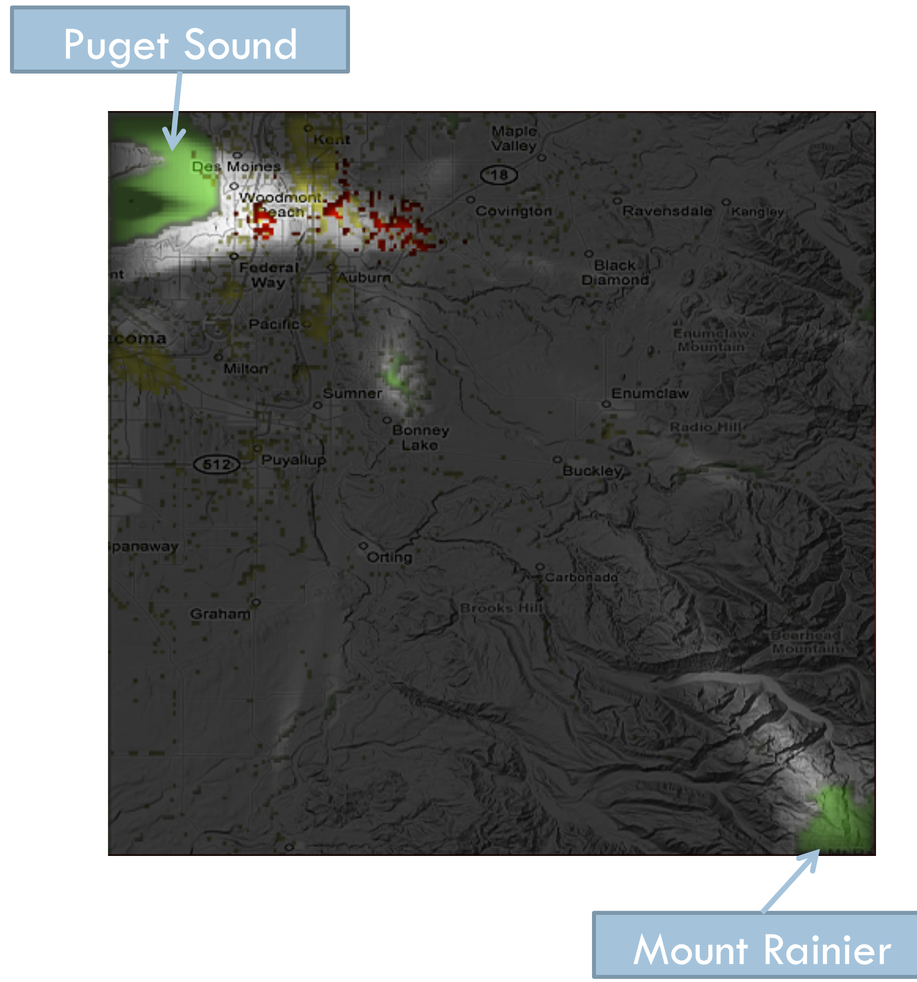


5. Modeling ES flows

Difference b/t theoretical & calculated provision

- The greater the flow, the more "illuminated" the area

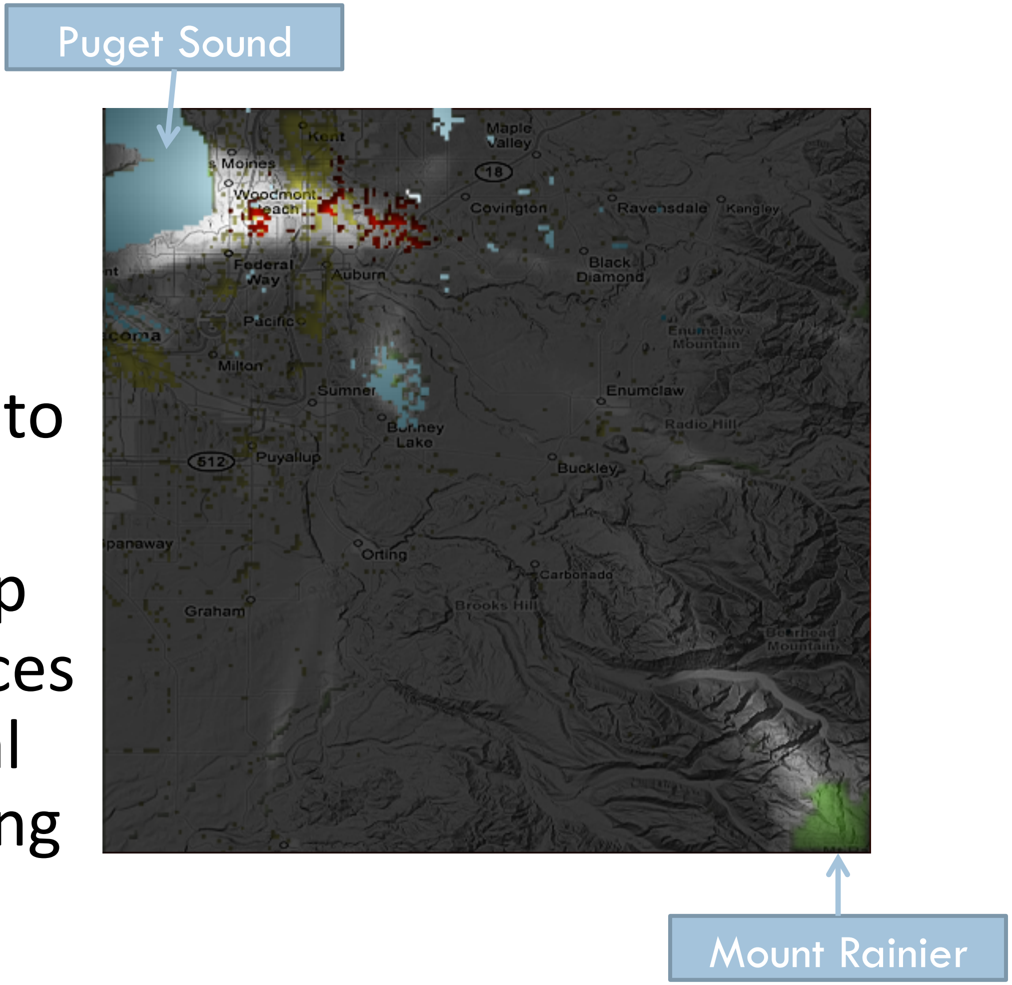
- Each service path depends on:
  - Level of provision
  - Likelihood of use
  - Amount of loss (sink)



5. Modeling ES flows

Accessible Provisioning Flows

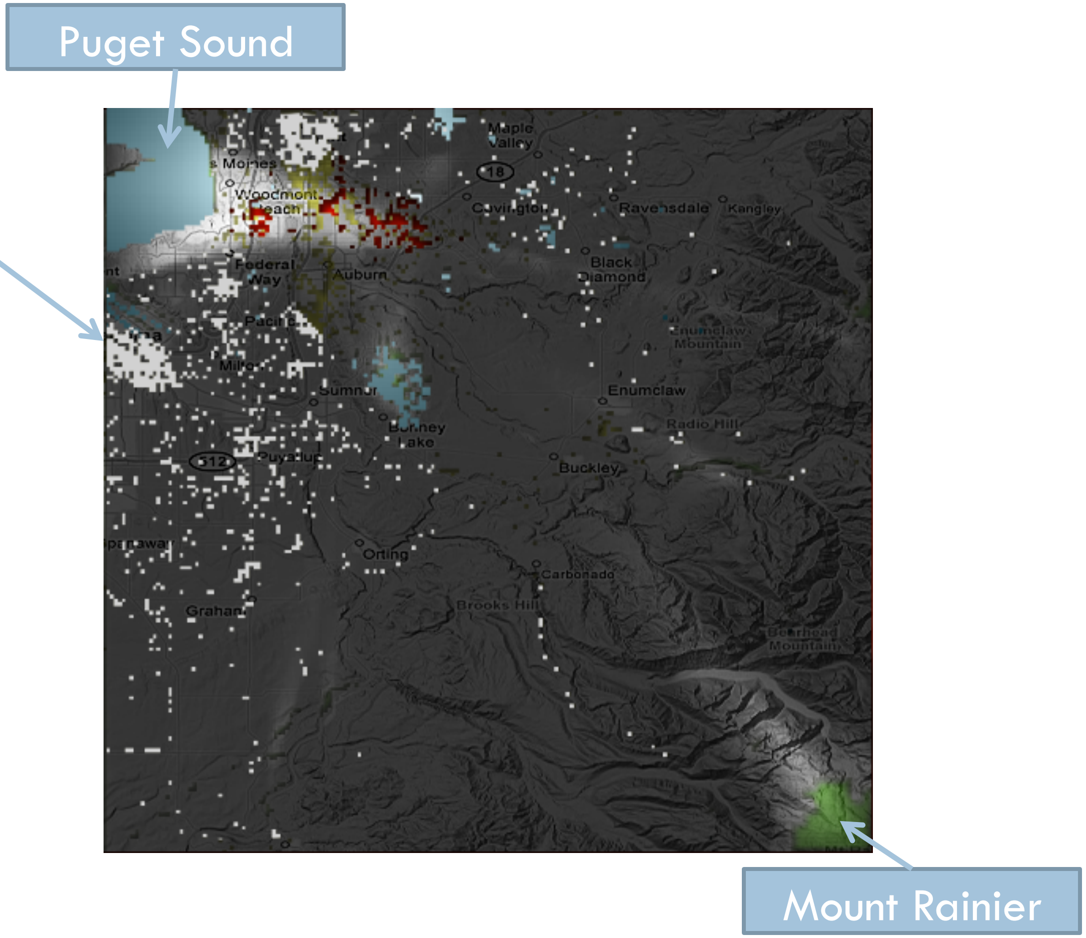
- Blue are *USABLE* components of the viewshed
- Green are BLOCKED to these beneficiaries due to blight or obstruction
- Scenario analysis to help understand consequences of locating further visual obstructions or relocating current ones



5. Modeling ES flows

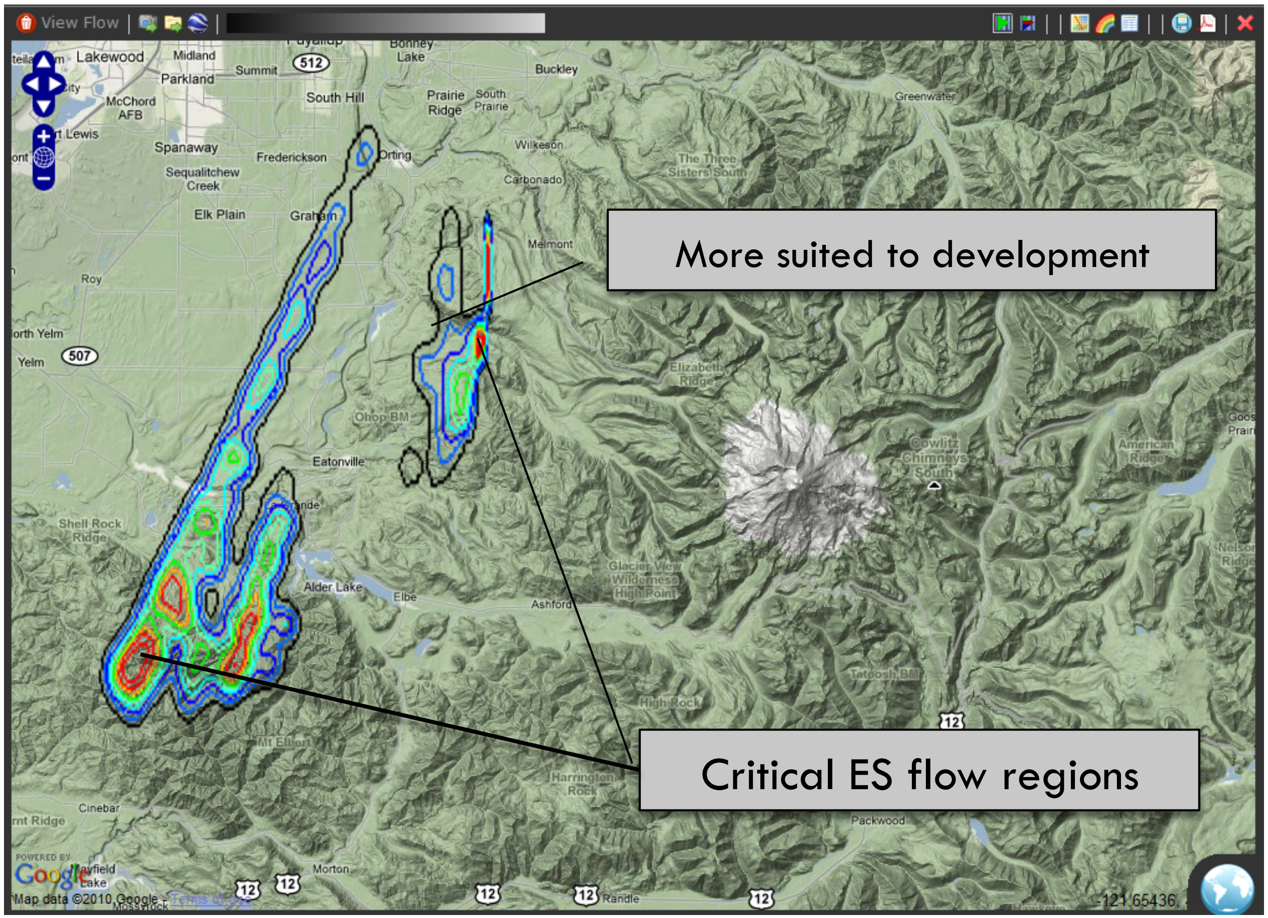
Inaccessible Sinks

- White dots are "negative" areas (ES sinks) that do not detract from service provision to a given beneficiary.
- Potential areas that will not affect service provision to this group of beneficiaries.



5. Modeling ES flows

Critical Flows Analysis



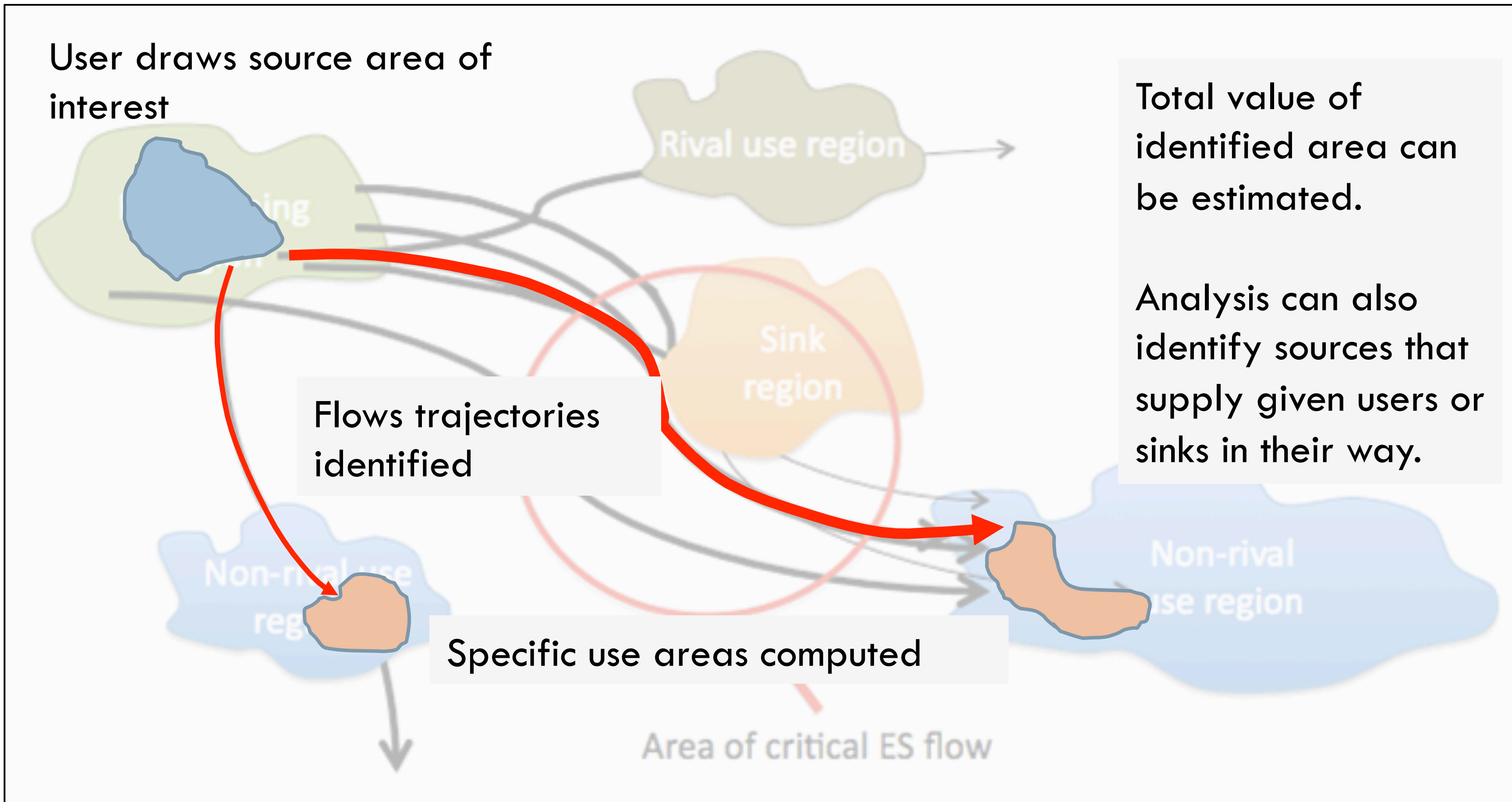
Critical flow paths show areas most critical to ensure ES flow to the intended beneficiaries.

Regions of high flow density should be protected or <u>enhanced for positive impact</u>

Regions of lower flow density can be developed without impacting ES provision.

5. Modeling ES flows

Targeting Areas



5. Modeling ES flows

Novel Results

- Flow analysis yields maps to assist decision-making, such as **critical flow contours**, **unmet service demand** or **unused service production**.

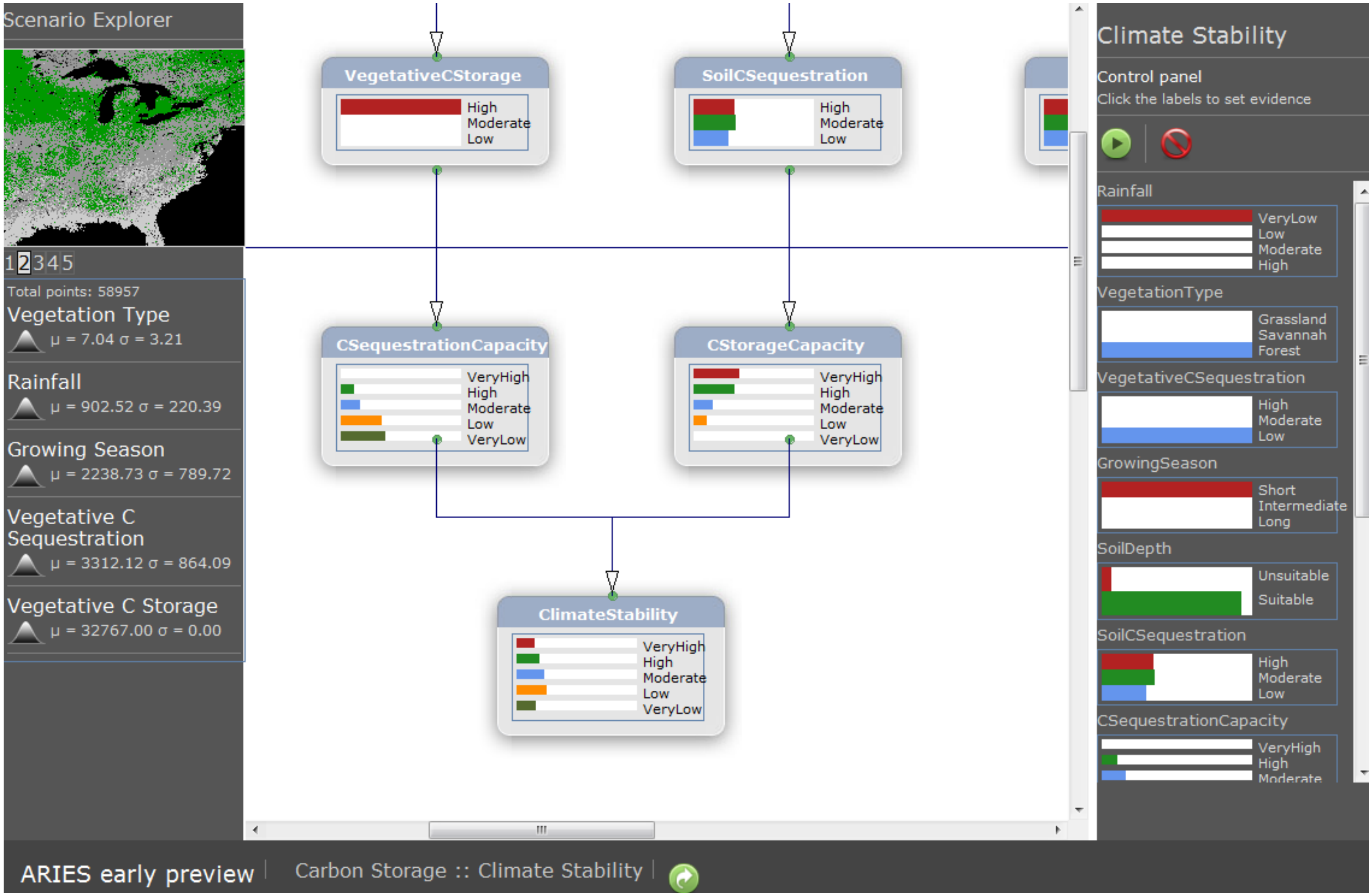
- Quantification is based on flow **strength**, **use** and **provision**.
  - **Policy scenarios** can be analyzed by comparing such contextual information, resulting in more accurate, beneficiary-dependent, science-based estimates of values.
  - **Uncertainty** is preserved in flow computation and can be visualized.

- **Value transfer** can be done by comparing such contextual information, resulting in more accurate, beneficiary-dependent, science-based estimates of value.

Scenario analysis

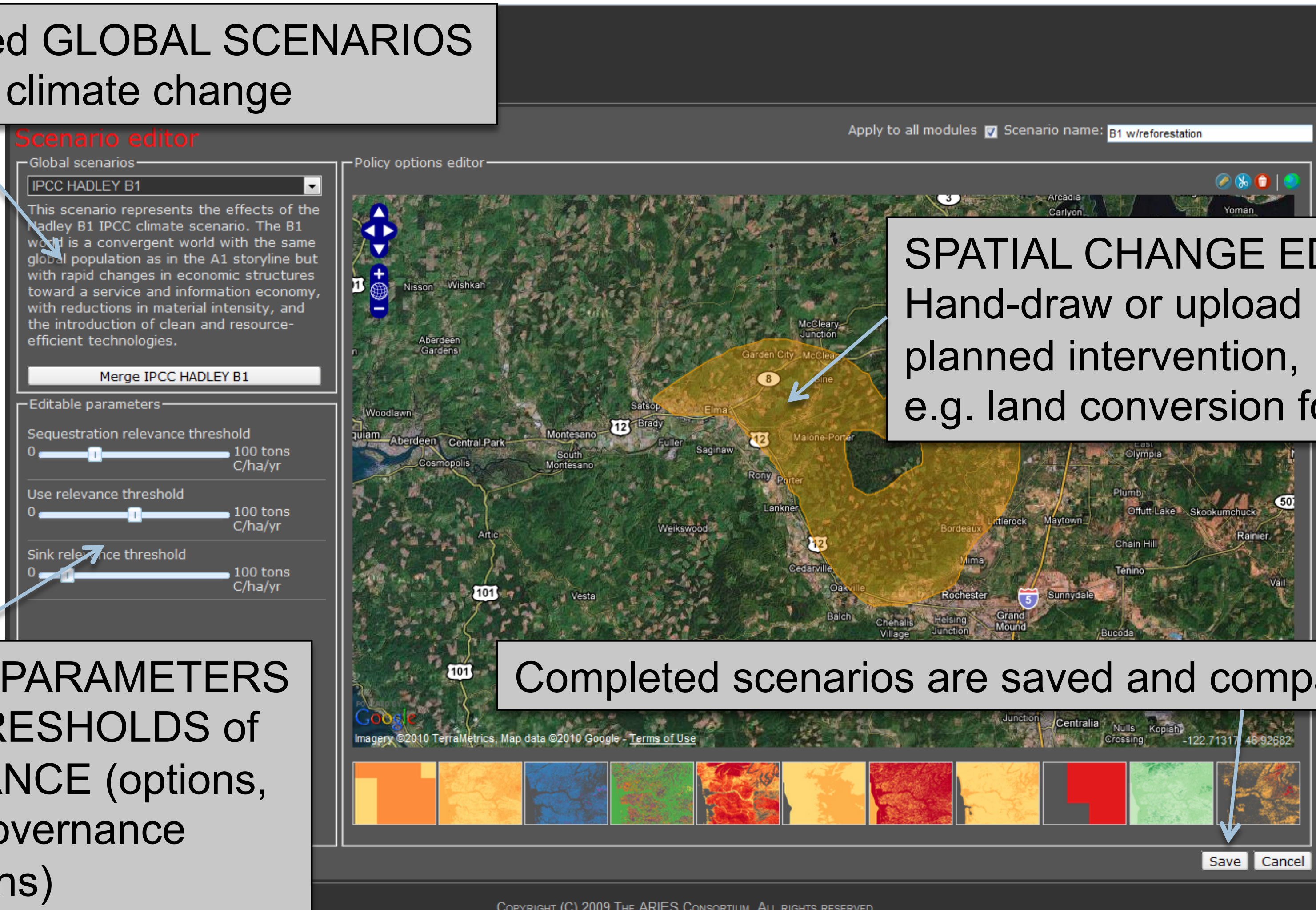
Users can change levels of variables and view the effect on probability of ES provision

Scenarios can be saved and reports produced for each of them



Ex-ante scenario definition

Pre-defined GLOBAL SCENARIOS
e.g. IPCC climate change



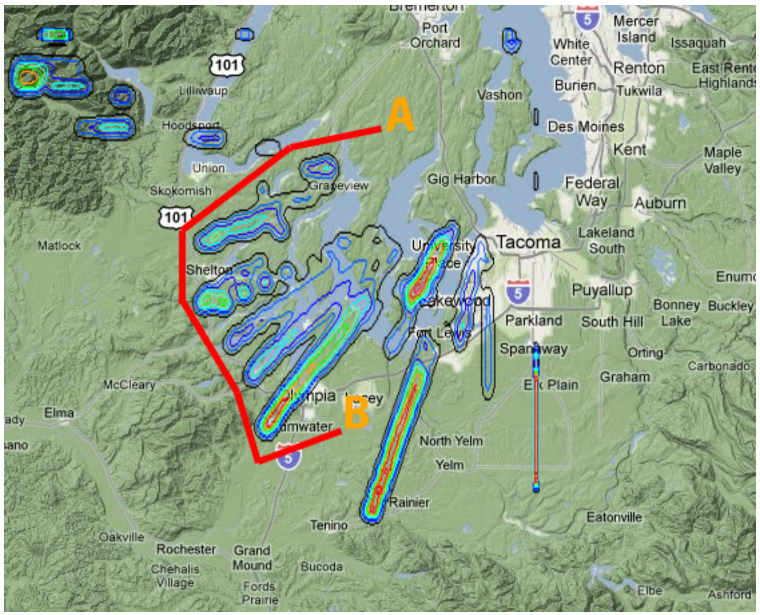
SPATIAL CHANGE EDITOR
Hand-draw or upload planned intervention,
e.g. land conversion forest

MODEL PARAMETERS and THRESHOLDS of RELEVANCE (options, law or governance indications)

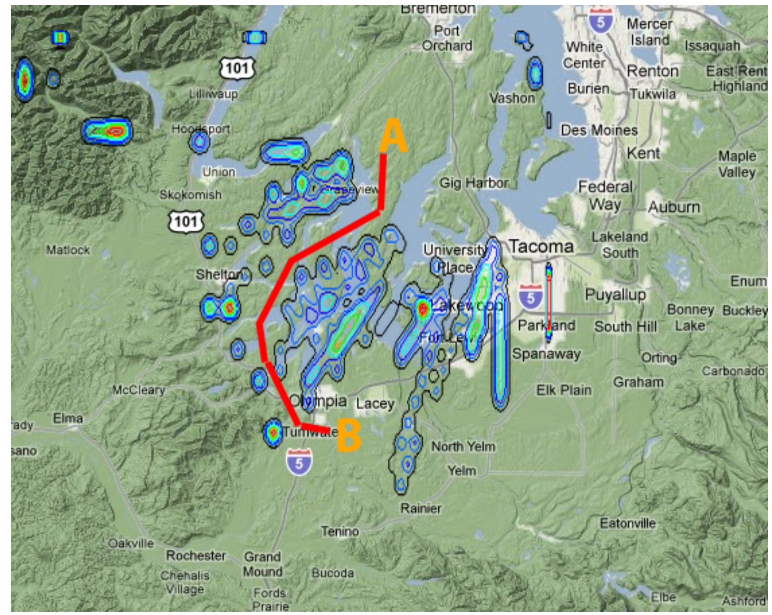
Completed scenarios are saved and compared

Routing linear features

Scenario 1: Baseline



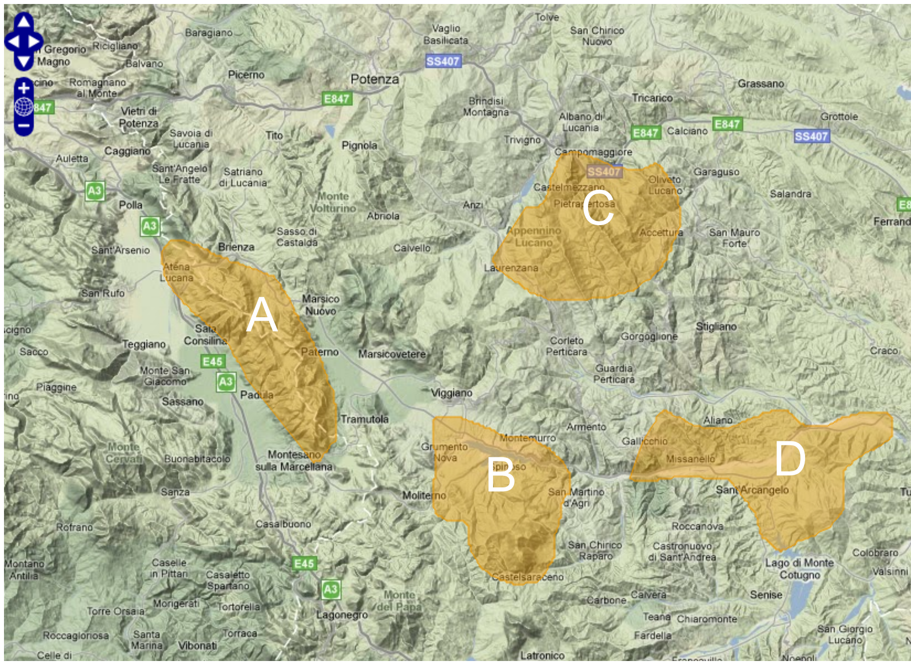
Scenario 2: Reforestation



Routing that minimizes impact ES flows in *business as usual* scenario. Long feature required to avoid impacting water provision.

Routing that minimizes impact on flows of ES with reforested corridors. Shorter feature offsets reforestation costs.

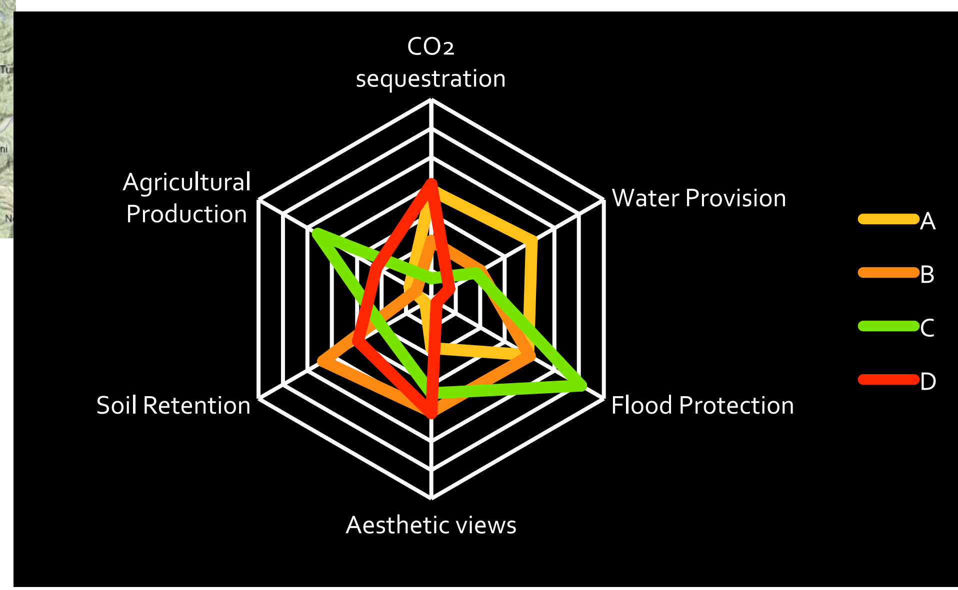
Identification and ranking of areas for offsetting impacts



ARIES can produce a full ES profile for a set of areas under consideration for offsetting, under baseline or ex-ante intervention scenarios.

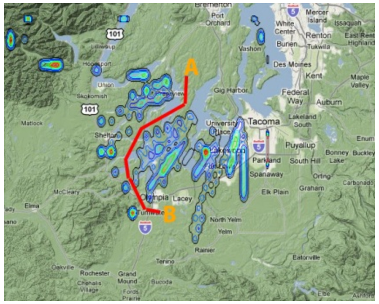
Such profiles help selection of areas and documentation of ES offsets.

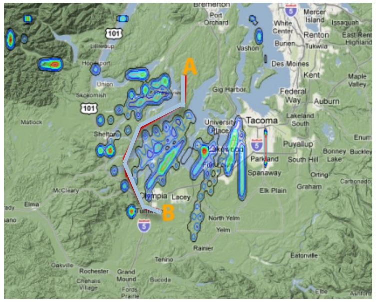
Multiple Criteria analysis allows customizing the ES profiles to pre-existing priorities or legal constraints.

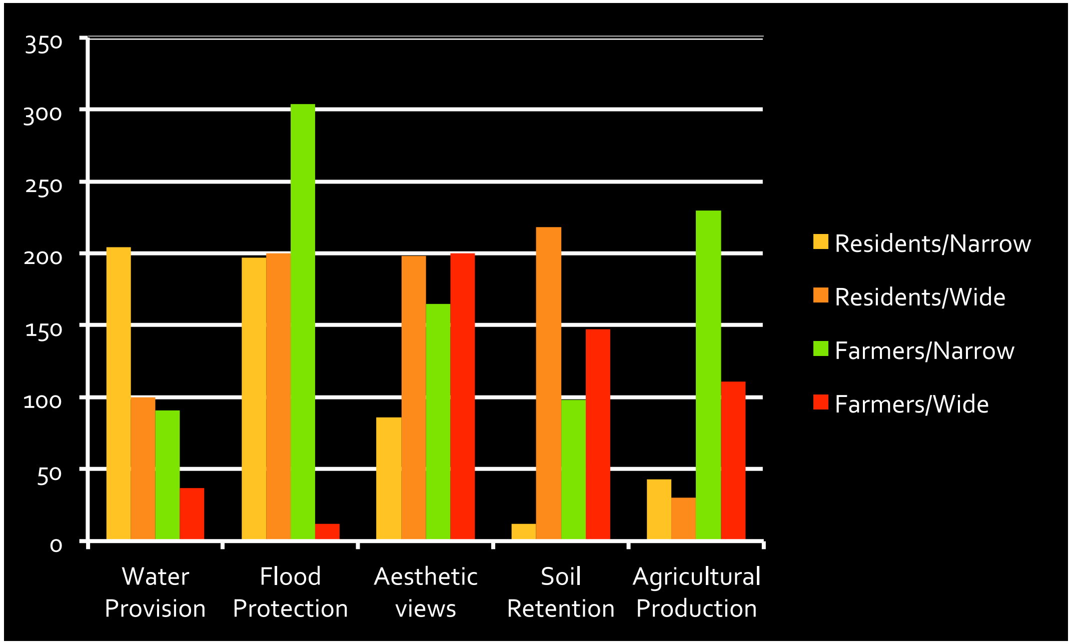


Stakeholder impacts

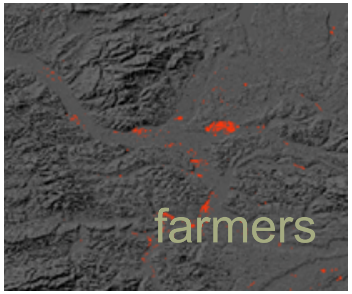
Quantify impact of alternatives on specific stakeholders







Two alternative options (different buffer zone widths) evaluated for impact on ecosystem services…

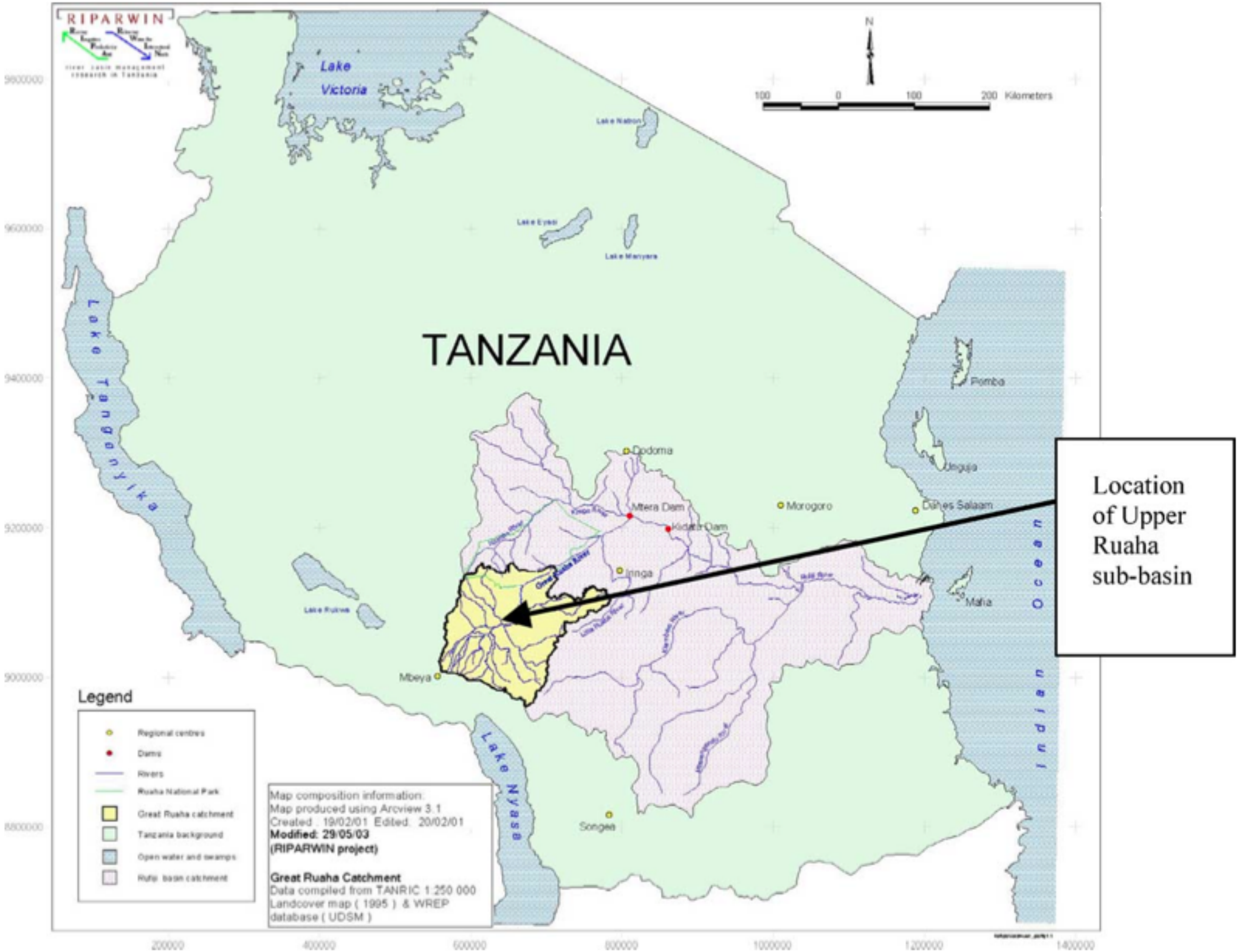


…against the different needs of two different stakeholder groups.

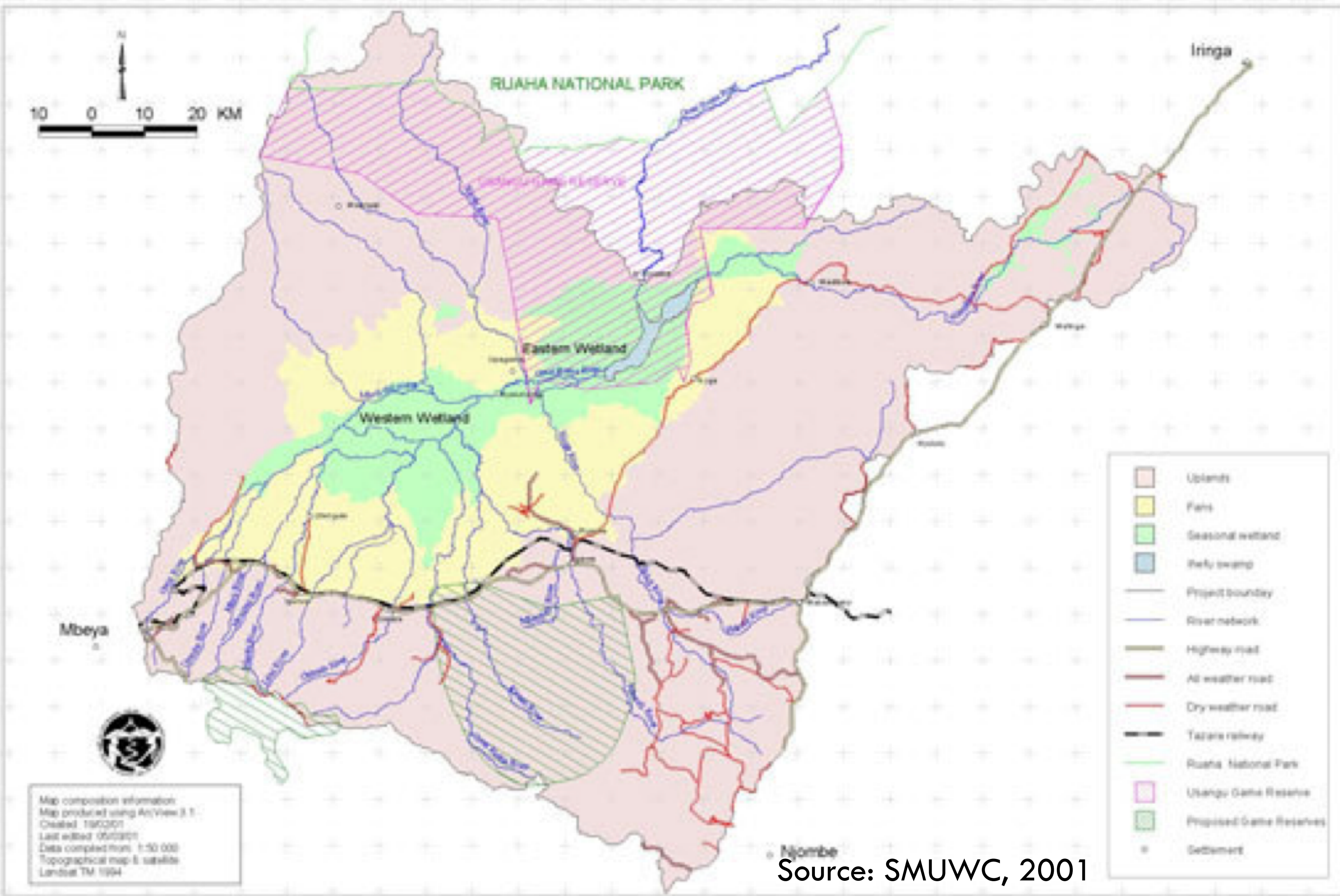



GREAT RUAHA RIVER BASIN

Rufiji River Basin



Upper Ruaha Sub-Basin / Usangu Wetlands

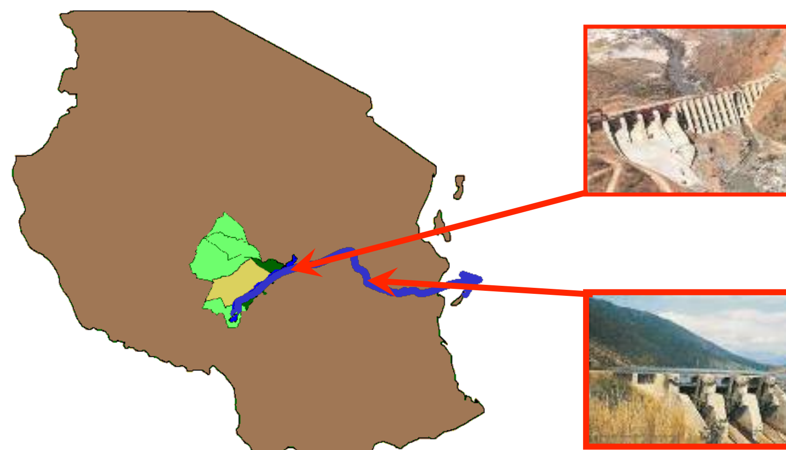


Source: SMUWC, 2001

Importance of the Ruaha Landscape

Conservation Significance

Resources for Rural Livelihoods



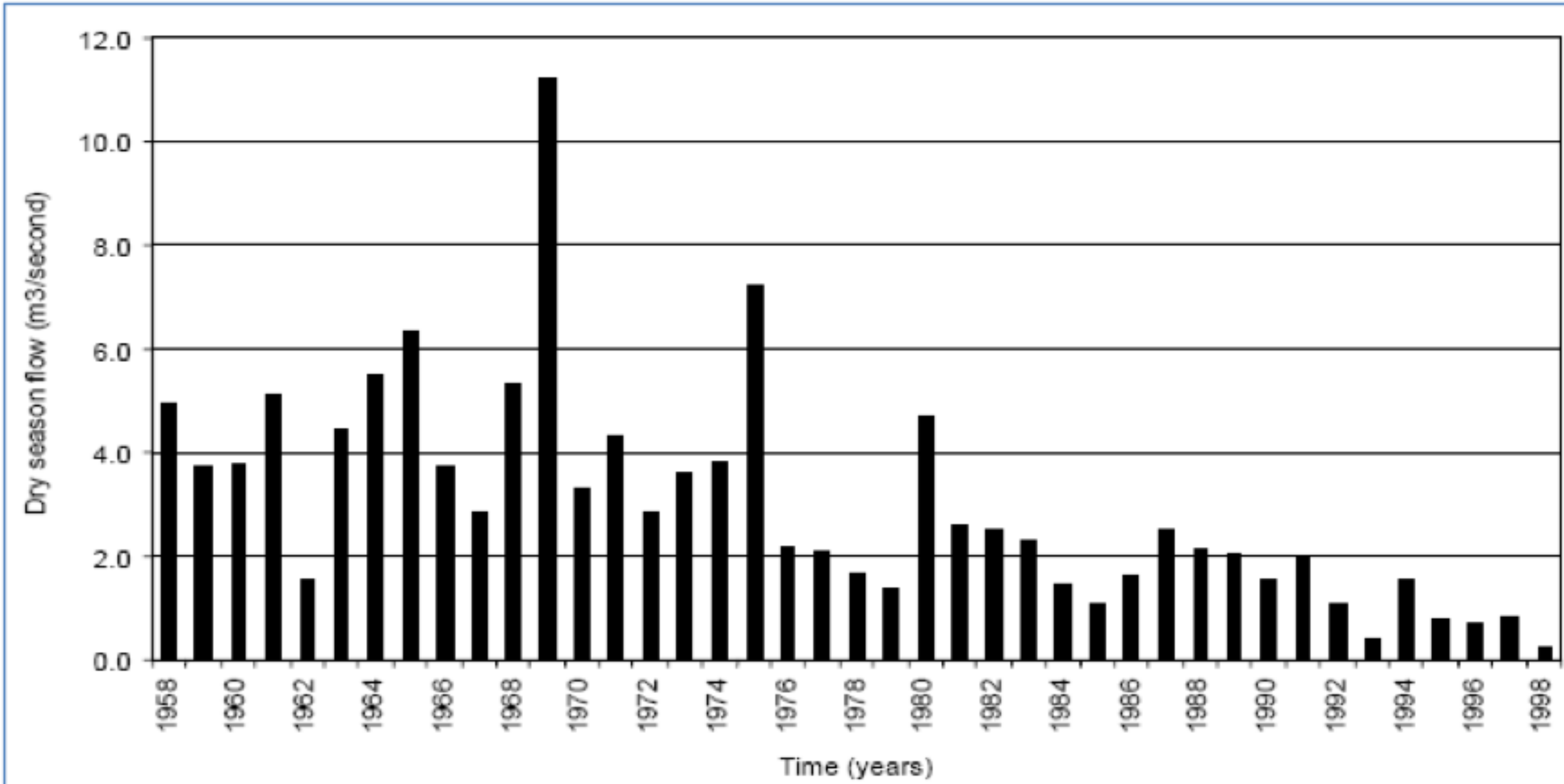
National Development

Drying of the Great Ruaha River

Pre-1993:
Flow of Great Ruaha all year

2005:
119 days of no flow

Average Dry Season Flow at Msembe Gauge 1958-1998



Source: SMUWC, 2001

Selected Studies

1960	FAO, *Hydrology and Water Resources in the Rufiji Basin*
1978	Commonwealth Fund for Technical Co-operation (CFTC), *The Development Potential of the Usangu Plains of Tanzania*
1983	FAO, *Usangu Village Irrigation Project*
1995	DANIDA / World Bank, *Joint study of integrated water and land management in the Great Ruaha Basin*
1996	World Bank, *River Basin Management and Smallholder Irrigation Project: Staff Appraisal Report*
2002	UK DFID, SMUWC (Sustainable Management of the Usangu Wetland and it Catchment)
2004	UK DFID, RIPARWIN (Raising Irrigation Productivity and Releasing Water for Intersectoral Needs)
2010	WWF, *Environmental Flow Assessment*

Water Policy Highlights

1971 Rural Water Supply Program (1971-1991)

Access to adequate, safe, dependable water supply within a walking distance of 400 metres from each household

1974 Water Utilization (Control and Regulation) Act, No. 42

1981, 1989, 1997, 1999 Amendments

2002 Tanzania National Water Policy (NAWAPO)

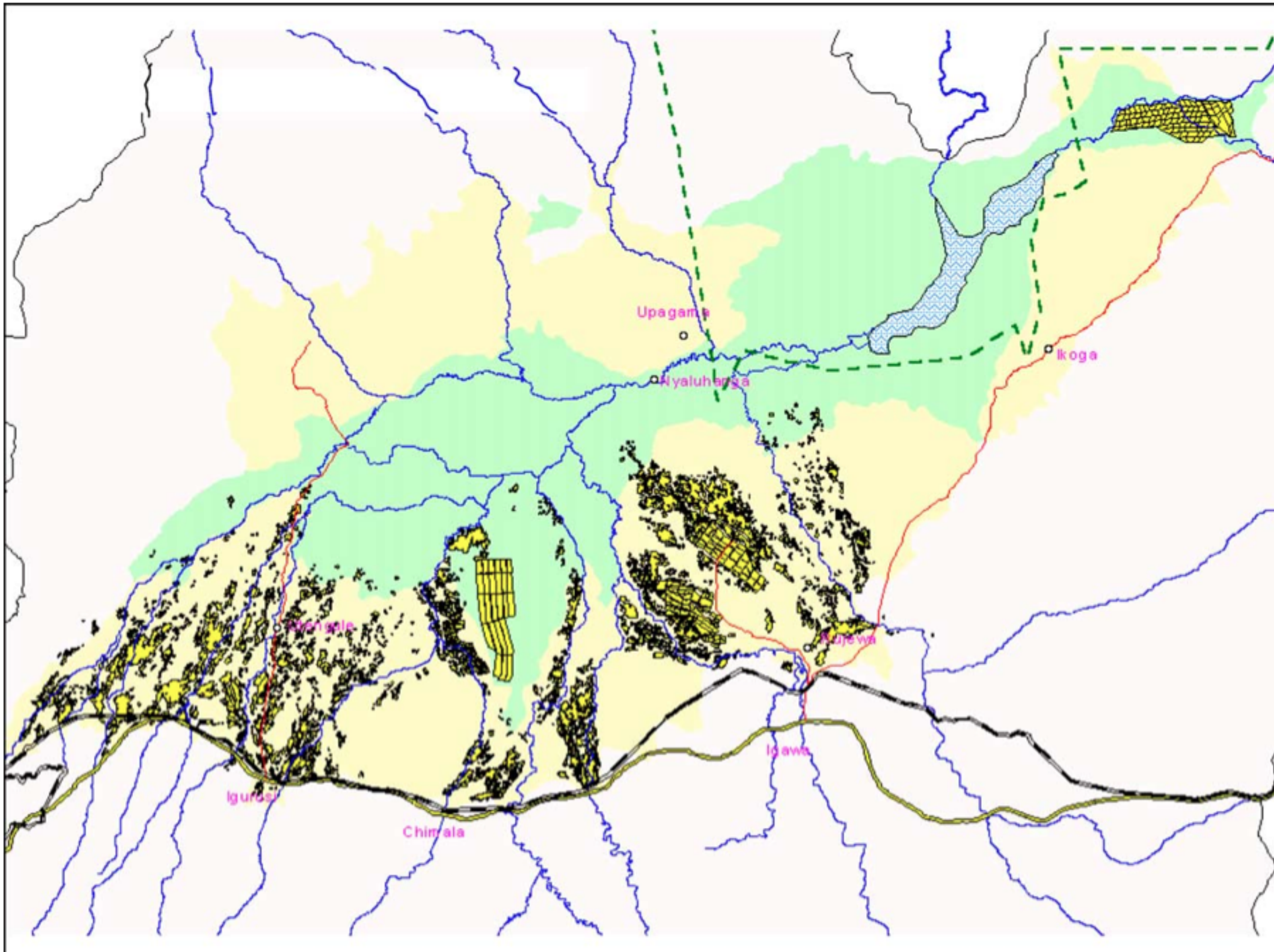
2005: National Water Sector Development Strategy (5-year plan)

2007: Water Sector Development Programme (WSDP)

2009 Water Resources Management Act, No. 11 (Replacing 1974 Water Utilization Act and all amendments)

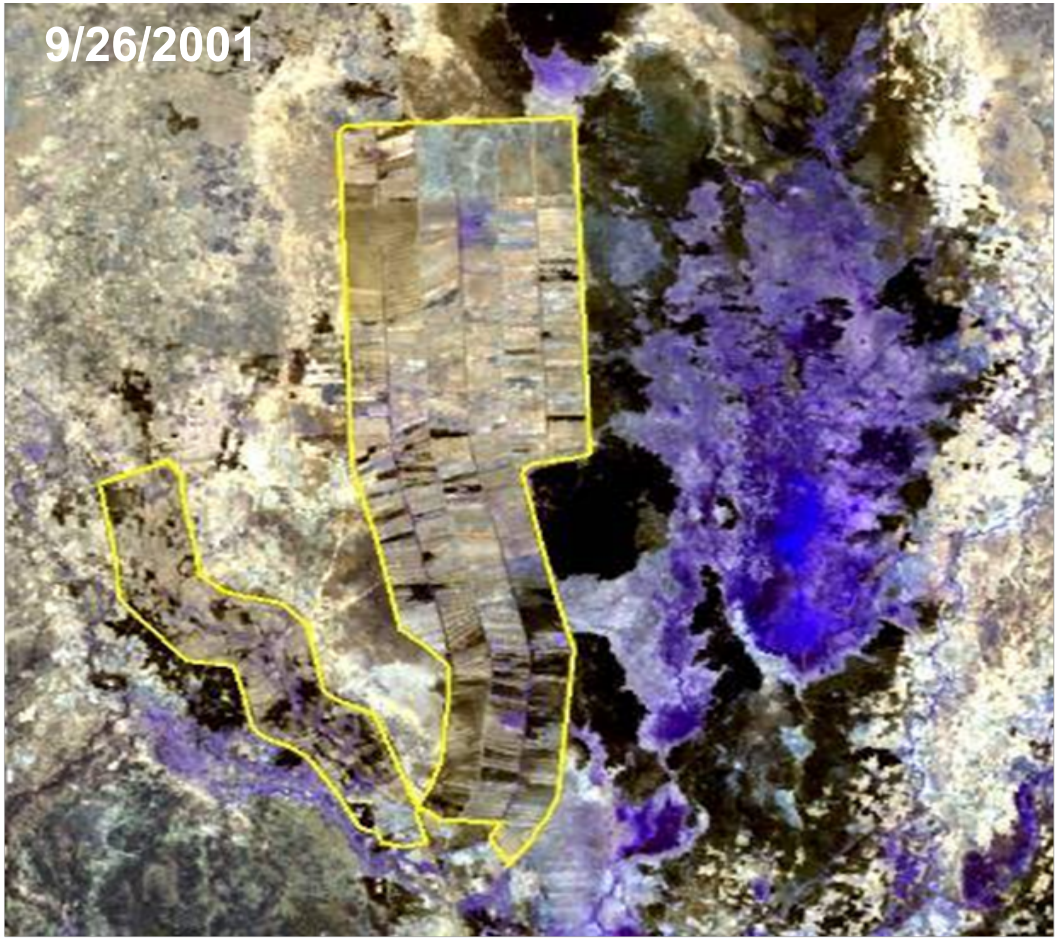
Establishes: National Water Board, Catchment (9) and Sub-catchment Water Committees, Integrated Water Resources Plans, Protection of Water Resources, Management of Groundwater, Dam Safety and Flood Management, Financial Provisions, and Transboundary Water Resources.

Irrigation Pressures



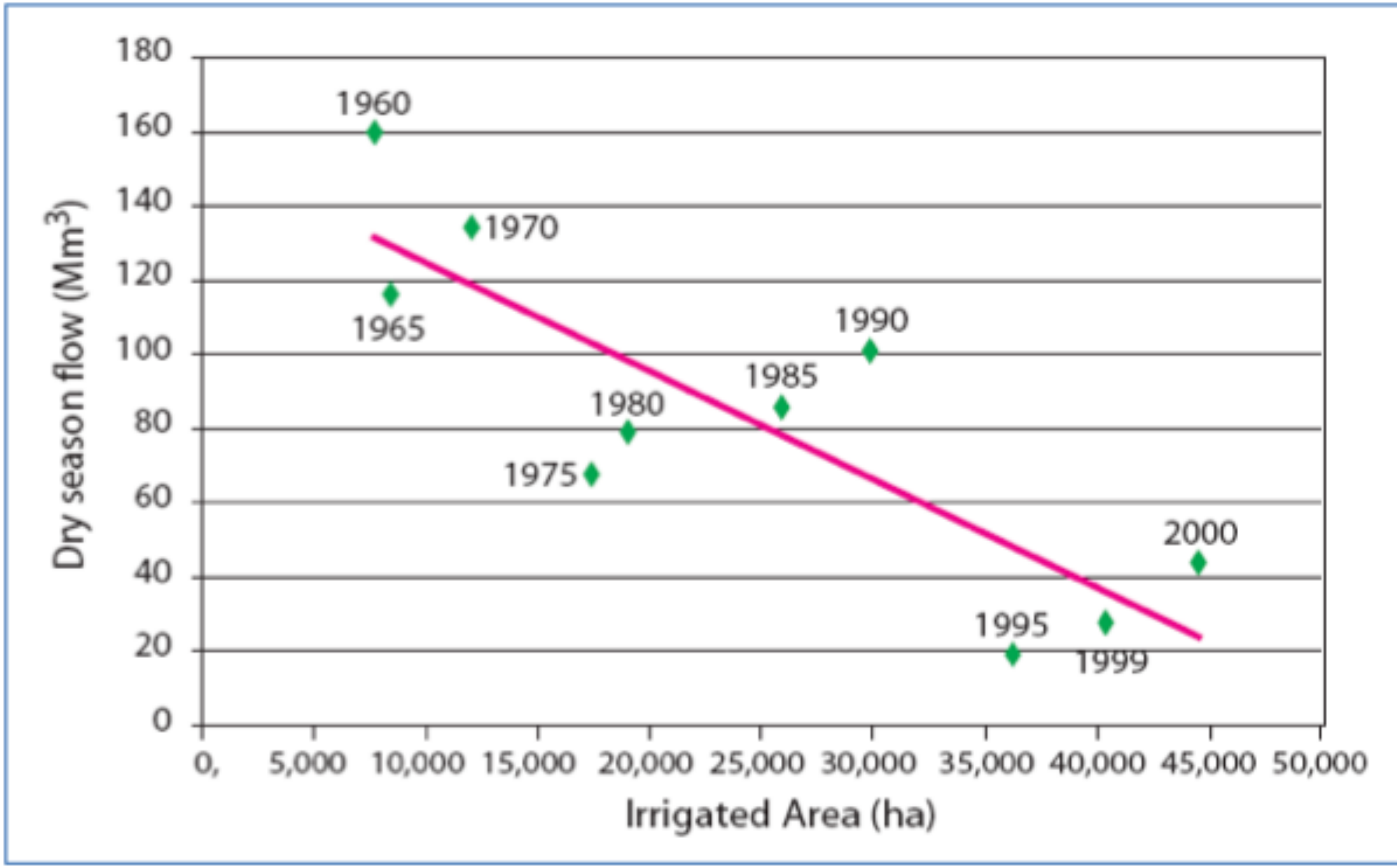
Source: SMUWC

Irrigation Pressures



Presumed extent of irrigation vs. observed flooded areas (WCS, 2006)

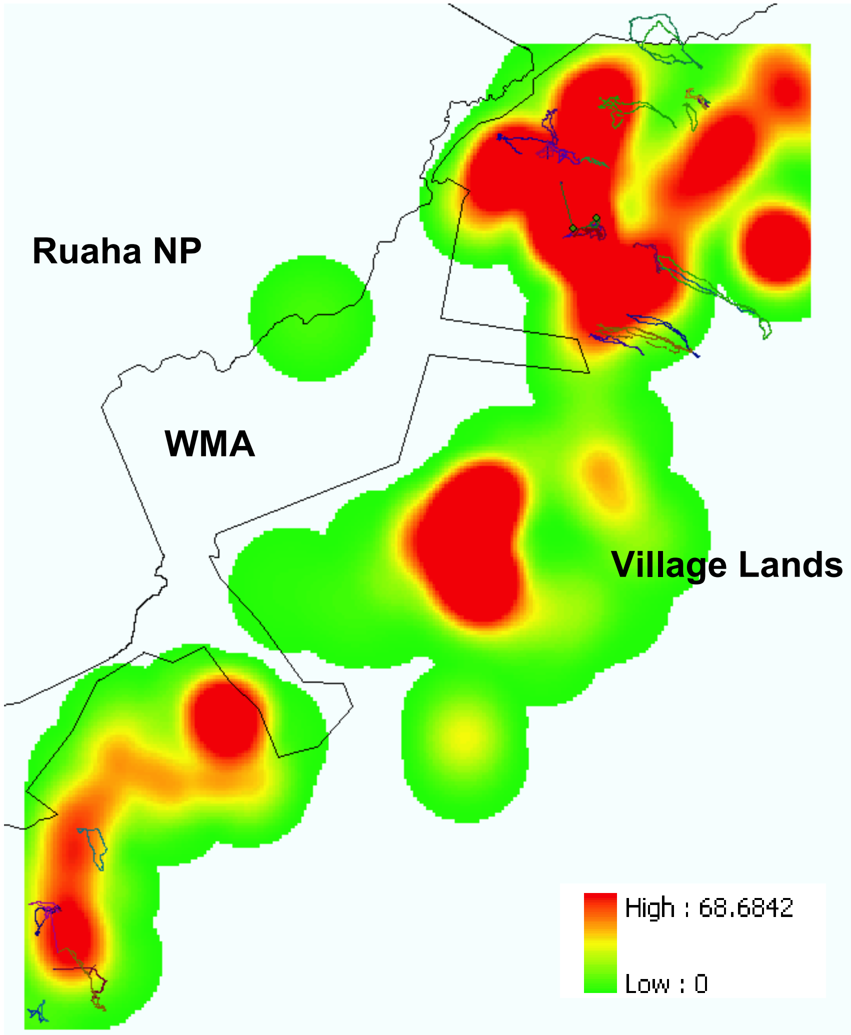
Irrigation Pressures



Dry Season Flow at Msembe plotted against Irrigated Area in the Usangu Plains

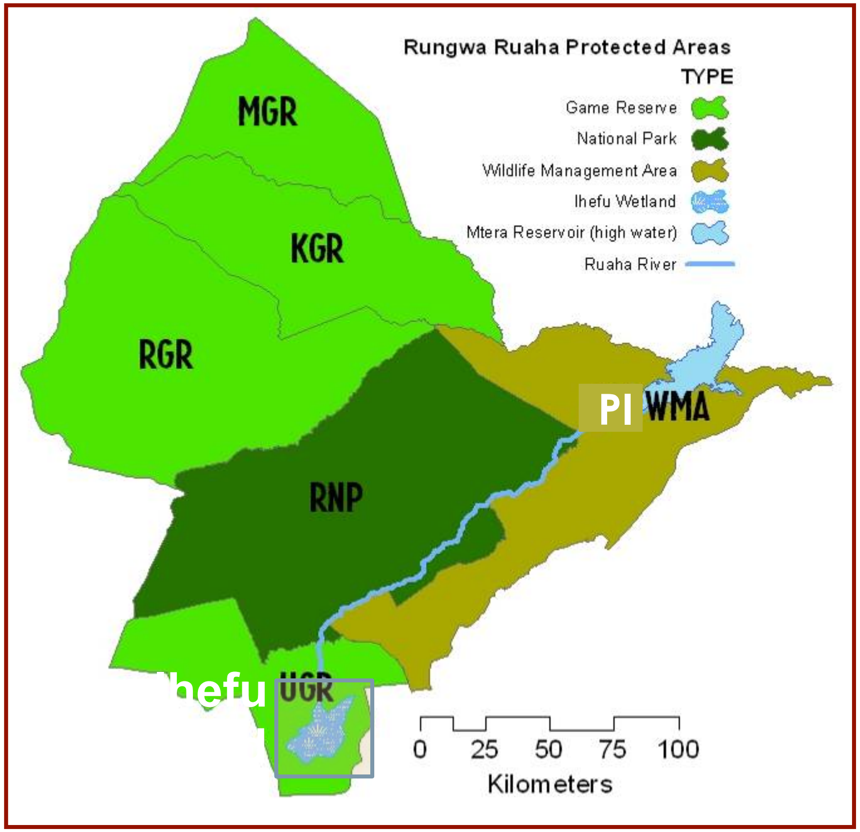
Source: WWF, 2010 [IWMI Research Report]

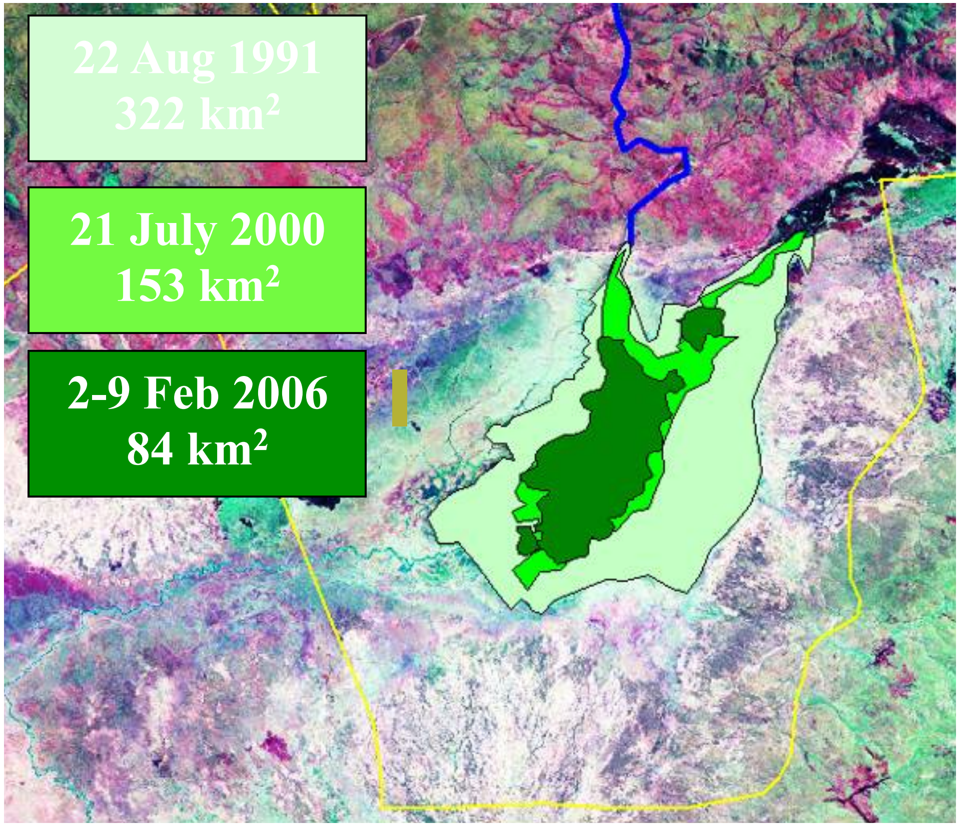
Grazing Pressures



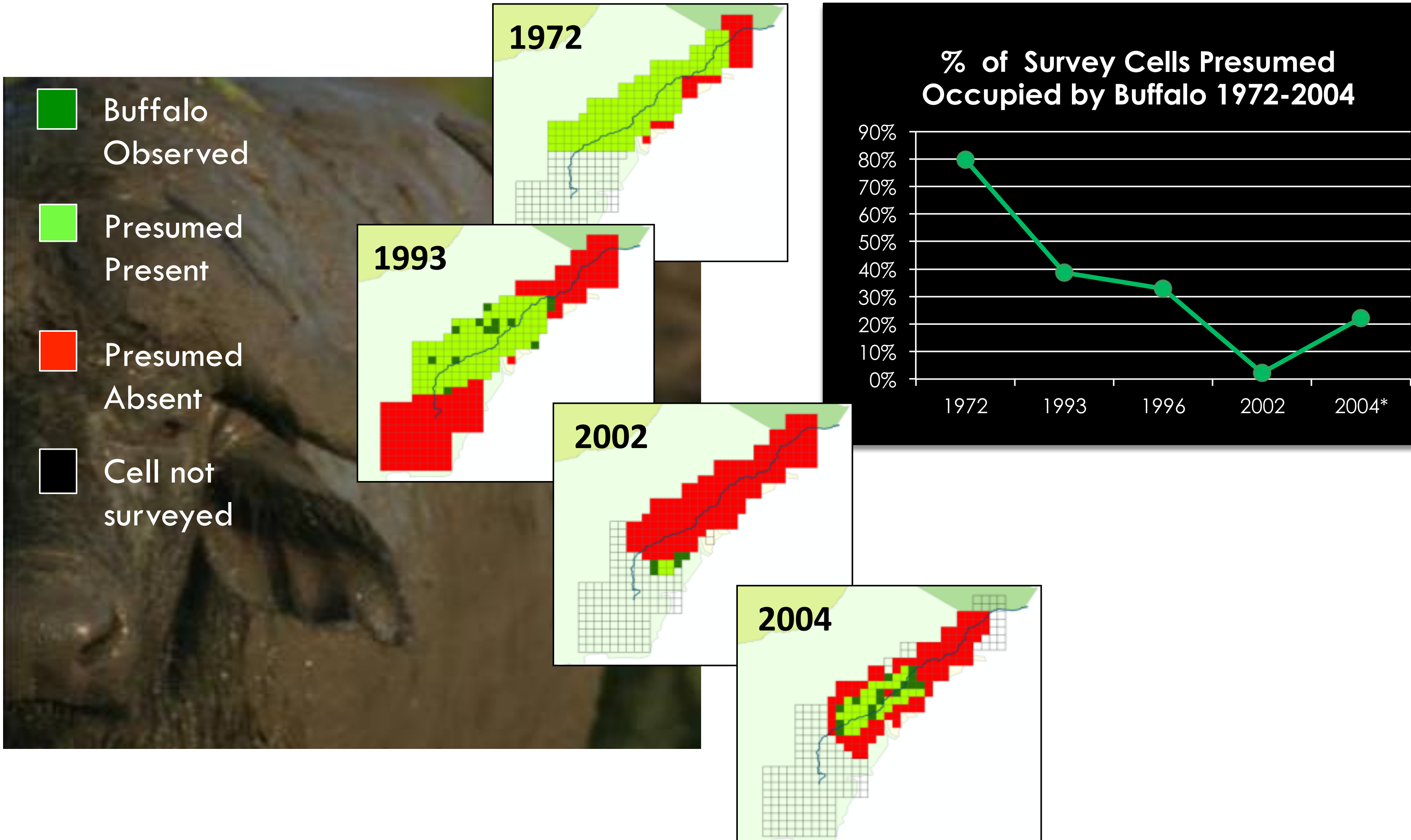
Cattle density (#/km2) at boundary of RNP, WMA, & village lands (WCS, 2008)

Decline of the Ihefu Wetland



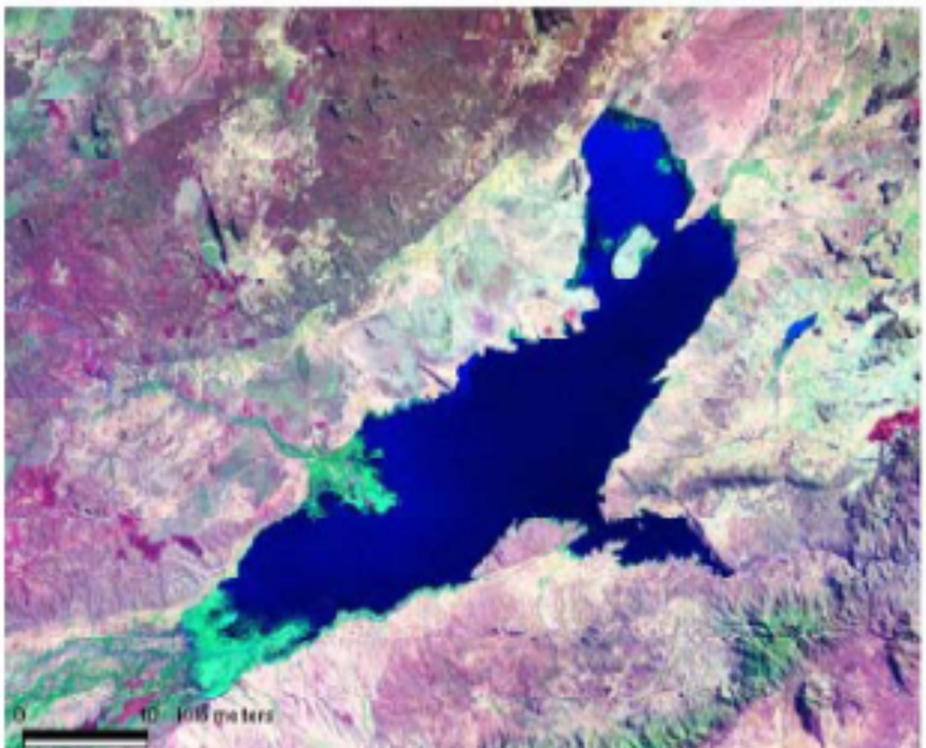


Collapse of African Buffalo Range



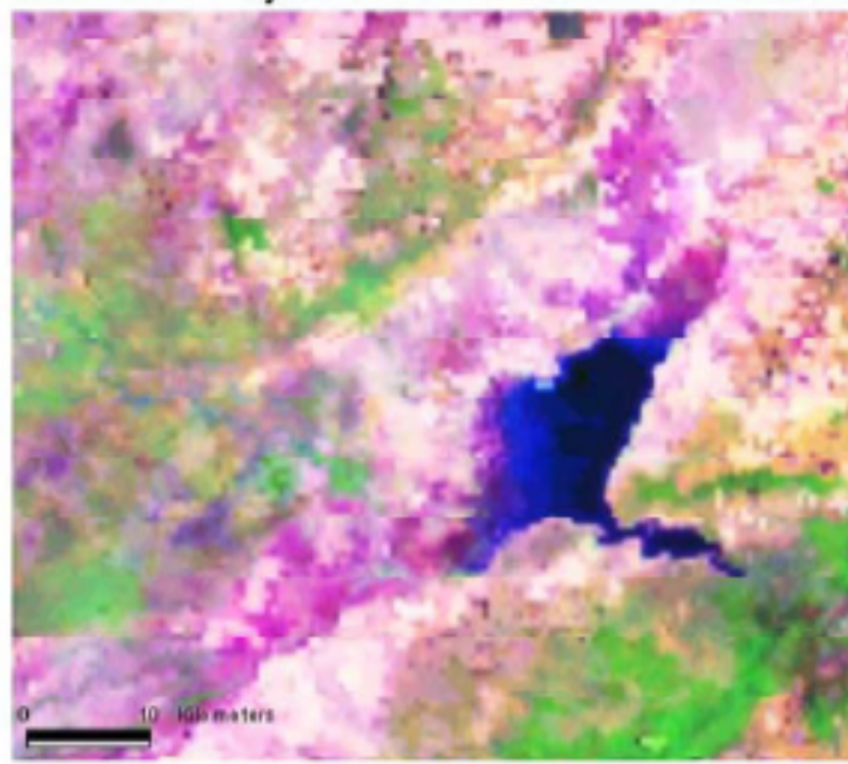
Drying of the Mtera Reservoir

1 December 1984: 605 km2



Landsat TM 28.5 m

2-9 February 2006: 170 km2



Modis Spectral Reflectance 500m

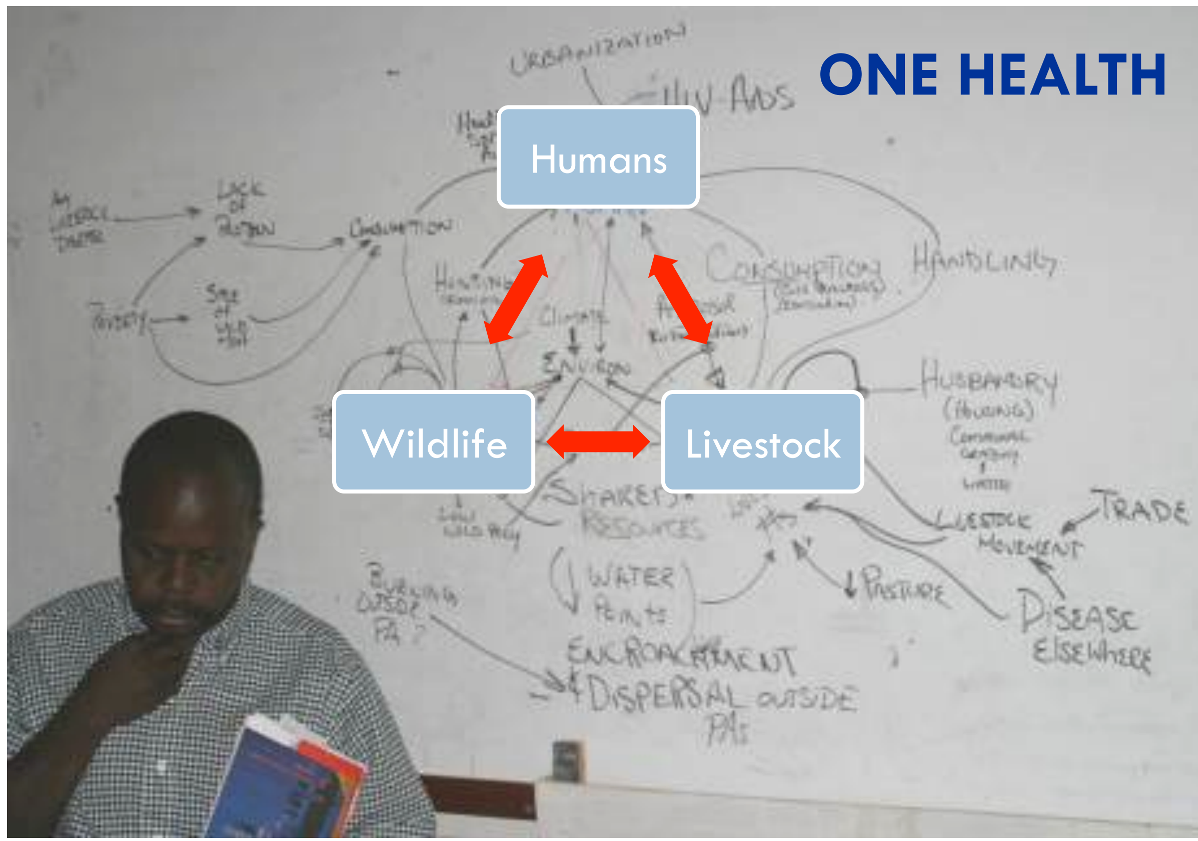
Consequences of Change

- ↑ Livestock-horticulture conflict
- ↑ Grazing pressure
- ↑ Wildlife conflicts & poaching
- ↓ Tourism revenues
- ↓ Wildlife
- ↓ Water & Water quality
- ↓ National economy
- ↑ Disease?

Stakeholder-Research Partnership

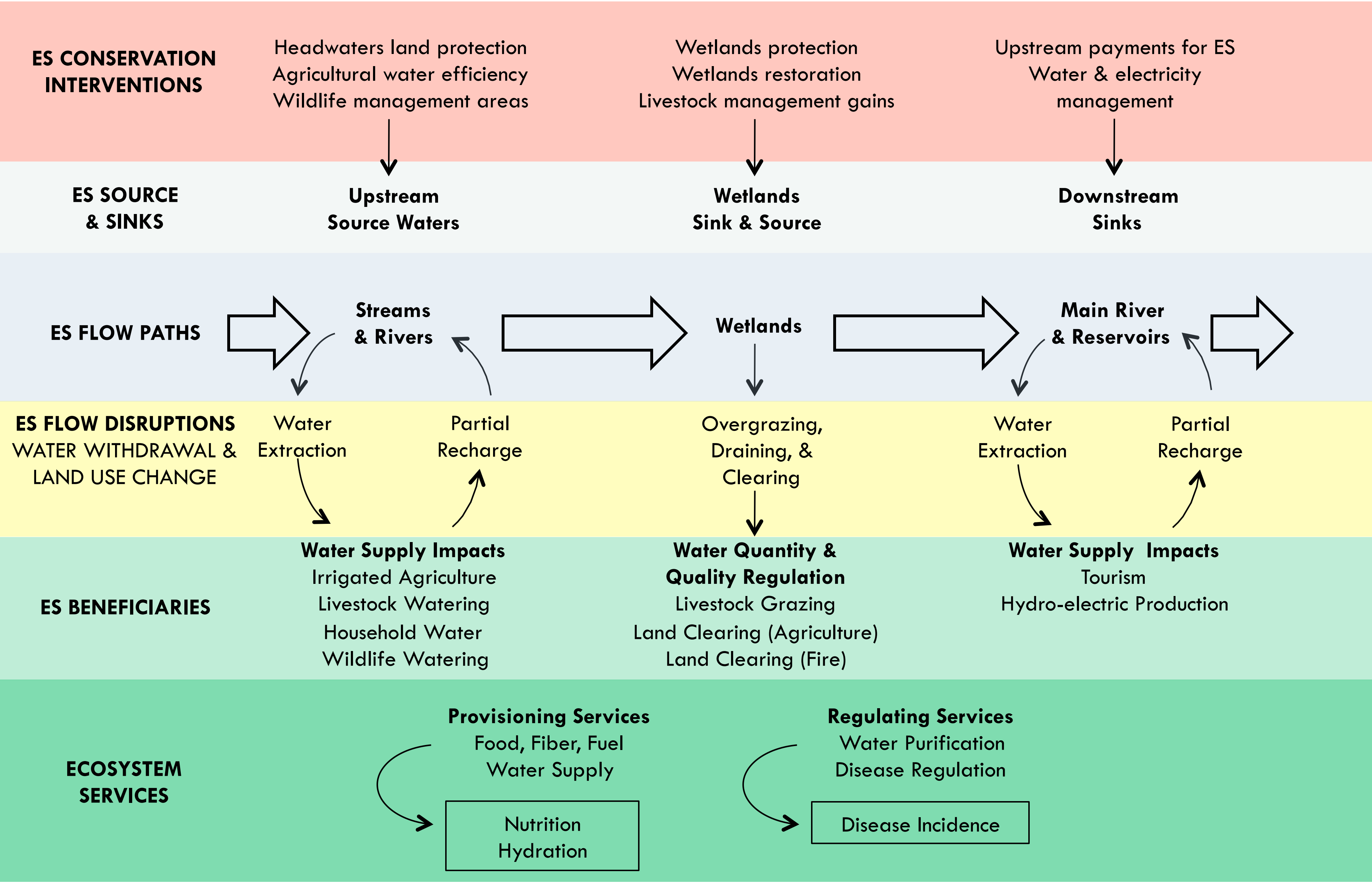
Identifying the Problem Model

- Pastoralist interviews
- Field visits
- Pre-project stakeholder workshop



Health for Animals and Livelihood Improvement (HALI) Project

Jon Erickson's Brain Dump



Ruaha Landscape Surface Water Source Data

- Annual Precipitation
  - Global: WorldClim
  - Local: Meteorological stations throughout Ruaha landscape
- Springs ?
- Inter-basin transfers ?

Ruaha Landscape Surface Water Sink Data

- Evapotranspiration & Soil Infiltration
- Weather: Annual maximum temperature
  - WorldClim
- Hydrologic Soils Group: Soil classification grouping soils that feature the same runoff potential under similar storm and cover conditions
  - Soils: ???
- Streams:
  - Digital Chart of the World
  - 1:100-m, 1:300-m, 1:500-m, 1:50,000-m

Ruaha Landscape Surface Water Sink Data

- Mountainfront Recharge Zones: surface water to groundwater
  - LULC + DEM + Soils
- % Impervious, % Canopy Cover, % Vegetation, Vegetation Type:
  - NOAA-NGDC: Global Land Cover
  - Food and Agriculture Organization Africover
  - European Space Agency GlobCover
- Runoff: Average annual runoff
  - SAGE: Global
  - Existing data models: SMUWC Study; RIPARWIN Study; WWF; WCS; Rufiji Water Basin Office

Ruaha Landscape Surface Water Sink Data

- Slope data
  - Derived from SRTM (90-m)
- Baseflow:
  - Stream gauge data from throughout Ruaha landscape

Ruaha Landscape Surface Water Beneficiary Groups

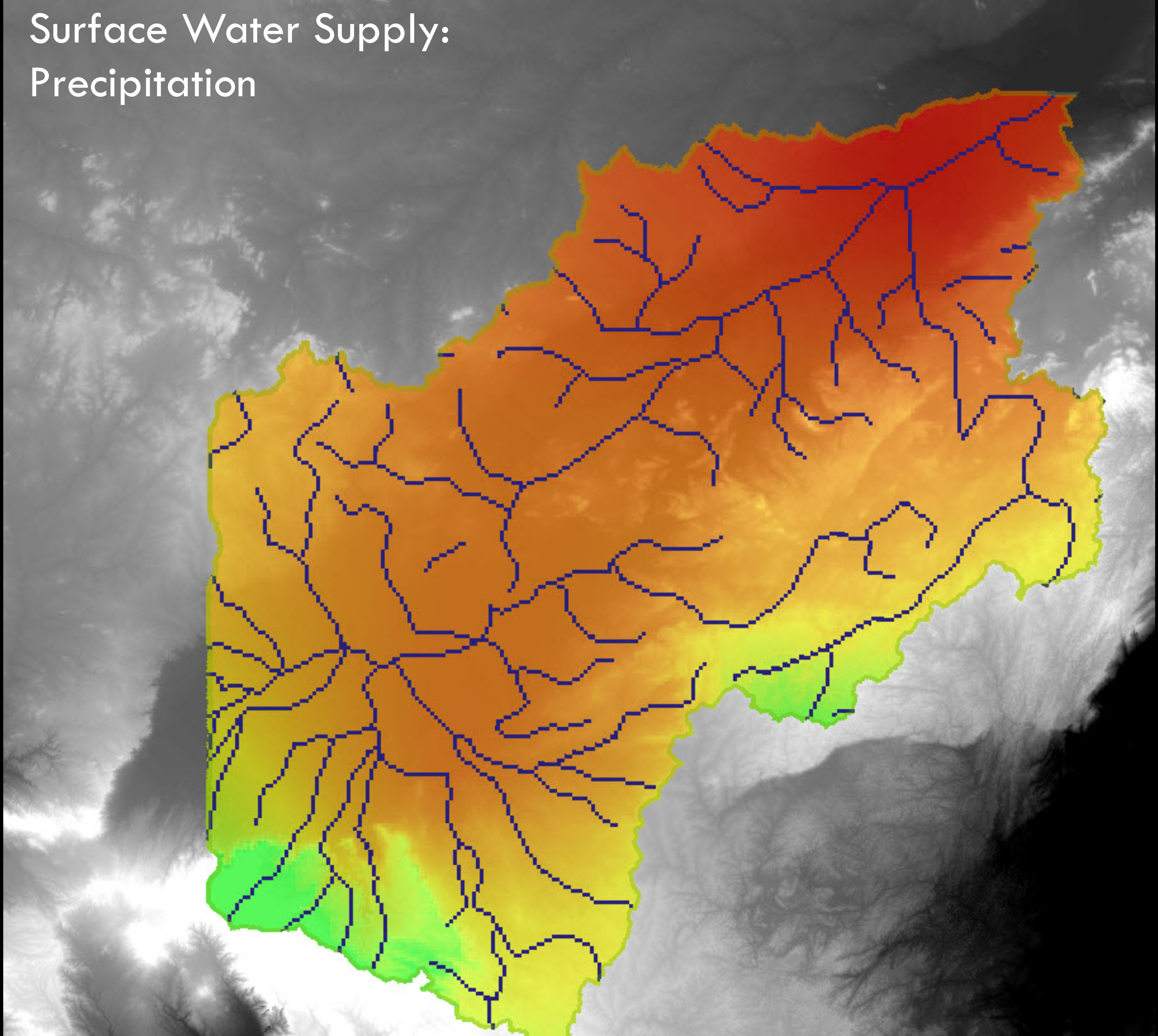
Beneficiary	Water Demand
Agricultural producers: Slopes, rangeland & rain-fed maize	Evapotranspiration for vegetative growth
Domestic users in villages	In-stream needs for cooking, drinking, bathing, etc.
Agricultural producers: Irrigated agriculture, rice	Evapotranspiration, seepage for vegetative growth and open water evaporation
Livestock producers: Permanent & seasonal wetland	Evapotranspiration/evaporation & in-stream consumption and water diversion (water holes)
Tourism: Ruaha National Park	In-stream needs for wildlife and drinking needs
Power producers: Mtera/Kidatu HEP Stations	Release for hydro-electricity power
Urban power users	Light, power, heating, cooling

Modified from Lankford et al 2004

Ruaha Landscape Surface Water Beneficiary Groups Data

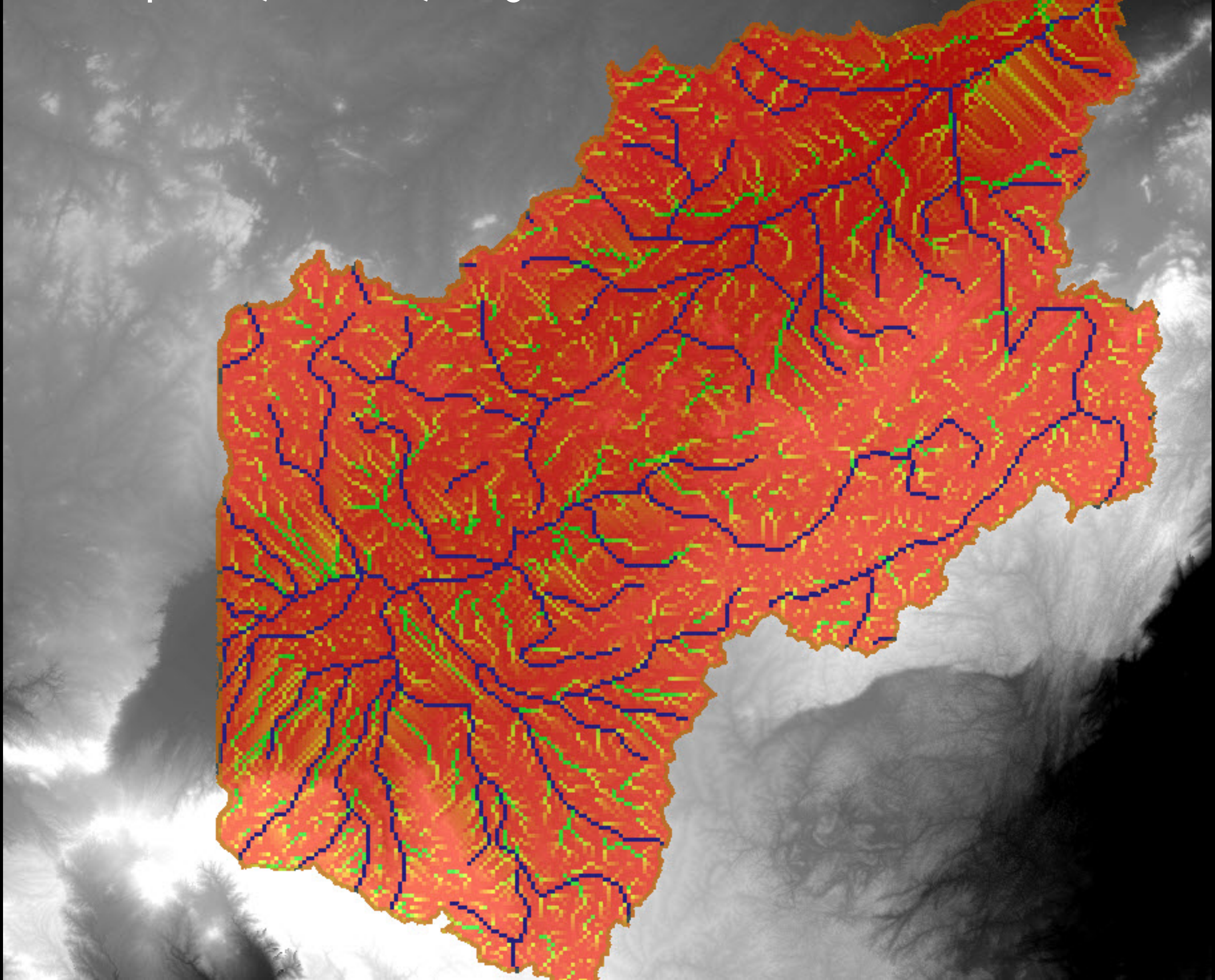
- Surface diversions: Stream diversions to supply irrigated agriculture, livestock watering holes, and municipal and private water supplies (piped water)
- Water supply wells: Location, capacity, depth, use type (residential, commercial, industrial)
- Water rights: Legally binding water allocations
- Land use / Land cover: urban areas, residential, commercial, industrial, impervious surface, forest canopy cover, wetlands, water, farmland, open space, barren land, mining
- Pastoralist households

Surface Water Supply: Precipitation

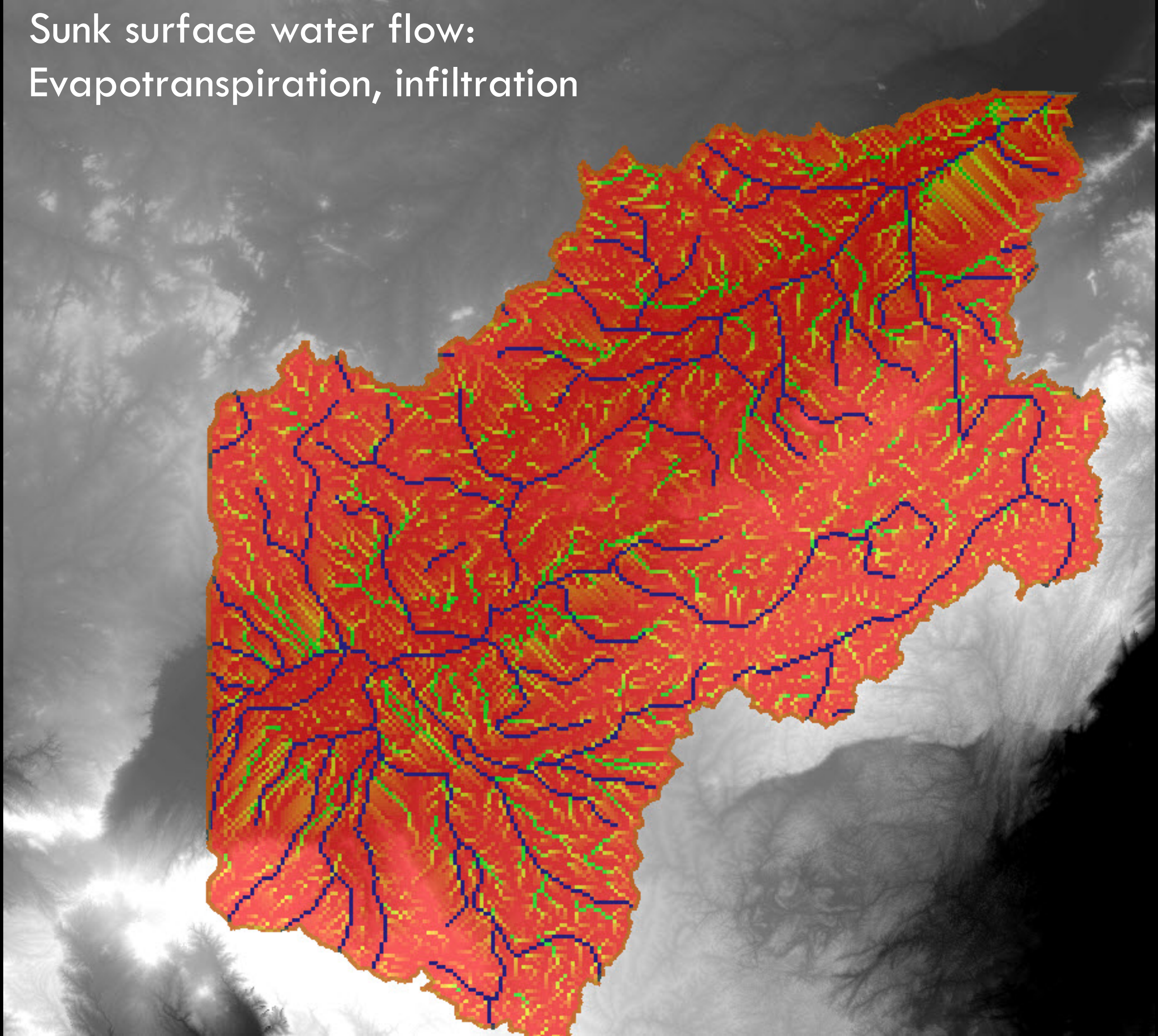


Possible surface water flow:

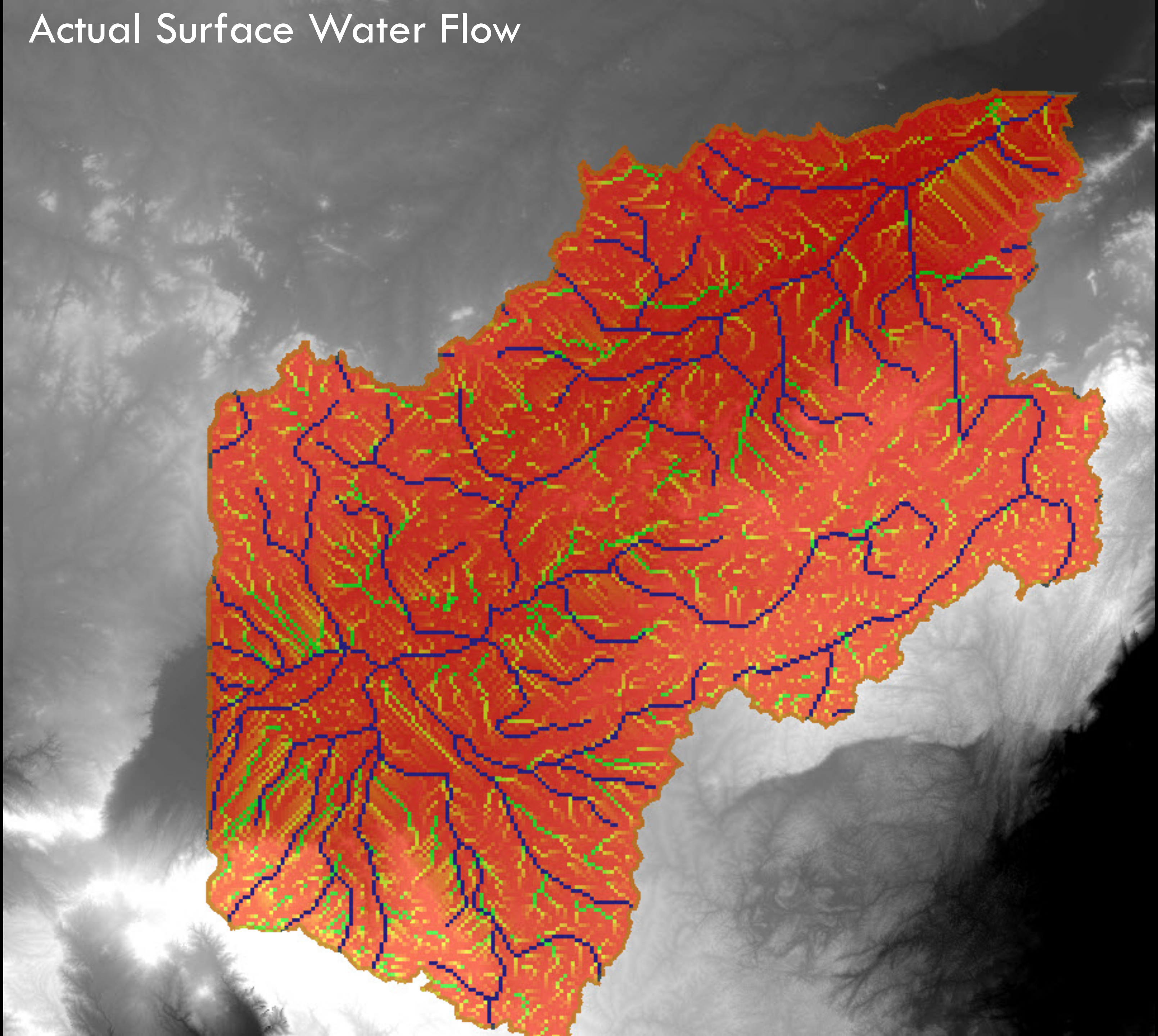
Atmospheric, surface, or groundwater transitions



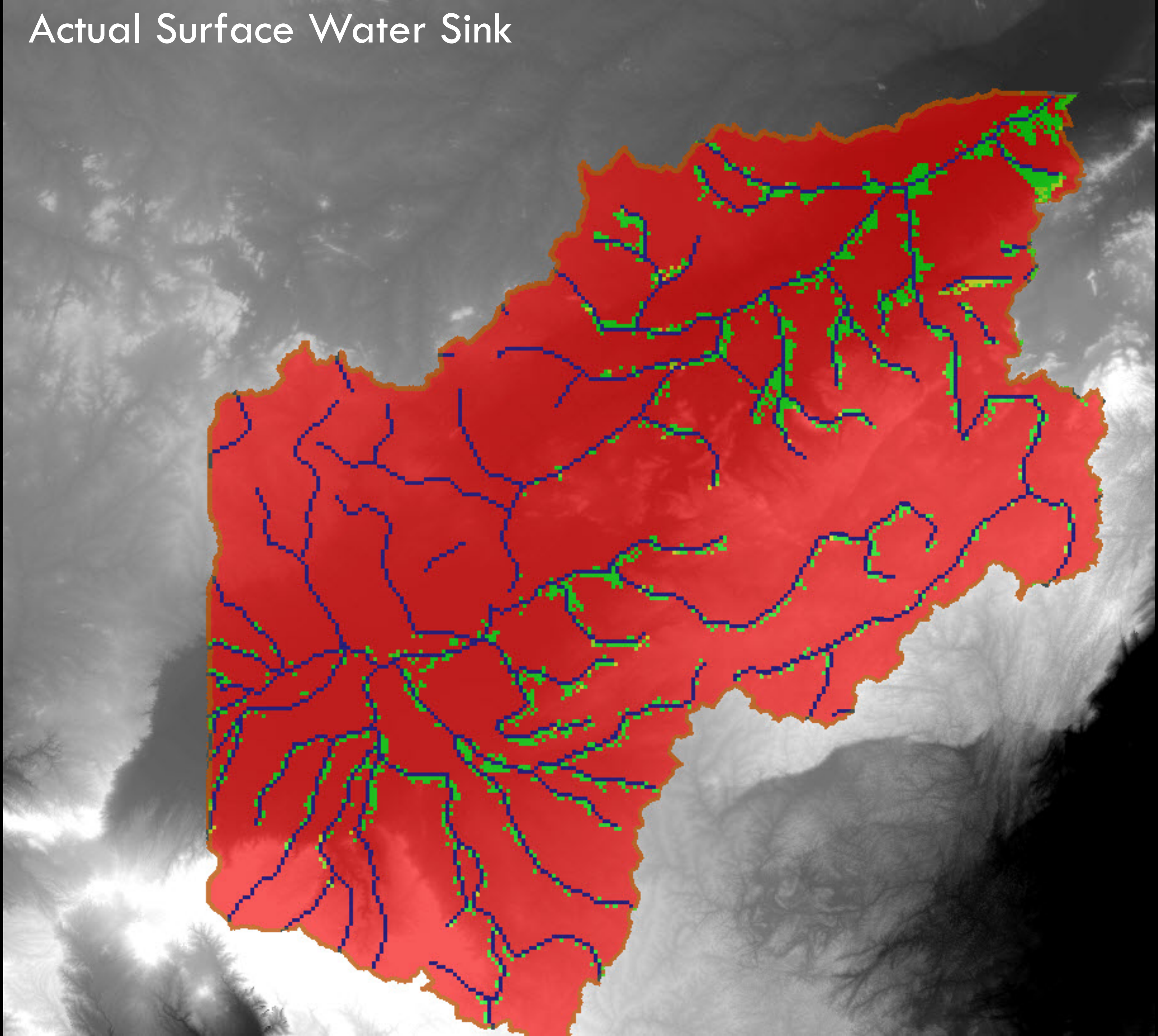
Sunk surface water flow:
Evapotranspiration, infiltration



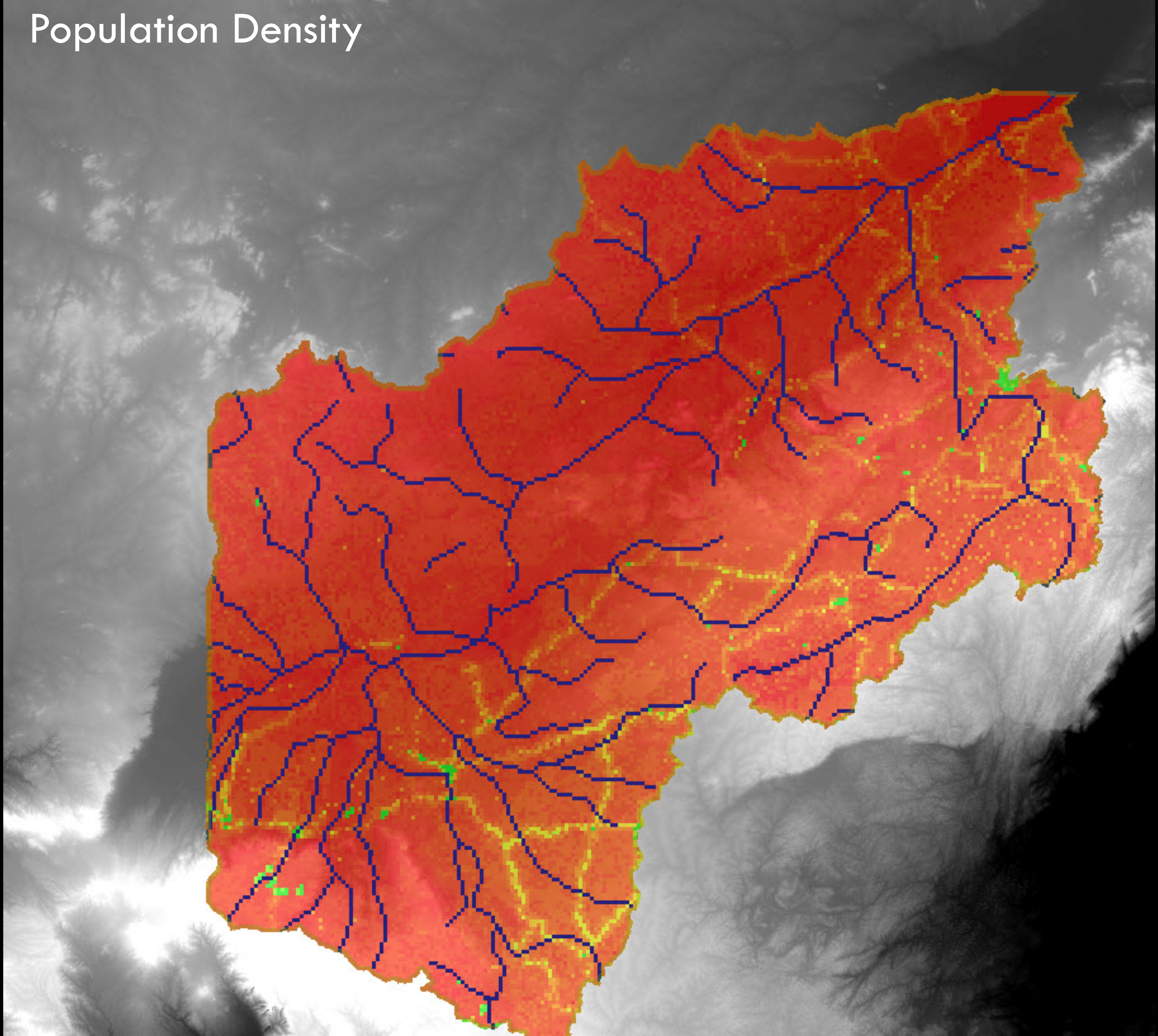
Actual Surface Water Flow



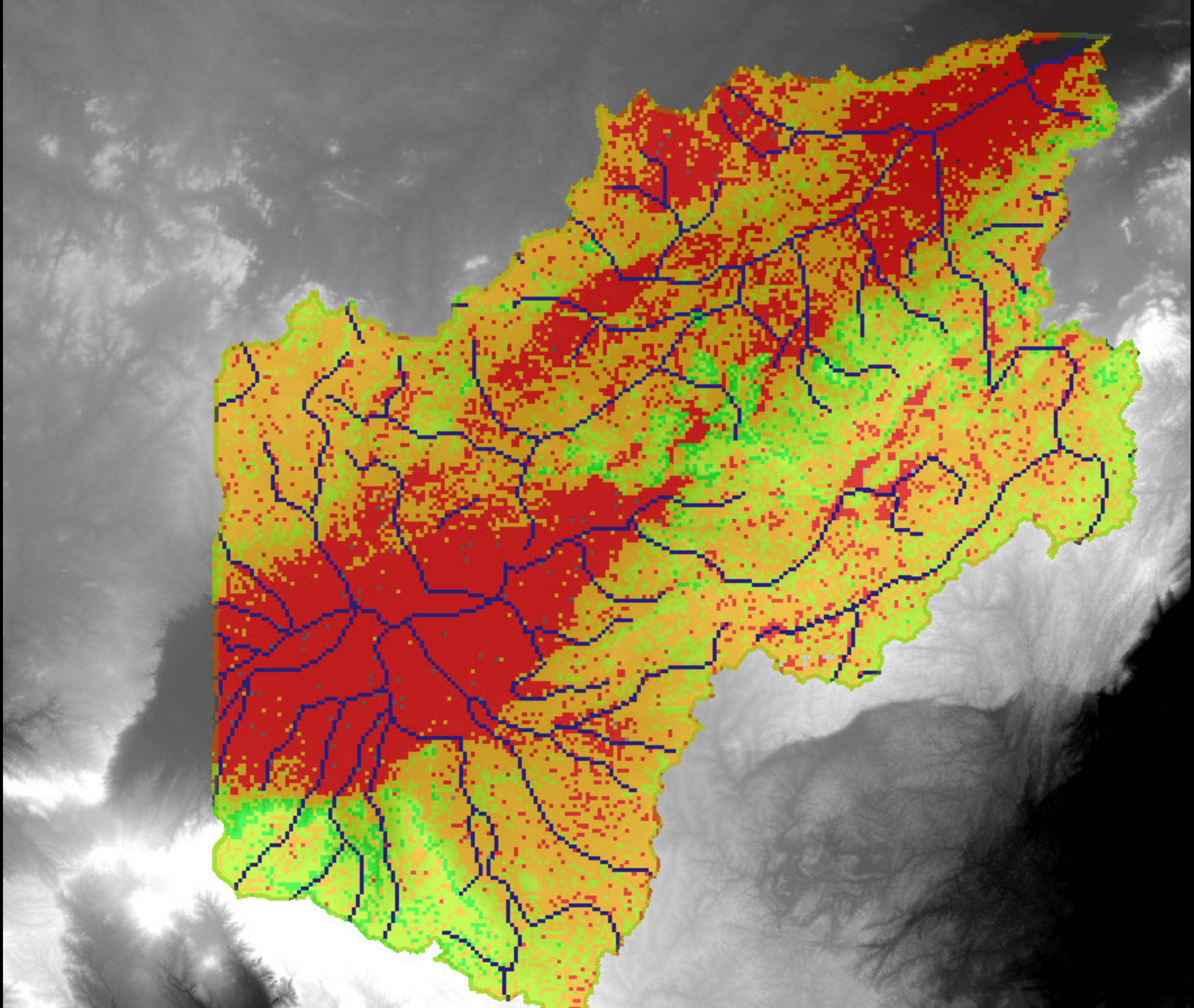
Actual Surface Water Sink



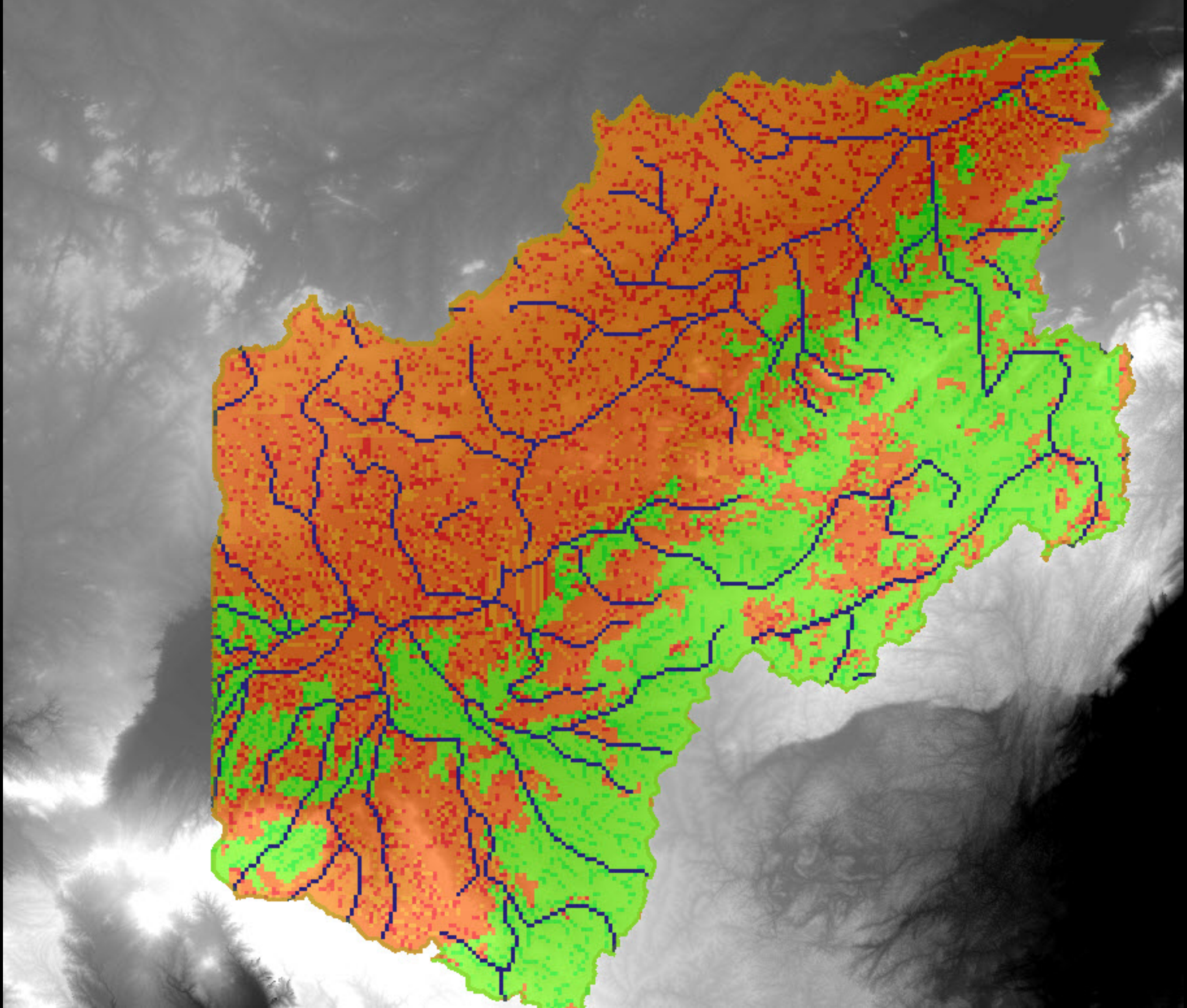
Population Density



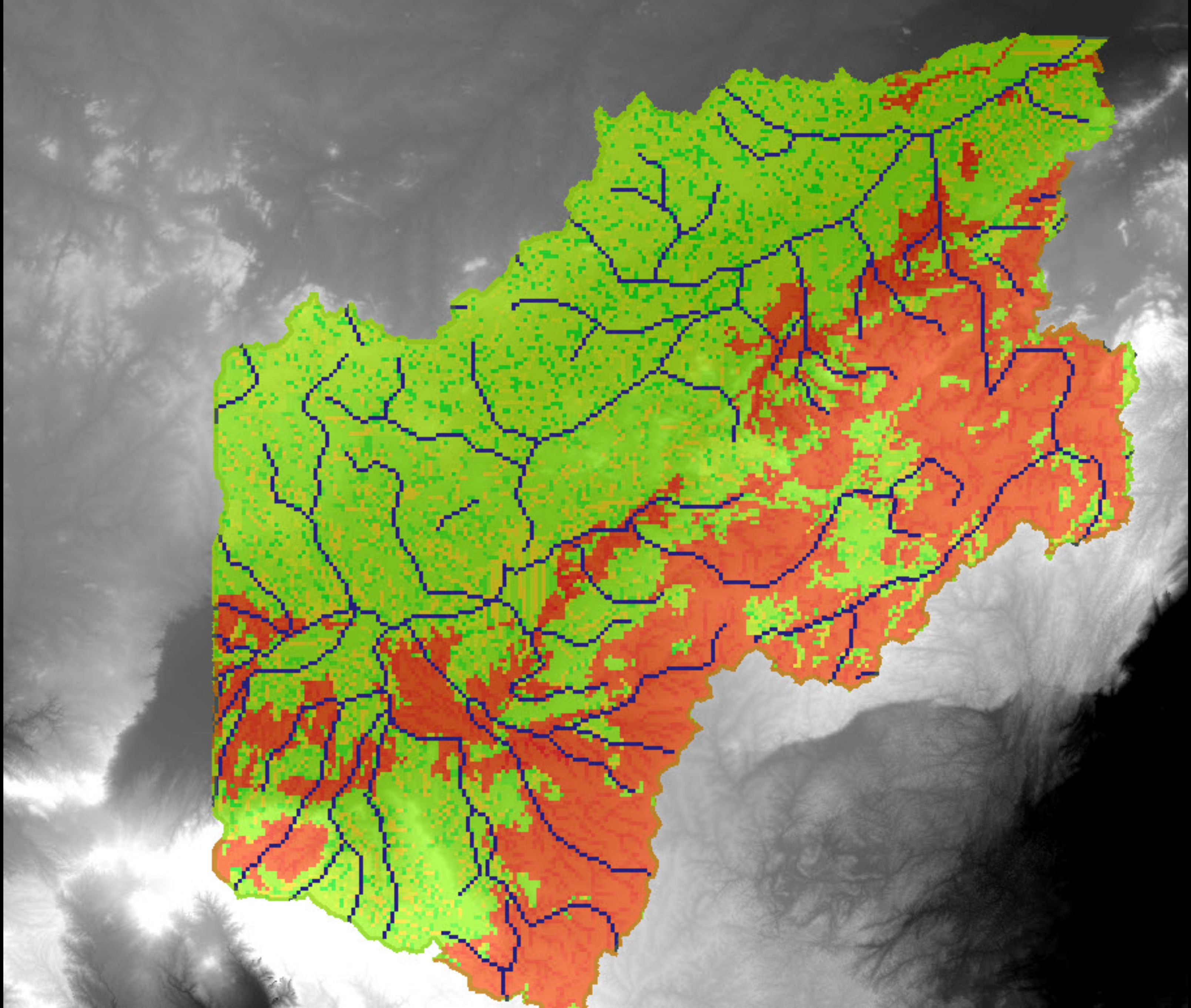
Lane Cover / Land Use



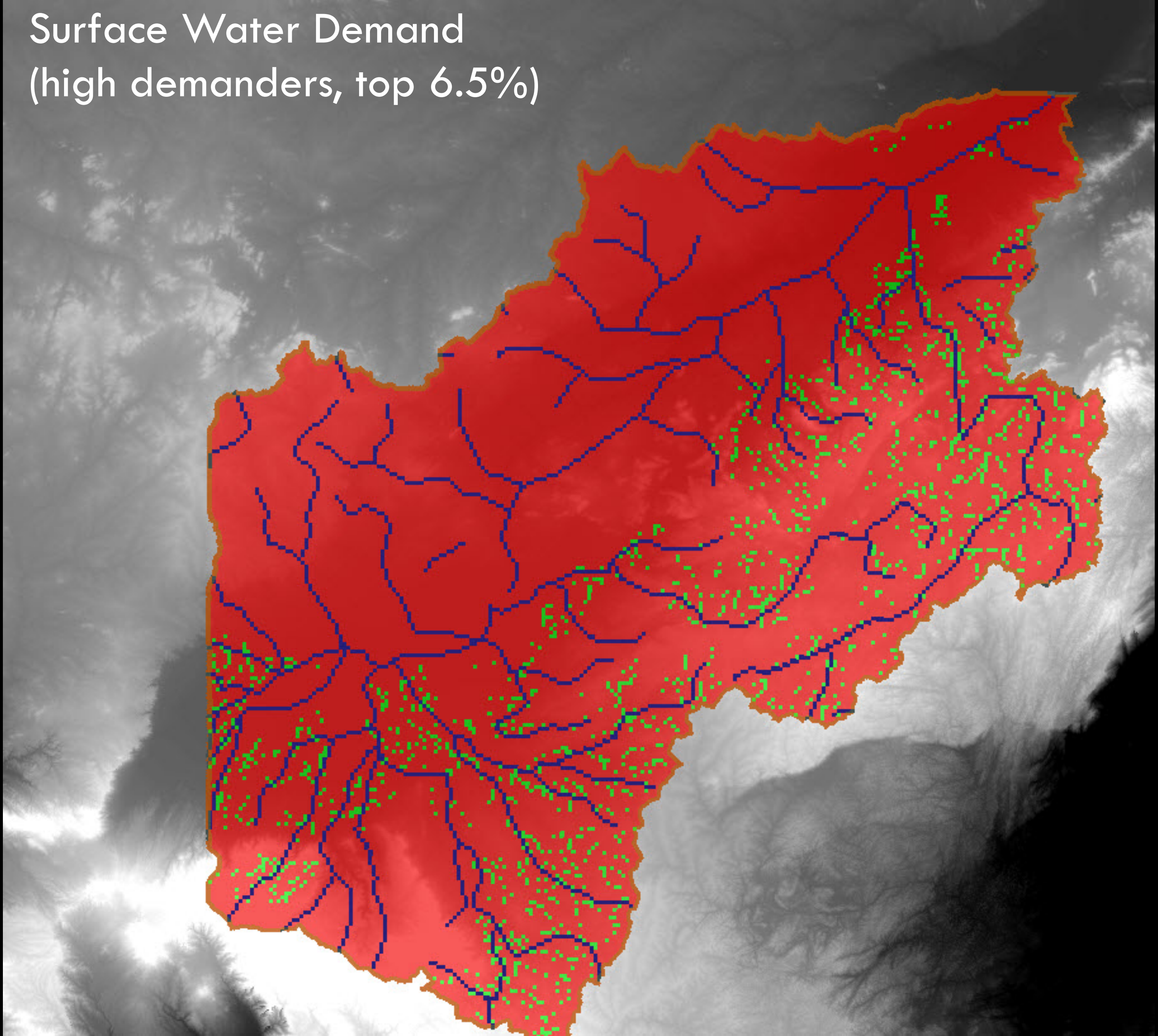
Agricultural Surface Water Use



Agricultural Surface Water Use ***Uncertainty***



Surface Water Demand
(high demanders, top 6.5%)



Blocked Surface Water Flow
(high blockage, top 6.5%)