UNIVERSITÉ LAVAL

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# HEM FOR RIVER BASIN MANAGEMENT

## OUTPUTS AND PERFORMANCE INDICATORS

PROF. AMAURY TILMANT
DÉPARTEMENT DE GÉNIE CIVIL ET DE GÉNIE DES EAUX

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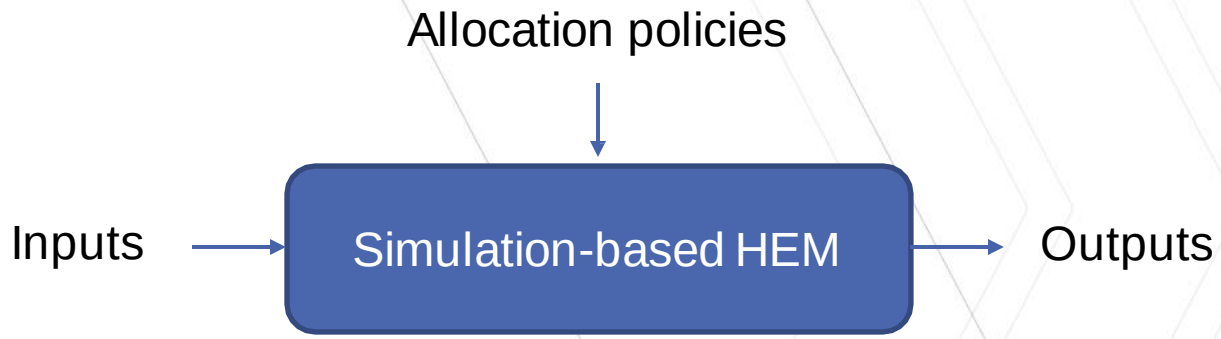
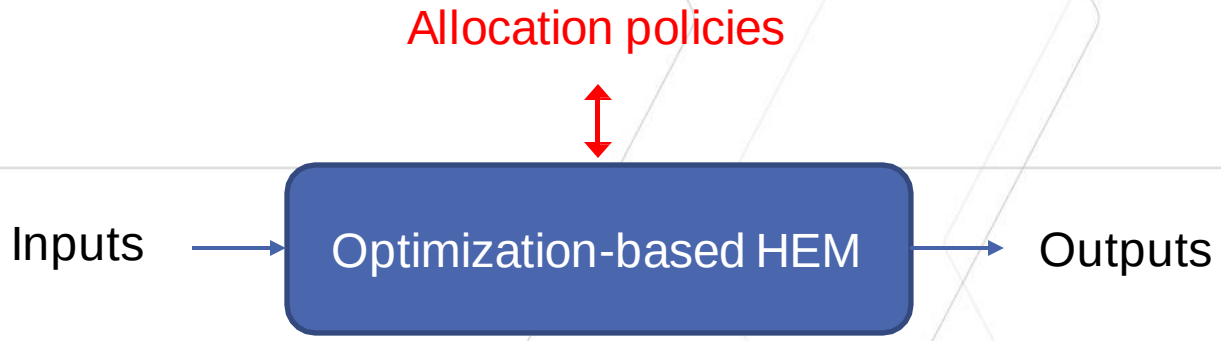
ITALIAN AGENCY FOR DEVELOPMENT COOPERATION

# RIVER BASIN MANAGEMENT

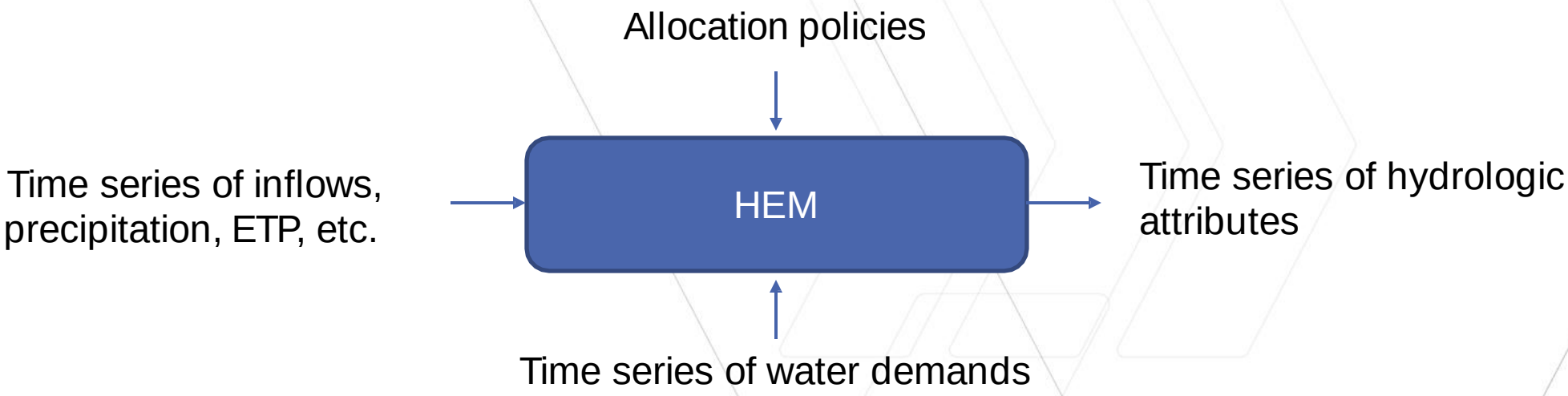
- Two categories of modeling tools: optimization versus simulation



# OUTPUT

- Output = time series of hydrologic attributes (flows, storages, pollutants, …)

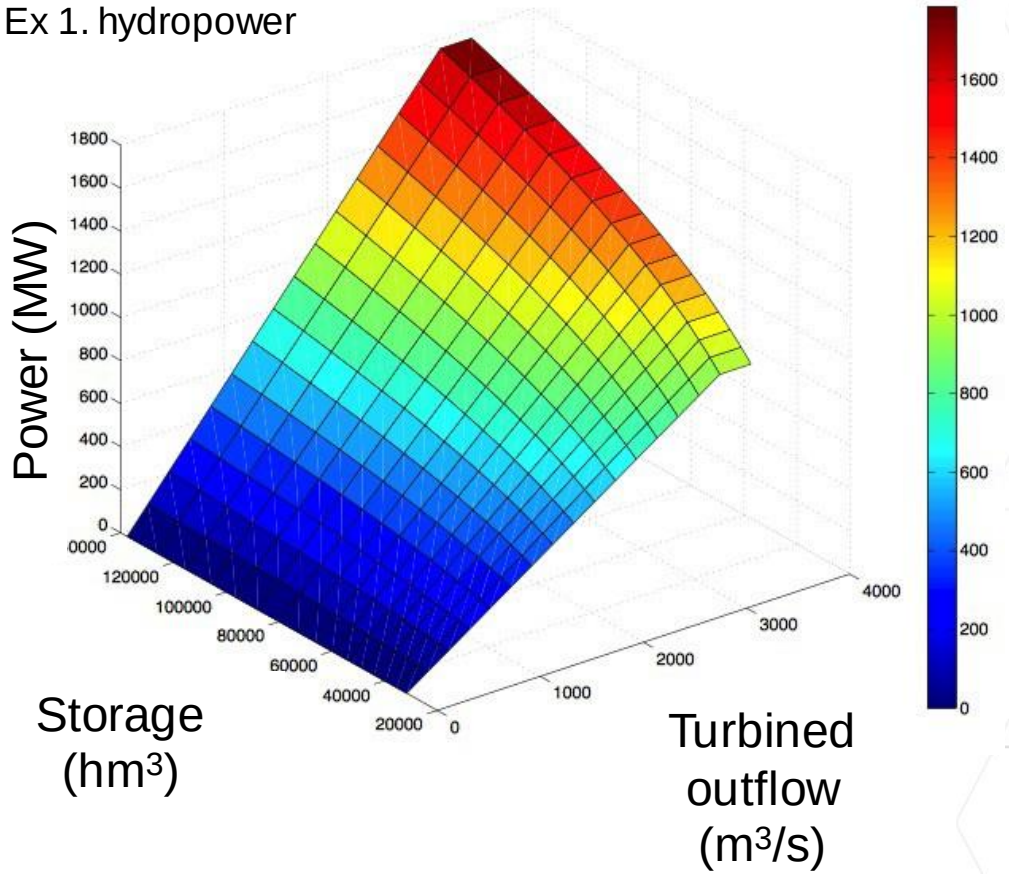



- To assess the performance of the water resources system, we need to transform the time series of hydrologic attributes into time series of performance indicators (energy, crop production, industrial production, navigation, fisheries, etc.)

# HEM OUTPUT → PERFORMANCE INDICATOR

- Relationship between the performance indicator and at least one hydrologic attribute

Ex 1. hydropower



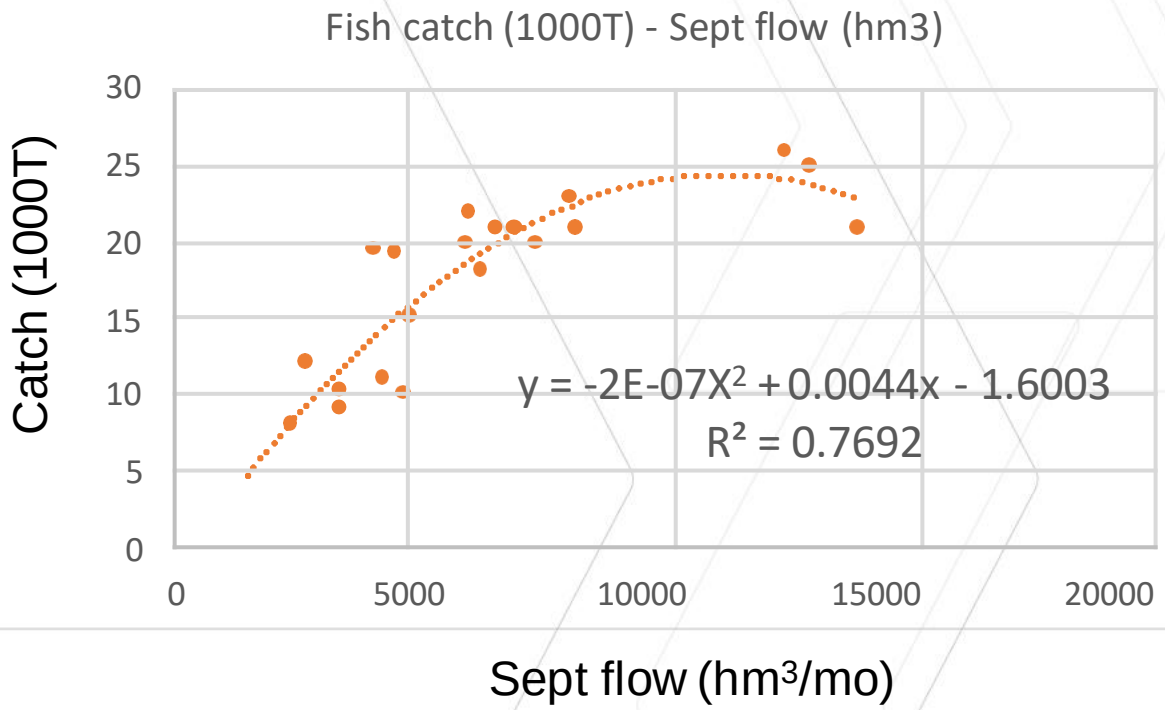

$$P = \rho g h r \in$$

P = power (Watt)
ρ = density (kg/m³)
g = gravity (m/s²)
h = head (m)
r = outflow (m³/s)
ε = efficiency (-)

# HEM OUTPUT → PERFORMANCE INDICATOR

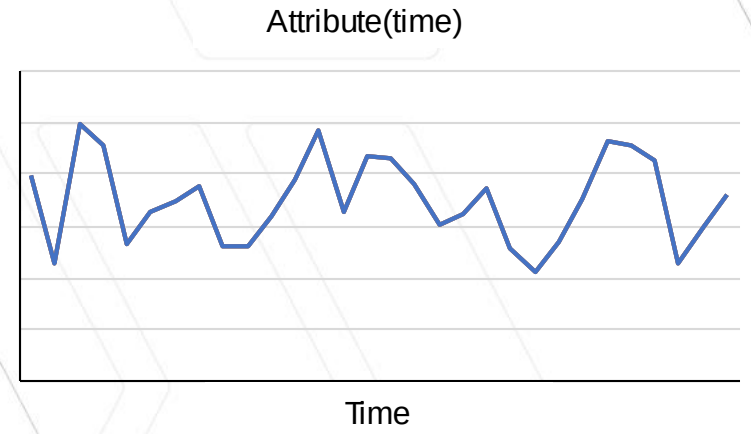
- Relationship between the performance indicator and at least one hydrologic attribute

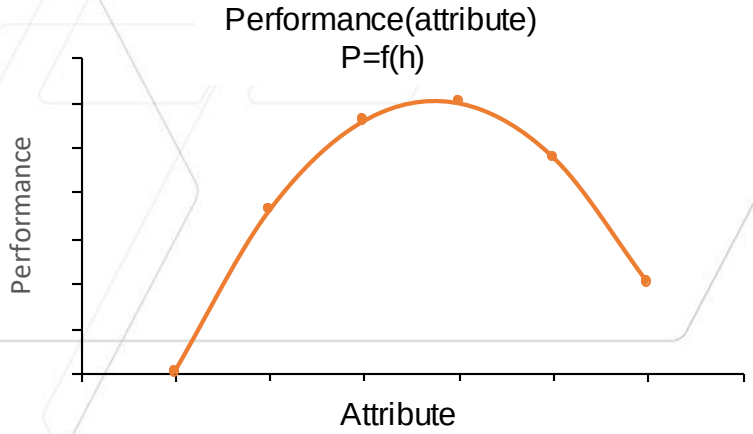
Ex 2. Fisheries



# HEM OUTPUT → PERFORMANCE INDICATOR

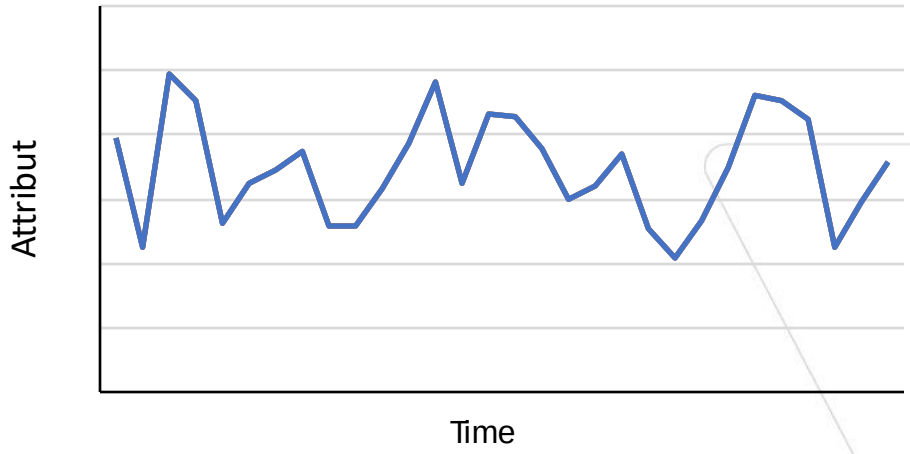
- Simulate water allocation policies over a planning period of several years
- Output = time series of hydrologic attributes $h_t$
  - **Flow**
  - **Storage**
  - **Concentration**
- Performance indicator *P* for each operating objective
  - **Functional relationship between $P_t$ and $h_t$**



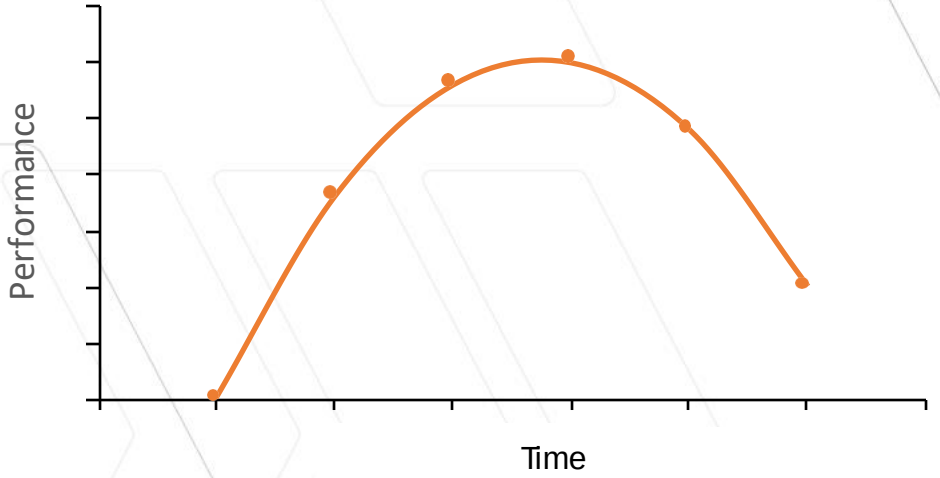



# HEM OUTPUT → PERFORMANCE INDICATOR

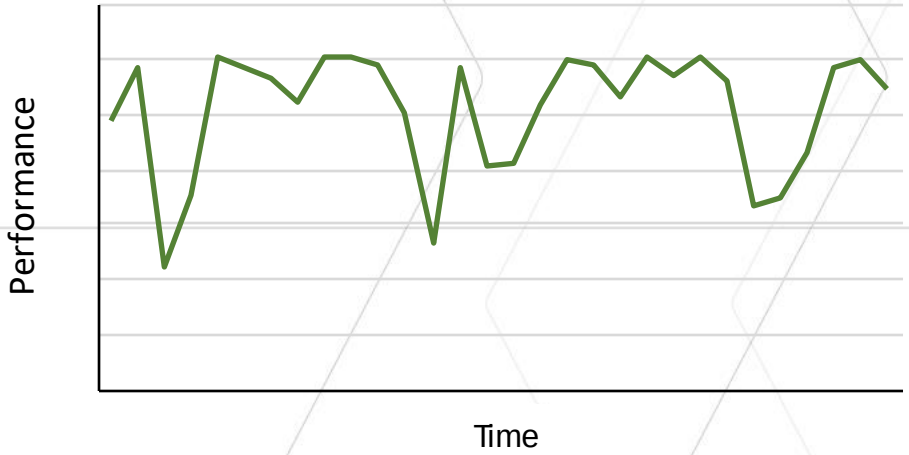
Attribute(time) $\{h_1, h_2, \ldots, h_T\}$




Performance(attribute) $P = f(h)$




Performance(time) $\{P_1, P_2, \ldots, P_T\}$



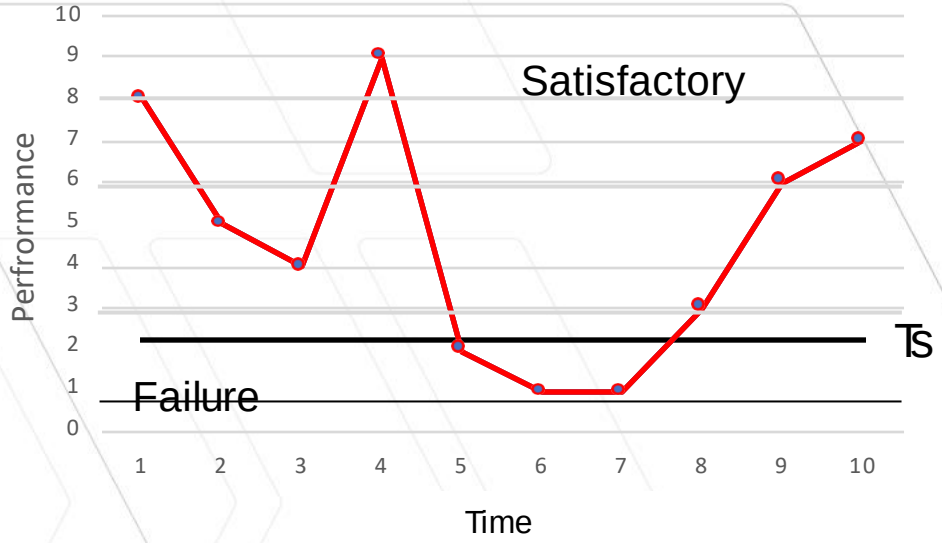
# RISK-BASED INDICATORS

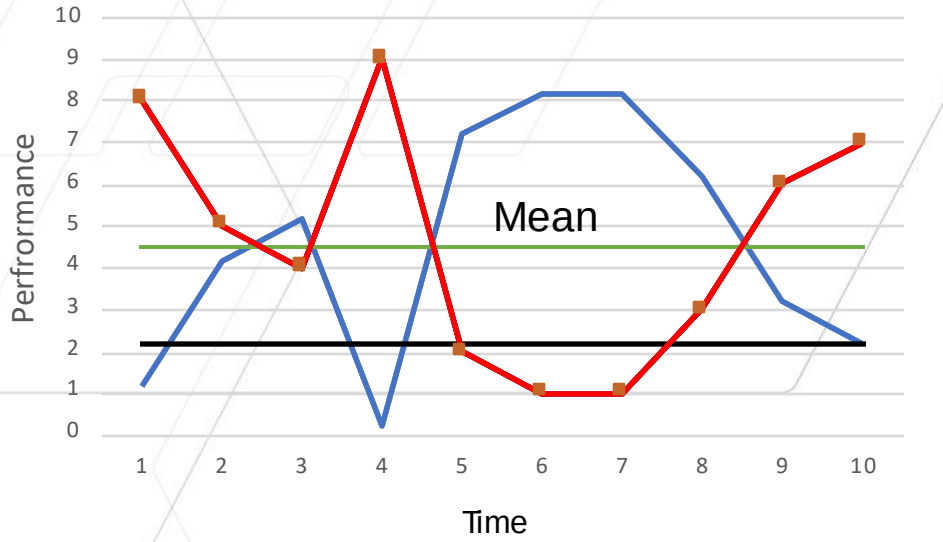
- Time series of a performance indicator

$$\{P_1, P_2, \ldots, P_T\}$$

- Threshold Ts
  - **If performance ≥ Ts → ok**

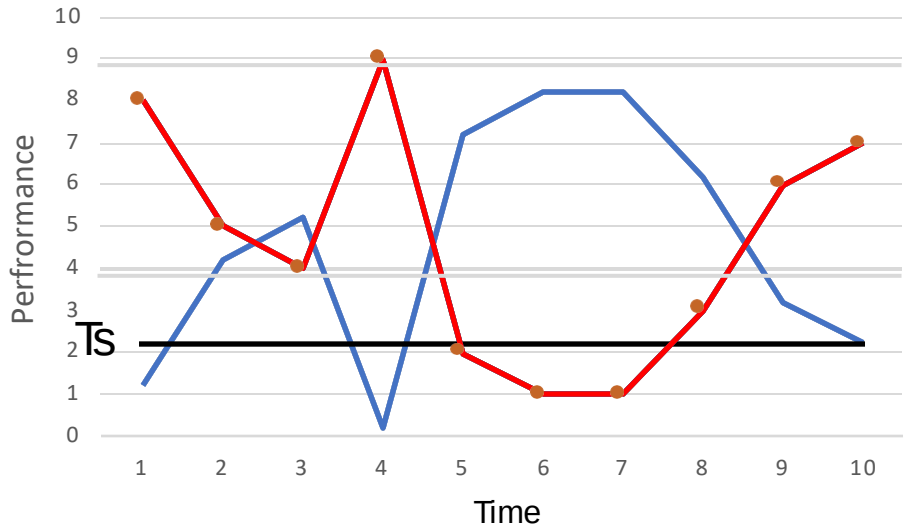
- Taking the upside-down image with respect to the mean, we get the blue curve
- Both time series have the same mean (4.6) and standard deviation (2.7)



# RISK-BASED INDICATORS

- Reliability
  - **How often does system fail?**
  - **Probability of being in a satisfactory**




$$\text{Reliability} = Pr\,(P_t \geq Ts)$$

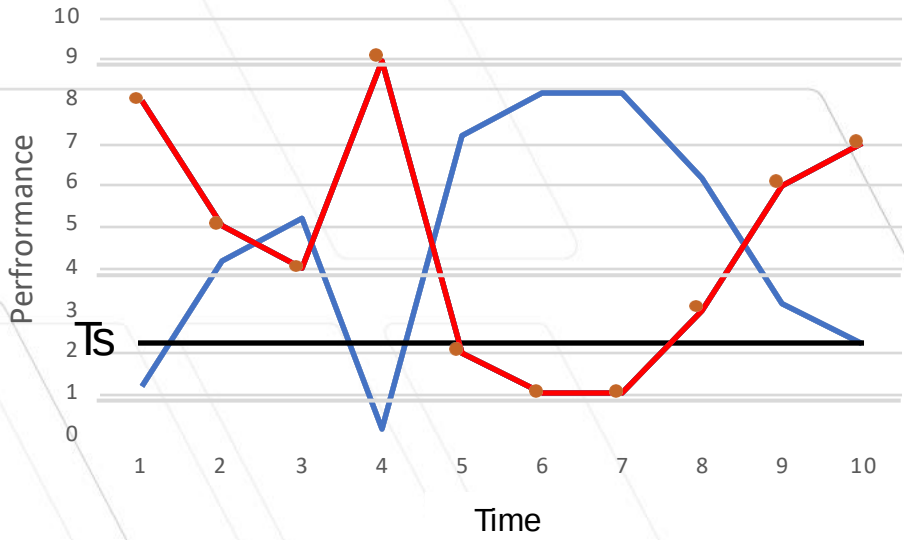
Risk = 1 - reliability

| Time | Red | Blue |
|---|---|---|
| 1 | 8 | 1.2 |
| 2 | 5 | 4.2 |
| 3 | 4 | 5.2 |
| 4 | 9 | 0.2 |
| 5 | 2 | 7.2 |
| 6 | 1 | 8.2 |
| 7 | 1 | 8.2 |
| 8 | 3 | 6.2 |
| 9 | 6 | 3.2 |
| 10 | 7 | 2.2 |

# RISK-BASED INDICATORS

- Resilience
  - **How quickly does system recover from failure?**
  - **Probability to move from unsatisfactory state at time t to a satisfactory state at time t+1**

$$Resilience = Pr(P_t \geq Ts | P_{t-1} < Ts)$$




| Time | Red | Blue |
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| 1 | 8 | 1.2 |
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| 10 | 7 | 2.2 |

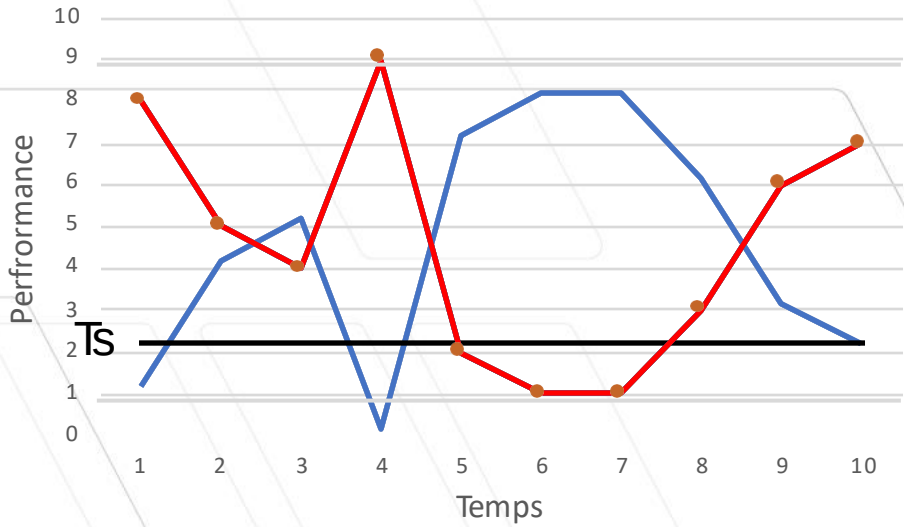
- What is the resilience of the two time series (red et blue)?

# RISK-BASED INDICATORS

- Vulnerability
  - **Measures the extent of failure**

$$Vulnerability = \frac{\sum_{t=1}^{T} \max(Ts - P_t, 0)}{Pr(P_t < Ts) * T}$$

- What is the vulnerability of the two series?




| Time | Red | Blue |
|---|---|---|
| 1 | 8 | 1.2 |
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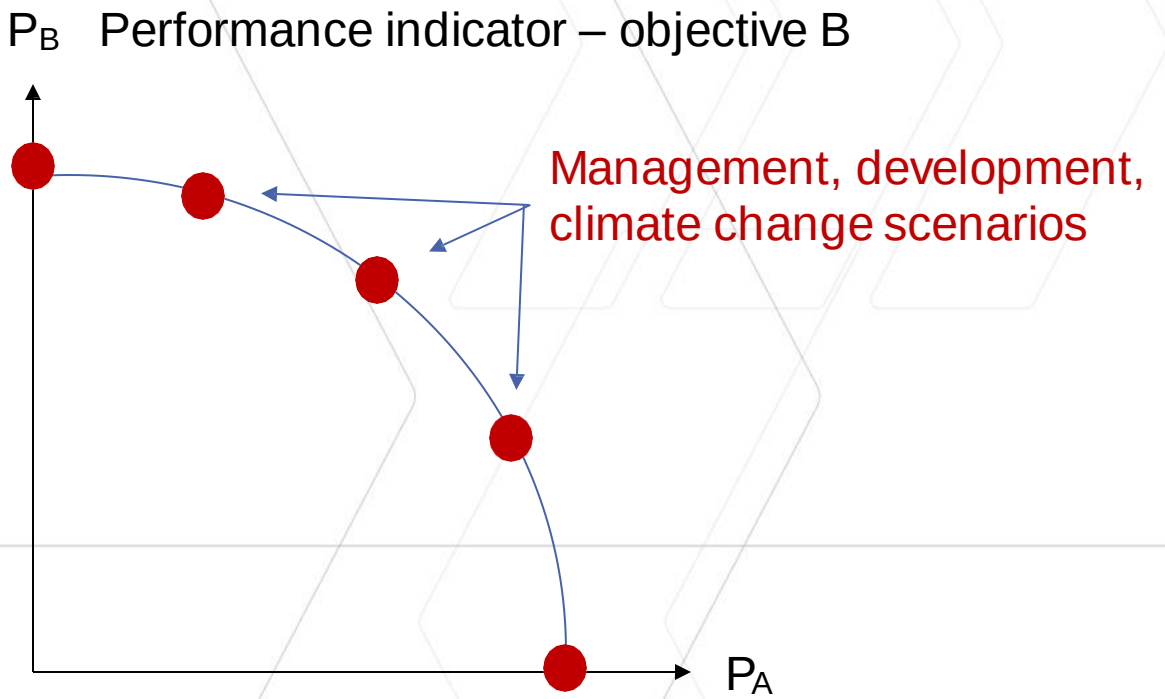
# TRADE-OFFS VISUALIZATION

- Water resources management often involves conflicting objectives
- Important to discover trade-offs between multiple objectives
- For two-dimensional problems (objectives A and B), a trade-off curve can be traced out after interpolating between Pareto optimal solutions in the objective space



# TRADE-OFFS VISUALIZATION

- In a parallel-coordinate plot, the *N* objectives are displayed as *N* equally-spaced vertical lines (axes) such that a point in the N-dimensional space is actually a line crossing the vertical axes at the value corresponding to the performance
- Example: Senegal River Basin