Integrated Flood Management: Data, Models, and AI - Uncertainty and Knowledge

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Water Scarcity Challenges

• Water Scarcity Challenges • Freshwater shortage • Population growth • Quality degradation • Impacts on stability & economy	• Criticality in Semi-Arid to Arid Regions • High vulnerability • Social & economic stress • Environmental fragility

Dual Nature of Water

- Essential good
- High-risk hazard
- Increasing threats globally

Climate-Induced Water Hazards

- Droughts
- Floods
- Pollution
- Water quality degradation

Climate-Floods: A Global Challenge

- Most widespread natural disaster (≈37%)
- Increasing frequency & intensity
- Heavy socio-economic losses

Dam Breaks

- Mechanical failure
- Man-made or natural causes
- High-risk flood category

Limitations of Classical Approaches

- Dams, levees, dykes
- Watershed management
- Focus on prevention

Human Activities & Flood Risk

- Urbanization
- Land-use changes
- Poor planning
- Questions on interactions

Societal Responses

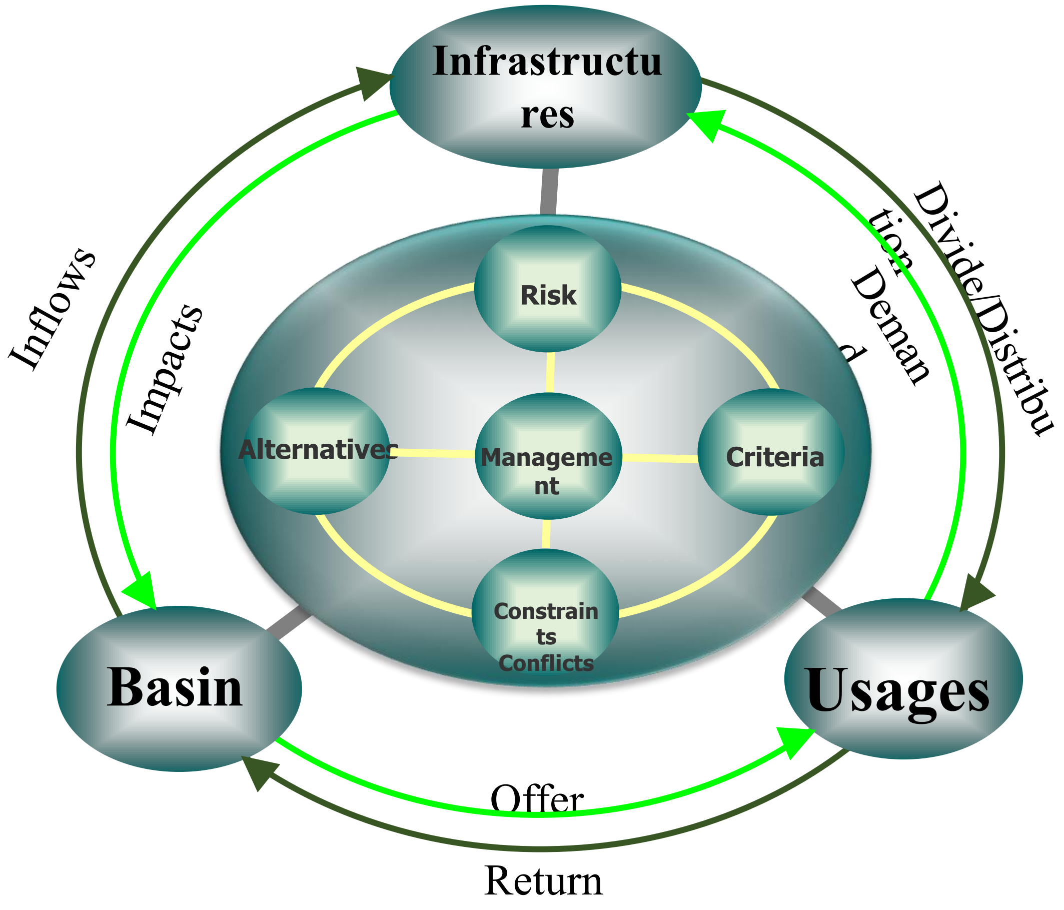
- Perceptions differ
- Political processes
- Local issues shape decisions

Early Warning Importance

- Accurate & timely alerts
- Essential for evacuation
- Reduces losses

IFM/IWRM - Components

Climatic Context



Socio-Economic
Environment/ Context

IWRM/IFM Features

- Data of stochastic nature
- Data is Spatial
- Multi-sources scalar/spatial datasets, Multi-Scale, Multi-Models (physic-chemico-biological processes, deterministic/stochastic)
- Heterogeneous data-formats and standards
- Large simulations are becoming unavoidable tackling all the scientific aspects at multiple scales
- The advent, speed of progression and acceleration of conventional and generative AI

The Transfer Paradigm

- Inputs (Data)
- Processes (Models)
- Outputs (Results)
- Traditional engineering approach

The Transfer Paradigm Cont.

Input (s) → Causes → **Model system** → Effects → **Output (s)**

Uncertainty levels

- **Input data and parameters**
- **Model abstraction**
- **Domain configuration**
- **Initial and boundary conditions**
- **Computational model**
- **Hardware used**

Hydrological & Hydraulic Models

- Foundation of flood forecasting
- Require long-term calibration
- Data-dependent

AI as a Complementary Tool

- Enhances predictions (Need for faster and more reliable forecasts)
- Handles heterogeneous data
- Supports rapid decision-making
- AI as a complement to hydrology and hydraulics
- Extreme climate chocs
- Contamination
- Cyberattacks

AI Advantages

- Integration of sensors, satellite, forecasts
- Better drought/flood predictions (Data matters)
- High-resolution risk mapping
- Faster than traditional models
- Handles large and complex datasets
- Effective for flash floods

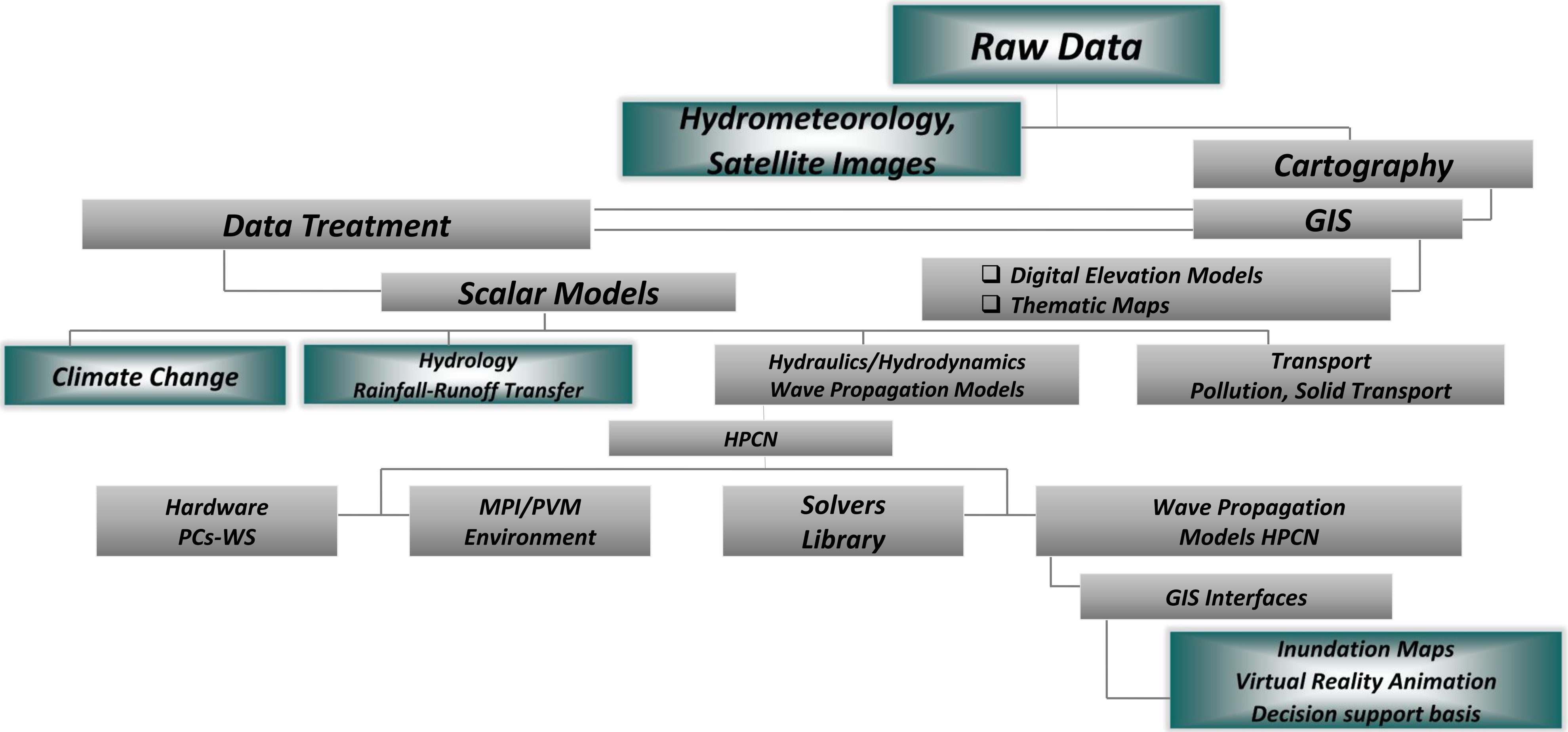
AI Advantages for Ungauged Basins

- Improved forecasts
- Early warnings
- Wider coverage

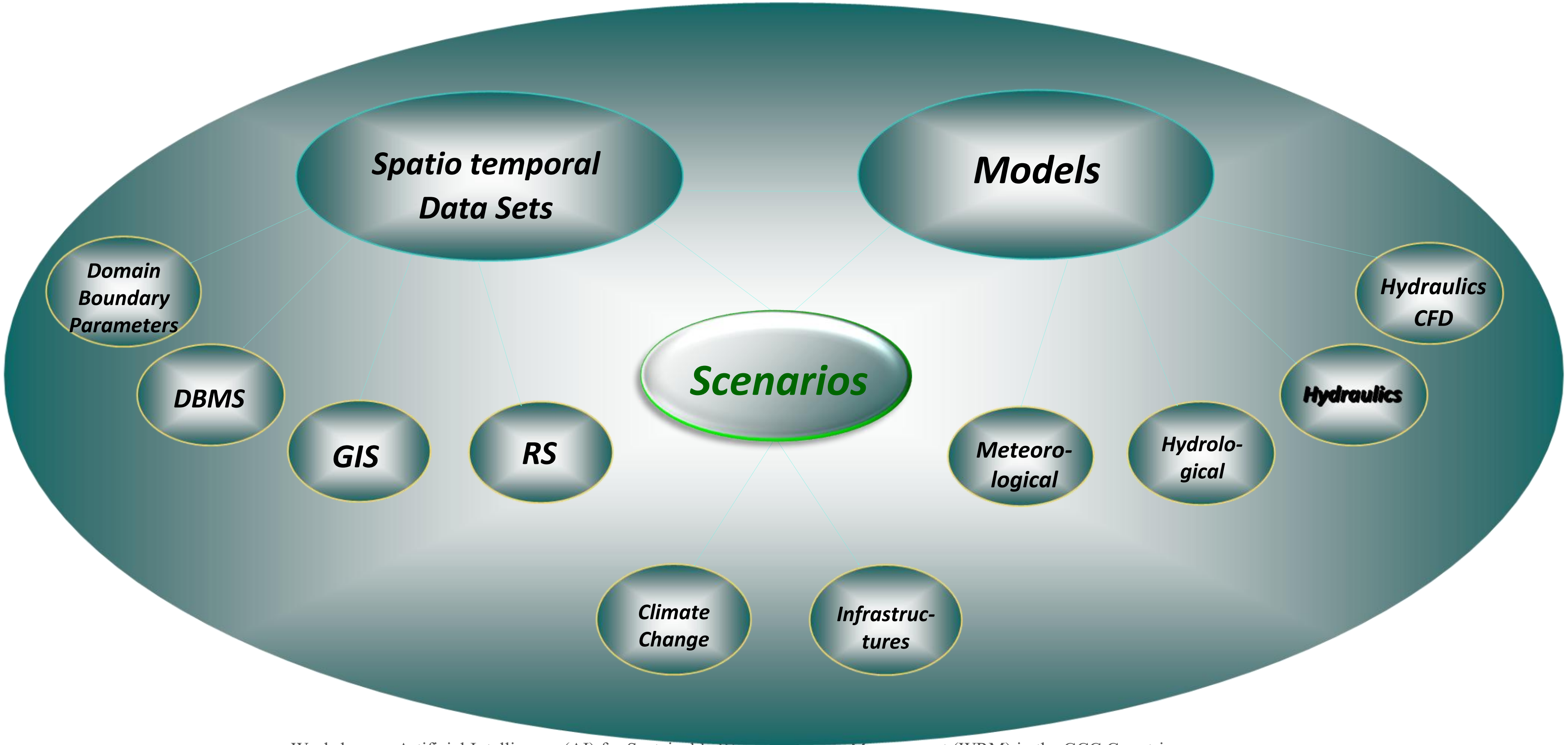
Integrated Flood Management AI impact

- Data / Big Data
- Models
- Uncertainty
- Knowledge

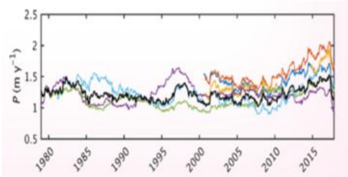
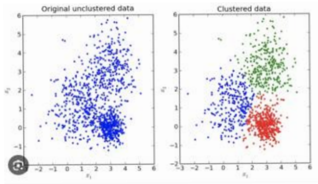
Global Vision



IFM – Computational Aspects



AI Supply Chain: Several Angles for Using the Models (Provided Enough Reliable Data)

PAST	PRESENT	FUTURE
Time Series Patterns/Clusters   	Current time Behavior	Insight of Projections Forecasts

Data Exploited by AI for Flood Forecasting

- Rainfall: radar, satellites, gauges
- River flow and water levels
- Topography (DEM, LiDAR)
- Land use and urban drainage data
- Satellite images (optical & SAR)
- Historical flood records

AI Models for Flood Forecasting

- Machine Learning: Random Forest, Gradient Boosting
- Deep Learning: ANN (Artificial Neural Networks), LSTM (Long Short-Term Memory networks) for rainfall–runoff
- Fast prediction of river levels and flood probability
- Suitable for real-time early warning

Inundation Mapping with AI

- Deep learning (Convolutional Neural Networks CNNs) for flood detection from satellite image
- Rapid estimation of flood extent and depth
- AI surrogates replacing slow 2D hydraulic models
- Near real-time flood maps

Early Warning & Decision Support

- Probabilistic flood forecasts
- Impact-based warnings (population, infrastructure)
- Support to emergency response
- Loss and damage responses (Insurance companies)
- Reservoir and urban drainage operation optimization

Key Challenges/Limitations for AI

- Sparse networks
- Data dependency
- Data gaps
- Poor historical records
- So-called Data Driven Models
- Need for hybrid AI–physics approaches
- Cost

AI applications for water as a good or as a risk: A great asset

- Governance and sustainable water use
- Management actions with stakeholders engagement, share ownership and higher acceptance)
- Augmented models with scenarios and impacts- Data to Results
- Making Complex Models Understandable
- Monitoring and geospatial Databases (Data, Meta Data Foundation, Reliability, Accessibility, Transparency, Water Data)
- Guidelines development and capacity building enhancements.

Other AI Outputs for Water Management

- Transparency
- Accountability
- Public Engagement
  - Real Time Dashboards for communicating results (Citizens)
  - Explaining Decisions through interpretable Models

Open Issues

- Regulation gaps
- Water usage in data centers
- Water usage for hydrogen production
- Trade-offs (cost/performance/environment)
- Climate uncertainty
- Geographic inequity

Concluding Remarks: Water as a Good or as a Risk

- Climate has changed: OBSERVATIONS – INTERNATIONAL BODIES
- Climate will continue to change: INTERNATIONAL BODIES (IPCC, World Bank, FAO, etc.)
- Climate requires change at all levels (citizens, society, education, R&D, governance, management, planning, Intensive integration and exploitation of AI paradigms)

Thank You