# An interdisciplinary approach to analyzing vulnerability in freshwater social-ecological systems

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## Conceptual Foundation

- Sustainability under increasing anthropogenic pressures and uncertain climate futures requires **interdisciplinary approaches to problem solving**.
- We envision a hierarchical approach for analyzing social-ecological systems (SES) by applying it to water-centric resource management.
- SES complexity is conceptualized here as a multi-functional hierarchy of decision systems comprised of distinct organizational levels:
- **Ecosystem** provides goods and services
- **Operational** and **Community** domains operate through direct interaction (i.e., monitor and use).
- **Institutional** level consists of members who regulate the operation and use of water resources
- **Policy** level has the ability to grant or restrict rights and change the regulating responsibilities of the institutional level

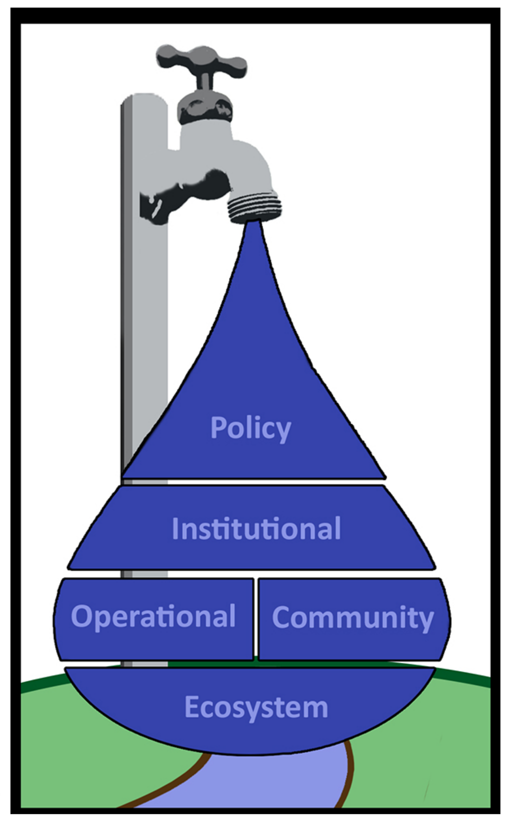
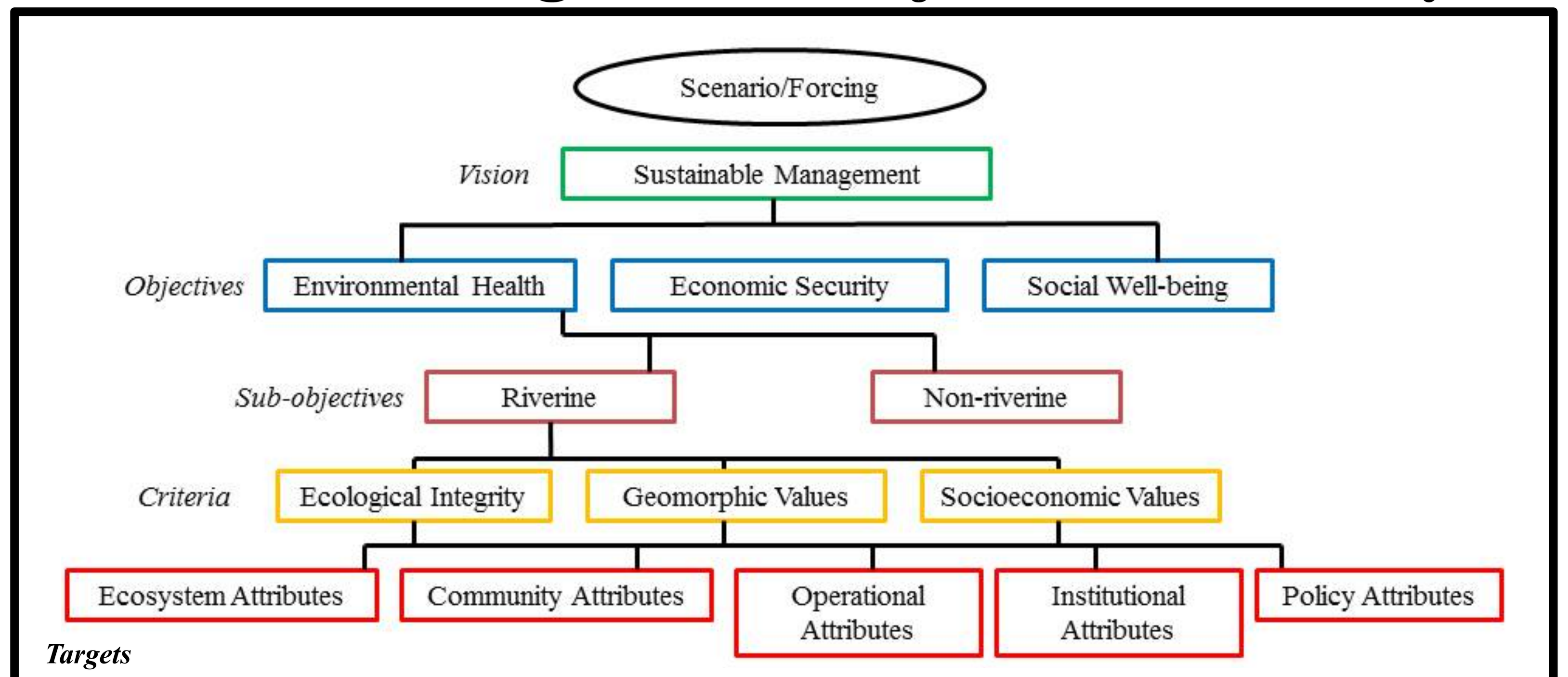



*Figure adapted from Ciriacy-Wantrup and Bishop (1975)*

## Decision aiding with an objectives hierarchy

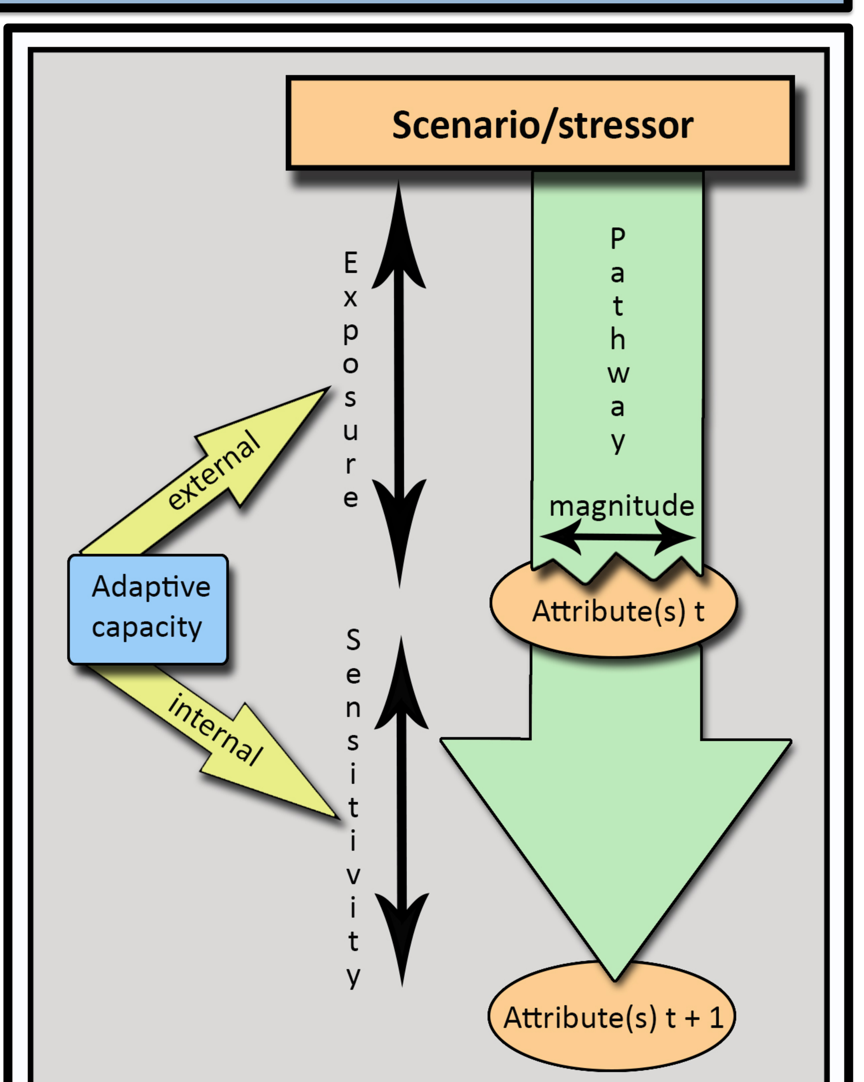



## Methods

We present a framework for assessing vulnerability of important SES attributes through a characterization of its **exposure**, **sensitivity**, and **adaptive capacity**.

Attributes within a SES are exposed to a specific scenario or stressor through distinct pathways resulting in time-sensitive responses and feedbacks.

Interest lies in understanding which attributes are most vulnerable and may be influential variables to consider in decision analyses for assessing potential changes in SES functionality.




## Example Application

Here we use qualitative explanatory variables to characterize each attribute's exposure, sensitivity, and adaptive capacity as pertains to the scenario of interest:

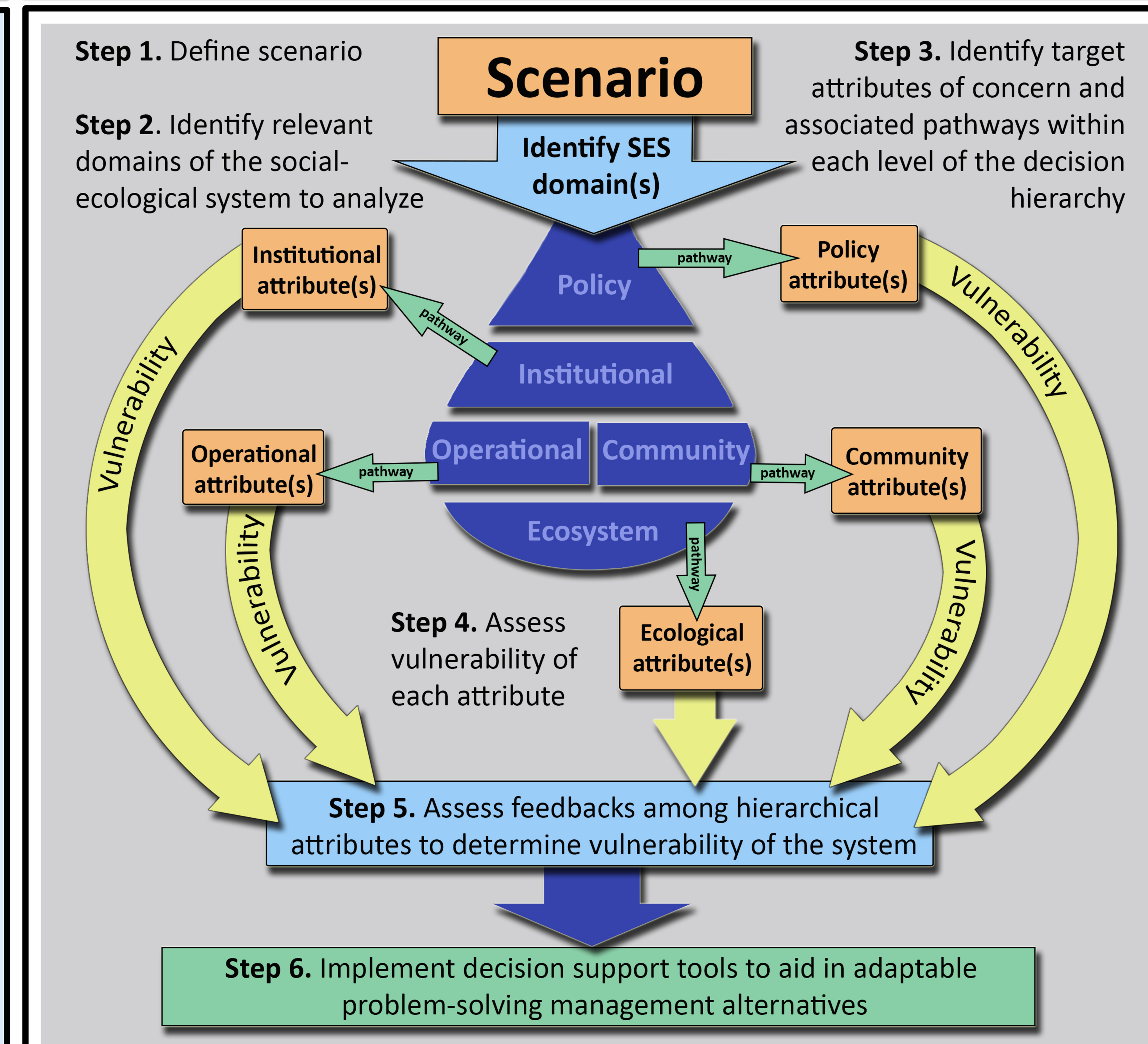
**Scenario: Increased instream flow variability due to proposed irrigation and water supply project**

| | | Definition | Ecosystem Variable Rubric | Community Variable Rubric | Operational Variable Rubric | Institutional Variable Rubric | Ranking |
|---|---|---|---|---|---|---|---|
| Attribute | | Desirable system component | Instream Habitat | Whitewater Boating | City Water Quality Standards | Meeting Beneficial Use Water Rights | |
| Pathway | | Mechanism(s) by which scenario affects the attribute | Min. base flows, peak flows, min. temperature | High flows | Instream nutrient loading | Instream flow availability | |
| Exposure | Magnitude | | Low: Within historical range of variability | Low: Flow depth within historical range of variability | Low: Concentrations below future TMDL standards | Low: Fulfills beneficial use allocations | 0 |
| | | | Medium: Exceeds 50% of historical range of variability | Medium: Flow depth below 50% of historical range of variability | Medium: Concentration exceeds standards within an order of magnitude | Medium: Fulfills senior rights | 1 |
| | | | High: exceeds 75% of historical range of variability | High: flow depth below 75% of historical range of variability | High: concentration exceeds future TMDL standards by orders of magnitude | High: does not fulfill senior rights | 2 |
| | Duration | | Short: magnitude of change persists in hours-day | Short: magnitude of change persists in hours-day | Short: no or brief exceedence of TMDL standards | Short: no or brief (1-year) interruption | 0 |
| | | | Intermediate: magnitude of change persists in days-weeks | Intermediate: magnitude of change persists in days-weeks | Intermediate: exceedence persists for days | Intermediate: allocations interrupted for a year | 1 |
| | | | Long: magnitude of change persists in weeks-months | Long: magnitude of change persists in weeks-months | Long: exceedence persistent/chronic | Long: persistent/ chronic interruption of water allocations | 2 |
| Sensitivity | | Degree of change in system attribute that may result from scenario forcings. | Low: stable system, resilient to external forcing | None: no disruption of summer whitewater visitor days | Low: existing BMPs and current treatment plans meet regulatory standards | None: sufficient storage capacity and transferability fulfills all water allocations | 0 |
| | | | Medium: moderate stability, structure, function | Moderate: moderate change in visitor days | Medium: uncertainty in current operations to meet some regulatory standards | Moderate: sufficient storage capacity and transferability fulfills senior water allocations | 1 |
| | | | High: unstable, low resiliency | Extreme: early end of whitewater recreation season | High: existing BMPs and current treatment plans unable to meet regulatory standards | Extreme: insufficient storage capacity and/or transferable right to meet water allocations | 2 |
| Adaptive Capacity | | Ability to mitigate the degree of exposure or sensitivity of each attribute, thereby maintaining functionality of the system | Low: no process-based resources and restoration infrastructure to maintain habitat | Low: in-sufficient ability of business management to accommodate changing | Low: in-effective local BMP and technologies | Low: resources and future planning alternatives are not available | 0 |
| | | | Moderate: limited process-based resources and/or restoration | Moderate: limited ability of business management planning efforts | Moderate: limited resources are available to mitigate | Moderate: resources and planning alternatives limited | 1 |
| | | | High: stream restoration able to maintain habitat structure and function | High: ability of business management to accommodate changes and water rights available | High: local BMP and technologies are able to respond to future changes | High: existing resources and planning are able to mitigate future changes | 2 |

- We are currently developing an approach to systematically characterize attributes into meaningful qualitative variables that capture important dimensions of each hierarchical level.
- We quantify an overall vulnerability score (*Exposure*Sensitivity-Adaptive Capacity*) using the following scale:

| Vulnerability Score | Importance | Vulnerability Description |
|---|---|---|
| 0 | None | Attribute is not vulnerable to external or internal pressures. |
| 1 | Weak | The functionality of the attribute is weakly affected by external or internal pressures. |
| 2 | Moderate | The functionality of an attribute is moderately susceptible to external or internal pressures. |
| 3 | Strong | Scenario forcings are likely to degrade an attribute's functionality into an undesirable/impaired state. |
| 4 | Extreme | Attribute highly susceptible to scenario forcings. Management actions critical to sustaining attribute functionality. |

## Flow Chart




## Alternatives Analysis

**Quantitative**: Input vulnerability scores into an *integer programming solver,* incorporating feedbacks to identify inter and intra-level hierarchical constraints.

- Collaborate with stakeholders to identify desirable attributes, known feedbacks, and key constraints to assess sustainable management actions for a given scenario.

**Qualitative**: Use *multi-criteria decision analysis* (MCDA) methods to evaluate system functionality under alternative management actions.

- Work with stakeholders to assign priority weights and/or thresholds of potential concern.
- Tailor MCDA methods to meet stakeholder requirements and goals.
- Evaluate alternative management options using MCDA.

## Future Directions and Expectations

We anticipate that this framework will provide decision makers with a *useful structure for framing interdisciplinary water resource problems*. This particular focus evaluates key attributes within the hierarchical context of the broader SES. Our next steps are to *collaborate with stakeholders in on-the-ground research projects* that identify objectives, criteria, and desirable system attributes and *develop spatially-explicit decision support tools* to advance sustainable management of freshwater SES.

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**References**

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