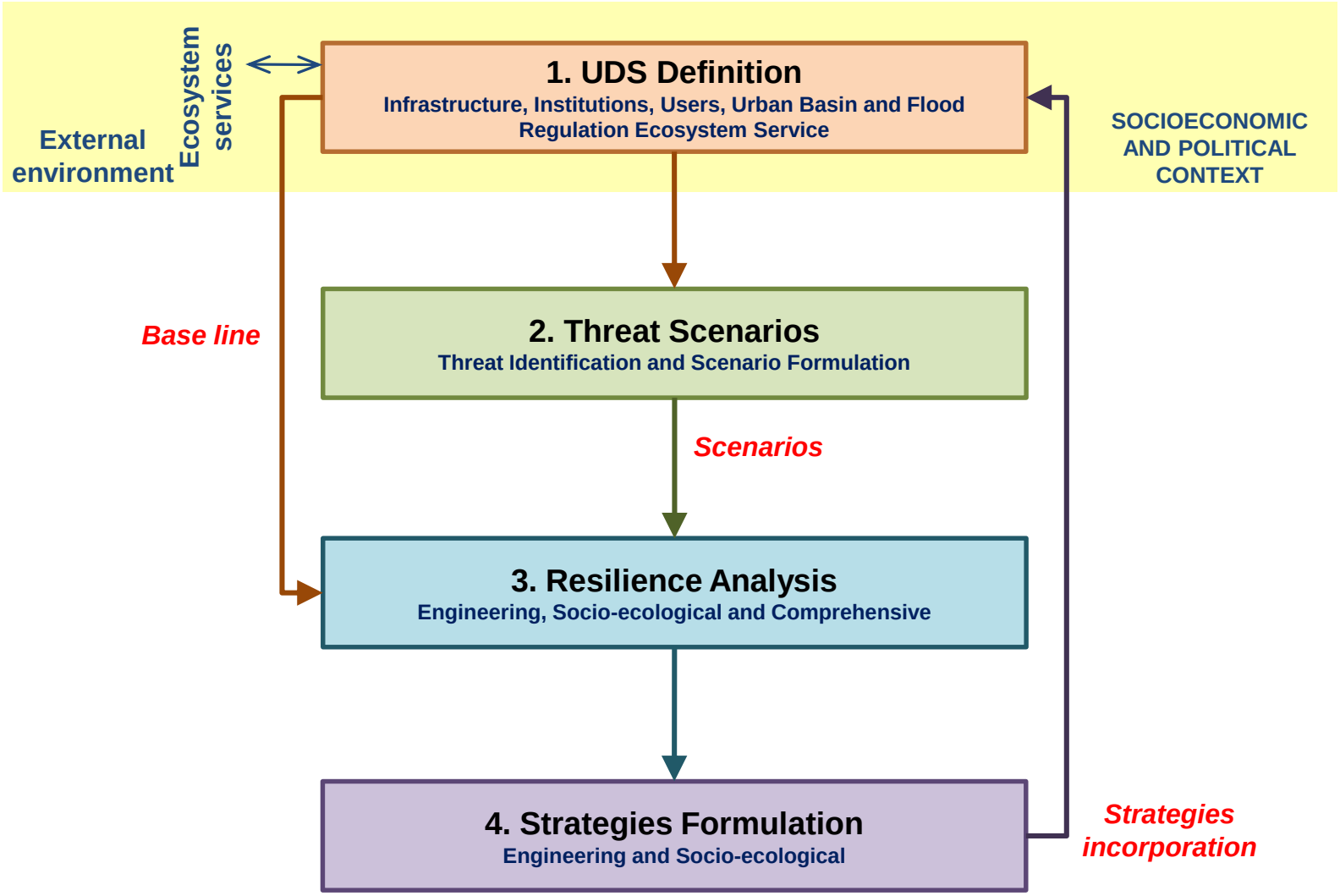
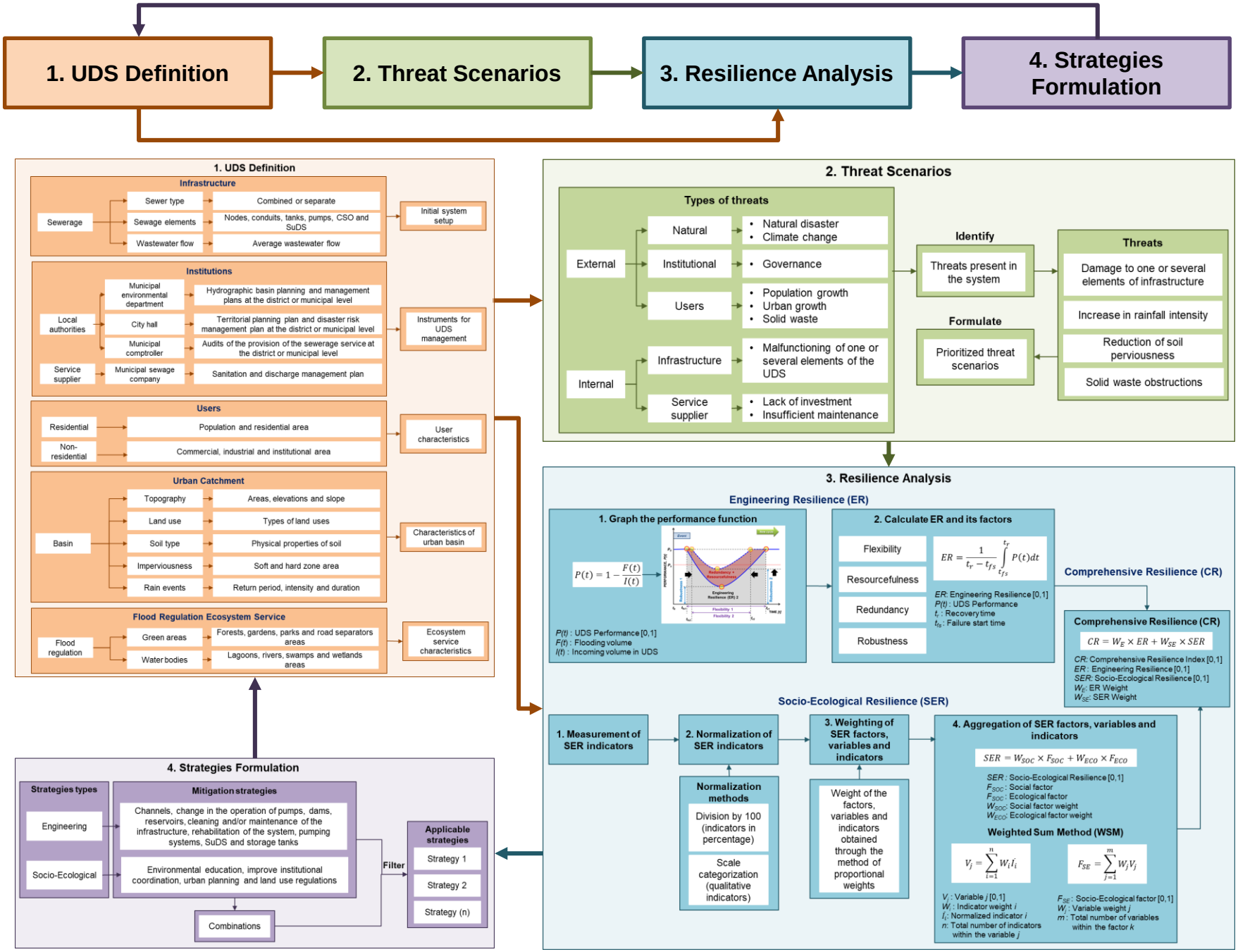
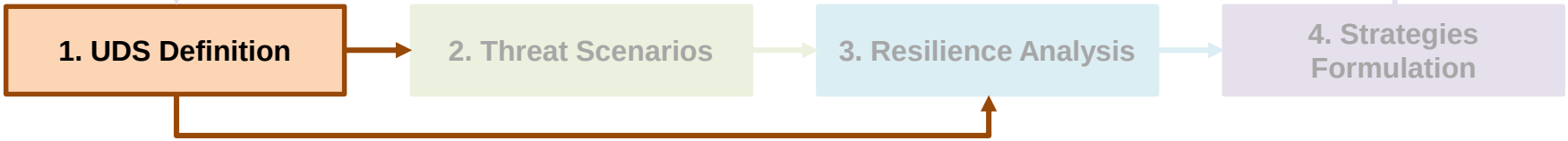
Conceptual framework for the comprehensive analysis of resilience in urban drainage systems (UDS)




1. UDS Definition
2. Threat Scenarios
3. Resilience Analysis
4. Strategies Formulation
1. UDS Definition
Infrastructure
Sewerage
Sewer type
Combined or separate
Sewage elements
Nodes, conduits, tanks, pumps, CSO and SuDS
Wastewater flow
Average wastewater flow
Initial system setup
Institutions
Local authorities
Municipal environmental department
Hydrographic basin planning and management plans at the district or municipal level
City hall
Territorial planning plan and disaster risk management plan at the district or municipal level
Municipal comptroller
Audits of the provision of the sewerage service at the district or municipal level
Service supplier
Municipal sewage company
Sanitation and discharge management plan
Instruments for UDS management
Users
Residential
Population and residential area
Non-residential
Commercial, industrial and institutional area
User characteristics
Urban Catchment
Basin
Topography
Areas, elevations and slope
Land use
Types of land uses
Soil type
Physical properties of soil
Imperviousness
Soft and hard zone area
Rain events
Return period, intensity and duration
Characteristics of urban basin
Flood Regulation Ecosystem Service
Flood regulation
Green areas
Forests, gardens, parks and road separators areas
Water bodies
Lagoons, rivers, swamps and wetlands areas
Ecosystem service characteristics
2. Threat Scenarios
Types of threats
External
Natural
Natural disaster
Climate change
Institutional
Governance
Users
Population growth
Urban growth
Solid waste
Internal
Infrastructure
Malfunctioning of one or several elements of the UDS
Service supplier
Lack of investment
Insufficient maintenance
Identify
Threats present in the system
Formulate
Prioritized threat scenarios
Threats
Damage to one or several elements of infrastructure
Increase in rainfall intensity
Reduction of soil perviousness
Solid waste obstructions
3. Resilience Analysis
Engineering Resilience (ER)
1. Graph the performance function
$P(t) = 1 - \frac{F(t)}{I(t)}$
P(t) : UDS Performance [0,1]
F(t) : Flooding volume
I(t) : Incoming volume in UDS
2. Calculate ER and its factors
Flexibility
Resourcefulness
Redundancy
Robustness
$ER = \frac{1}{t_r - t_{fs}} \int_{t_{fs}}^{t_r} P(t)dt$
ER: Engineering Resilience [0,1]
P(t) : UDS Performance
t_r : Recovery time
t_{fs} : Failure start time
Comprehensive Resilience (CR)
Comprehensive Resilience (CR)
$CR = W_E \times ER + W_{SE} \times SER$
CR: Comprehensive Resilience Index [0,1]
ER : Engineering Resilience [0,1]
SER: Socio-Ecological Resilience [0,1]
W_E: ER Weight
W_{SE}: SER Weight
Socio-Ecological Resilience (SER)
1. Measurement of SER indicators
2. Normalization of SER indicators
Normalization methods
Division by 100 (indicators in percentage)
Scale categorization (qualitative indicators)
3. Weighting of SER factors, variables and indicators
Weight of the factors, variables and indicators obtained through the method of proportional weights
4. Aggregation of SER factors, variables and indicators
$SER = W_{SOC} \times F_{SOC} + W_{ECO} \times F_{ECO}$
SER : Socio-Ecological Resilience [0,1]
F_{SOC} : Social factor
F_{SOC} : Ecological factor
W_{SOC}: Social factor weight
W_{ECO}: Ecological factor weight
Weighted Sum Method (WSM)
$V_j = \sum_{i=1}^{n} W_i I_i$
$F_{SE} = \sum_{j=1}^{m} W_j V_j$
V_j : Variable j [0,1]
W_i : Indicator weight i
I_i: Normalized indicator i
n: Total number of indicators within the variable j
F_{SE}: Socio-Ecological factor [0,1]
W_j : Variable weight j
m : Total number of variables within the factor k
4. Strategies Formulation
Strategies types
Engineering
Socio-Ecological
Mitigation strategies
Channels, change in the operation of pumps, dams, reservoirs, cleaning and/or maintenance of the infrastructure, rehabilitation of the system, pumping systems, SuDS and storage tanks
Environmental education, improve institutional coordination, urban planning and land use regulations
Combinations
Filter
Applicable strategies
Strategy 1
Strategy 2
Strategy (n)



1. UDS Definition

Infrastructure

Sewerage	Sewer type	Combined or separate	Initial system setup
	Sewage elements	Nodes, conduits, tanks, pumps, CSO and SuDS	
	Wastewater flow	Average wastewater flow	

Institutions

Local authorities	Municipal environmental department	Hydrographic basin planning and management plans at the district or municipal level	Instruments for UDS management
	City hall	Territorial planning plan and disaster risk management plan at the district or municipal level	
	Municipal comptroller	Audits of the provision of the sewerage service at the district or municipal level	
Service supplier	Municipal sewage company	Sanitation and discharge management plan	

Users

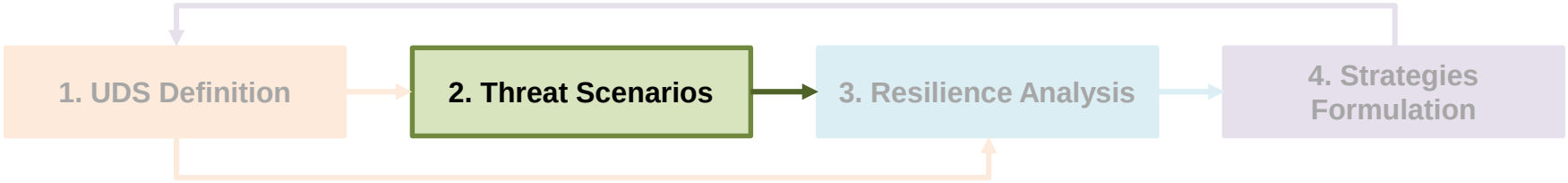
Residential	Population and residential area	User characteristics
Non-residential	Commercial, industrial and institutional area	

Urban Catchment

Basin	Topography	Areas, elevations and slope	Characteristics of urban basin
	Land use	Types of land uses	
	Soil type	Physical properties of soil	
	Imperviousness	Soft and hard zone area	
	Rain events	Return period, intensity and duration	

Flood Regulation Ecosystem Service

Flood regulation	Green areas	Forests, gardens, parks and road separators areas	Ecosystem service characteristics
	Water bodies	Lagoons, rivers, swamps and wetlands areas	



2. Threat Scenarios

Types of threats

- External
  - Natural
    - Natural disaster
    - Climate change
  - Institutional
    - Governance
  - Users
    - Population growth
    - Urban growth
    - Solid waste
- Internal
  - Infrastructure
    - Malfunctioning of one or several elements of the UDS
  - Service supplier
    - Lack of investment
    - Insufficient maintenance

Identify

Threats present in the system

Formulate

Prioritized threat scenarios

Threats

- Damage to one or several elements of infrastructure
- Increase in rainfall intensity
- Reduction of soil perviousness
- Solid waste obstructions

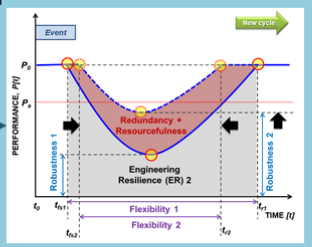
1. UDS Definition → 2. Threat Scenarios → **3. Resilience Analysis** → 4. Strategies Formulation

3. Resilience Analysis

Engineering Resilience (ER)

1. Graph the performance function

$$P(t) = 1 - \frac{F(t)}{I(t)}$$



P(t) : UDS Performance [0,1]
F(t) : Flooding volume
I(t) : Incoming volume in UDS

2. Calculate ER and its factors

- Flexibility
- Resourcefulness
- Redundancy
- Robustness

$$ER = \frac{1}{t_r - t_{fs}} \int_{t_{fs}}^{t_r} P(t)dt$$

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Socio-Ecological Resilience (SER)

1. Measurement of SER indicators → **2. Normalization of SER indicators** → **3. Weighting of SER factors, variables and indicators** → **4. Aggregation of SER factors, variables and indicators**

Normalization methods

- Division by 100 (indicators in percentage)
- Scale categorization (qualitative indicators)

Weight of the factors, variables and indicators obtained through the method of proportional weights

4. Aggregation of SER factors, variables and indicators

$$SER = W_{SOC} \times F_{SOC} + W_{ECO} \times F_{ECO}$$

SER : Socio-Ecological Resilience [0,1]
F_{SOC} : Social factor
F_{SOC} : Ecological factor
W_{SOC}: Social factor weight
W_{ECO}: Ecological factor weight

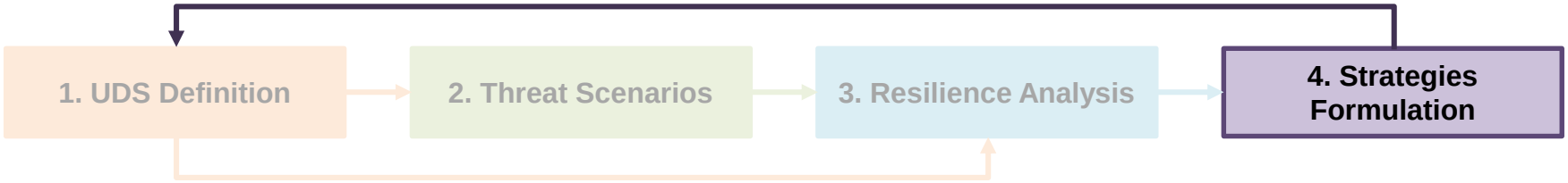
Weighted Sum Method (WSM)

$$V_j = \sum_{i=1}^{n} W_i \bar{I}_i$$

V_j : Variable *j* [0,1]
W_i : Indicator weight *i*
$\bar{I}_i$: Normalized indicator *i*
n: Total number of indicators within the variable *j*

$$F_{SE} = \sum_{j=1}^{m} W_j V_j$$

F_{SE} : Socio-Ecological factor [0,1]
W_j : Variable weight *j*
m : Total number of variables within the factor *k*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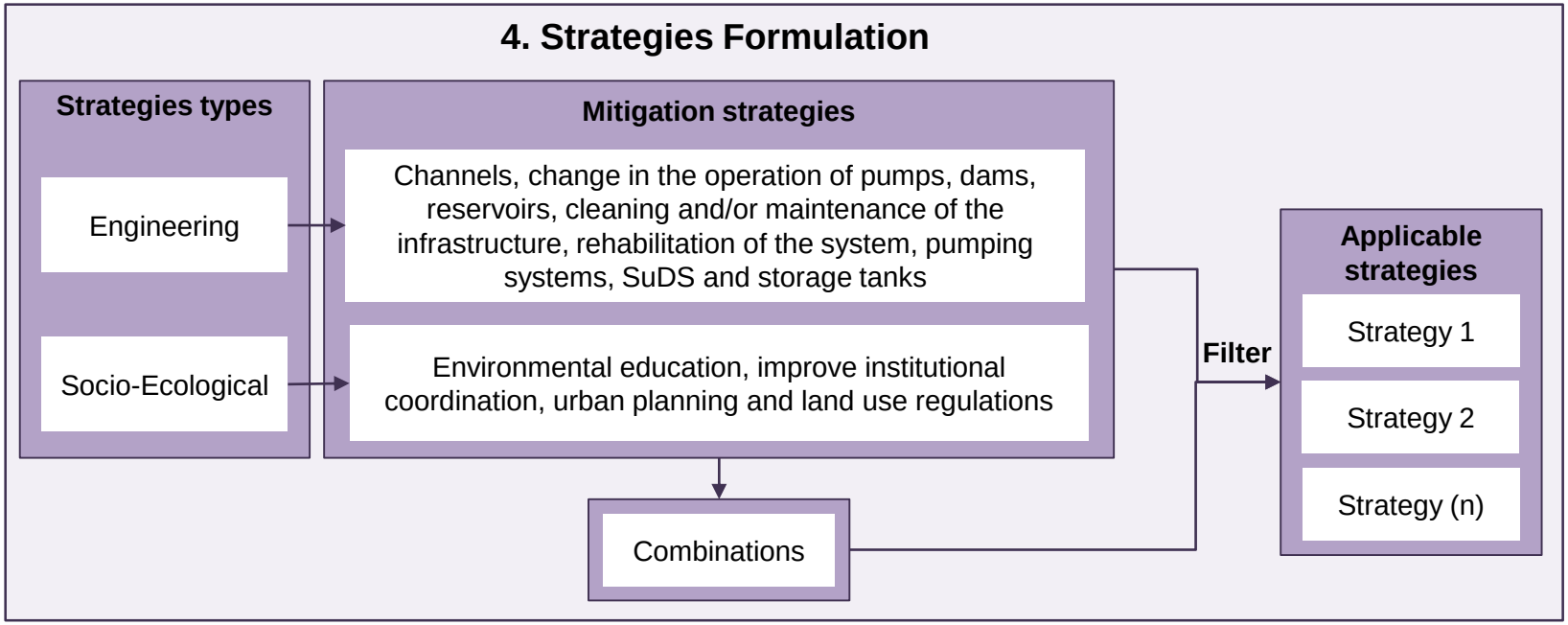
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