# Strengthening Flood Forecasting in ASEAN Member States through Regional Trainings and Coordination

## *Hydrological Processes and Modeling*

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Centre
Under the auspices
of UNESCO

ICHARM
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PWRI
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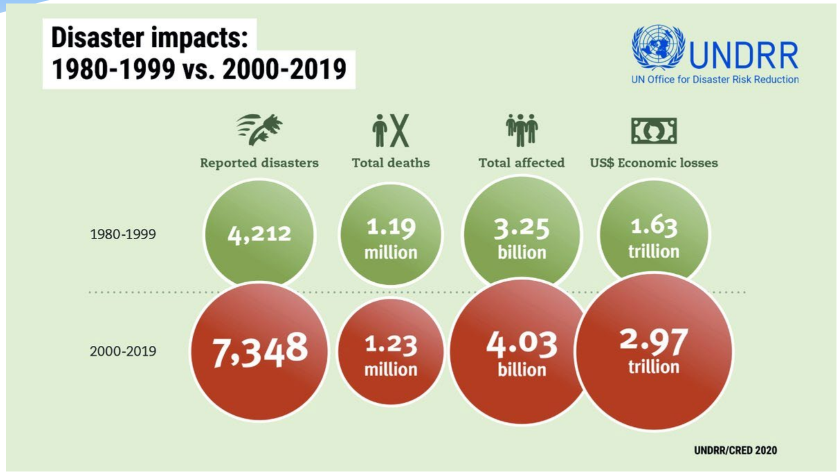
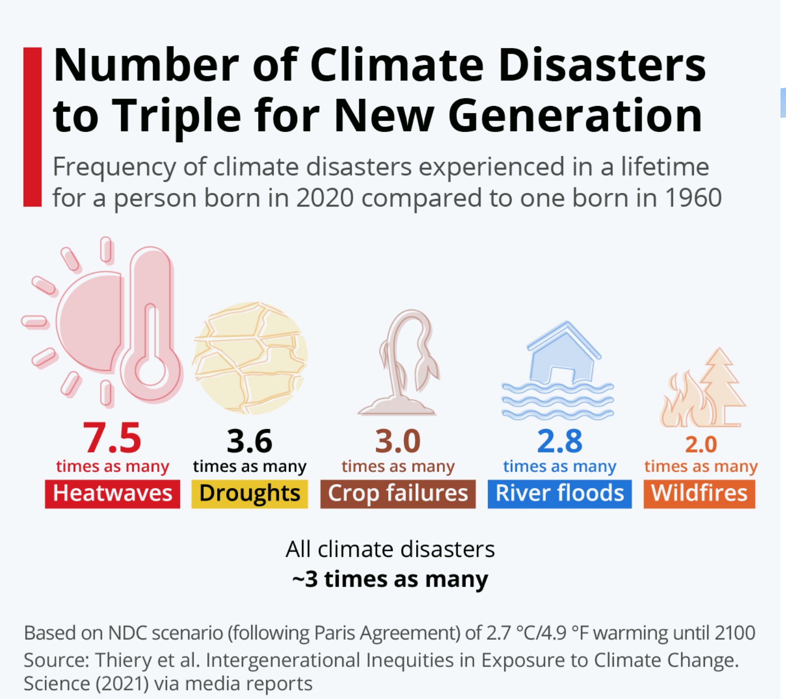
# Background




**water-related disasters show an increasing trend, particularly the developing countries becoming more vulnerable.**

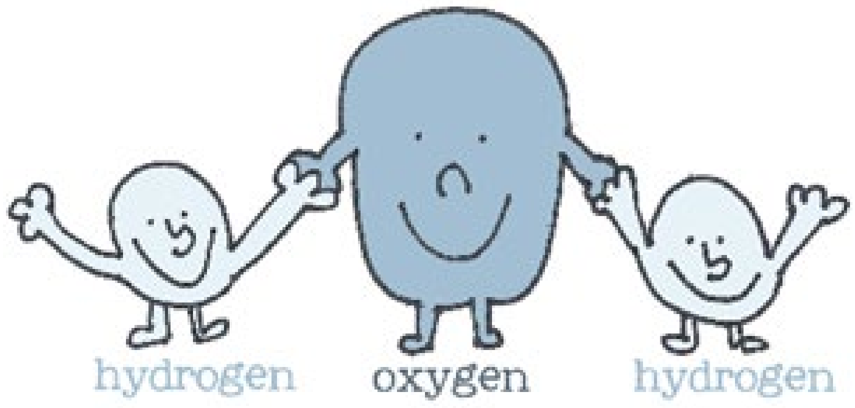


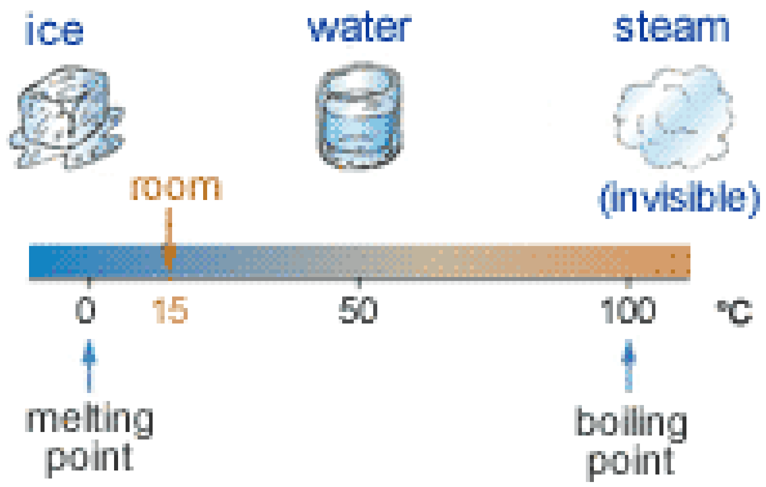

**<u>IPCC AR6 - Flood and drought will be more frequent and severe in the years to come)</u>**

How can we, the hydrological science community, help the world move to a sustainable and resilient path under climate change?

The future is uncertain. However, we need to produce and share reliable & actionable information on water-related disaster resilience and sustainable development goals, food, energy, urban and ecosystem.

# WATER




Water is unique

it is the only natural substance that is found in all three physical states

Liquid, Solid, and Gas

at the temperatures normally found on Earth.

# WATER

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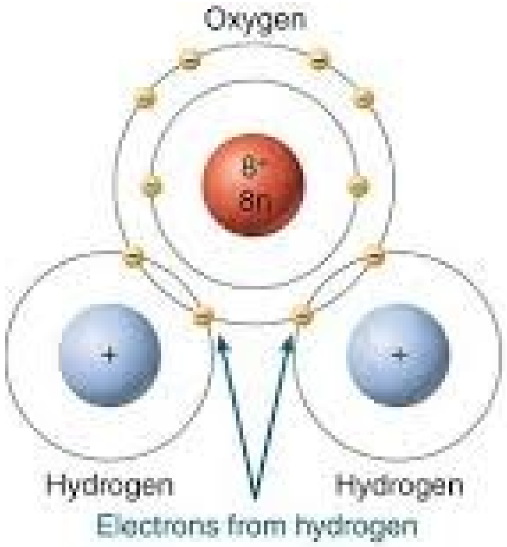
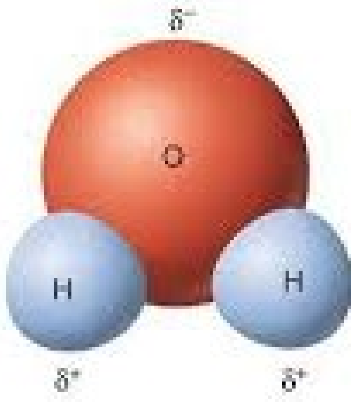
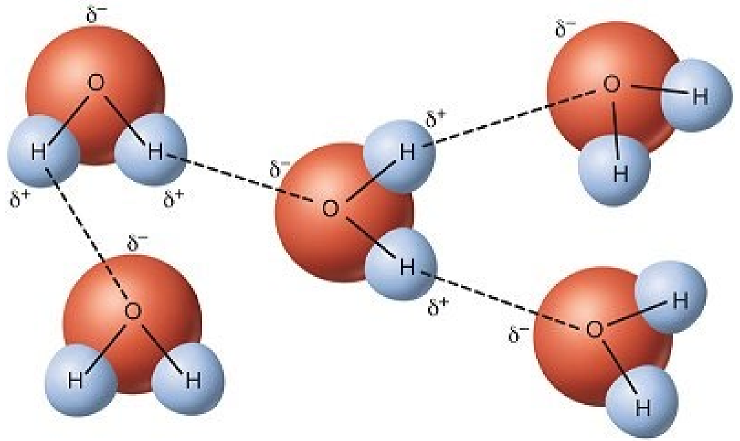
The properties of water arise from
- ✓ properties of water molecules
- ✓ their arrangement
- ✓ functions



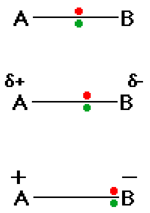

(a) Electron shells in a water molecule




(b) Distribution of partial charges in a water molecule




**Extraordinary Properties that are a result of hydrogen bonds.**




- No electronegativity difference between two atoms leads to a pure non-polar covalent bond.
- A small electronegativity difference leads to a polar covalent bond.
- A large electronegativity difference leads to an ionic bond.

# Hydrology

Hydrology is a field which covers the entire history of the cycle of water on the earth.

Hydrology is the science which deals with

the waters of the earth,

their occurrence, circulation and distribution on the planet,

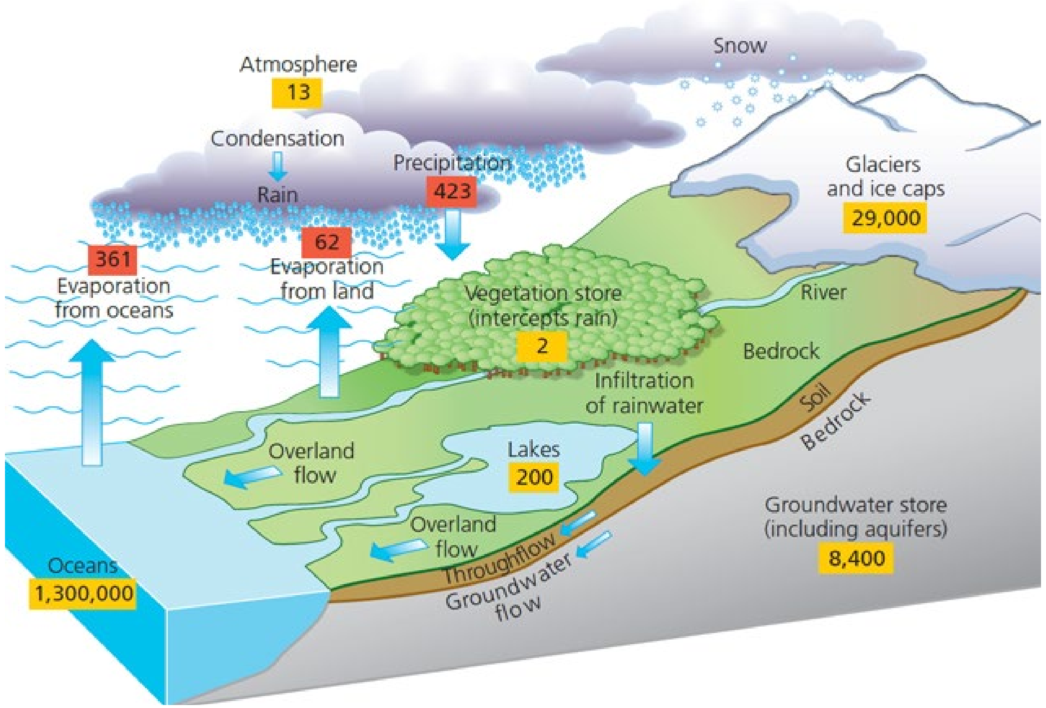
their physical and chemical properties and

their interactions with the physical and biological environment,
including their responses to human activity.

*defined by UNESCO, 1964*

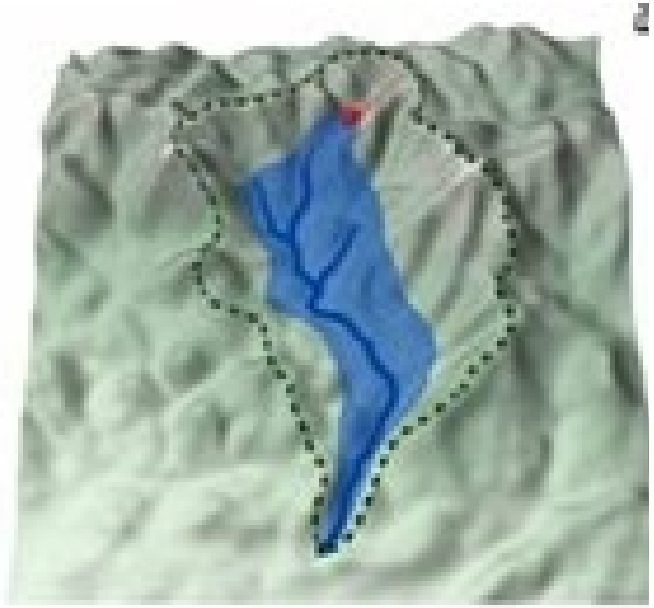
Hydrology can be divided into two main categories:

## The Global Hydrology




The objective of this field is to understand the water circulation and its budget on the earth at the global scale

## The Catchment or Watershed Hydrology



The objective of this field is to understand the water circulation and its budget at the catchment scale

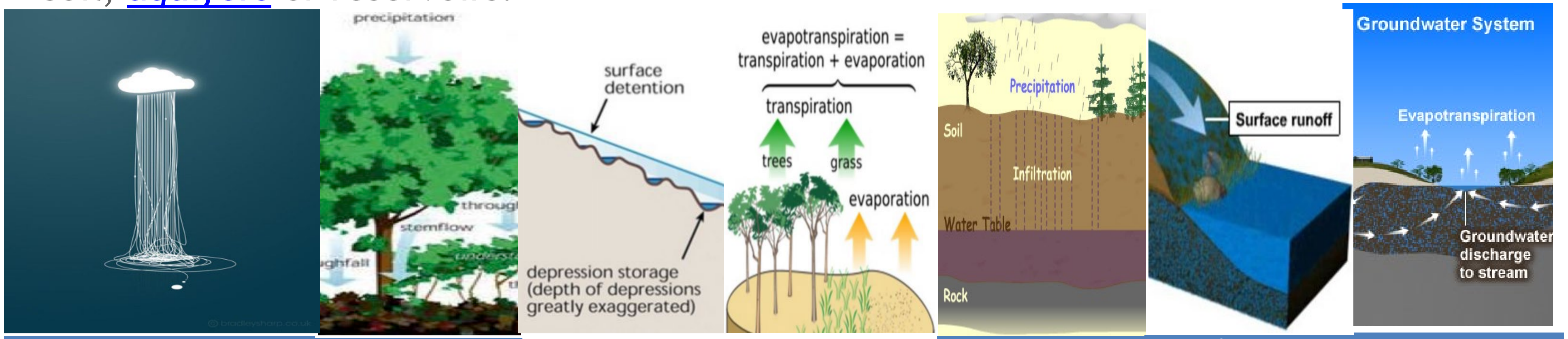
A drainage catchment is defined as any area of land where precipitation is collected and drained off into a common outlet

# Catchment Hydrology: Water Budget

**The water entering an area has to leave the area or be stored within the area.**
**“conservation of Mass”**

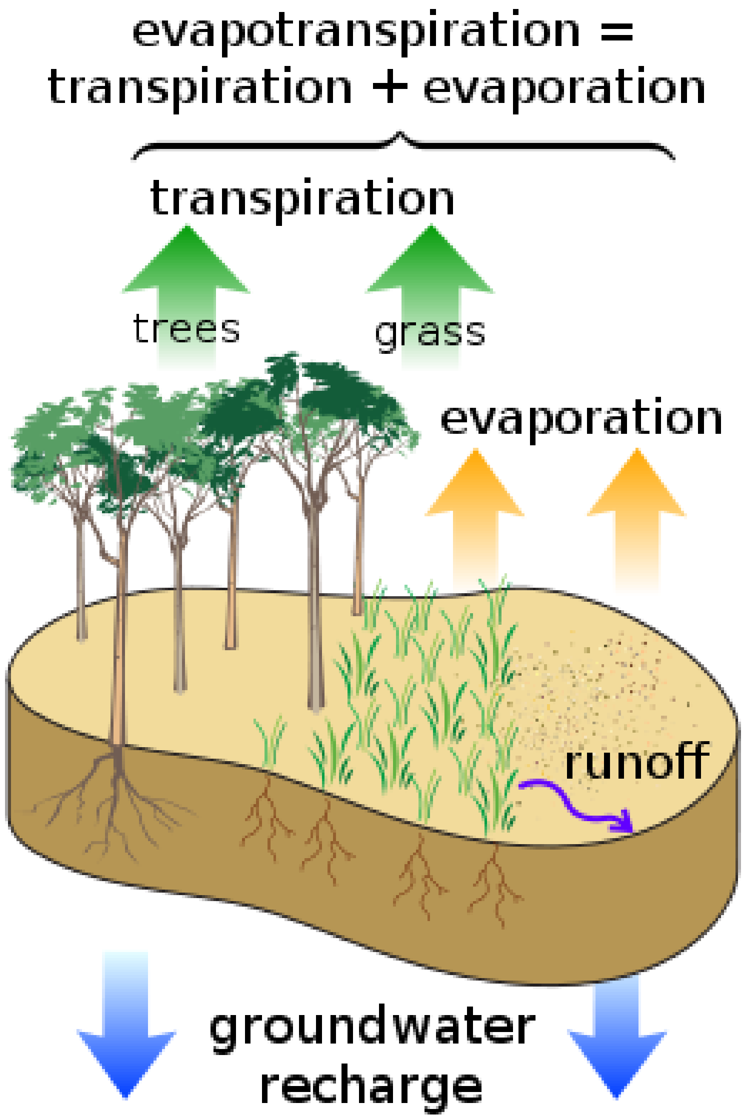
**P = Q + E ± ΔS**

Where, *P* is *precipitation*, *Q* is *runoff*, E is *evaporation* and ΔS is the storage in the soil, *aquifers* or reservoirs.




Precipitation = Interception + Surface Storage + Evaporation - transpiration + Infiltration + Surface Runoff + Ground Water Flow

# Evaporation & Transpiration linking water & energy cycle



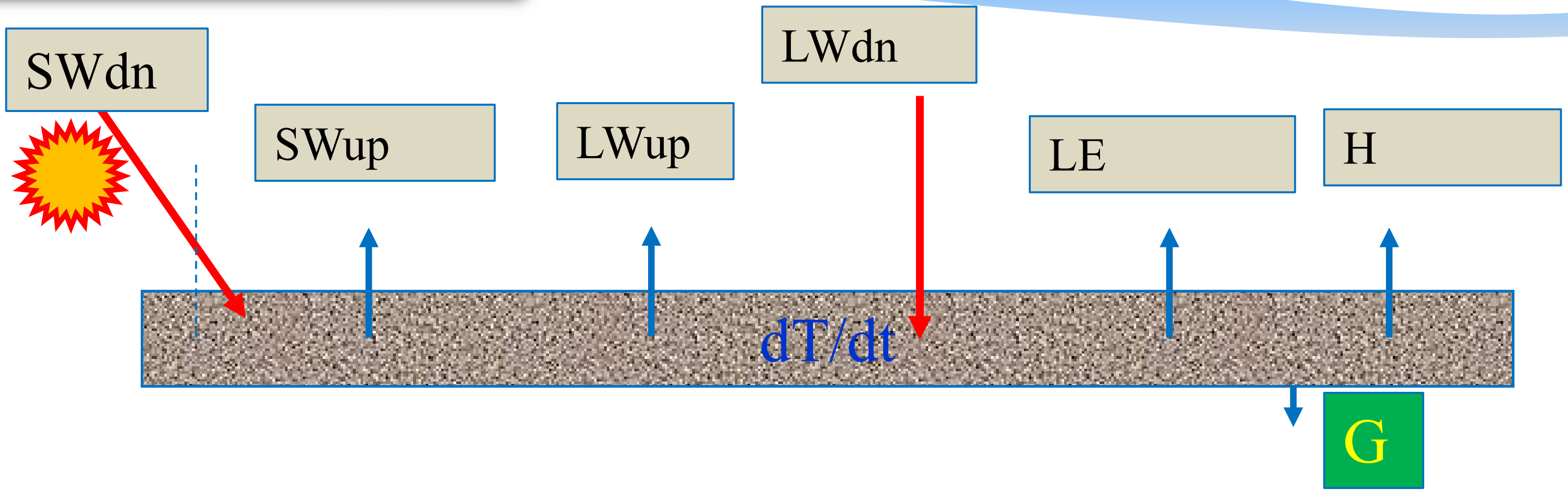

**Globally, 62% of precipitation that falls over continents is evapotranspirated**

- 97% over land (evaporation and transpiration)
- 3% over open water on continents (evaporation)

**In arid and Semi-arid regions a quantitative knowledge of the loss of water by actual ET is crucial in hydrological modeling**

- ✓ It plays a key role in runoff and water availability.
- ✓ ET is the primary link in the global hydrologic cycle between the land and the atmosphere, and thus links the energy cycle.

# SURFACE ENERGY BUDGET




Incoming shortwave (SWdn) +
Incoming longwave (LWdn) =
Reflected shortwave (SWup) +
Emitted longwave (LWup) +
Latent heat flux (LE) +
Sensible heat flux (H) +
Ground heat flux ( G)

**Therefore, to address the water related issues, particularly, in arid and Semi-arid regions, we require a hydrological model that addresses both water and energy budget simultaneously.**

# Hydrological Modeling

A tool to simulate Rainfall - Runoff - Inundation responses

- ✓ Flood and drought forecasting and predicting
- ✓ Flood peaks and flood extent estimation
- ✓ Runoff or discharge volumes estimation
- ✓ Water availability and management ( dam operation, hydropower generation, irrigation practices)

Important when we have no prior recorded experience

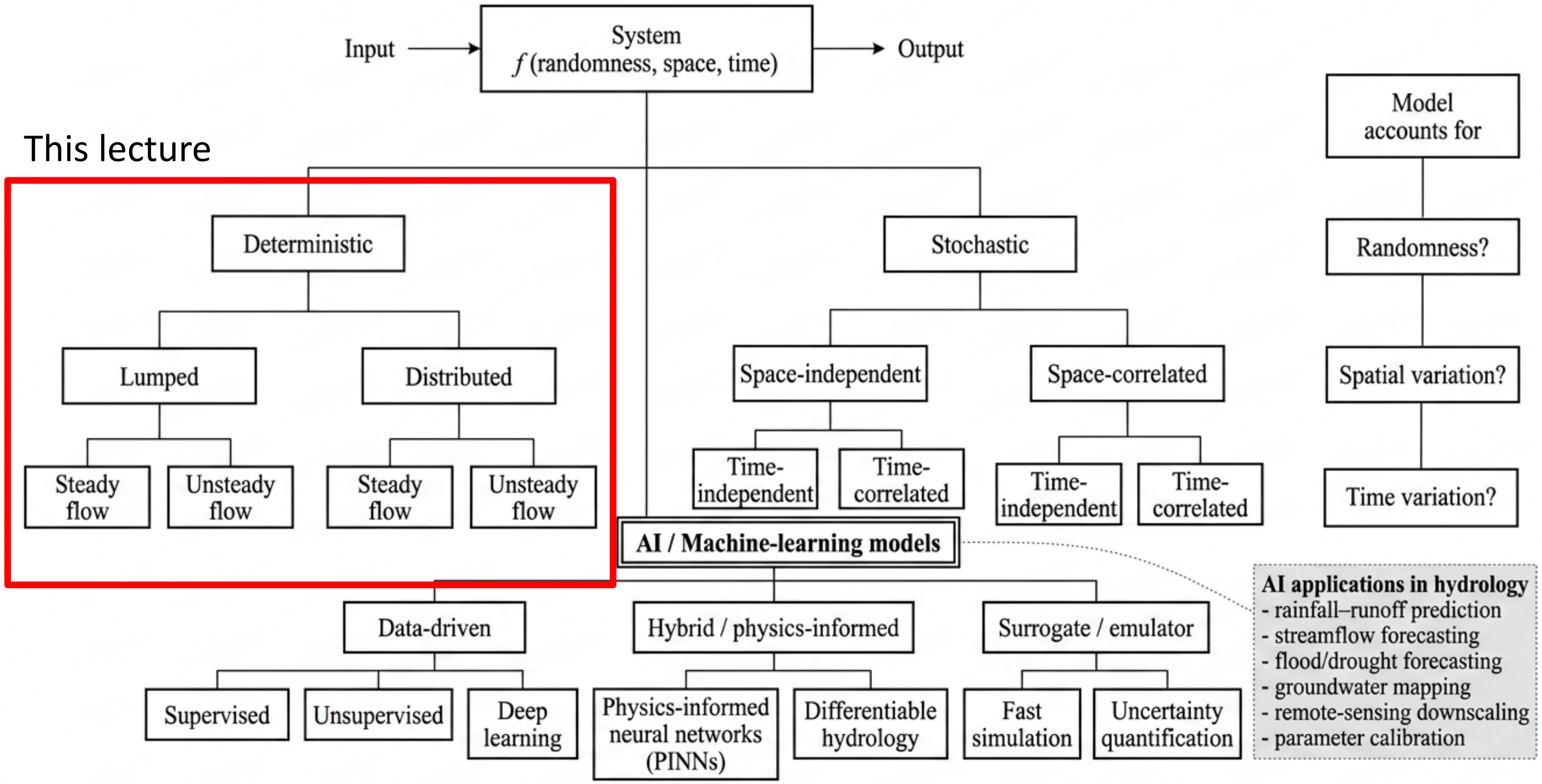
- ✓ Major land-use changes
- ✓ Altered climatic regimes
- ✓ Extreme flood producing rains for design of water retaining structures (100 yrs. return period flood)

# Hydrological Model

Model that simulates various components or functions of the hydrologic cycle.

Simulation capabilities: vary in terms of both space and time

This lecture




Extended classification of hydrologic models including AI and machine-learning approaches.

# Hydrological Modeling

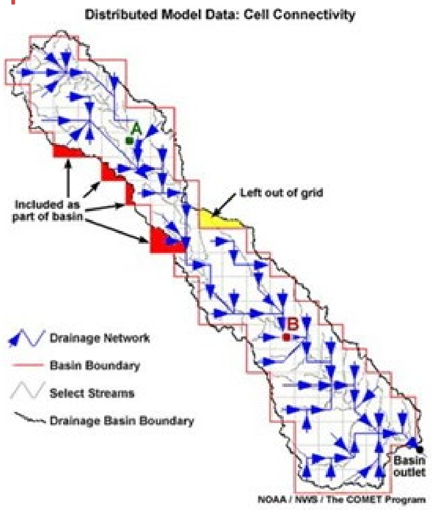
- ## Flow Routing : LUMPED model & DISTRIBUTED model

Hydrological Models wrt to Surface Characteristics Description

Lumped


Distributed

- Sub-Catchment
- Grids
- Geomorphological Unit




### Lumped Model:

- ✓ dependent variables of interest are a function of time alone
- ✓ solving a set of ordinary differential equations
- ✓ Watershed has been conceptualized as a simpler system
- ✓ obtained through statistical techniques.

### Distributed Model:

- ✓ dependent variables of interest are a function of time and Space
- ✓ Governed by continuity and momentum equations
- ✓ solving a set of partial differential equations
- ✓ Watershed has been conceptualized as a complex interconnected system
- ✓ Integrate the units in order to represent the spatiality of the variables .

# Distributed Routing

## Flow routing in channels

– Continuity equation

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}-q=0$$ Conservation form

– Momentum Equation

$$\frac{1}{A}\frac{\partial Q}{\partial t}+\frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\frac{\partial y}{\partial x}-g(S_o-S_f)=0$$

**What are all these terms?**

$$\frac{1}{A}\frac{\partial Q}{\partial t}+\frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\frac{\partial y}{\partial x}-g(S_o-S_f)=0$$

| Local acceleration term | Convective acceleration term | Pressure force term | Gravity force term | Friction force term |
|---|---|---|---|---|

$$\frac{\partial V}{\partial t}+V\frac{\partial V}{\partial x}+g\frac{\partial y}{\partial x}-g(S_o-S_f)=0$$

Kinematic Wave

Diffusion Wave

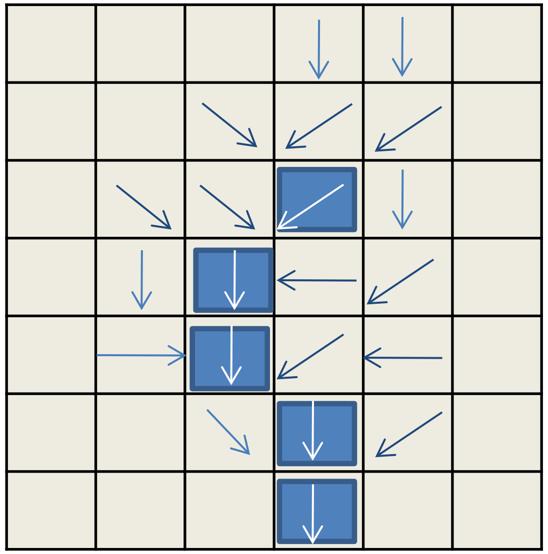
Dynamic Wave

- Kinematic wave: when gravity forces and friction forces balance each other (steep slope channels with no back water effects)
- Diffusion wave: when pressure forces are important in addition to gravity and frictional forces
- Dynamic wave: when both inertial and pressure forces are important and backwater effects are not negligible (mild slope channels with downstream control)

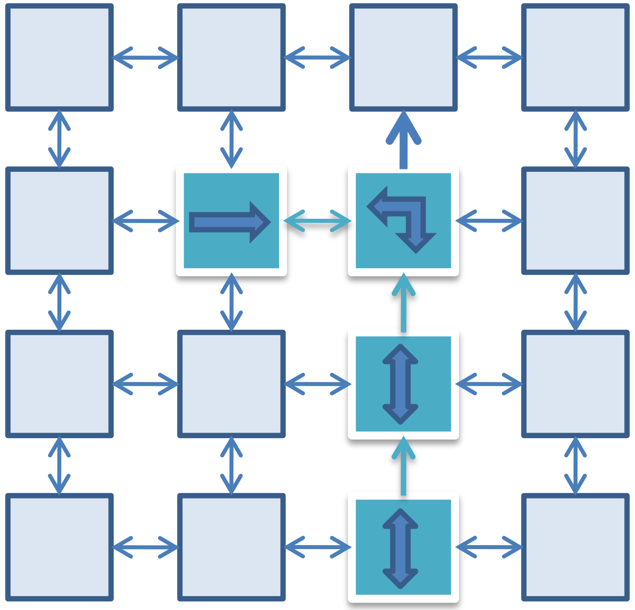
Distributed R-R Model
Kinematic Wave Approach

Distributed R-R Model
Diffusive Wave Approach

Flow directions are fixed based on topography

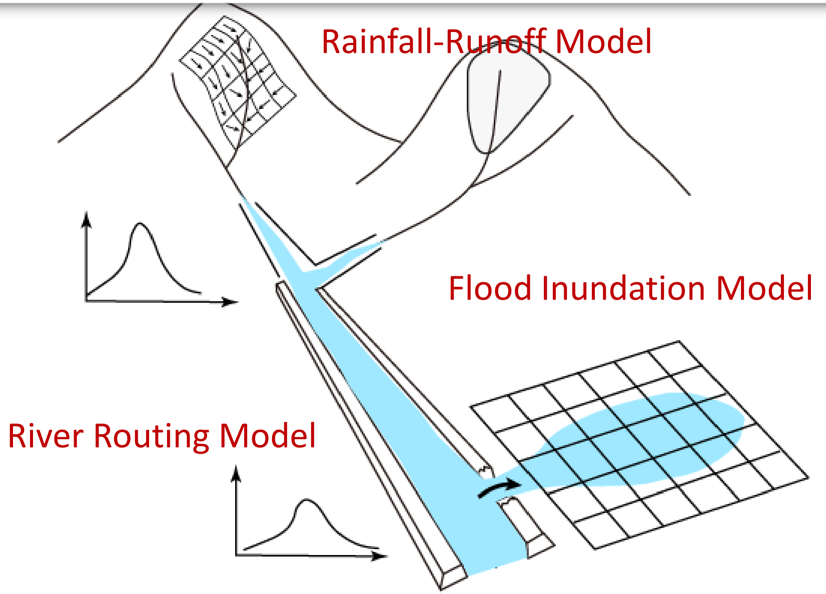


Flow directions change based on water levels

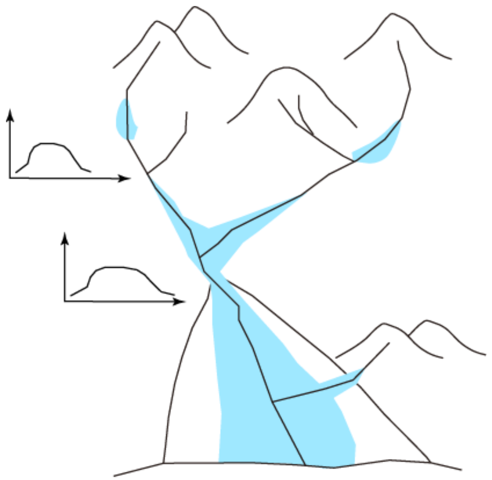



Kinematic wave models cannot simulated back water flow and the flood inundation as the direction of the flow is already fixed

# Rainfall-Runoff-Inundation Model




e.g. Japanese River Case



e.g. Chao Phraya River Case

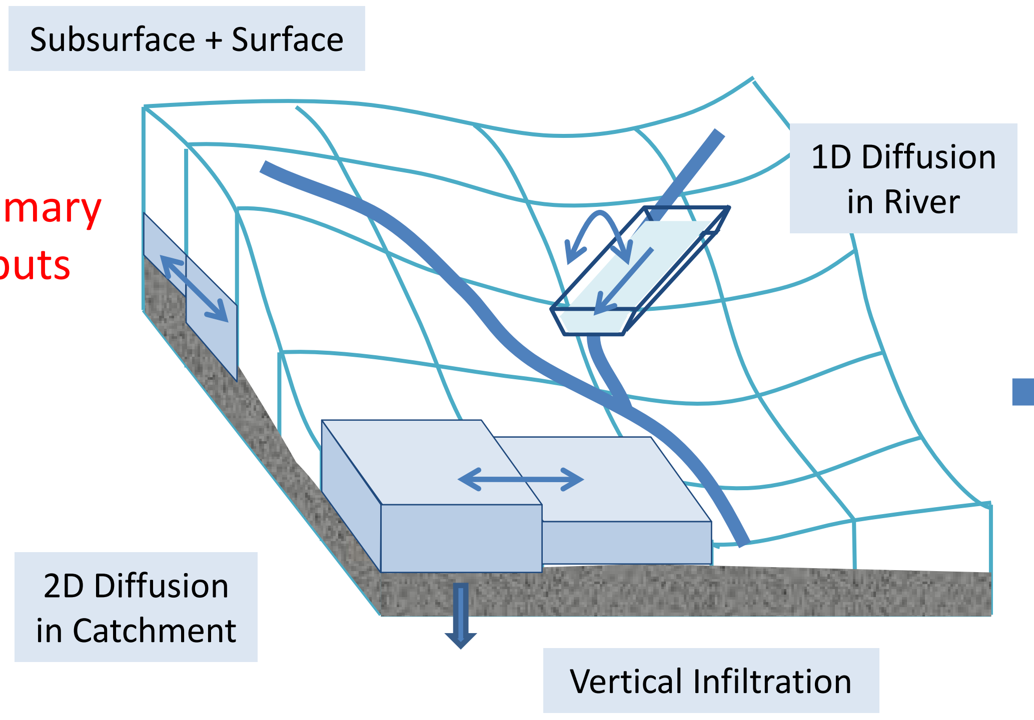
- ✓ **Ordinary Rainfall-Runoff models are incapable of simulating inundation effects.**
- ✓ **Flood inundation models are typically designed to be applied only to floodplains with boundary conditions from a breaching point (not suitable for large scale flooding).**
- ✓ **Rainfall-runoff and inundation processes should be simulated simultaneously for some cases for accurate estimation of water budget..**

# Structure of RRI Model

Input

- Rainfall
- DEM
- Land Cover
- Cross Sec.

Primary inputs



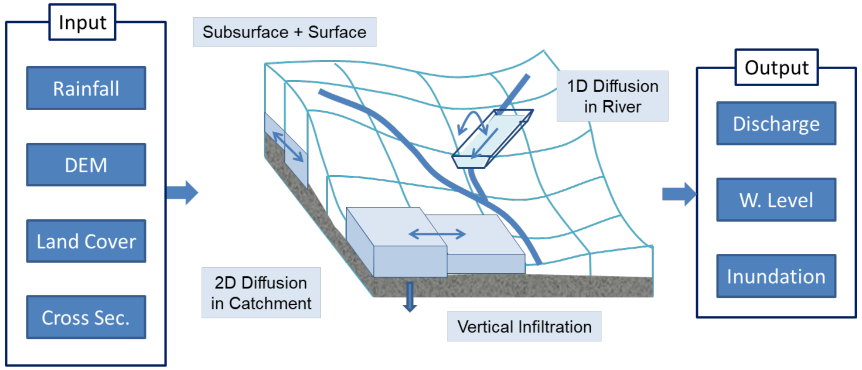

Output

- Discharge
- W. Level
- Inundation

- Two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously
- The model deals with slopes and river channels separately
- At a grid cell in which a river channel is located, the model assumes that both slope and river are positioned within the same grid cell

Sayama, T. et al.: Rainfall-Runoff-Inundation Analysis of Pakistan Flood 2010 at the Kabul River Basin, *Hydrological Sciences Journal*, 57(2), pp. 298-312, 2012.

## Structure of RRI Model

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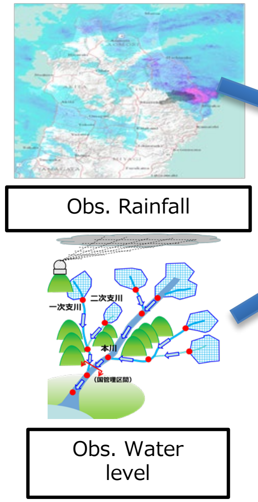
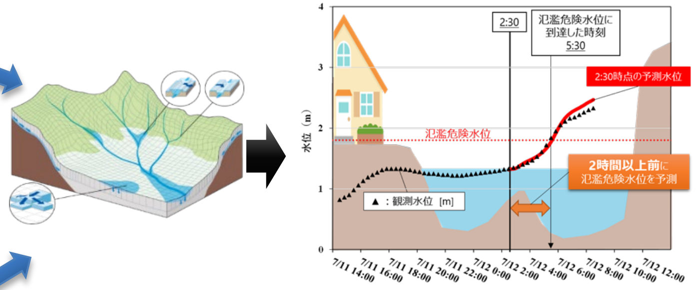
In modeling single floods,

- Evapotranspiration may be ignored during flooding
- Effects of interception and depression storage are neglected.
- The effect of the stream-aquifer interaction is also ignored → response time of the subsurface soil system >>> response time of the surface or direct runoff process.

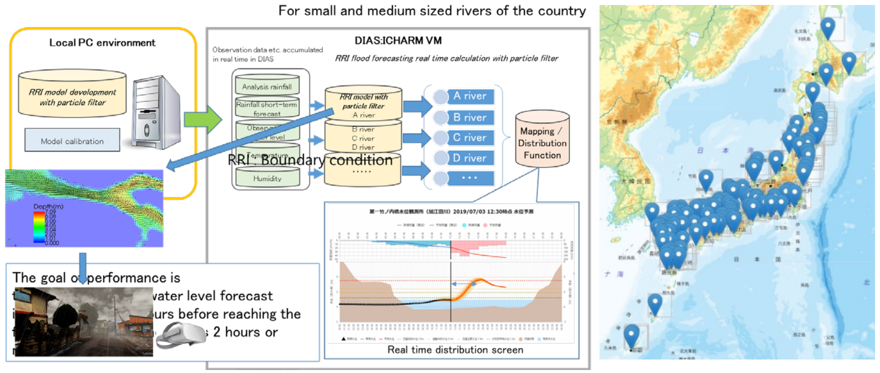
## 【PRISM】Real time flood forecasting system




Real-time water level forecasting by RRI model considering **data assimilation**.

**Particle filter – to improve the initial condition**




**Implemented in 200 Rivers**

An approach for data-rich regions

# THE EFFECT OF A PARTICLE FILTER ON THE WATER-LEVEL RESPONSE CHARACTERISTICS OF BASINS WITH DIFFERENT RUNOFF PROCESSES

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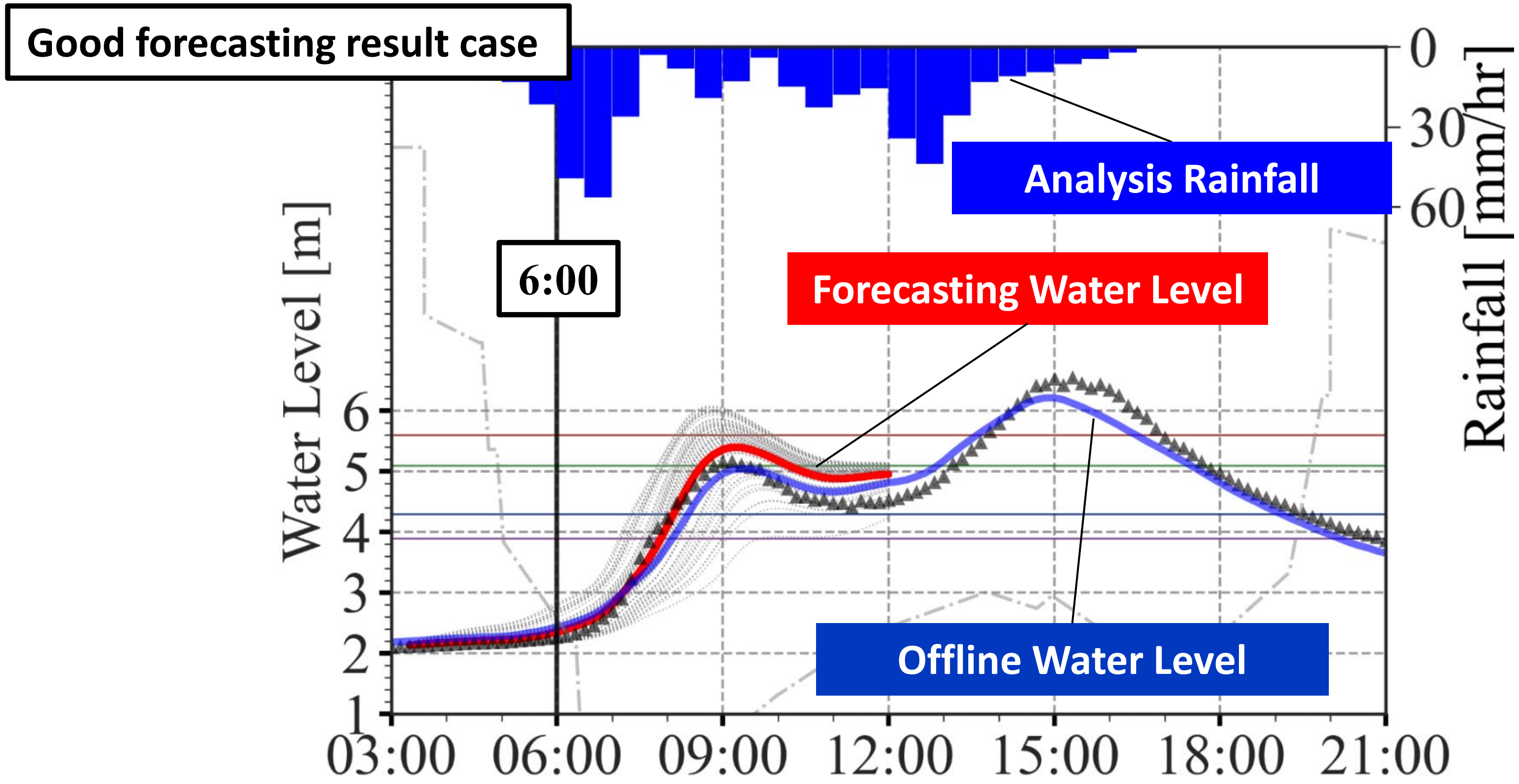
We investigated the response characteristics of the water level in the case of applying a particle filter to a rainfall runoff model that expresses runoff processes with different time constants such as surface flow, intermediate flow, and river channel flow.



# THREE CONDITIONS – ONE SYSTEM


**Flood • Normal • Drought — Hydrology does not stop at the boundaries between extremes.**

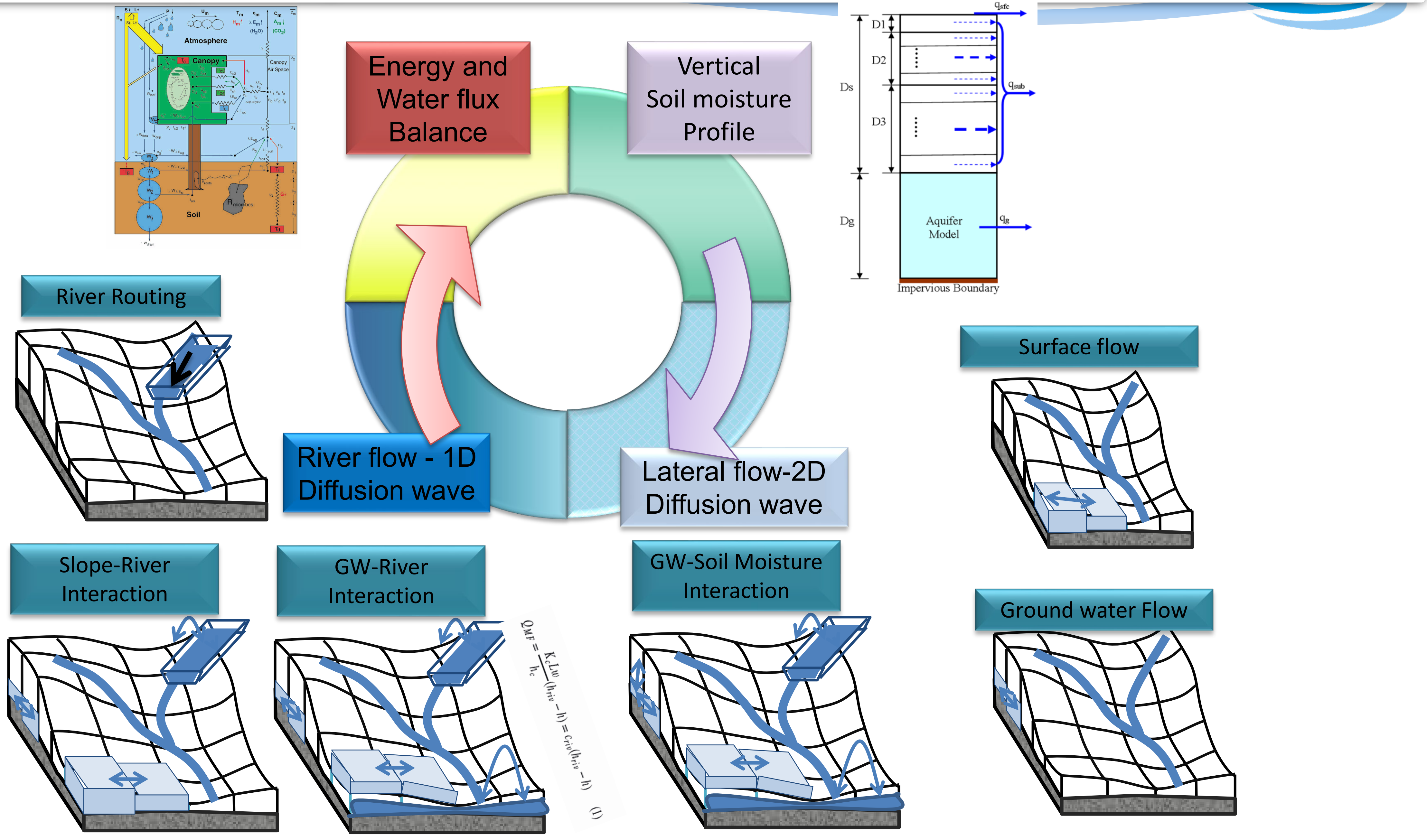
- Flood is an excess of surface water
- Enriches soil, and environments

- Drought is a prolonged shortage of soil water
- Initial moisture condition: triggering

- Conventional models address floods and droughts separately, limiting our ability to understand their interactions and manage water resources across the full hydrological spectrum and quantifying water-food-energy nexus.

- Need to develop a seamless approach to flood and drought risk management by taking into account of water-food-energy nexus

# Water and Energy Budget based RRI Model – 4 component modeling



# MERITS OF WEB-RRI MODEL

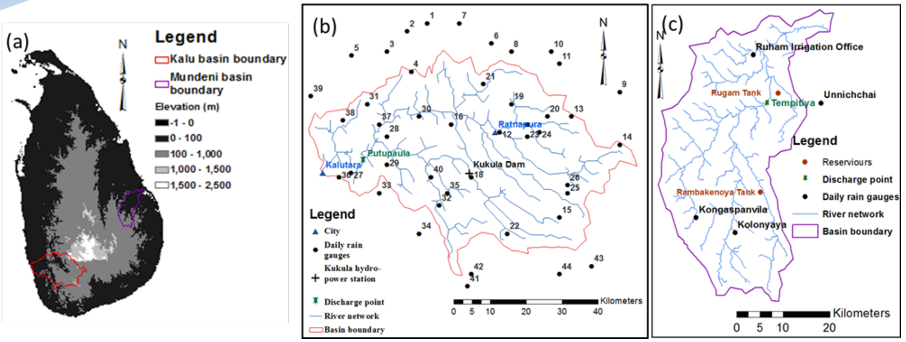
1. Physical formulations for ET, interception, and soil moisture dynamics, which will improve the accuracy of initial soil moisture condition, evapotranspiration, low flow estimation, the timing of flood onset, flood peak discharges, and inundation depths and extent → improve the reliability of flood and drought related assesement

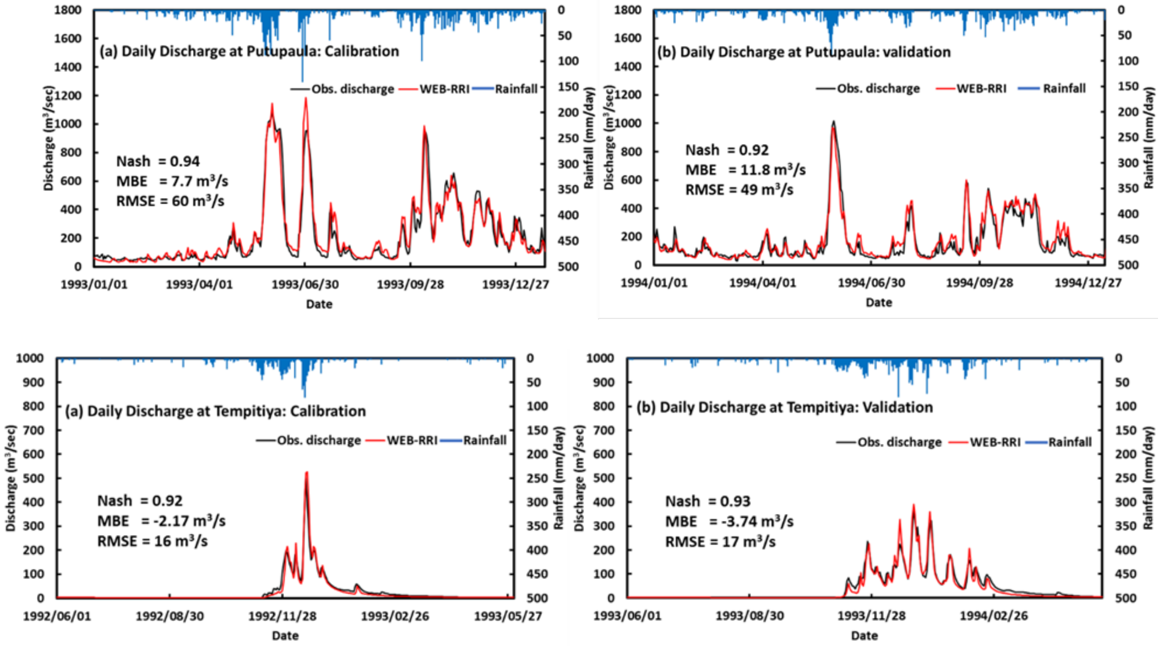
2. As the model takes more inputs (e.g. radiations, temperature, humidity, wind speed, leaf area index) in addition to the precipitation, the model will produce reliable responses to the water cycle variability as well as climate change scenarios → can be used for long term simulations and hydrological extremes of a catchment with a great confidence,

3. As the model inputs are compatible with numerical weather and climate model outputs, it can be coupled with their outputs directly to estimate the basin scale hydrological responses to the model predicted forcing data,

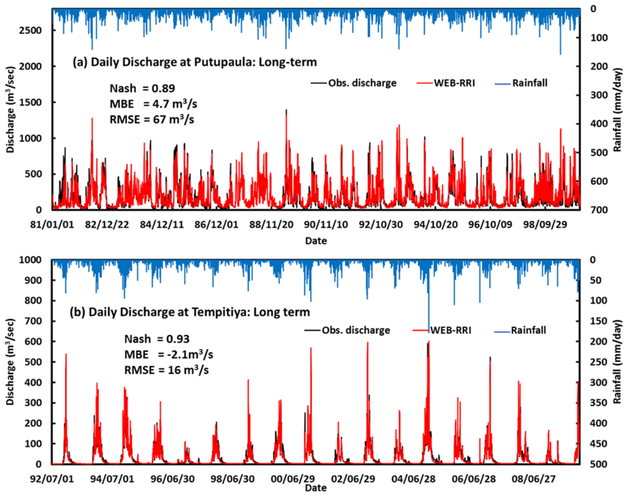
4. The model can reconstruct the actual conditions of hydrological parameters at each time steps (provided that input data is accurate enough), and then the model can be stopped at any time step and can be restarted from the previous history to reduce the computational burden of pre-running of the model in practical applications such as flood forecasting and seasonal predictions.

# WEB-RRI Model: Calibration & Validation

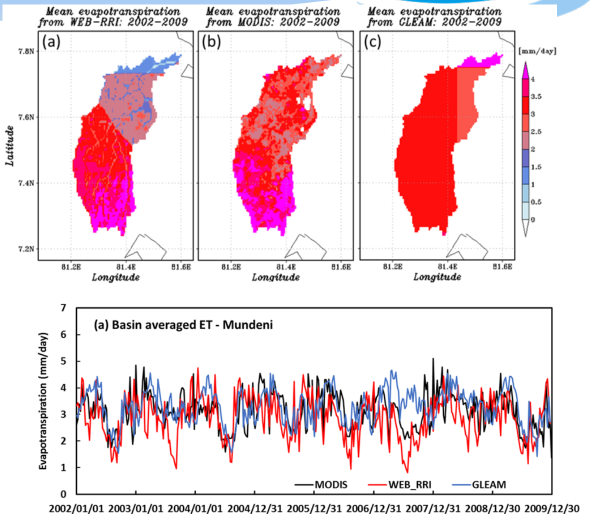


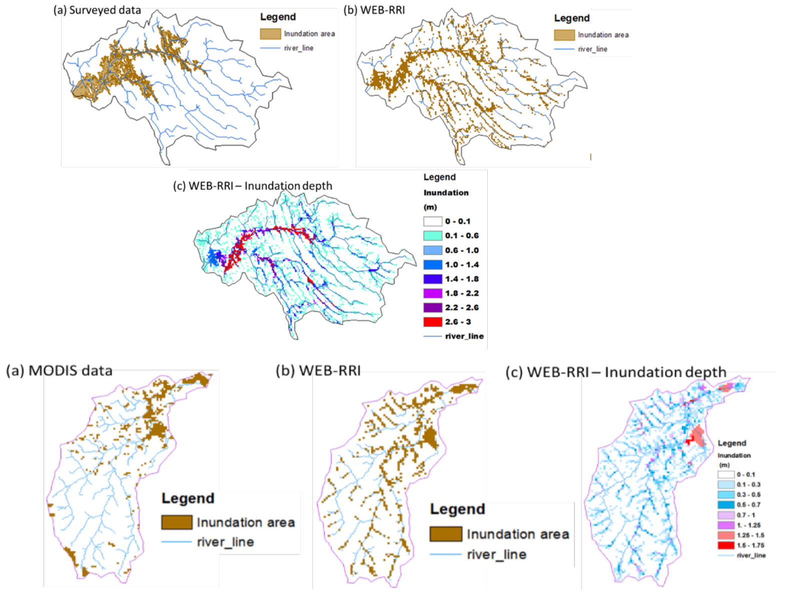

Calibration & Validation




Long-term - 20 years




Evapotranspiration




Flood Inundation

# END

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