Co-Designing Wetland Placement for Sustainable Adaptation

Upstream Solutions for Downstream Resilience

Amir Rezvani
rezvani@kth.se

KTH Royal Institute of Technology
Department of Sustainable Development, Environmental Science and Engineering (SEED)

Human activities & climate change exacerbate water management challenges

- Hydro-climatic variability
- Environmental degradation
- Socio-political tensions

Satellite images show Valencia before and after the flooding. Maxar Technologies

Photo: cnn.com/weather

Human activities & climate change exacerbate water management challenges

- Hydro-climatic variability
- Environmental degradation
- Socio-political tensions

Photo: bcbuae.com, Dubai

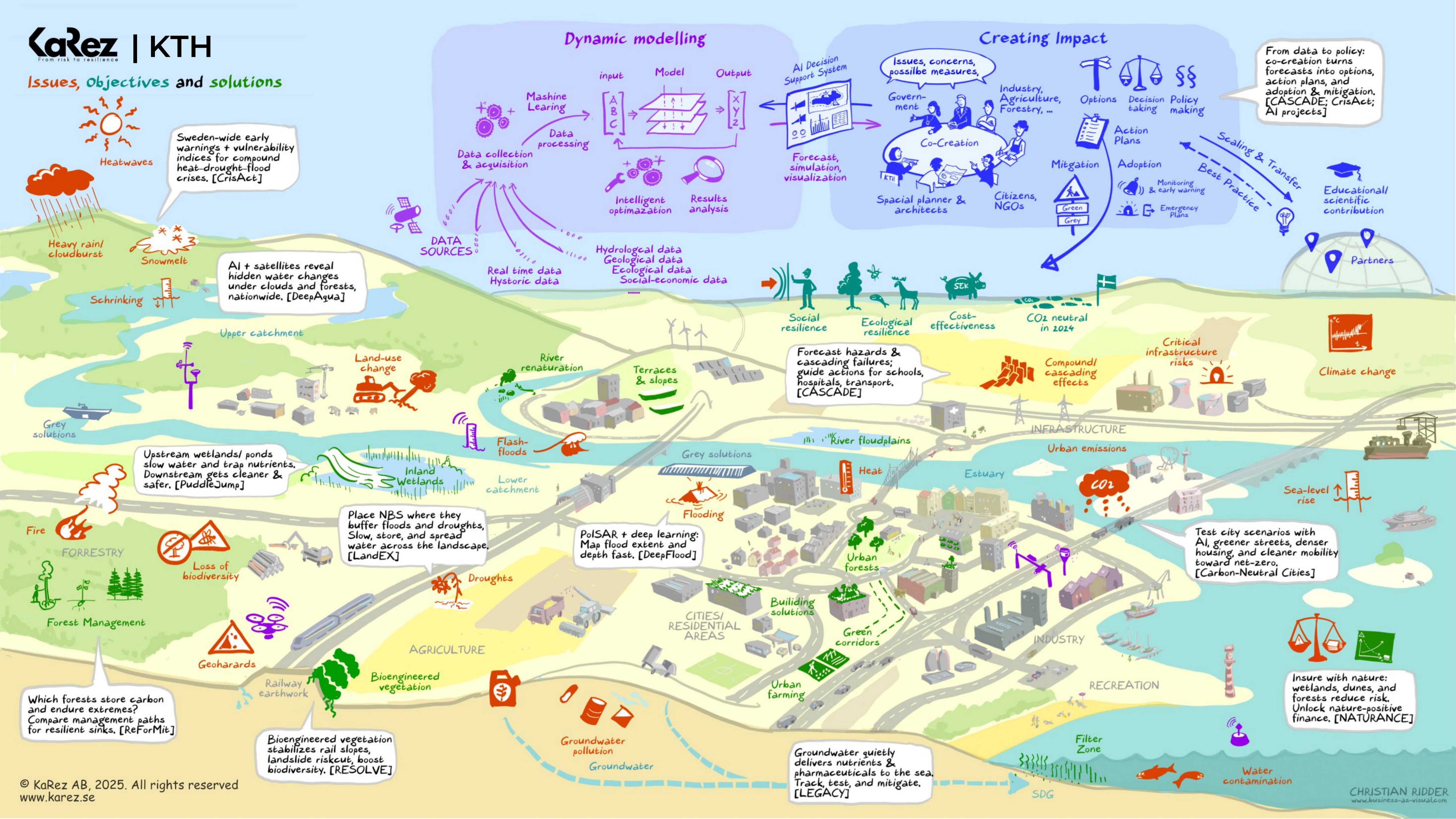
Human activities & climate change exacerbate water management challenges

- Hydro-climatic variability
- Environmental degradation
- Socio-political tensions

Need for holistic, integrated solutions

KTH VETENSKAP OCH KONST

Photo: bcbuae.com, Dubai



KaRez
From risk to resilience
| KTH
Issues, objectives and solutions
Dynamic modelling
Creating Impact
Heatwaves
Sweden-wide early warnings + vulnerability indices for compound heat-drought-flood crises. [CrisAct]
Heavy rain/ cloudburst
Snowmelt
Schrinking
AI + satellites reveal hidden water changes under clouds and forests, nationwide. [DeepAqua]
Upper catchment
Mashine Learing
Data collection & acquisition
Data processing
input
Model
Output
Intelligent optimazation
Results analysis
DATA SOURCES
Real time data
Historic data
Hydrologcal data
Geological data
Ecological data
Social-economic data
......
AI Decision Support System
Forecast, simulation, visualization
Issues, concerns, possilbe measures,
Govern-ment
Industry, Agriculture, Forestry, ...
Co-Creation
KTH
Spacial planner & architects
Citizens, NGOs
Options
Decision taking
Policy making
Action Plans
Mitgation
Adoption
Monitoring & early warning
Emergency Plans
Green
Grey
From data to policy: co-creation turns forecasts into options, action plans, and adoption & mitigation. [CASCADE; CrisAct; AI projects]
Scaling & Transfer
Best Practice
Educational/ scientific contribution
Partners
Social resilience
Ecological resilience
SEK
Cost-effectiveness
CO2 neutral in 2024
Land-use change
River renaturation
Terraces & slopes
Forecast hazards & cascading failures; guide actions for schools, hospitals, transport. [CASCADE]
Compound/ cascading effects
Critical infrastructure risks
Climate change
Grey solutions
Flash-floods
River floudplains
INFRASTRUCTURE
Urban emissions
Upstream wetlands/ ponds slow water and trap nutrients. Downstream gets cleaner & safer. [PuddleJump]
Inland Wetlands
Lower catchment
Grey solutions
Heat
Estuary
CO2
Sea-level rise
Fire
Flooding
FORRESTRY
Loss of biodiversity
Place NBS where they buffer floods and droughts. Slow, store, and spread water across the landscape. [LandEX]
PolSAR + deep learning: Map flood extent and depth fast. [DeepFlood]
Urban forests
Test city scenarios with AI, greener streets, denser housing, and cleaner mobility toward net-zero. [Carbon-Neutral Cities]
Droughts
Forest Management
Builiding solutions
CITIES/ RESIDENTIAL AREAS
Green corridors
INDUSTRY
Geoharards
AGRICULTURE
Railway earthwork
Bioengineered vegetation
Urban farming
RECREATION
Which forests store carbon and endure extremes? Compare management paths for resilient sinks. [ReForMit]
Bioengineered vegetation stabilizes rail slopes, landslide riskcut, boost biodiversity. [RESOLVE]
Groundwater pollution
Groundwater
Groundwater quietly delivers nutrients & pharmaceuticals to the sea. Track, test, and mitigate. [LEGACY]
SDG
Filter Zone
Insure with nature: wetlands, dunes, and forests reduce risk. Unlock nature-positive finance. [NATURANCE]
Water contamination
© KaRez AB, 2025. All rights reserved
www.karez.se
CHRISTIAN RIDDER
www.business-as-visual.com

resilience
resilience
Land-use change
River renaturation
Terraces & slopes
Forecast hazards & cascading failures; guide actions for schools, hospitals, transport. [CASCADE]
Flash-floods
River floudplains
Inland Wetlands
Lower catchment
Grey solutions
Heat
Flooding
Place NBS where they buffer floods and droughts, Slow, store, and spread water across the landscape. [LandEX]
Droughts
Urban forests
Builiding solutions
CITIES/ RESIDENTIAL AREAS
AGRICULTURE
Green corridors
Bioengineered vegetation
Urban

Urban Resilience
Needs Upstream Solutions

Nature-Based Solutions (e.g., wetlands) can support resilience, especially in peri-urban or upstream areas influencing cities downstream

- Offer ecological, economic, and socio-cultural benefits.
- Promote environmental stewardship and resilience.

Journal of Hydrology: Regional Studies 61 (2025) 102669

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

ELSEVIER

A holistic framework for wetland placement and ecosystem service delivery by integrating landscape connectivity and participatory decision analysis in two Swedish catchments

Amir Rezvani [a,*], Marco Cavalli [b], Stefano Crema [b], Faruk Djodjic [c], Martyn Futter [c], Carla Sofia Santos Ferreira [d,e], Pan Haozhi [f], Zahra Kalantari [a]

[a] Department of Sustainable Development, Environmental Science and Engineering (SEED), KTH Royal Institute of Technology, Stockholm, Sweden
[b] Research Institute for Geo-Hydrological Protection, National Research Council (CNR IRPI), Padua, Italy
[c] Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden
[d] Polytechnic University of Coimbra, Applied Research Institute, Coimbra, Portugal
[e] Research Center for Natural Resources, Environment and Society (CERNAS), Polytechnic University of Coimbra, Portugal
[f] School of International and Public Affairs, Shanghai Jiao Tong University, Shanghai, China

South Parklands Wetlands, Adelaide, Australia, tcl.net.au

Our Guiding Vision

A New Integrated Framework

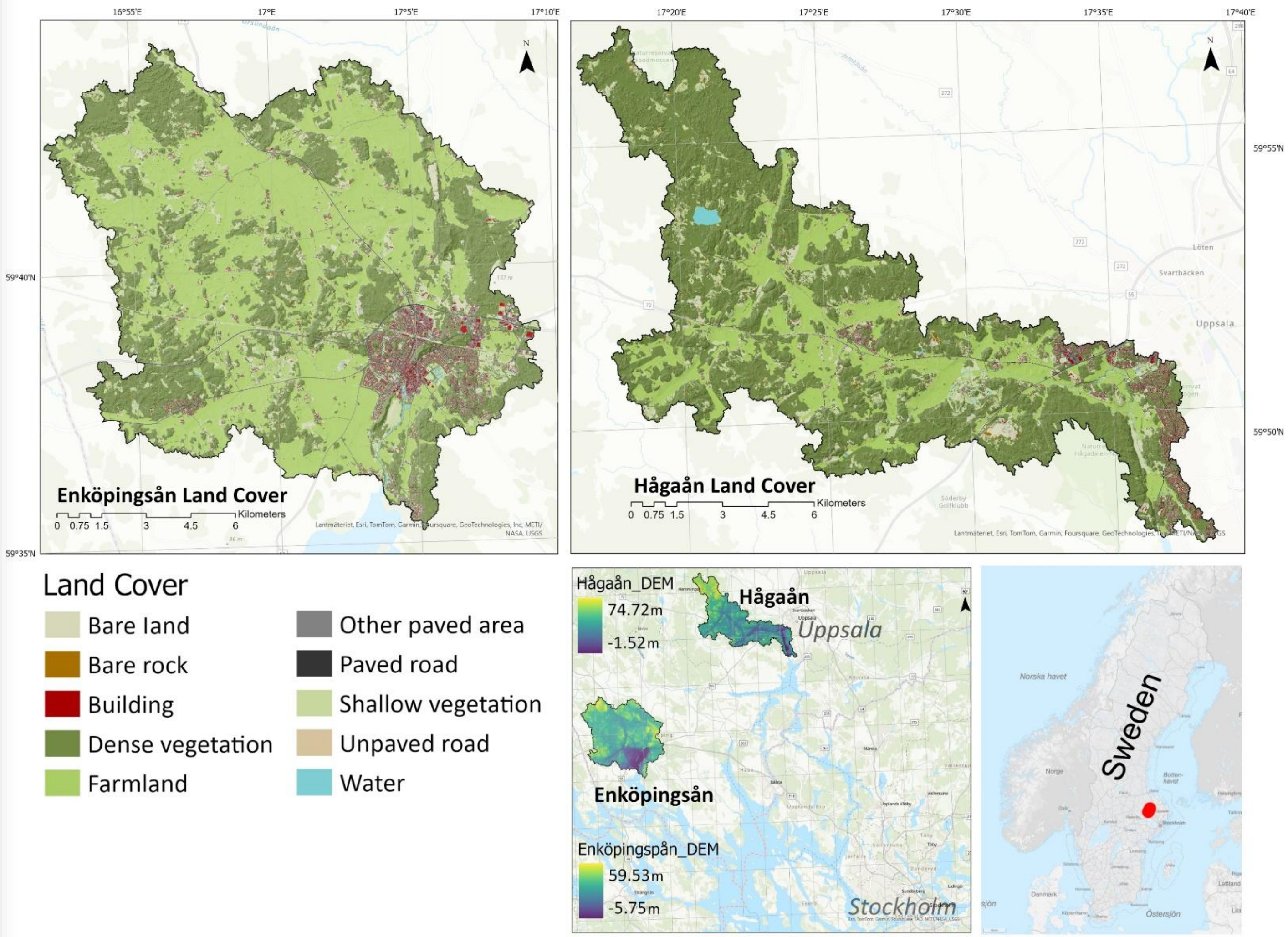
- Merge <u>hydrological modeling</u>
+ <u>sediment connectivity</u>
+ <u>stakeholder priority strategies</u>

- **Focus:** Strategic, multifunctional, and feasible wetland placement

- **Study area:** Swedish catchments draining into Lake Mälaren

Main morphometric parameters of the study basins.

	Enköpingsån	Hågaån
Catchment area (km^2)	167.4	118.6
Minimum elevation (m a.s.l.)	−5.7	−1.5
Mean elevation (m a.s.l.)	25.1	36.7
Maximum elevation (m a.s.l.)	59.5	75.7
Average slope (degree)	5.0	8.0



Rezvani et al., 2025,
https://doi.org/10.1016/j.ejrh.2025.102669

The Core Methodology

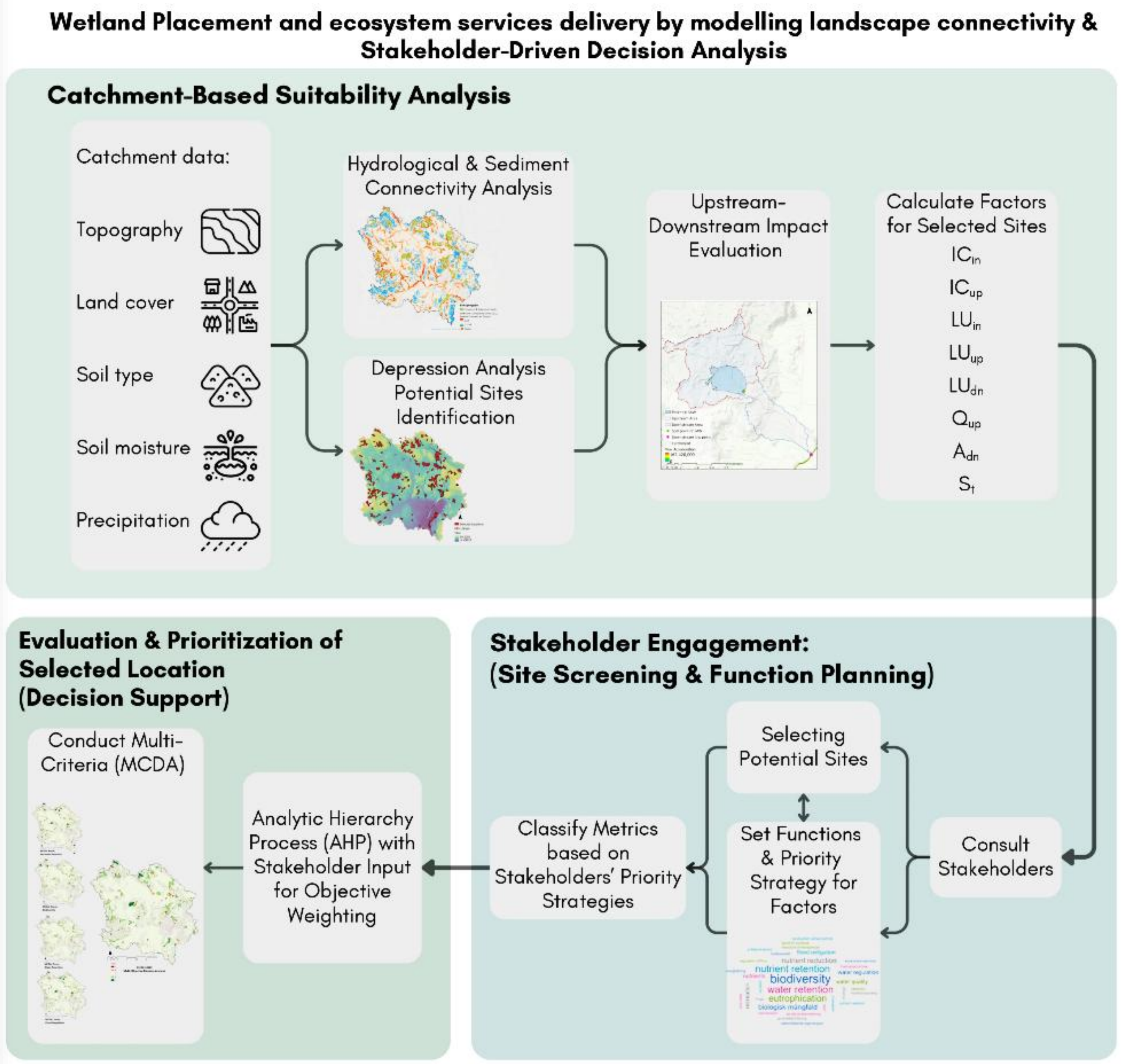
3-Phase Process: Data-Driven, Locally-Informed

I: Catchment-based suitability analysis

II: Stakeholder Engagement: (Site Screening & Function Planning)

III: Evaluation & Prioritization of Selected Location (Decision Support)

Rezvani et al., 2025, https://doi.org/10.1016/j.ejrh.2025.102669

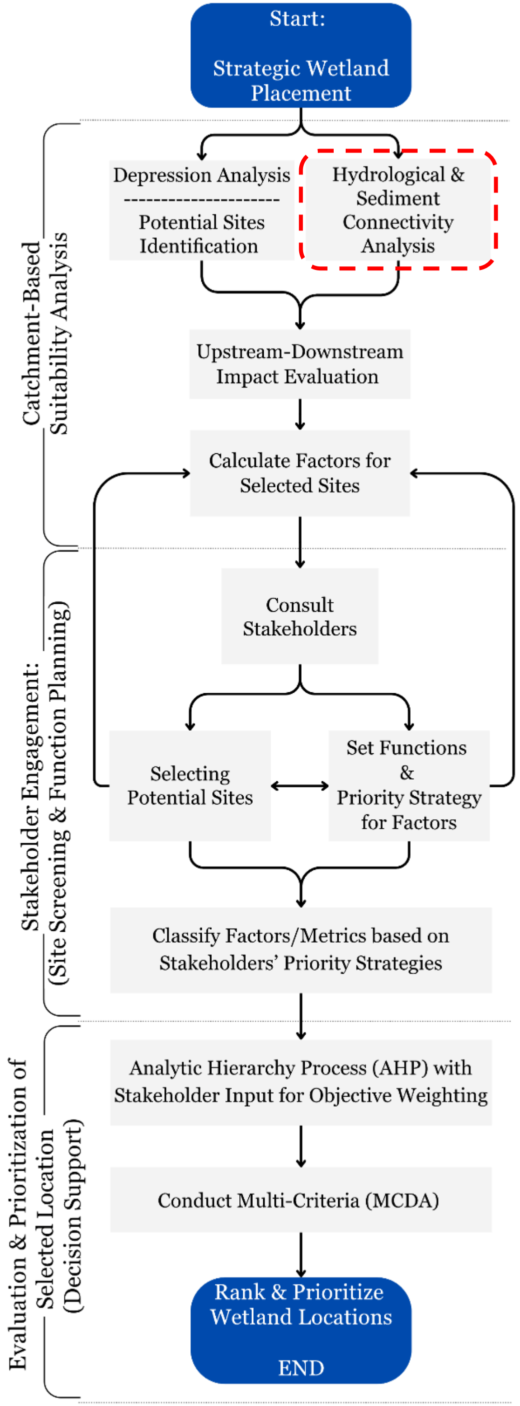


A scalable, stakeholder-informed framework integrates landscape connectivity modeling (IC), hydrological assessment, and multi-criteria decision analysis (MCDA) to prioritize multifunctional wetland locations.

I: Modelling in Action

Hydrological and Sediment Connectivity

How easily sediment moves from one point to another



Rezvani et al., 2025,
https://doi.org/10.1016/j.ejrh.2025.102669

Strategic Wetland Placement

I: Data Assessment & Suitable wetland Location Identification

Hydrological and Sediment Connectivity

Sedimentation in Matilija reservoir 2-11-2023
https://www.venturariver.org/

What is (sediment) connectivity?

- **Definition: the degree to which a system facilitates the transfer of water and sediment,** through coupling relationships between its components. (Heckmann et al., 2018)
- **How easily soil and sediment can move** through the landscape, especially during rain or floods. It helps us understand which **areas are more likely to lose sediment** or have it deposited, which is important for **managing erosion and water flow** in the environment."

Sarek National Park,
https://magnuslindbom.com/

Strategic Wetland Placement

I: Data Assessment & Suitable SAW Location Identification

Hydrological and Sediment Connectivity

Quantifying Connectivity

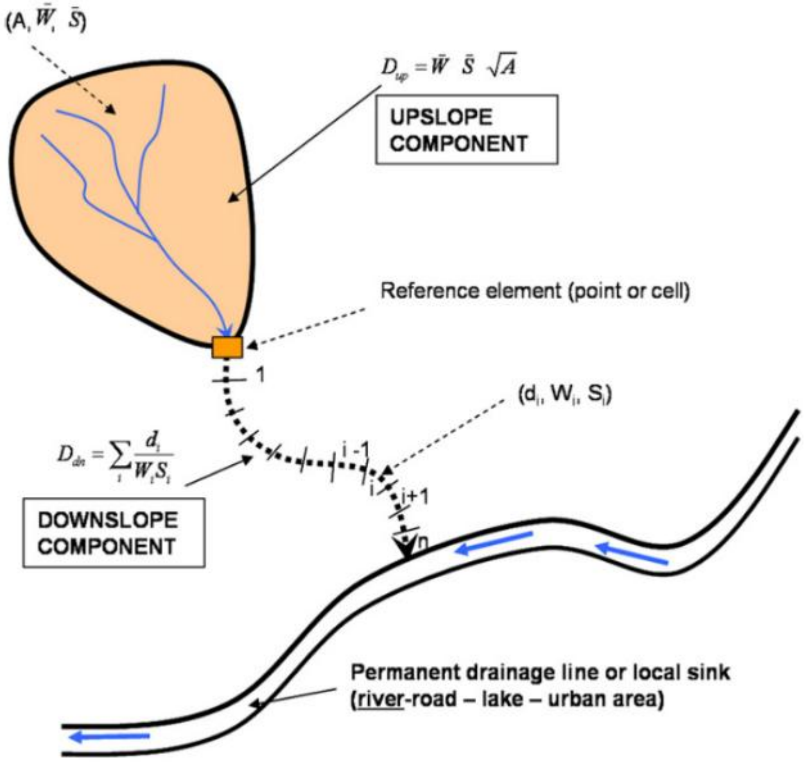
Connectivity Components:

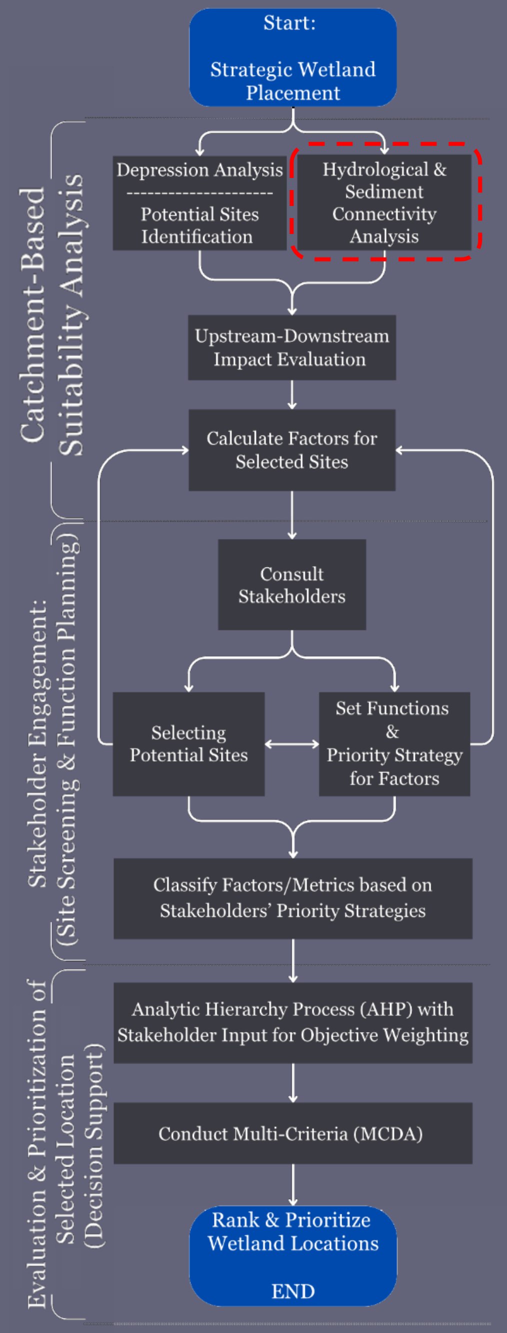
Upslope Component (D_up): Potential for downward routing due to upslope area, mean slope and impedance factor.

Downslope Component (D_dn): flow path length that a particle has to travel to arrive at the nearest target or sink.

$$p = p_u p_d \propto \frac{D_{up}}{D_{dn}} = \frac{\overline{W}\ \overline{S}\sqrt{A}}{\sum_i \frac{d_i}{W_i S_i}}$$

$\overline{W}$ average weighing factor of the upslope contributing area
$\overline{S}$ average slope gradient of the upslope contributing area (m/m)
A upslope contributing area (m2)





Strategic Wetland Placement

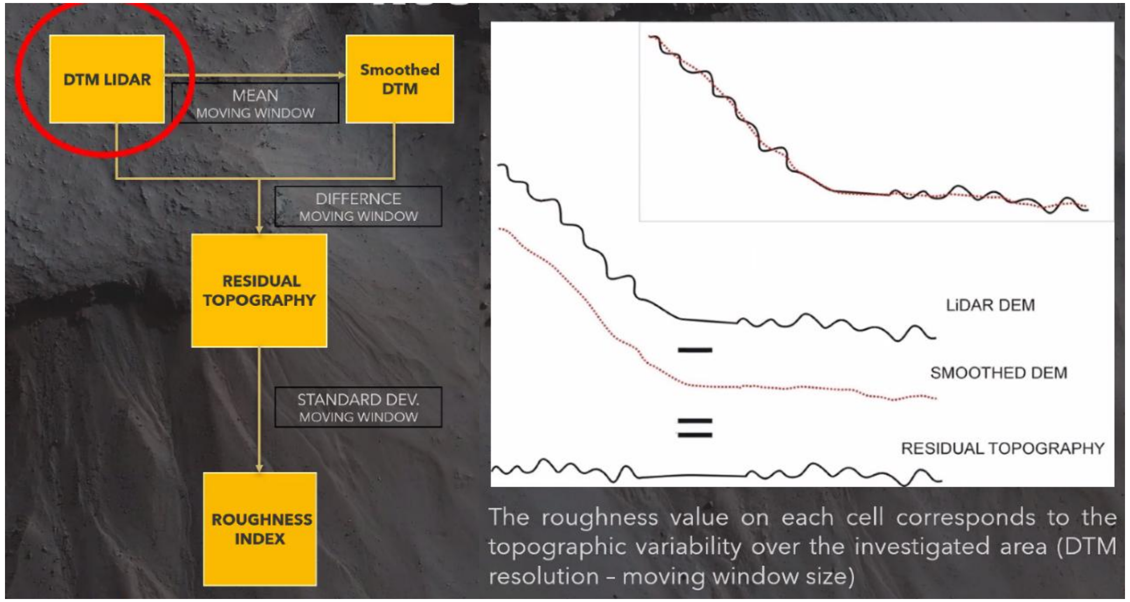
I: Data Assessment & Suitable SAW Location Identification

Hydrological and Sediment Connectivity

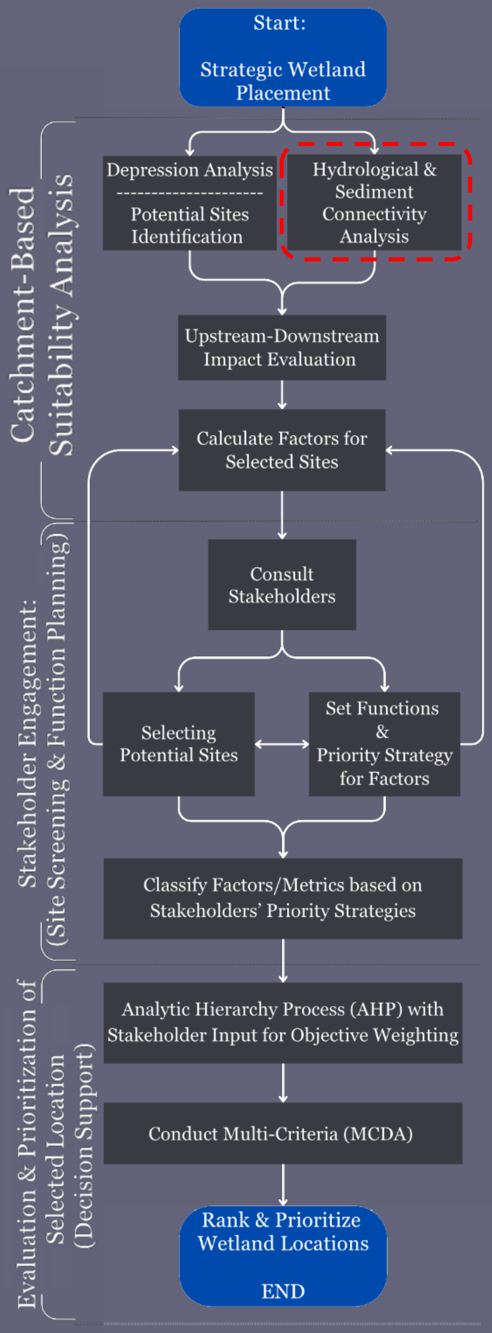
Weighting factor ~ Flow impedance

Borselli et al., (2008): W → C-factor of USLE–RUSLE models

Cavalli et al., (2013): $W_{cavalli}$ → $1 - \frac{RI}{RI_{max}}$ → DTM 5x5 cell (smoother topography)



Crema, S. (2024), Blue Planet Conference, WaterCentre@KTH



Strategic Wetland Placement

I: Data Assessment & Suitable SAW Location Identification

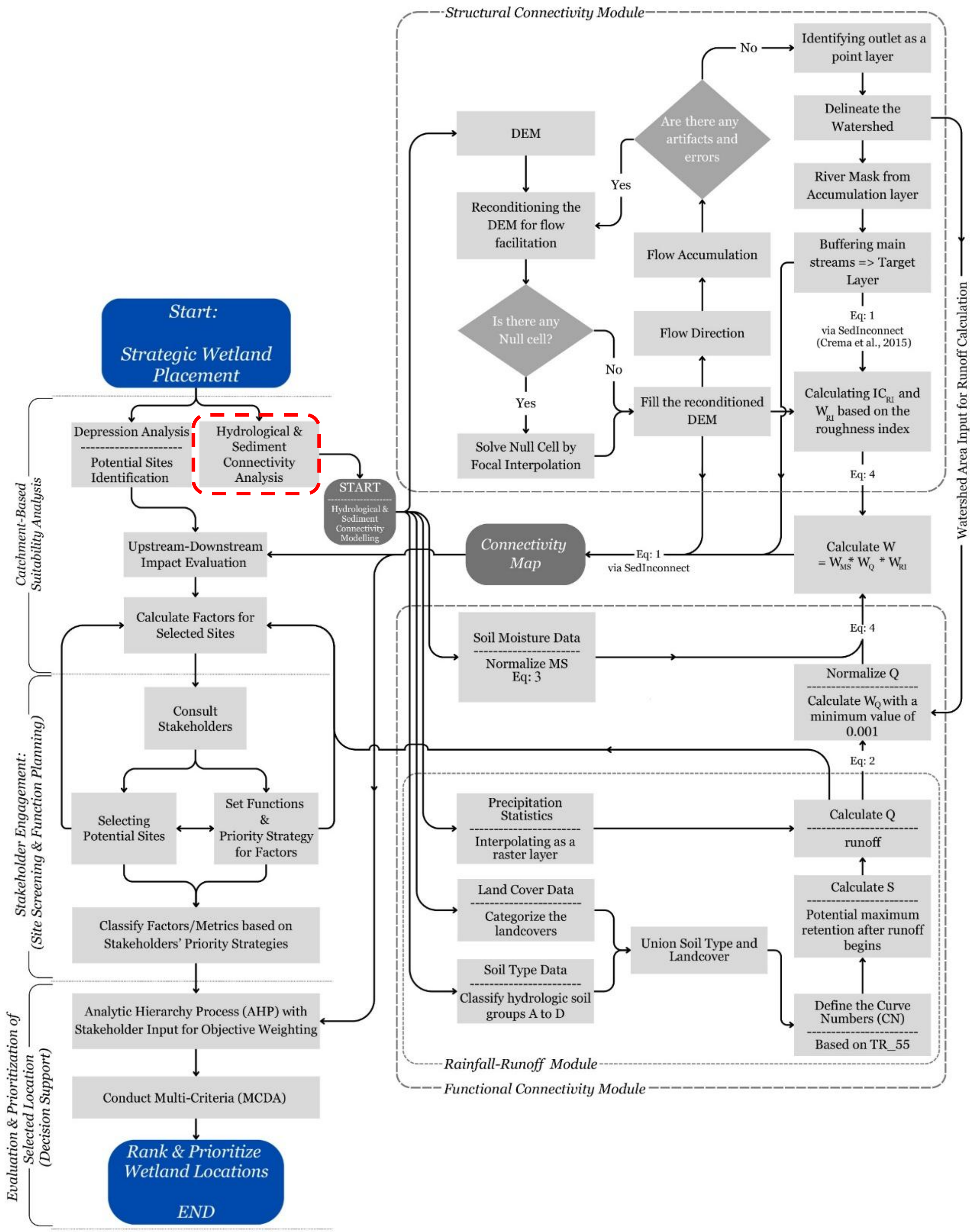
Hydrological and Sediment Connectivity

Weighting factor ~ Flow impedance

I: Modelling in Action

Hydrological and Sediment Connectivity

How easily sediment moves from one point to another



Rezvani et al., 2025, https://doi.org/10.1016/j.ejrh.2025.102669

Strategic Wetland Placement

I: Data Assessment & Suitable SAW Location Identification

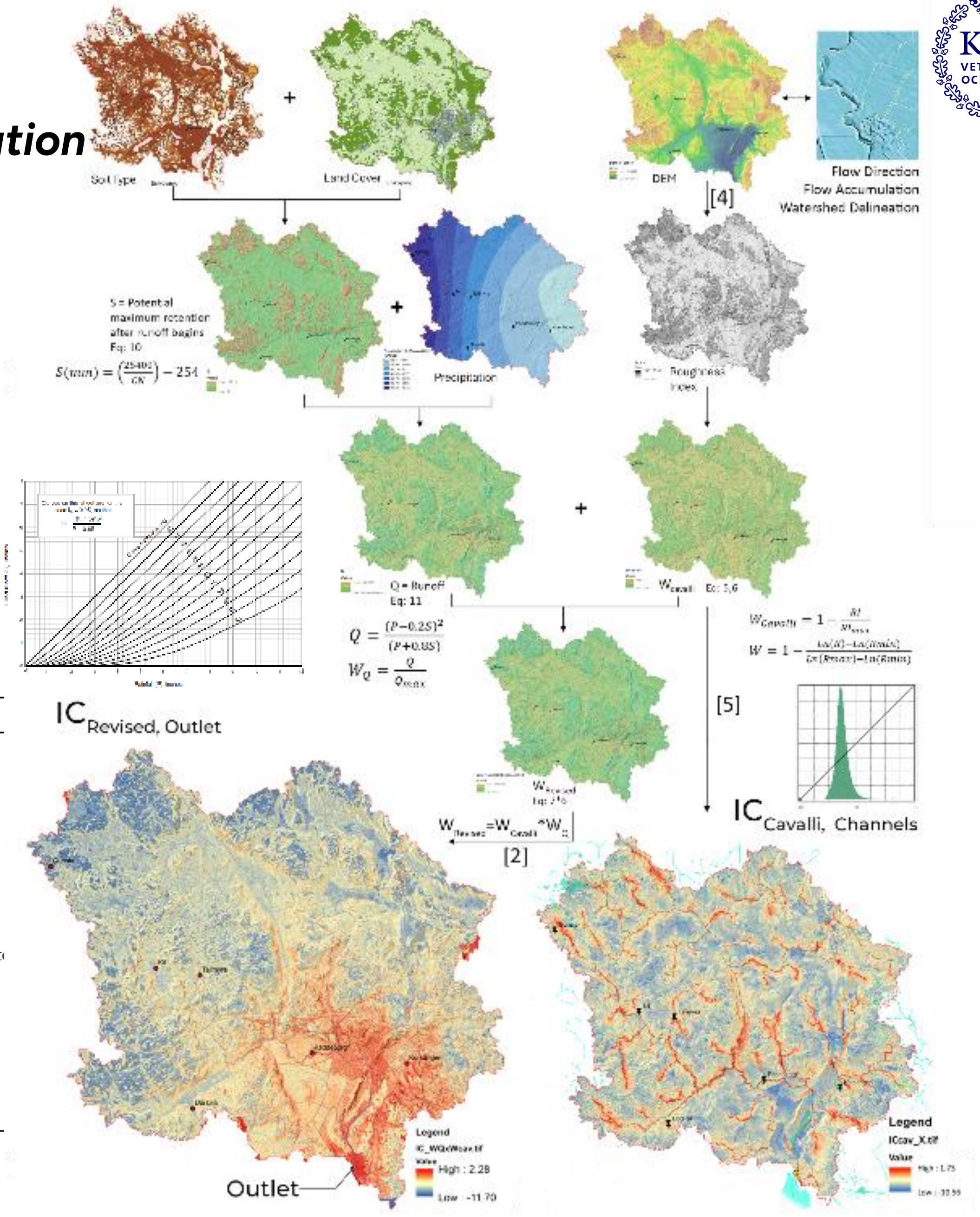
Hydrological and Sediment Connectivity

To evaluate how well the catchment facilitates water and sediment transfer.

- Topography (Landscape Morphology)
- Precipitation
- Land cover
- Soil type
- Soil moisture
- Run-off

Table 2
Summary of data sources and associated spatial and temporal resolutions used in the study.

Data Type	Dataset	Source	Spatial Resolution	Temporal Coverage
Topography (DEM)	Airborne LiDAR DEM	Lantmäteriet (2024)	1 m	2009–present
Hydrological Correction	Hydrography & SCALGO Live	Lantmäteriet (2024) and Scalgo (2024)	1 m	Current
Soil Data	Digital Arable Soil Map (for agricultural land) & SGU Soil Maps (for non-agricultural land)	(Piikki and Söderström, 2019), SGU	1:50,000	Current
Land Cover	SCALGO Live Land Cover (classification of vegetation, impervious surfaces, and water bodies)	Scalgo, (2024)	25 cm	Current
Precipitation	Historical Rainfall Data	(SMHI, 2024)	Point-based (interpolated)	Aug 14–17, 2021 (used t simulate extreme runoff conditions)
Soil Moisture	SLU Soil Moisture Model (integrating LiDAR-based terrain indices and machine-learning predictions)	Ågren et al. (2021)	2 m	Current
Stakeholder Prioritization	Workshop & Municipal Collaboration	Uppsala & Enköping Municipalities	N/A	2024–2025

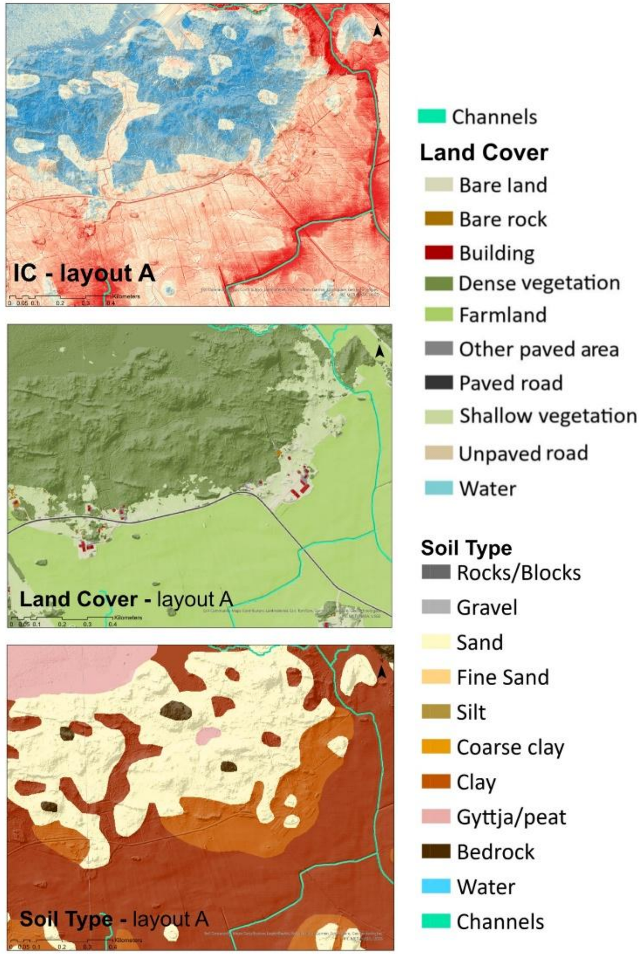


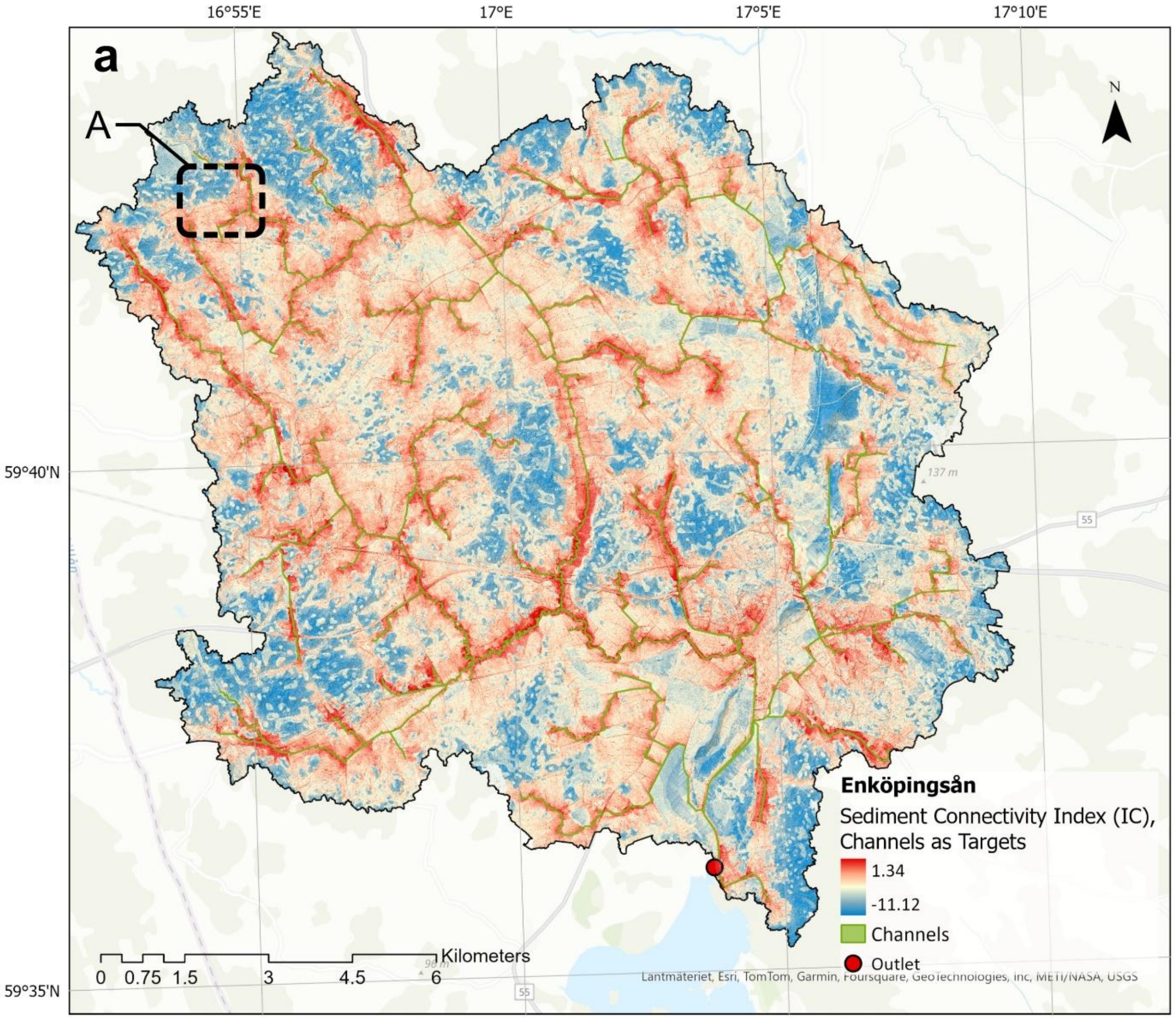
Rezvani et al., 2025,
https://doi.org/10.1016/j.ejrh.2025.102669

Strategic Wetland Placement

I: Data Assessment & Suitable SAW Location Identification

Hydrological and Sediment Connectivity





The sediment Connectivity Index maps relative to the channel network

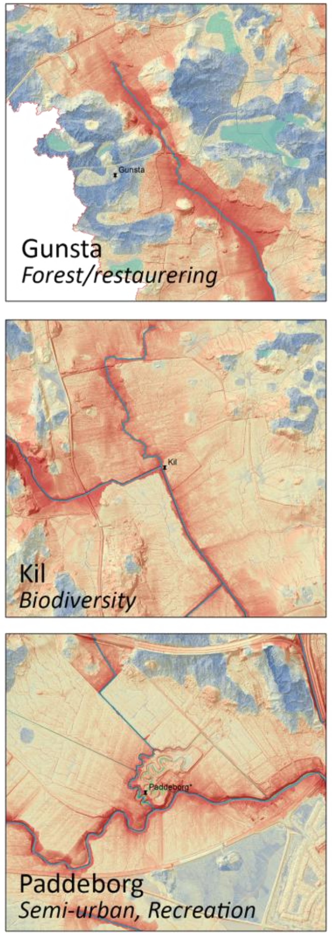
Rezvani et al., 2025,
https://doi.org/10.1016/j.ejrh.2025.102669

Strategic Wetland Placement

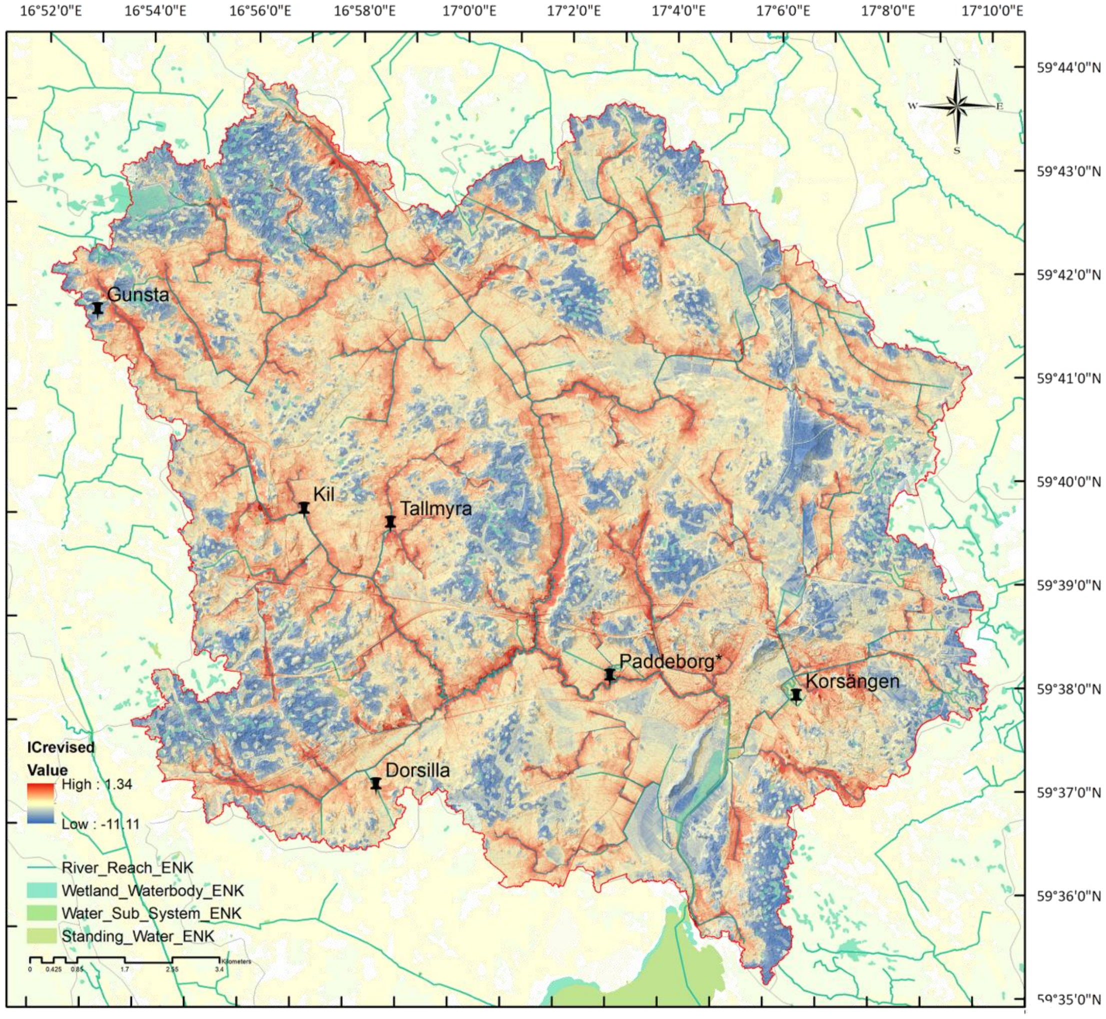
I: Data Assessment & Suitable SAW Location Identification

Hydrological and Sediment Connectivity

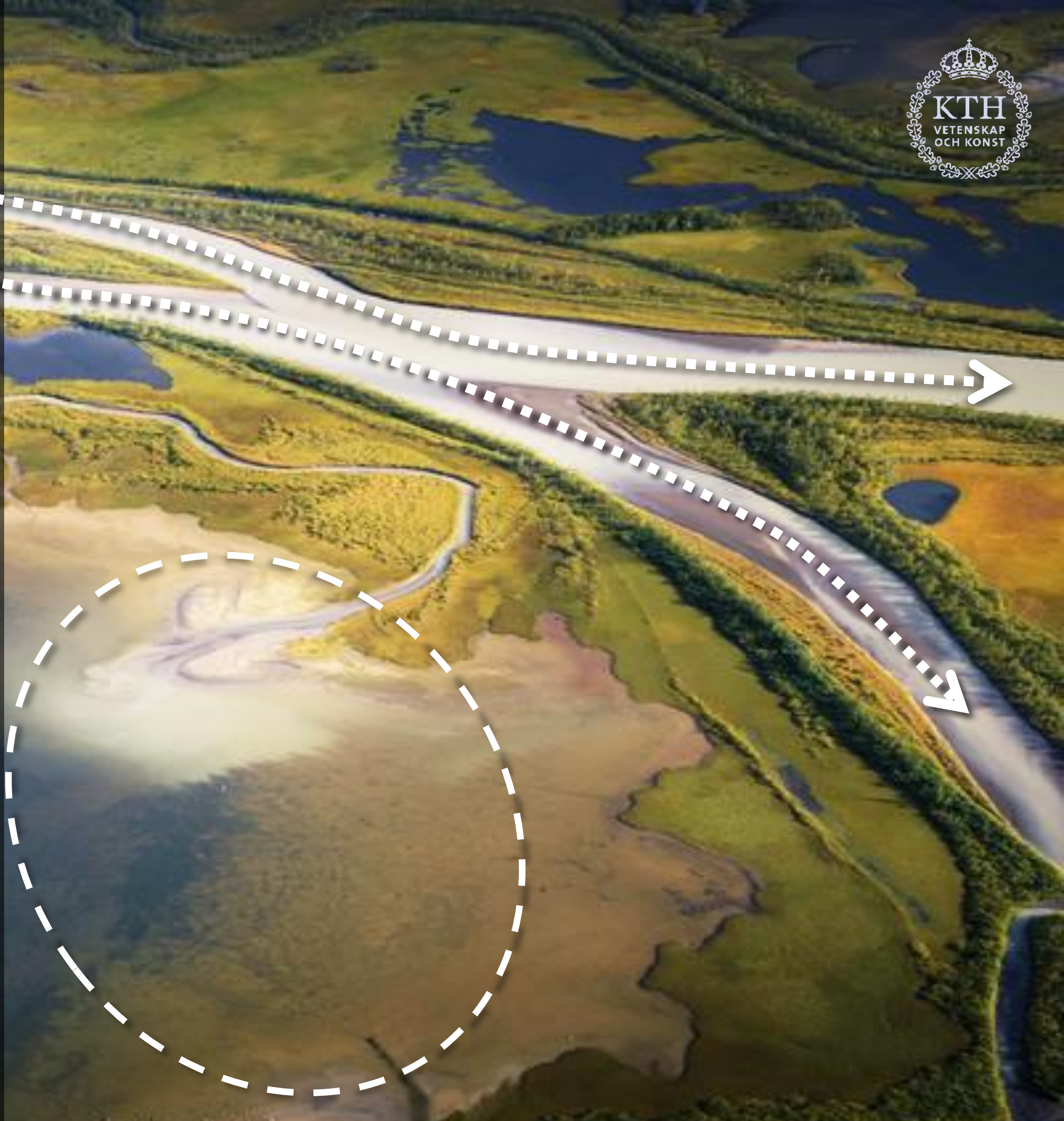
Discussed Sites
Preliminary Purpose



Enköpingsån



Strategic Wetland Placement



Optimising Wetland Design through Connectivity Mapping:

Strategic Deployment: Utilizes connectivity indices to **understand complex flow patterns** and pinpoint **critical zones** for catchment storage and discharge.

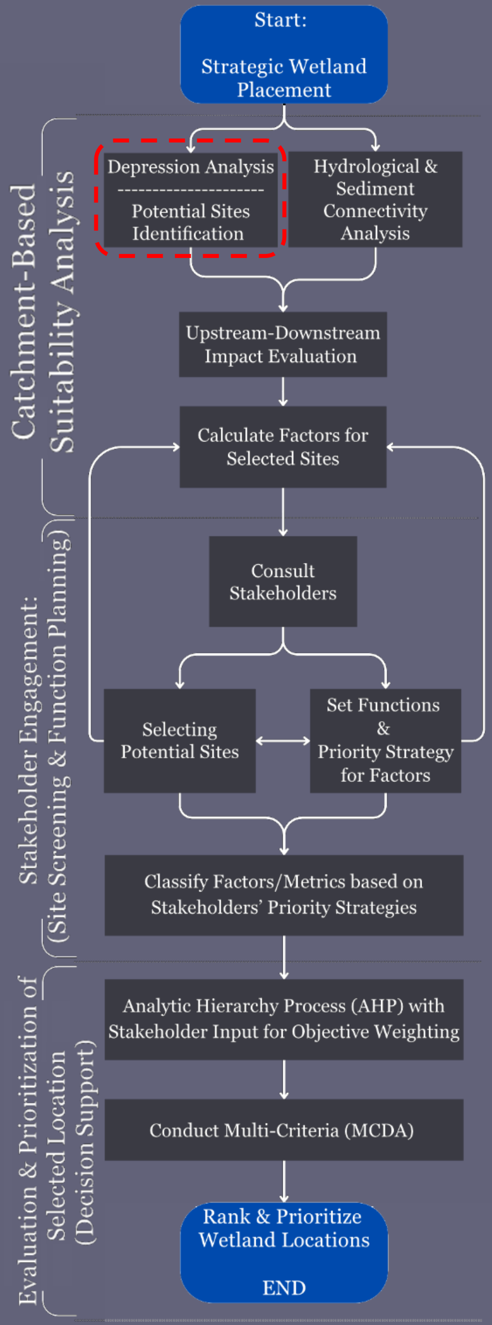
Example of Strategic Impact:
Wetlands positioned in areas with low connectivity but adjacent to high connectivity zones can effectively intercept flow paths, enhancing flood control and nutrient removal.

iStockPhoto.com/WoutervandenBroek
Landscape aerial photo from Skierfe top Sarek national park Sweden

I: Modelling in Action

Potential site identification

The output of catchment analysis includes a range of factors calculated based on simulating the construction of a 1-meter-high embankment from the lowest point on the boundary of each selected depression.



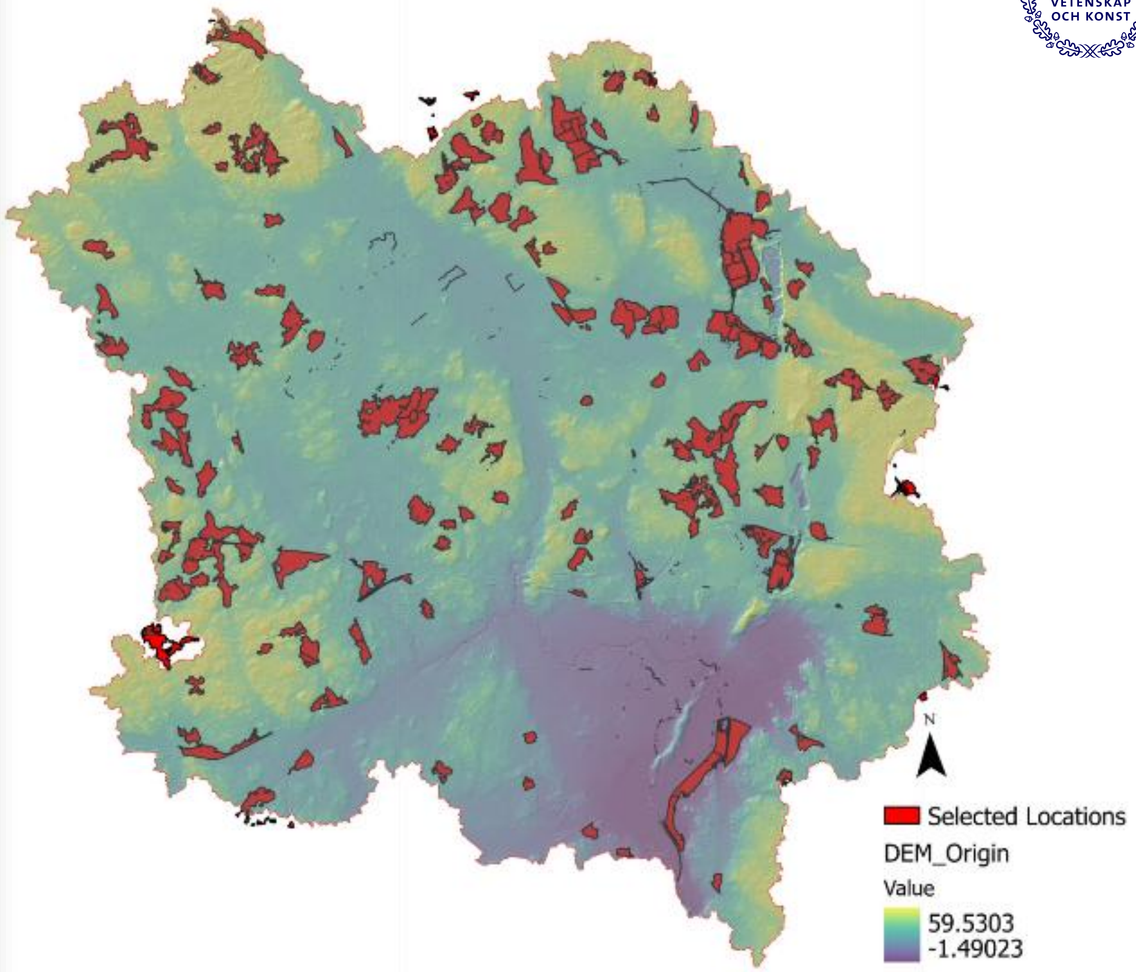


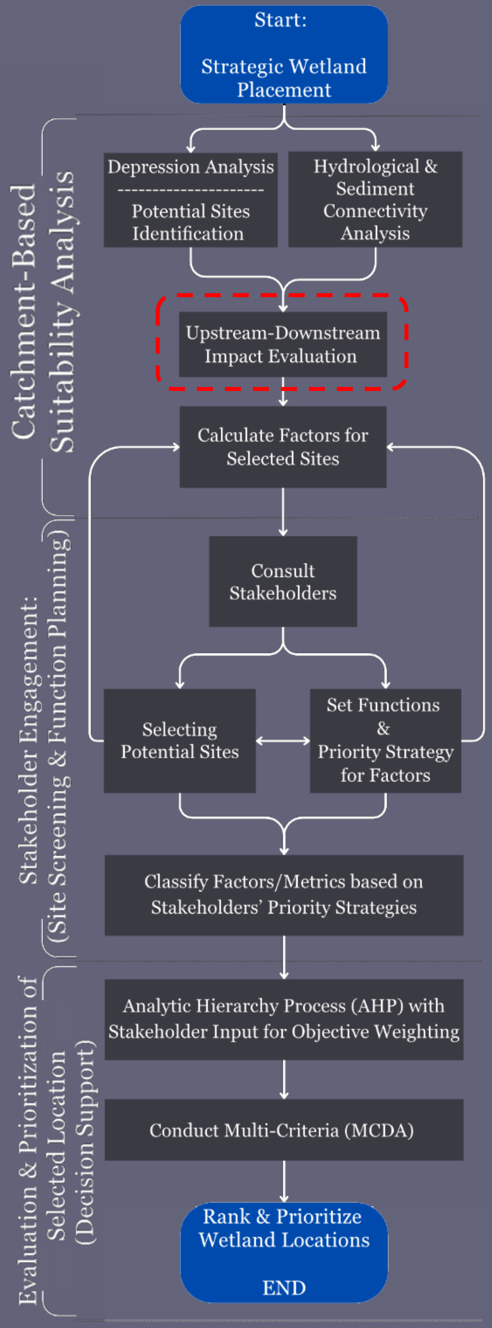
Table 3
Summary statistics of identified small artificial waterbodies (SAWs) across the study catchments.

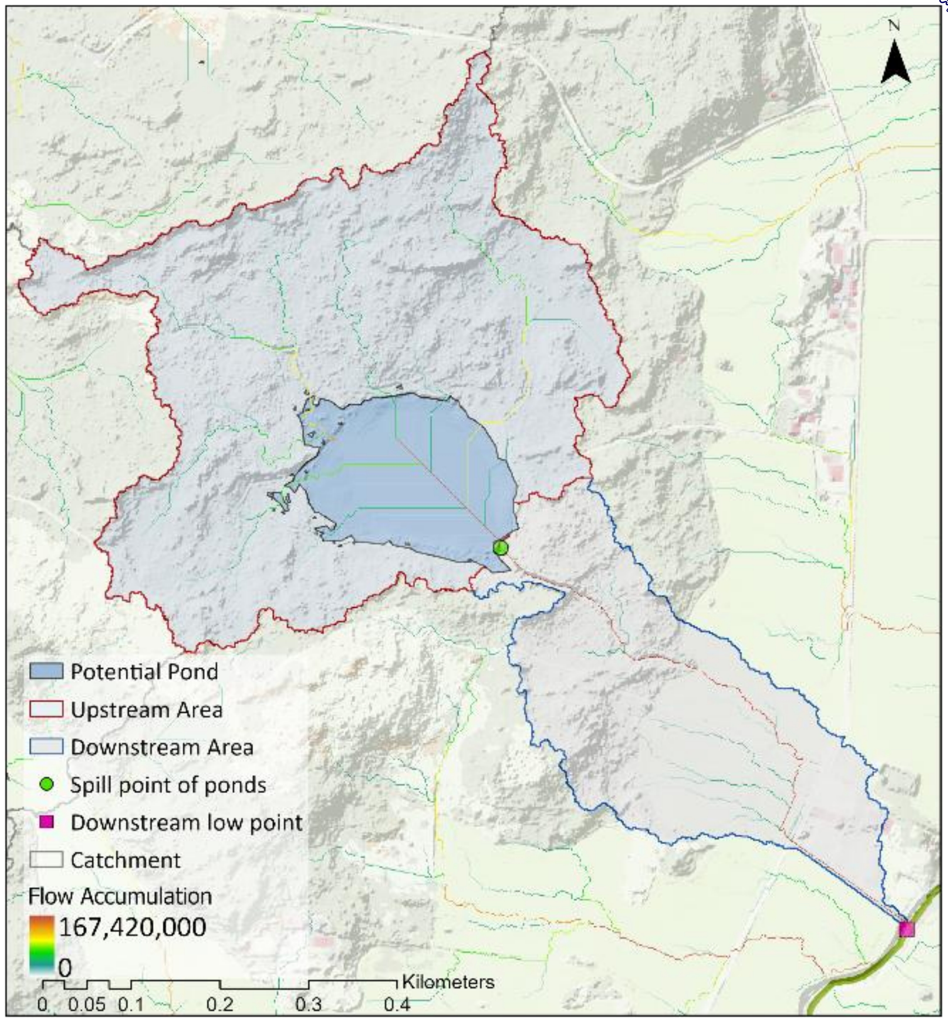
Metric	Area (ha)		Storage (m^3)		Avg Depth (m)	
	Enköpingsån	Hågaån	Enköpingsån	Hågaån	Enköpingsån	Hågaån
Mean	11.0	7.5	75477.9	57080.6	0.74	0.81
Minimum	1.2	0.2	4683.4	1289.4	0.21	0.19
Maximum	148.7	37.2	1009750.0	312126.0	1.62	5.34
Standard Deviation	19.1	6.2	132805.4	49099.5	0.30	0.42

Rezvani et al., 2025,
https://doi.org/10.1016/j.ejrh.2025.102669

I: Modelling in Action

Factors	
IC within SAW Area, channels as targets	IC_{in}
Upstream IC Wetlands and channels as targets	IC_{up}
Land Use within Wetlands	LU_{in}
Land Use Upstream	LU_{up}
Land Use Downstream	LU_{dn}
Upstream Runoff	Q_{up}
Downstream Area Size	A_{dn}
SAW Storage Potential	S_t

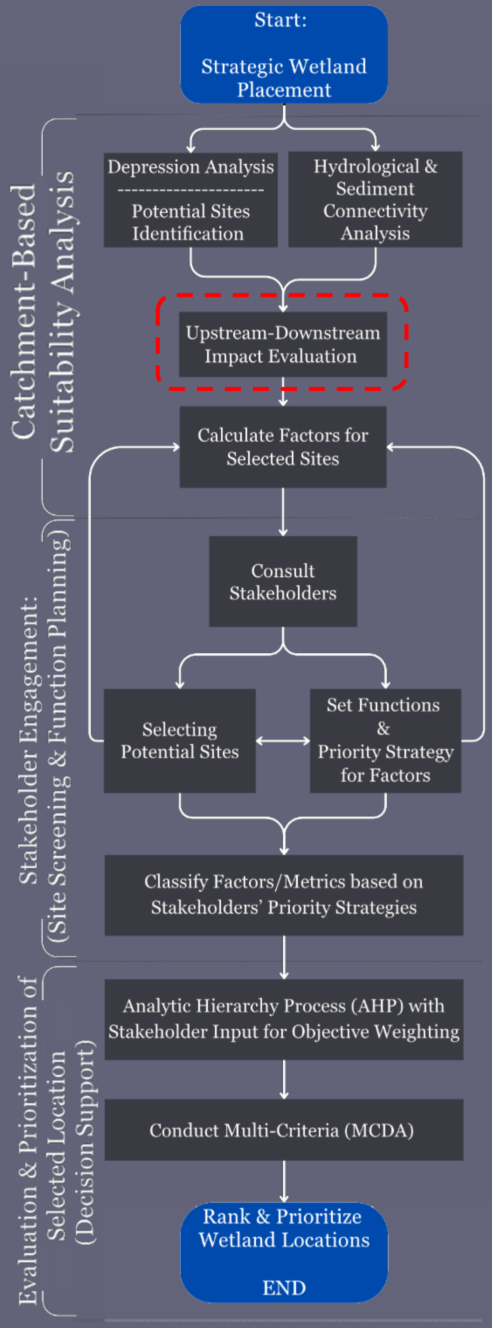


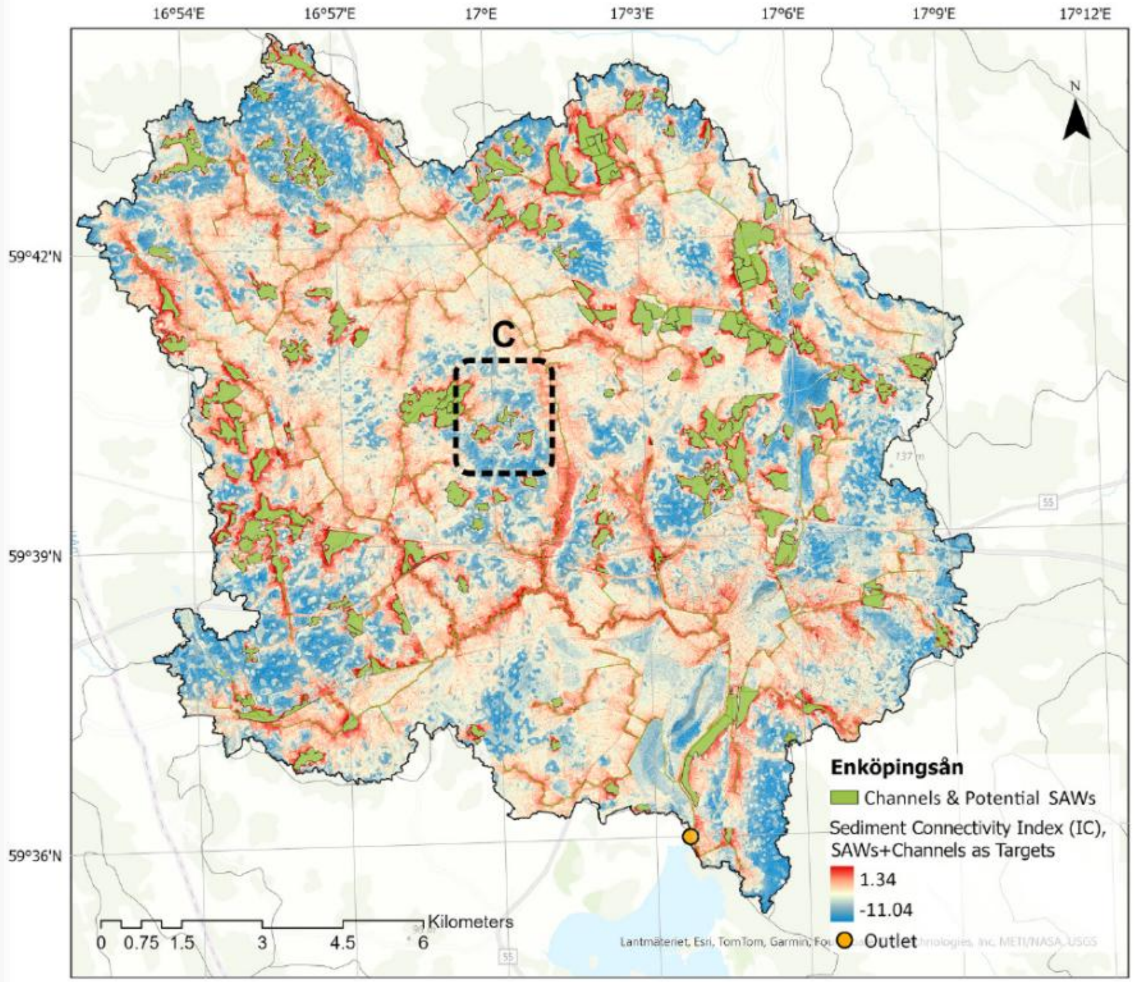


Hydrological delineation of a selected Small Artificial Waterbody (SAW) and its associated contributing and receiving areas.

I: Modelling in Action

Factors	
IC within SAW Area, channels as targets	IC_{in}
Upstream IC Wetlands and channels as targets	IC_{up}
Land Use within Wetlands	LU_{in}
Land Use Upstream	LU_{up}
Land Use Downstream	LU_{dn}
Upstream Runoff	Q_{up}
Downstream Area Size	A_{dn}
SAW Storage Potential	S_t

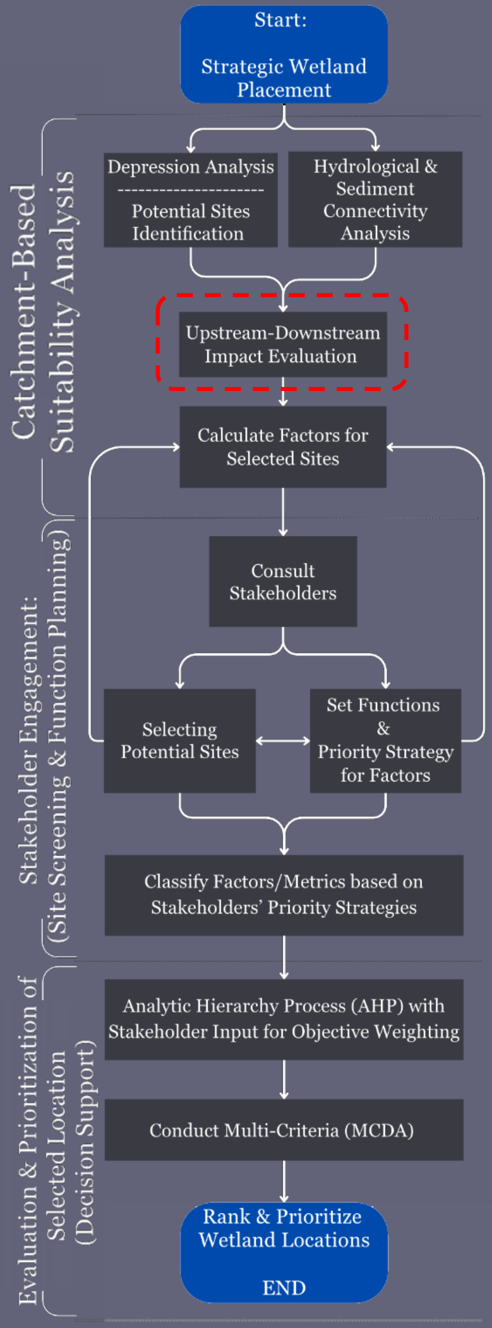


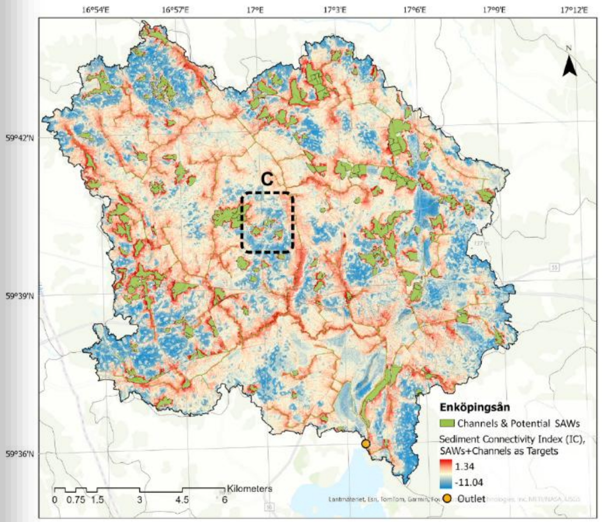


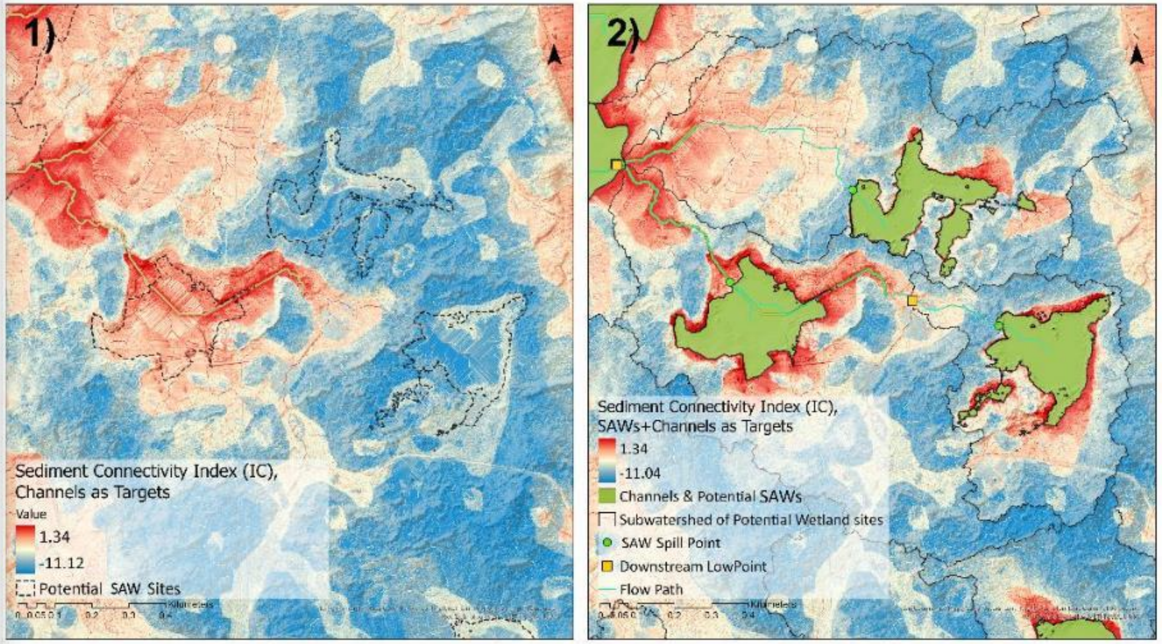
The IC maps illustrate how connectivity patterns shift when NBS are included as downstream targets.

I: Modelling in Action

Factors	
IC within SAW Area, channels as targets	IC_{in}
Upstream IC Wetlands and channels as targets	IC_{up}
Land Use within Wetlands	LU_{in}
Land Use Upstream	LU_{up}
Land Use Downstream	LU_{dn}
Upstream Runoff	Q_{up}
Downstream Area Size	A_{dn}
SAW Storage Potential	S_t



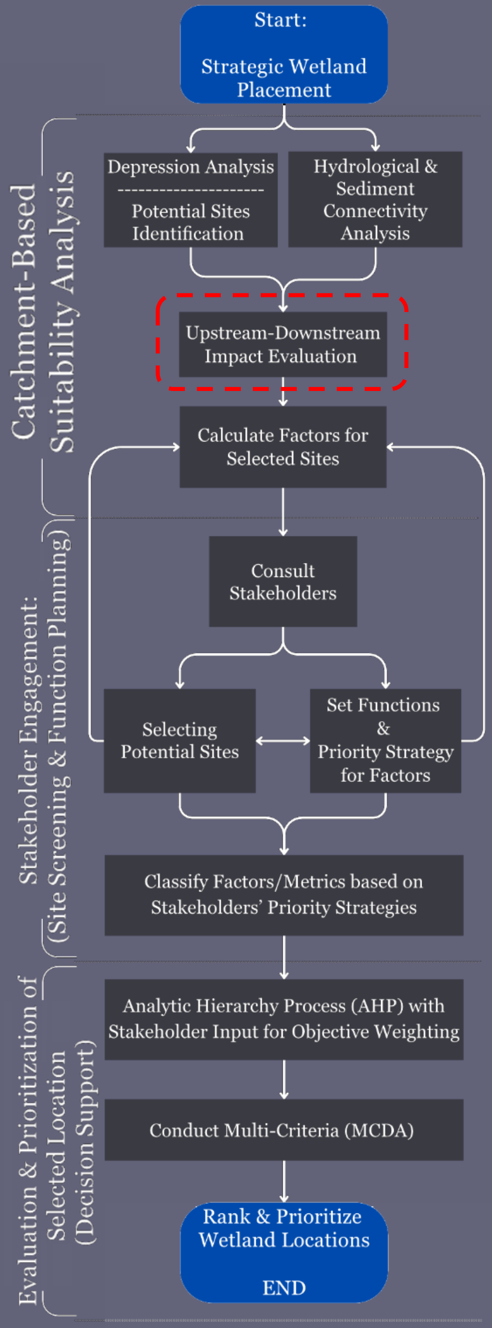


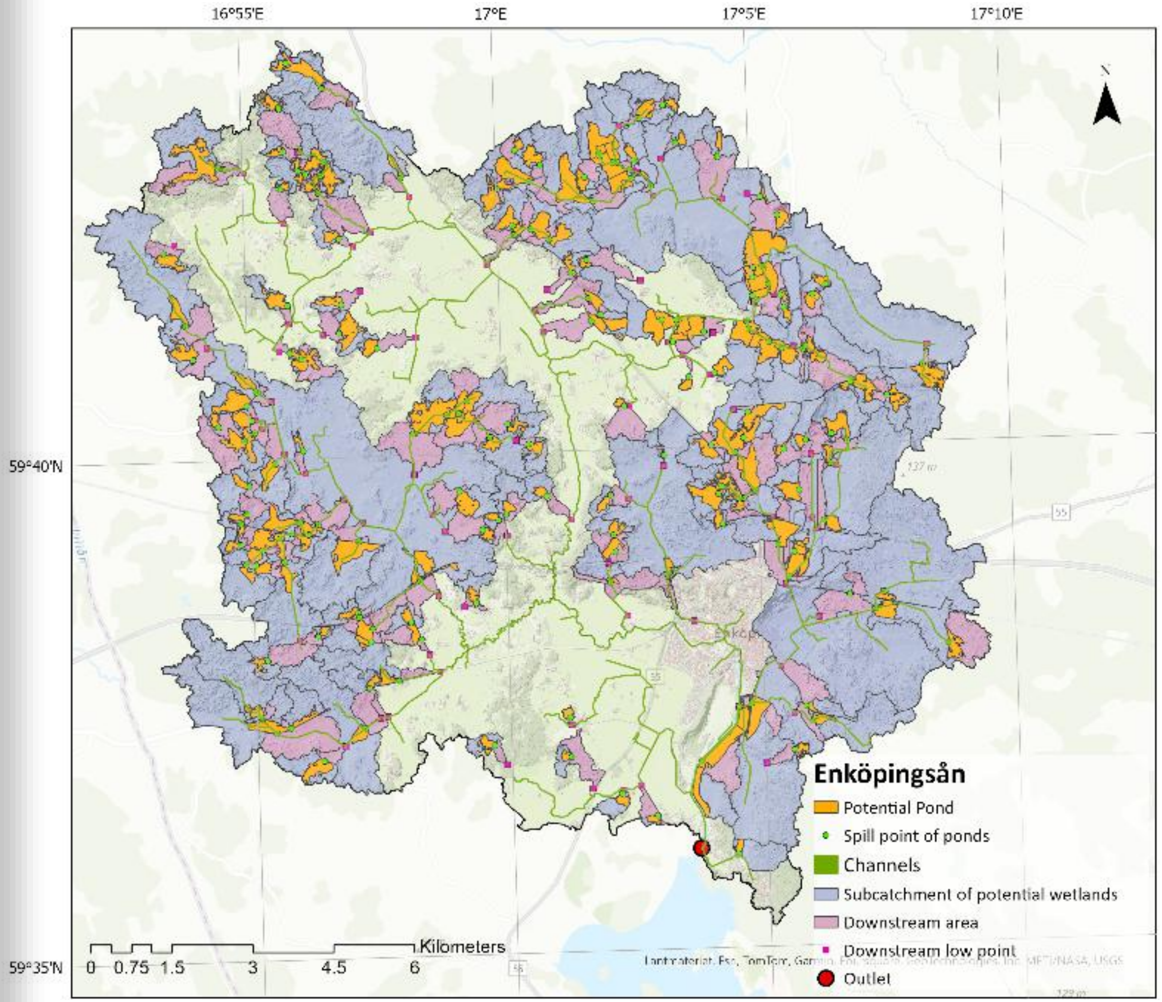


The IC maps illustrate how connectivity patterns shift when NBS are included as downstream targets.

I: Modelling in Action

Factors	
IC within SAW Area, channels as targets	IC_{in}
Upstream IC Wetlands and channels as targets	IC_{up}
Land Use within Wetlands	LU_{in}
Land Use Upstream	LU_{up}
Land Use Downstream	LU_{dn}
Upstream Runoff	Q_{up}
Downstream Area Size	A_{dn}
SAW Storage Potential	S_t





Coverage of potential wetland locations, their contributing subcatchments, and the directly influenced downstream areas, showing uncovered areas mainly in central arable lands and urban zones

II: Stakeholders Shape the Solution

From Models to Meaningful Decisions

- 300+ candidate wetlands screened with municipalities
- Workshops: 60+ participants ranked key functions

Top priorities:

Flood mitigation
Nutrient/sediment retention
Water storage
Biodiversity

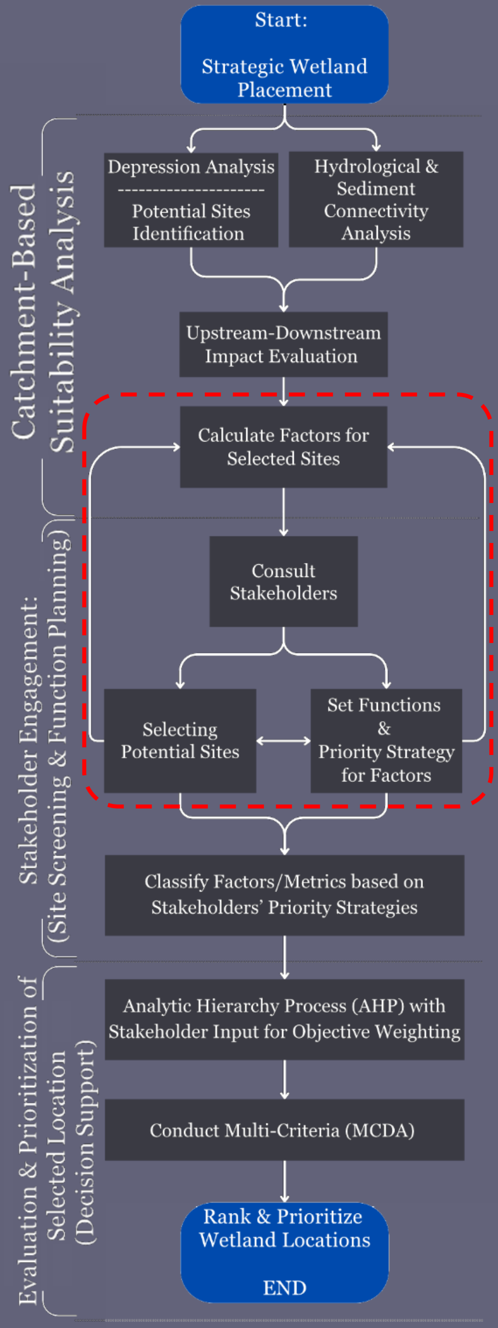


Table 5
Physical and hydrological metrics of each potential site, based on sediment connectivity and depression analysis.

Factor	Wetland Focus/ Function	Description	Priority Strategy	Notes
Sediment Connectivity Index within SAW Area *(IC with main channels as targets)*, (IC_{in})	Sediment & Nutrient Retention	IC measures how efficiently sediment is transported.	Moderate-High IC → Higher priority (Wetlands in high IC zones intercept more sediment and reduce erosion).	Avoid extremely high IC areas where sediment moves too fast to be captured.
	Biodiversity	IC impacts water stability and habitat conditions.	Lower IC → Higher priority (Stable water bodies support biodiversity better).	Focus on low-disturbance areas for long-term ecosystem stability.
	Flood Regulation	IC influences how fast water is delivered downstream.	High IC (but not extreme) → Higher priority (to slow down peak flows and reduce flood risks).	Helps in reducing peak discharge and buffering flood events.
	Water Retention	IC affects how water moves through the landscape.	Low-Moderate IC → Higher priority (Wetlands in these areas maximize storage while reducing rapid outflow).	Slower-moving water increases retention time and infiltration.
Upstream IC Contribution *(IC with Potential SAW locations and channels as targets)* (IC_{up})	Sediment & Nutrient Retention	Measures the percentage of high-IC areas in the upstream watershed.	More high-IC upstream → Higher priority (Wetlands can intercept more sediment).	Helps determine how much sediment and nutrients are likely to reach the SAW.
	Biodiversity	The connectivity of upstream flow to the SAW can affect water quality and biodiversity.	Lower IC upstream → Higher priority (Less disturbance ensures habitat stability).	
	Flood Regulation	Higher IC in upstream areas may increase runoff velocity and flood risks.	High IC (but not extreme) upstream → Higher priority (to slow and manage runoff).	Ensures wetlands are positioned in areas where they can buffer peak flows.
	Water Retention	The ability of upstream areas to contribute water to the SAW.	Moderate IC upstream → Higher priority (Wetlands in areas with moderate IC upstream can store and retain more water).	Ensures sustained water supply.
Land Use within SAW Area (LU_{in}), %	All four functions	Percentage of land types within each SAW polygon: - Arable land - Urban area - Forest and water - Open land	Higher priority: Open land → easier implementation. Lower priority: Arable land and Urban area (ownership issues). Medium priority: Forest (if high IC upstream or reasonable downstream exists).	Consider land ownership and cost of land conversion.
Land Use Upstream (LU_{up}), %	Sediment & Nutrient Retention	The type of land cover contributing to the SAW's inflow.	Higher priority: Agricultural upstream → more sediment and nutrient runoff to intercept. Lower priority: Forest upstream → already acts as a natural buffer.	High arable land upstream → higher need for sediment retention.
	Biodiversity	The impact of upstream land cover on water quality.	Higher priority: Natural or semi-natural landscapes upstream ensure better water quality.	Forested upstream areas provide natural water filtration.
	Flood Regulation	The ability of upstream land cover to buffer floods.	Higher priority: Impervious land upstream (e.g., urban areas) → stronger need for retention.	Impervious upstream areas contribute more runoff, requiring wetlands for buffering.
	Water Retention	Land cover determines infiltration capacity.	Higher priority: More pervious land (grasslands, forests) upstream → Slows runoff, increases infiltration, improves groundwater recharge.	Water retention is about quantity and quality, and vegetated upstream areas enhance both.
Land Use Downstream (LU_{dn}), %	All four functions	The type of land cover affected by the SAW downstream.	Higher priority: Urban areas and Arable land → more substantial need for flood mitigation and fresh water. Lower priority: Wetlands or forests → already provide retention.	If urban areas exist downstream, the SAW may reduce flooding and sediment-related damage.
Upstream Runoff (Q_{up}), m^3	All four functions	Amount of water supply to the SAW from its upstream catchment.	Higher runoff → Higher priority (ensures SAW has sufficient water supply).	Based on the SCS-CN rainfall-runoff model.

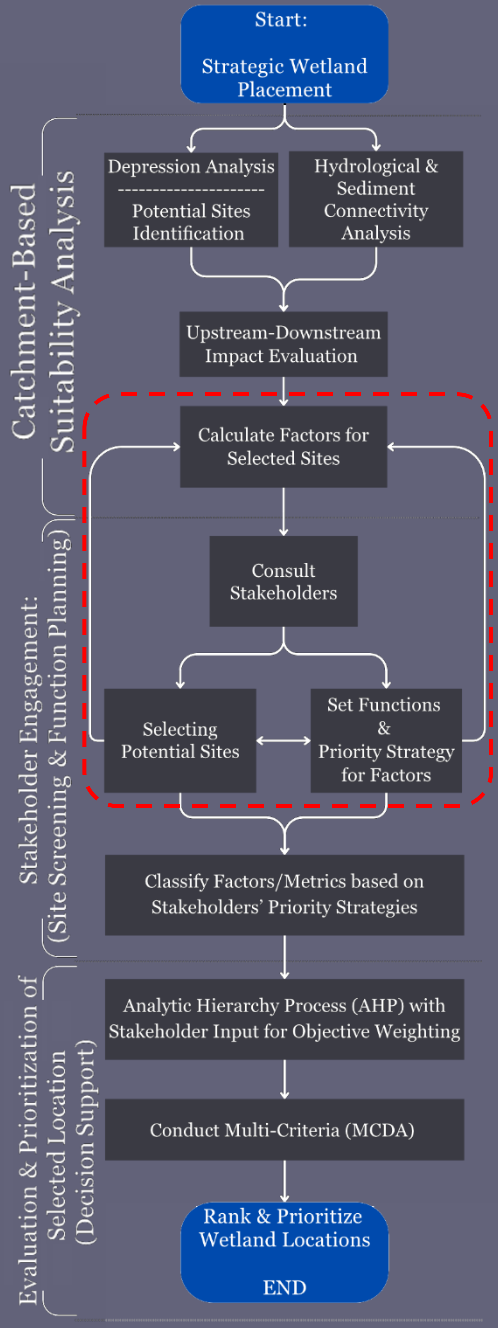
II: Stakeholders Shape the Solution

From Models to Meaningful Decisions

- 300+ candidate wetlands screened with municipalities
- Workshops: 60+ participants ranked key functions

Top priorities:

Flood mitigation
Nutrient/sediment retention
Water storage
Biodiversity



AHP, pairwise comparisons matrix.

Factors		IC_{in}	IC_{up}	LU_{in}	LU_{up}	LU_{dn}	Q_{up}	A_{dn}	S_t	Priority Weight	CR
IC within SAW Area, channels as targets	IC_{in}	1.00	2.00	0.50	4.00	3.00	2.00	5.00	1.00	18.4	$0.013 < 0.1$
Upstream IC Wetlands and channels as targets	IC_{up}	0.50	1.00	0.33	2.00	1.00	1.00	3.00	0.50	9.4	
Land Use within Wetlands	LU_{in}	2.00	3.00	1.00	5.00	5.00	3.00	5.00	2.00	29.1	
Land Use Upstream	LU_{up}	0.25	0.50	0.20	1.00	1.00	1.00	2.00	0.33	6.2	
Land Use Downstream	LU_{dn}	0.33	1.00	0.20	1.00	1.00	0.50	2.00	0.33	6.4	
Upstream Runoff	Q_{up}	0.50	1.00	0.33	1.00	2.00	1.00	3.00	0.50	9.4	
Downstream Area Size	A_{dn}	0.20	0.33	0.20	0.50	0.50	0.33	1.00	0.20	3.6	
SAW Storage Potential	S_t	1.00	2.00	0.50	3.00	3.00	2.00	5.00	1.00	17.6	
SUM		5.78	10.84	3.27	17.50	16.50	10.83	26.00	5.87	100.0	

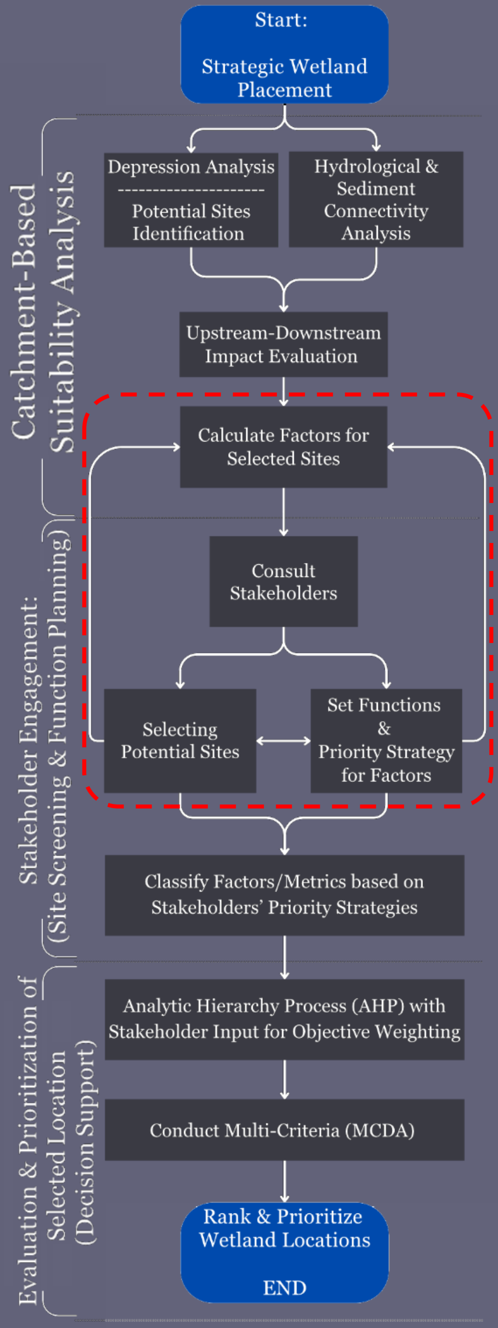
II: Stakeholders Shape the Solution

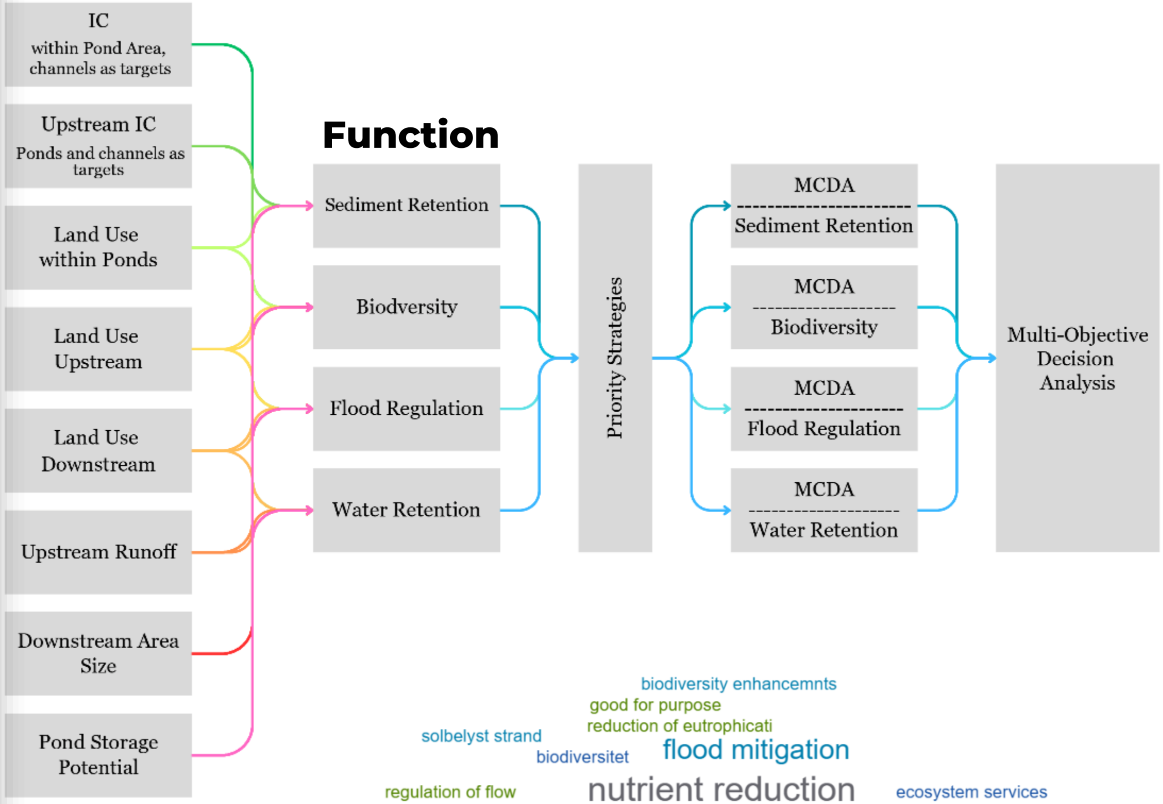
From Models to Meaningful Decisions

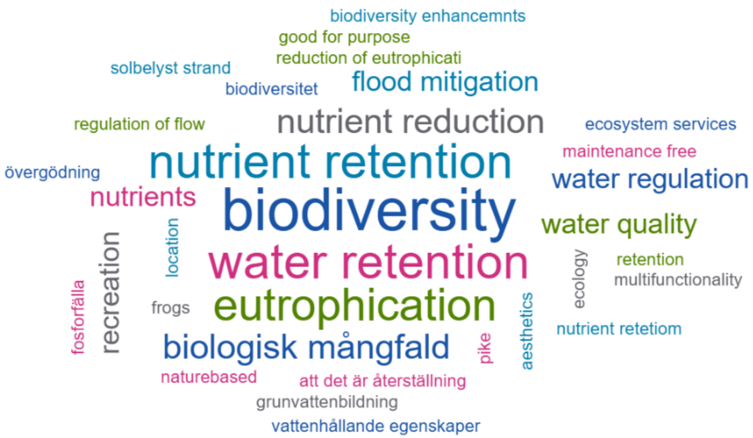
- 300+ candidate wetlands screened with municipalities
- Workshops: 60+ participants ranked key functions

Top priorities:

Flood mitigation
Nutrient/sediment retention
Water storage
Biodiversity



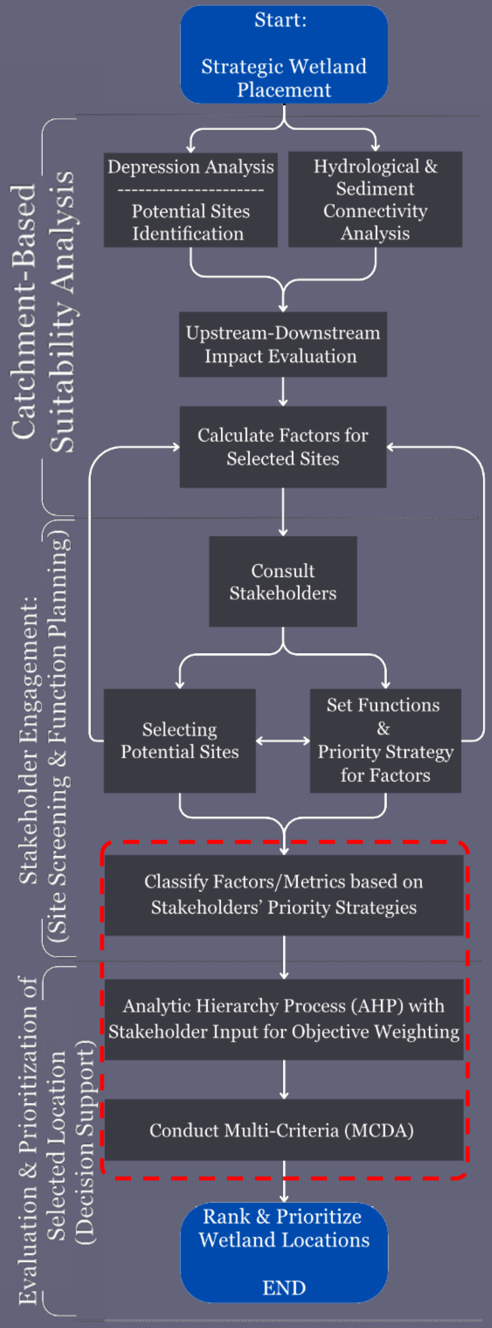


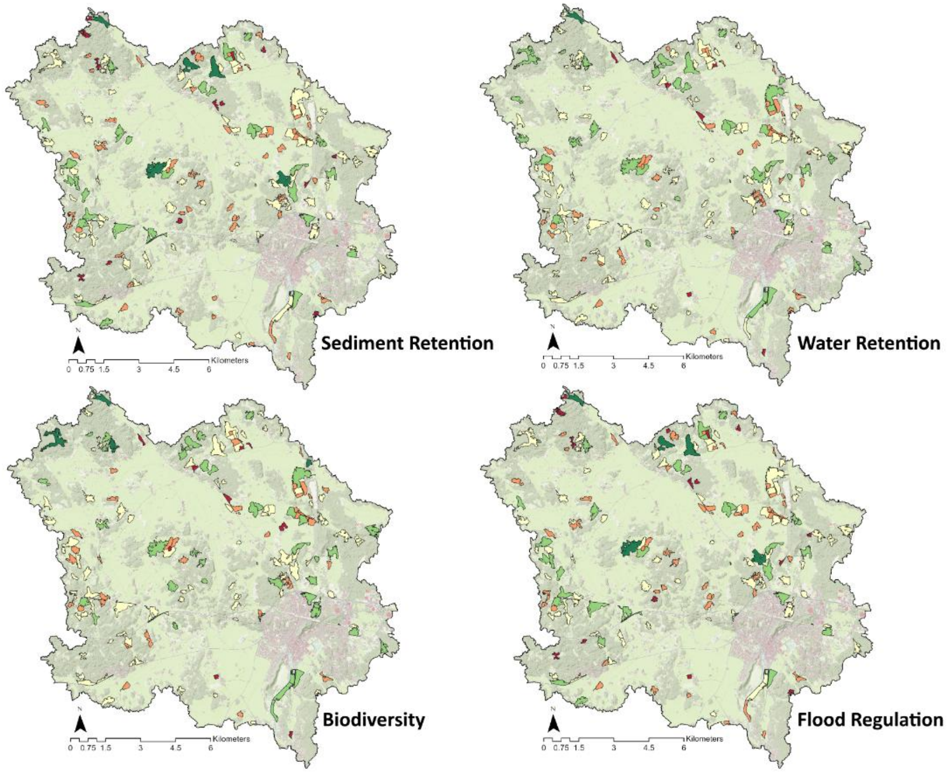


III: From Complexity to Clarity

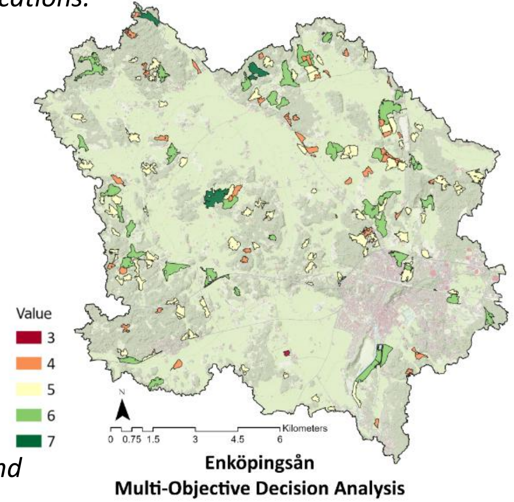
Prioritized Wetlands with Maximum Impact

- AHP weights + MCDA overlays + MODA composite map
- Final sites balance hydrology, land use, and stakeholder goals.
- Strategic wetlands
  = multi-benefit solutions





Prioritized wetland locations.



Optimal sites for multifunctional wetland implementation.

Scalable Insights for Urban Resilience in the Mediterranean

- Framework developed in Swedish catchments is **highly transferable** to Mediterranean contexts
- Addresses key challenges:
  - Flash floods, water scarcity, and rapid urbanization
  - Climate variability and fragmented governance
- Combines:
  - Hydrological & sediment connectivity modeling
  - Stakeholder-driven prioritization
  - Decision-support for multifunctional NBS placement
- Supports climate adaptation through:
  - Strategic wetland implementation
  - Co-designed, locally tailored solutions

Bridging science and policy for just and sustainable adaptation

PUDDLE JUMP: Promoting Upstream-Downstream Directed Linkages in the Environment: “Joined-Up” Management Perspectives

LandEX: Improving Landscape resilience by integrating measures to adapt and mitigate hydrological EXtremes

CASCADE: Combining Advanced Systems for Climate Adaptation and Disaster Enhancement in Stockholm

RESOLVE: Developing climate-resilient and eco-sustainable railway earthwork by mitigating geohazards while balancing biodiversity

AI-Driven Sustainable Spatial Planning: Advancing Climate-Neutral Cities through Digital Innovation

KTH VETENSKAP OCH KONST

rezvani@kth.se