EGU General Assembly 2020

HS2.3.1

Water quality at the catchment scale: measuring and modelling of nutrients, sediment and eutrophication impacts

An ecosystem-based approach to support water quality assessment and management under climate and land-use condition

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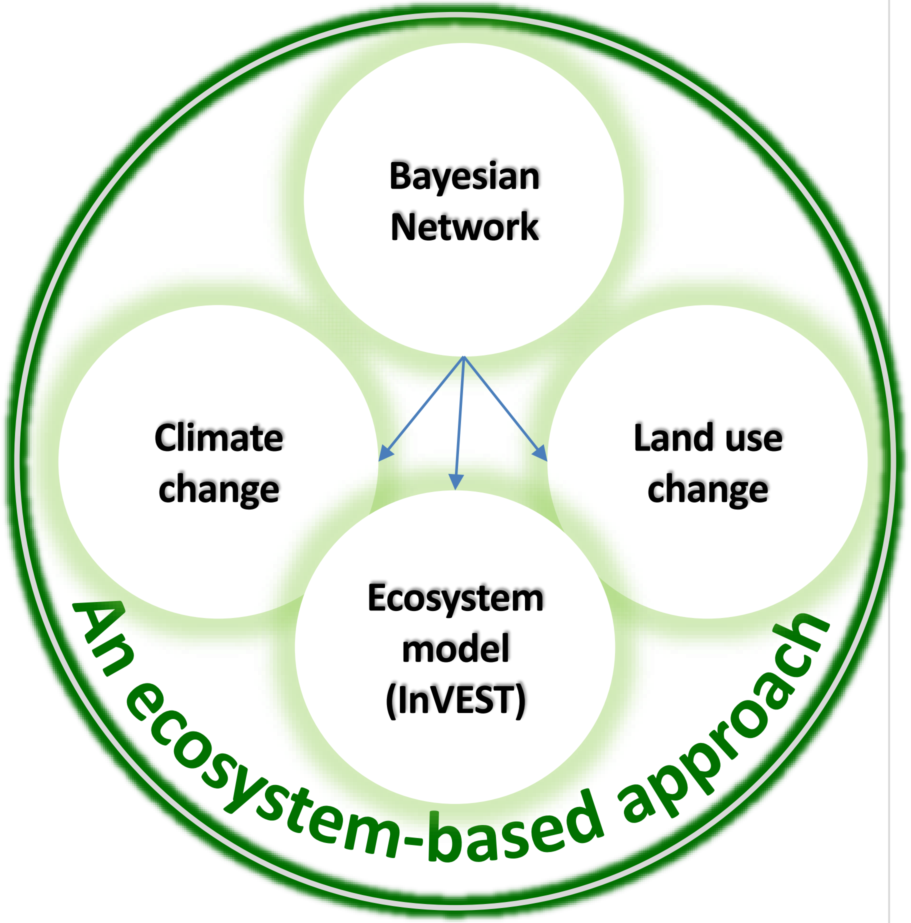
Introduction

Freshwater ecosystem services

Objectives

Develop an <u>integrated approach</u>, coupling the **outputs of ecosystem services model (InVEST)**, **climate (COSMO-CLM)** and **land use (LUISA)** change models into Bayesian Networks to:

- identify critical factors that allow optimizing the supply of ES;
- assess the potential space to improve the capacity of ES;
- quantify the capacity of ES under thousand scenarios to assist decision-makers.



Case study

intensive agricultural practices

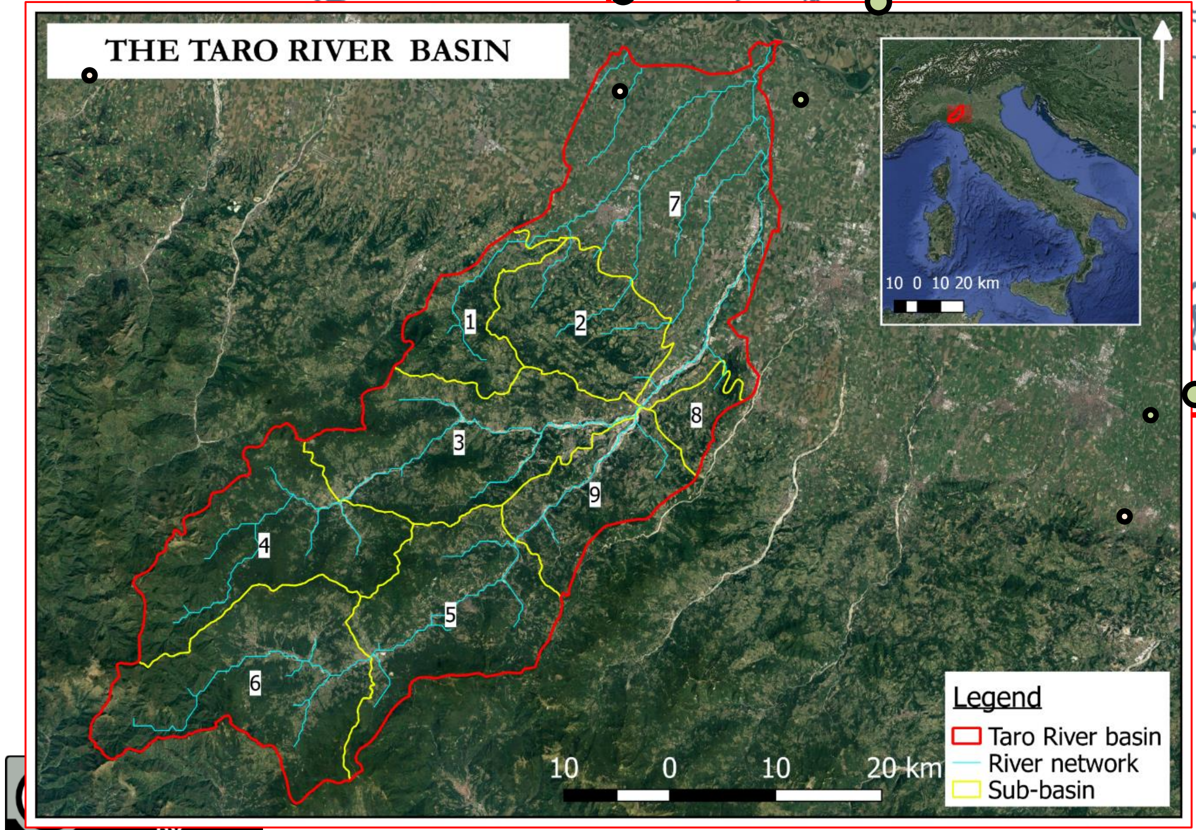
extracted from the groundwaters

morphological change

floods

construction of engineered flood defenses

- The total length is about 126 km
- The total area is about 2,026 km^2
  - P_{annual} is about 2,600 mm
  - T_{mean} is 12.0 degree C
  - Q_{annual} is 31 $m^3 s^{-1}$

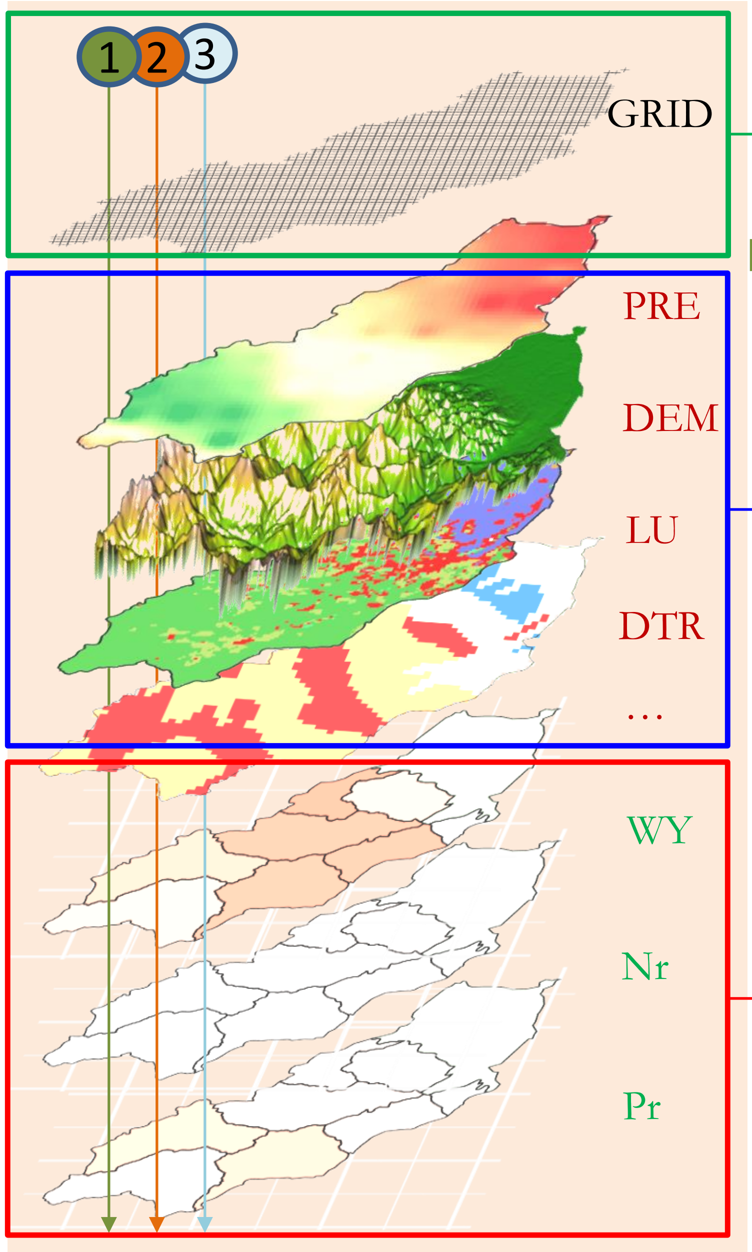


LAND USE

- Woodlands (53%)
- Agriculture (42%)
- Urban (3%)

Input data and the discretization of spatial data using gridded cells

PRE	Precipitation	mm
AET	Actual evapotranspiration	mm
LU	Land-use	-
DTR	Depth to root restricting layer	mm
PAWC	Plant available water content	-
ETO	Reference evapotranspiration	mm
KC	Evapotranspiration coefficient	-
RD	Root depth	mm
WD	Water demand	m3/yr
YEAR	Year	-
Neff	Nitrogen retention efficiency	-
Peff	Phosphorous retention efficiency	-
DEM	Digital elevation model	mm
Ns	Nitrogen source	kg/yr
Ps	Phosphorous source	kg/yr
Nl	Nitrogen load	kg/yr
Pl	Phosphorous load	kg/yr
Ne	Nitrogen export	kg/yr
Pe	Phosphorous export	kg/yr
Nr	Nitrogen retention	kg/yr
Pr	Phosphorous retention	kg/yr
WY	Water Yield	m3/yr



ID	PRE	DEM	LU	DTR	
1	120	3.25	Urban	1200	...
2	150	5.24	Forest	3500	...
3	160	6.78	Urban	2700	...
...	...	...	...	...	

Bayesian network

Defined grid cells to discrete spatial data.

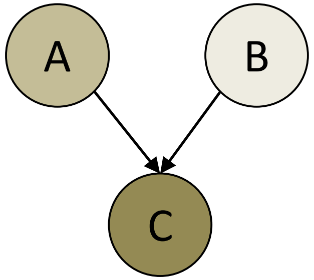
Collected data

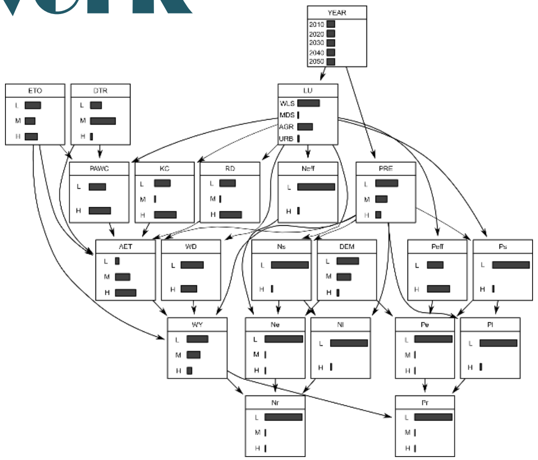
Outputs from InVEST model

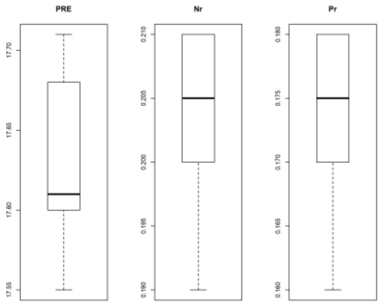
Pham et al., 2019. “Coupling Scenarios of Climate and Land – Use Change with Assessments of Potential Ecosystem Services at the River Basin Scale.” *Ecosystem Services* 40 (May): 101045. https://doi.org/10.1016/j.ecoser.2019.101045.

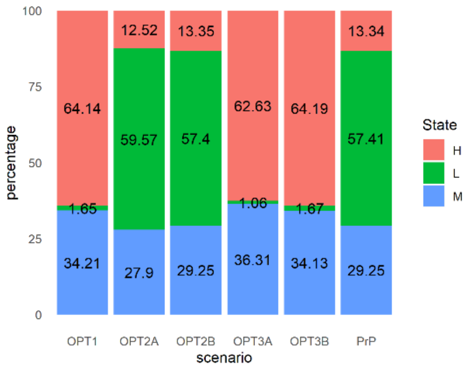
Methodology – practical steps in Bayesian network

Bayesian network









CONCEPTUAL MODEL

Define the structure, main variables and relationships using a conceptual/ influence **'nodes and arrow'** diagram, and by applying different learning processes to automatically extract the network structure

MODEL PARAMETRIZATION

Define **states** for all variables (interval, boolean, etc.) and calculate the associated **prior probability** resulting from data distribution and relationships among nodes as the **conditional probability** distributions.

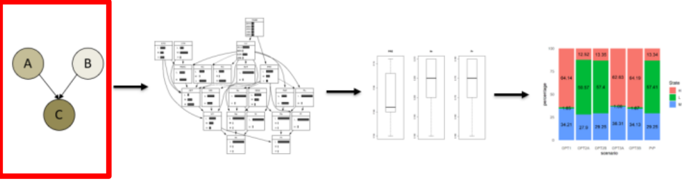
CALIBRATION and VALIDATION

Evaluate the prediction accuracy of the BN model through different types of validation methods:

- the data-based validation;
- the qualitative evaluation.

SCENARIOS ANALYSIS

Inferring behavior of variables under different conditions by setting specific state/s of a node/s (**evidence**) and then propagating information among nodes based on the Bayes theorem, thus, resulting in **the posterior probability.**



Conceptual model

Initial model

(black nodes and arcs)

Structural learning

(red arcs)

Score based

hill-climbing

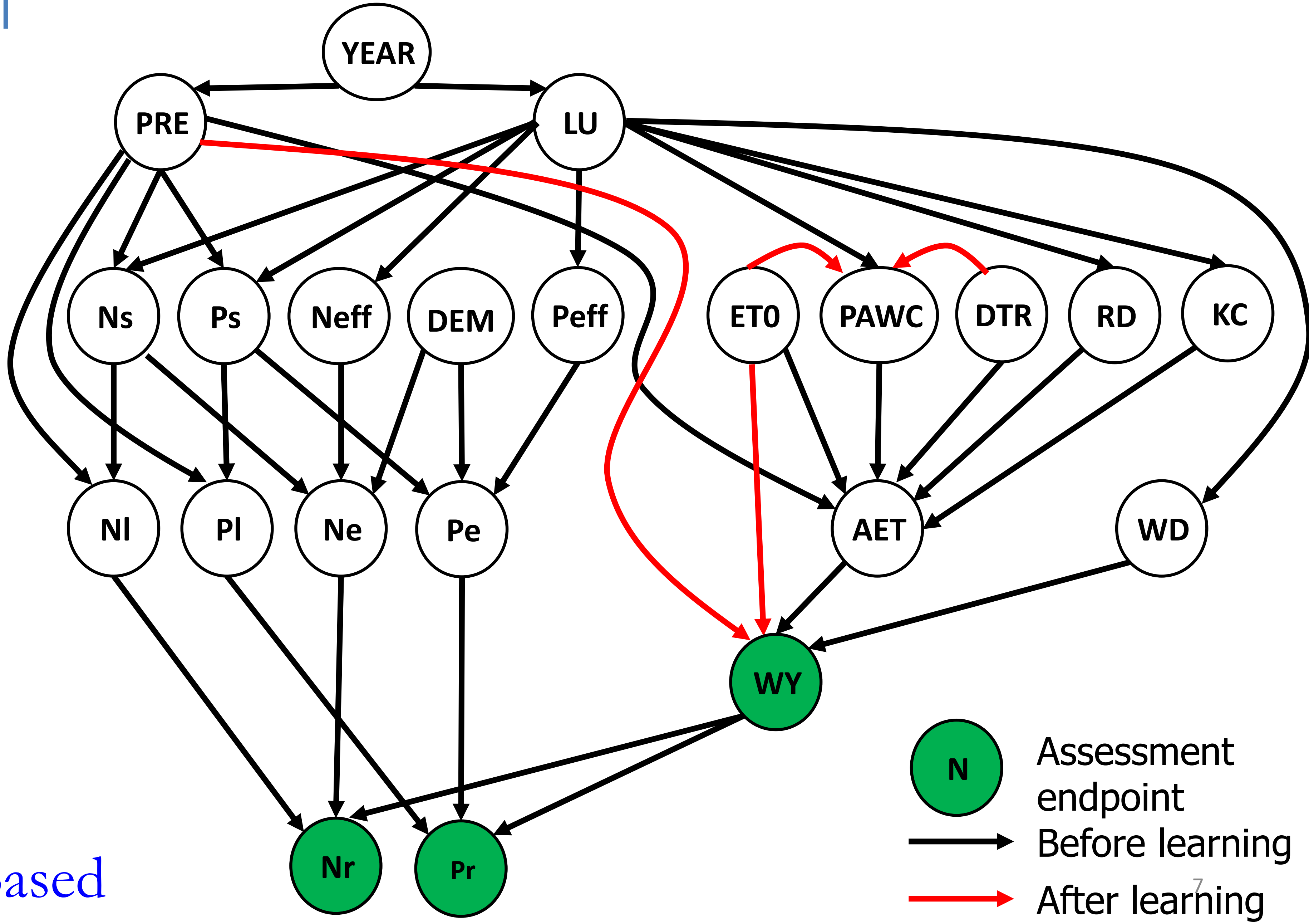
tabu search

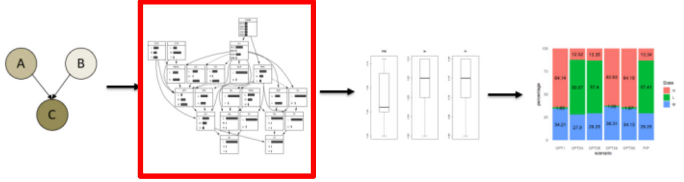
Constraint based

grow-shrink

incremental association

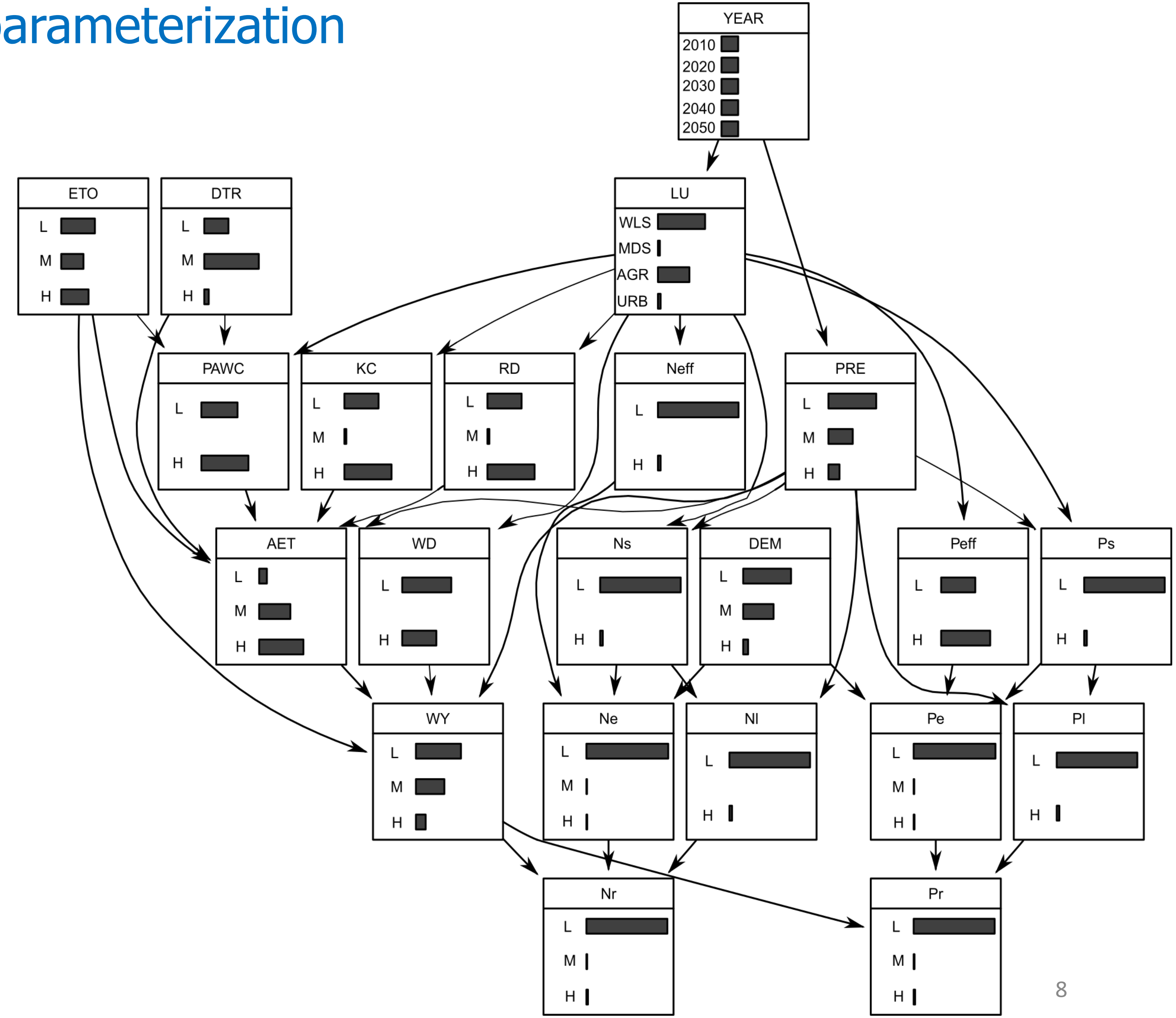
Expert-based

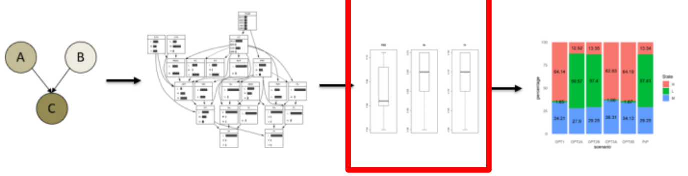




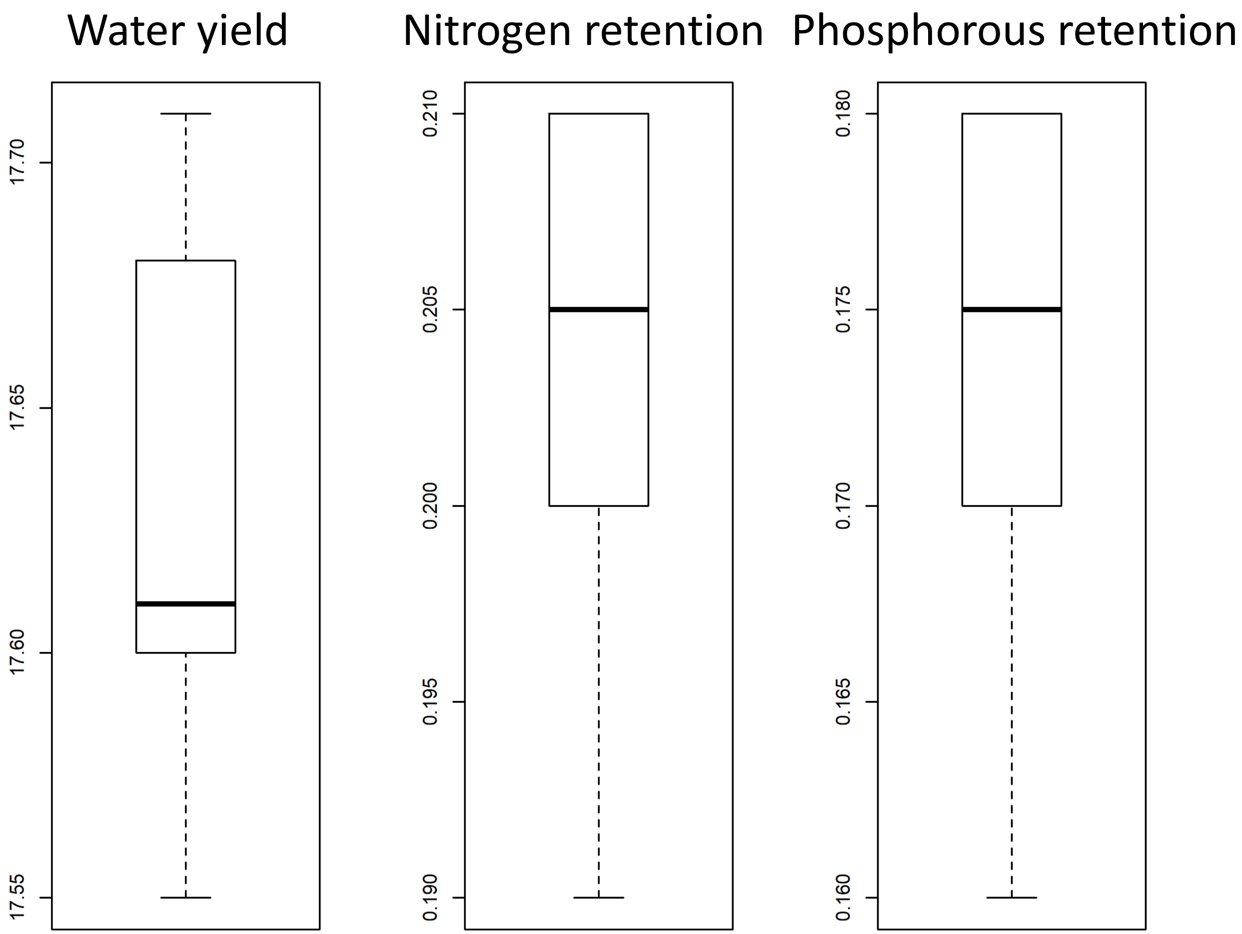
Model parameterization

- **BN** was **trained with collected data and output of InVEST** model in 2010, 2020, 2030 2040, and 2050;
- The **prior probability** was calculated **from data distribution and relationships** among nodes as the conditional probability distributions
- The **numbers of states** for each variable (or node) **depended on its natural characters** (e.g. the node “LU” was discretized into four states since the land-use was classified as Woodland, Meadowland, Agriculture, and Urban)





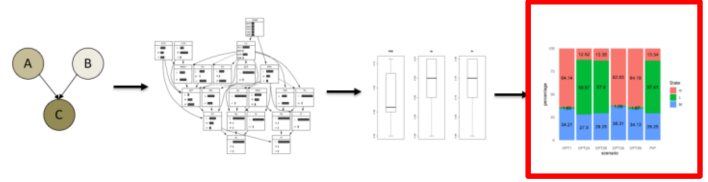
Calibration and validation



CLASSIFICATION ERROR

k-fold validation

- The **predictive accuracy of the classifier** was checked by using cross-validation to obtain an estimate of the predictive classification.
- The **golden standard** is 10 runs of **10-fold** cross-validation, using **bn.cv()** with method = "k-fold"
- The mean model losses (classification error) of water yield (WY), nitrogen retention (Nr) and phosphorous retention (Pr) were 17.6%, 0.2% and 0.2%, respectively.



Scenario analysis

Diagnostic/upward inference

The OPT scenarios focus on the maximization of ES (WY, Nr, Pr) using **upward propagation** to find **the best combination** of the key drivers such as **PRE, LU, and WD**

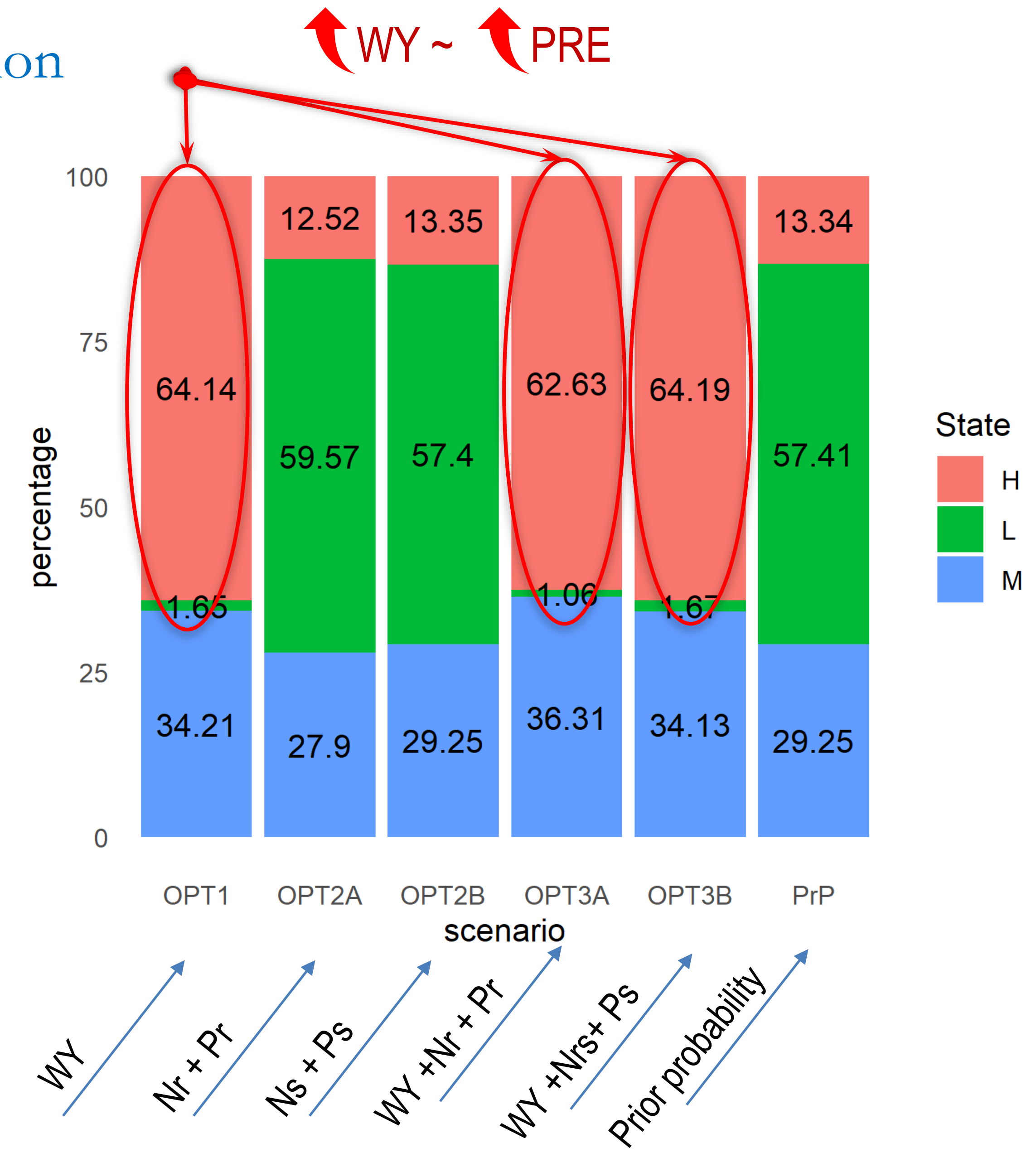
OPT1	Maximization of Water Yield
OPT2A	Maximization of nutrient retention (Nr and Pr)
OPT2B	Minimization of nutrient source (Ns and Ps)
OPT3A	Maximization of WY, Nr and Pr
OPT3B	Maximization of WY and minimization of Ns and Ps

Prognostic/downward inference

The prognostic inference aims to **find the distribution of ES**, given the distributions of the main inputs (e.g. **LU, PRE, and WD**). To to consider the **uncertainty of input variables** in the real world, this analysis considered **5000 scenarios.**

Results

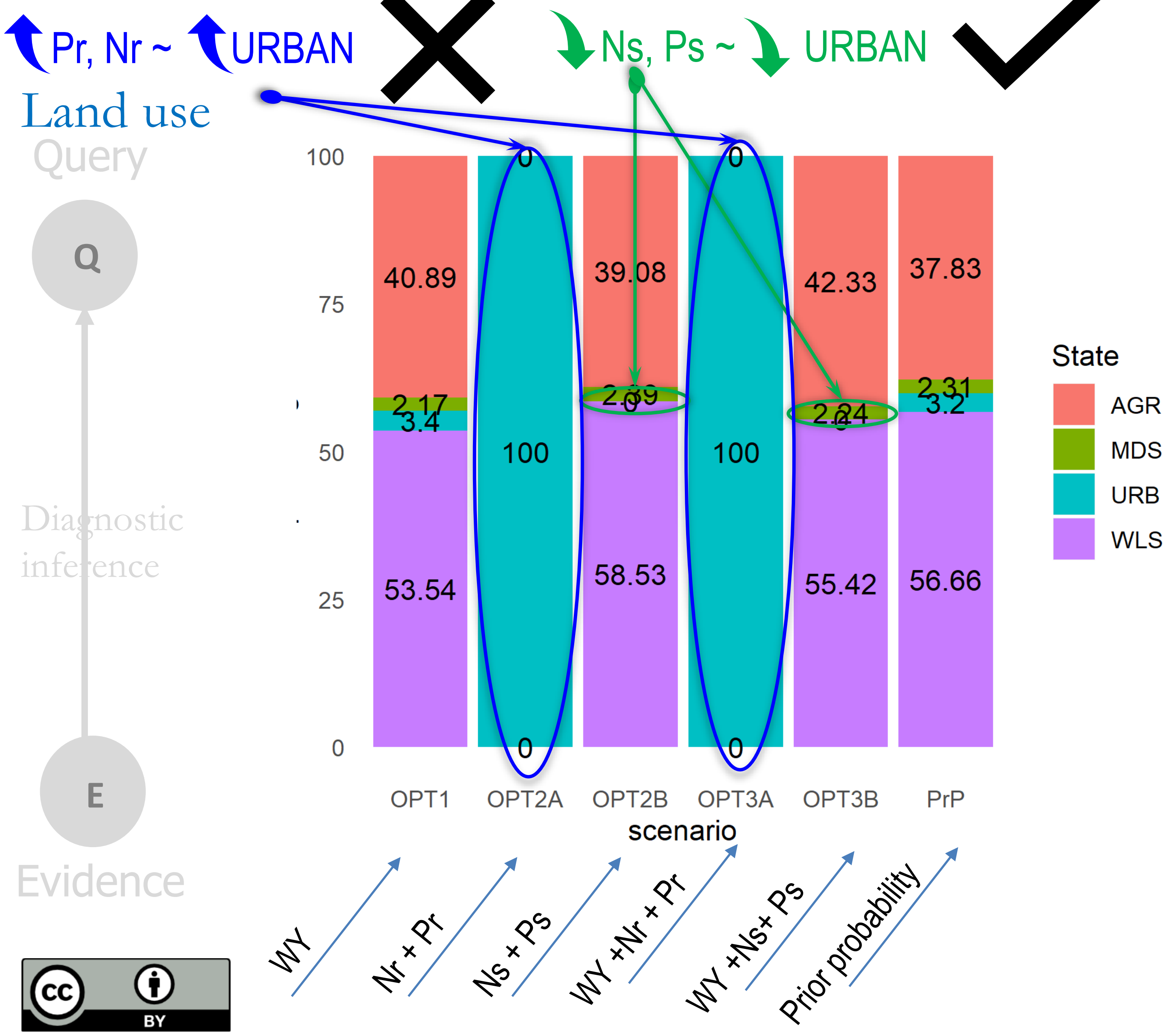
Precipitation



- When considering to **optimize Water Yield (WY),** the results of scenario OPT1, OPT3A, and OPT3B suggested that **shifting the state of precipitation (PRE) distribution from low (L) to high (H)** could lead to the **high value of of WY.**

- Nevetherless, **shifting the states of PRE** did **not have an important impact on Nr and Pr**, as seen in the scenario OTP3A and OTP3B.

Results



- When **maximize nutrient retention** (Nr and Pr), the results of scenario OPT2 and OPT3 suggested that **Nr and Pr could reach the maximum value if all land-use classes were converted to urban (URB)** => non-feasible solution

- When **minizime nutrient source** (Ns and Ps), the results of OPT2B and OPT3B suggested that we could **improve ES by the transformation of urban into "greener" land-use types** such as **wetlands** and **agriculture**

=> Urban sources had significant impact on water quality related services.

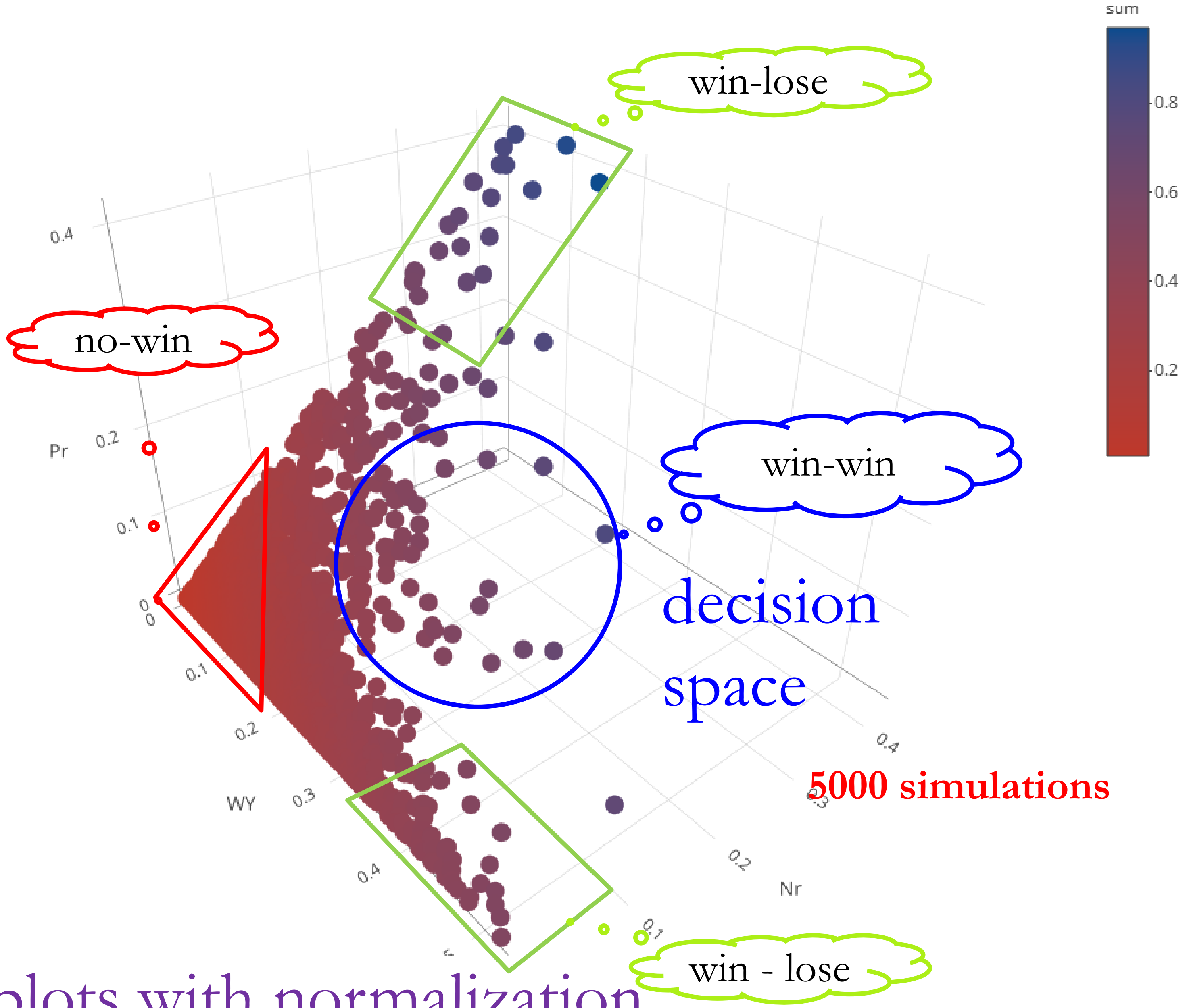
Results

- All the outputs are transformed into a "**decision space**" where the **values of selected services** are plotted in the **space of ES:**

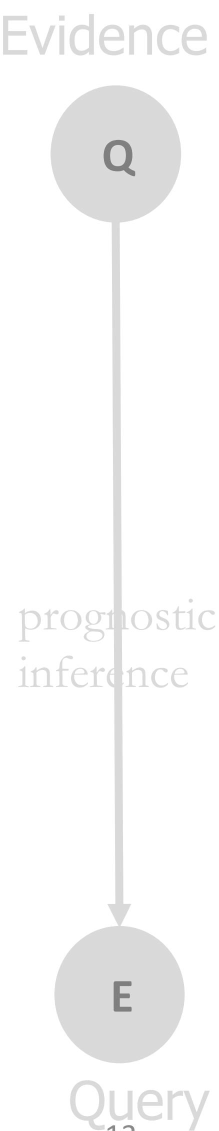
✓ no-win: low value for all services

✓ win-lose: maximizing one services while the value of other services are low

✓ win-win: balancing all services.



3D plots with normalization



Implication for decision-makers

III II I

- The obtained results provide valuable support to identify and **prioritize the best management practices** for sustainable water use, **improving water quality**, and **balancing the tradeoffs among services** provided by freshwater;
- This analysis allows **decision-makers** to pick up one scenario with a specific configuration of landuse and water **demand to optimize water quality (e.g. TN, TP) relevant ESs** within their basin;
- All the combinations of model's inputs are transformed into a "**decision space**" where the values of selected services are plotted in the space of ES to **represent the gain/loss of each decision**.