WES-BCA

Water and Environment Support - Biodiversity and Climate Action

in the Neighbourhood South region

Regional Training on Flood and Stormwater Adaptation Solutions

C1_REG/ST-6: Adaptation Measures for flood and storm water management

Wednesday 22 April 2026

Nice, France

Title of Presentation: Review of software and models for hydrological analysis and flood-adaptation design

Presented by:
Mr. Stelios VAVOULOGIANNIS, Junior Nature-Based Solutions Expert, WES-BCA

LDK CONSULTANTS S.A.

Funded by the European Union

Introduction (1/2): Flood as a hazard

Between 1970 and 2019, water-related hazards accounted for 50% of all disasters and 45% of all reported deaths. Since 2000, the number of recorded flood-related disasters has risen by 134% compared with the two previous decades (UNDRR).

This is a consequence of (WMO):
- changes in upstream land-use
- a continuously increasing concentration of population and assets in flood-prone areas and
- the increasing frequency of heavy precipitation

Al Mizan (الميزان) Balance between human development and nature.

"…That you not transgress within the balance (Mizan) and establish weight in justice and do not make deficient the balance (Mizan)" (Quran 55:1-9)

© Gideon Mendel

Introduction (2/2): Why models are useful

WES-BCA
Water and Environment Support - Biodiversity and Climate Action
in the Neighbourhood South region

- ✓ Flood and stormwater problems are becoming more complex
- ✓ Software helps turn data into analysis, scenarios, and decisions
- ✓ Tools support planning, design, mapping, and communication
- ✓ Focus: practical use in hydrological analysis and flood-adaptation design

A model is a simplified representation of a real system used to describe, explain, or predict its behaviour.

- ➢ Helps us understand hydrological and flood processes under certain conditions
- ➢ Helps us predict and compare scenarios under limited data
- ➢ Helps us support design and decision-making

"All models are wrong, but some are useful"
George E. P. Box, 1979

Water Modelling Tools Categories

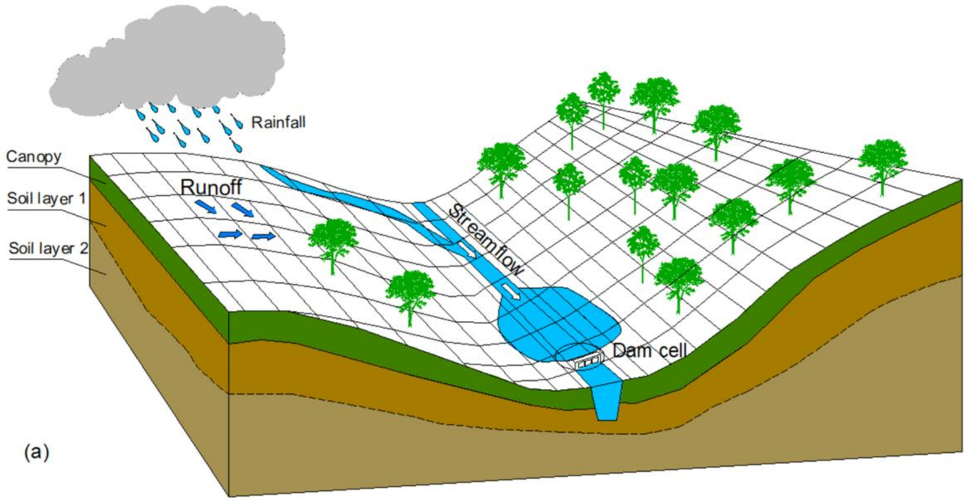
WES-BCA
Water and Environment Support - Biodiversity and Climate Action in the Neighbourhood South region

- **Hydrological models** for rainfall analysis (historical records, IDF curves, design storms/streamflows), rainfall–runoff modelling (event-based or continuous),
- **Hydraulic models** for hydraulic routing and floodplain simulation (1D, 2D or coupled), flood hazard mapping (depth, velocity, extent), exposure and risk assessment (infrastructure, population, land use), adaptation measures design (detention basins, NBS, levees) and scenario comparison (current vs future climate or land-use conditions)
- **Urban stormwater models** analyse drainage systems and pluvial flooding
- **Flood Awareness Systems** for operational flood, early warning, risk management and crisis response.

Hydrological (Rainfall-Runoff) Modelling Tools

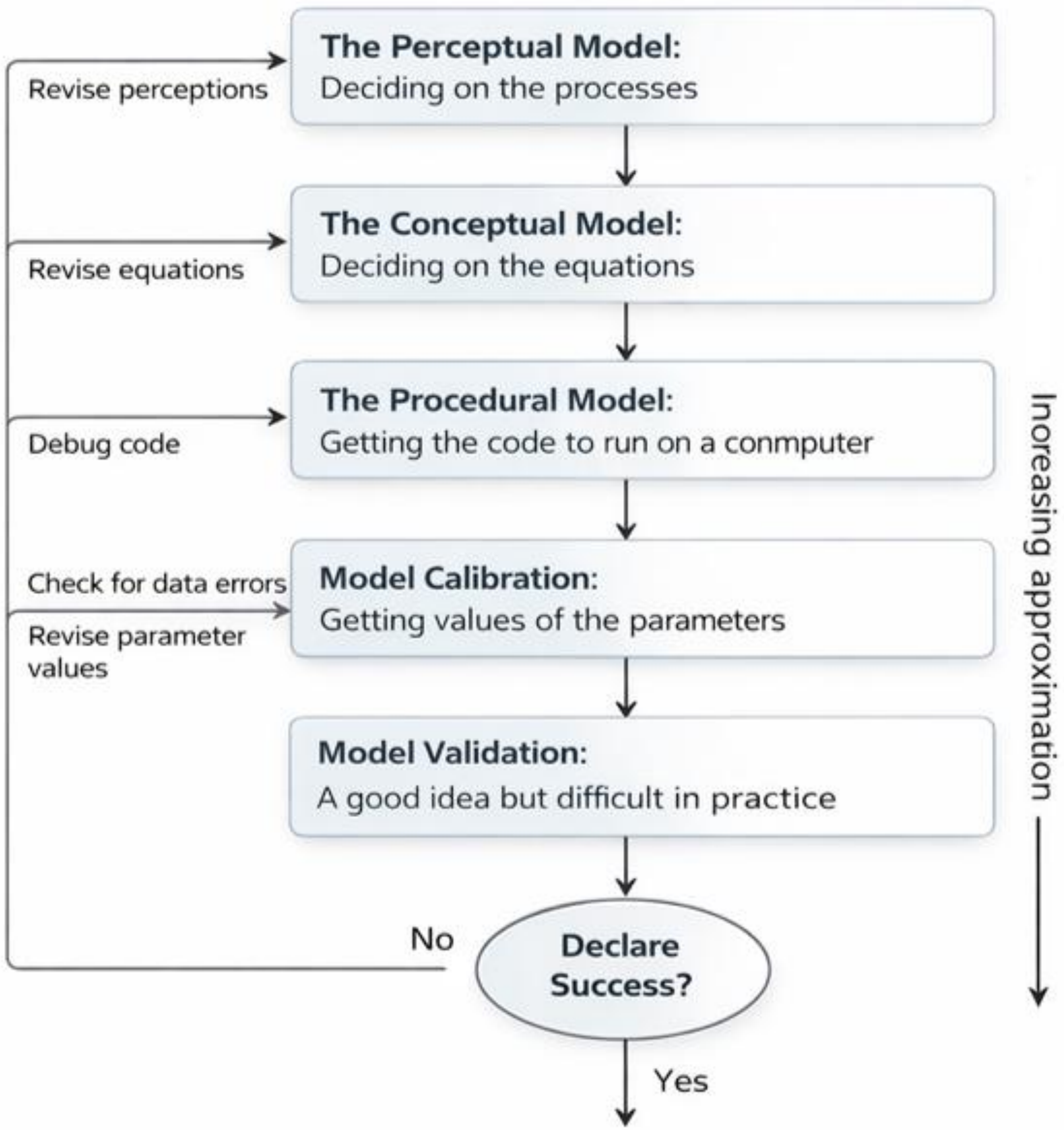
WES-BCA
Water and Environment Support - Biodiversity and Climate Action in the Neighbourhood South region

- ✓ Estimate how precipitation is transformed into runoff and streamflow
- ✓ Help assess peak discharge, runoff volume, and timing
- ✓ Support event-based, continuous, and scenario-based analysis
- ✓ Useful for testing land-use change, infiltration, storage, and climate effects
- ✓ Provides the discharge for the hydraulic models that calculate flood inundation
- ✓ Often provide the first analytical link between rainfall and flood decision-making



✓ Catchment / watershed level

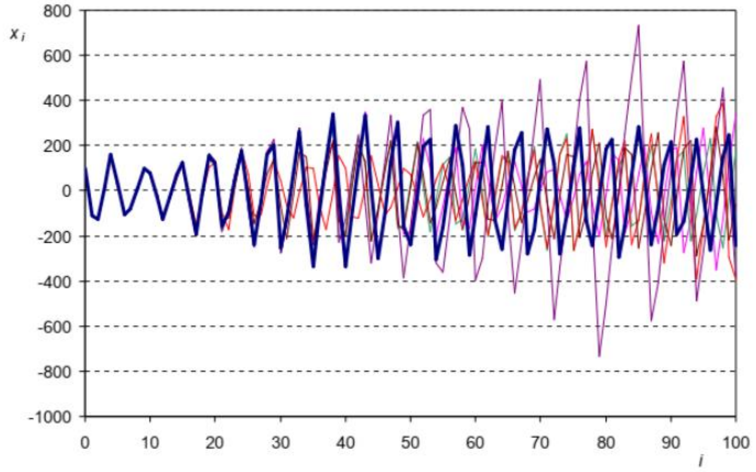
Rainfall-Runoff Modelling Process



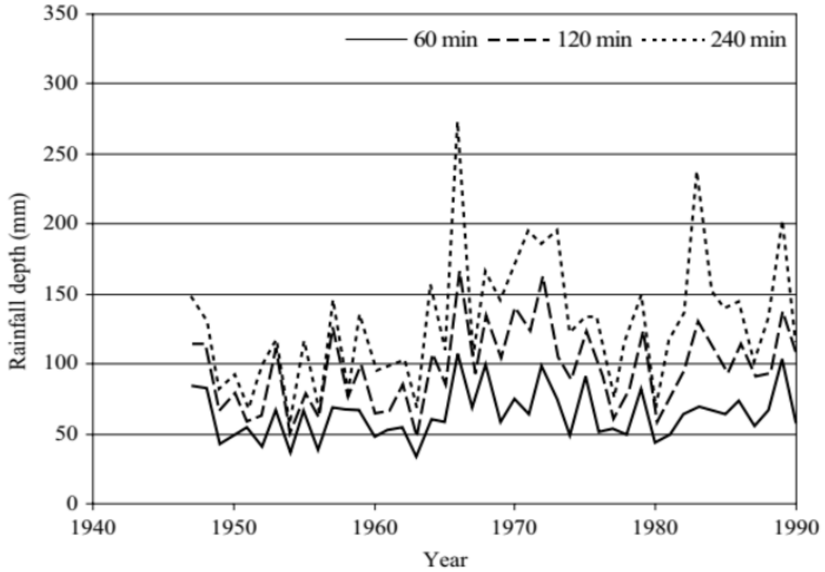
A schematic outline of the steps in the modelling process (Keith Beven, Rainfall-Runoff Modeling - The Primer)

The importance of Uncertainty

Uncertainty in hydrology may stem both from the inherent stochastic behavior of natural processes and from limitations in our knowledge, data and modelling capacity



A simulation with 1% uncertainty in initial conditions Koutsoyiannis (2010)



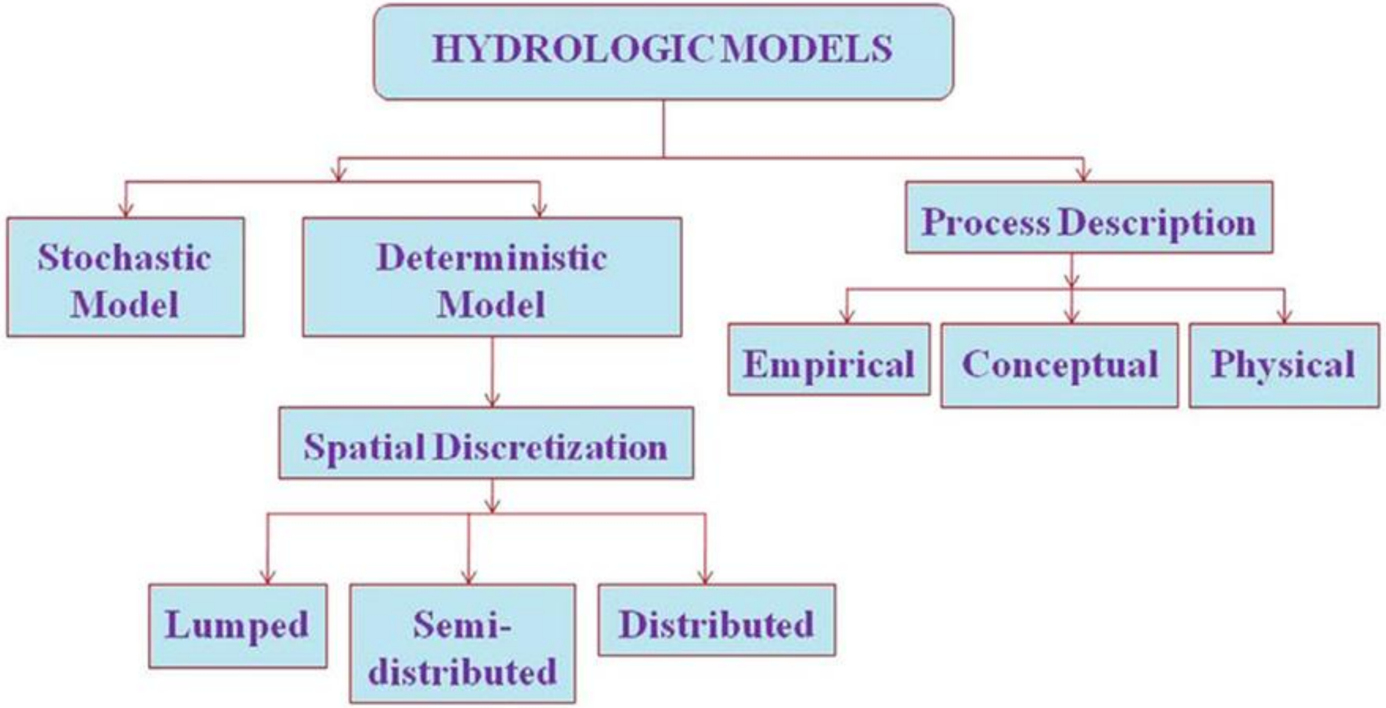
Annual maximum rainfall series of different durations (1947–1990) at Hong Kong Observatory, Hong Kong (Tung and Yen, 2005)

LDK CONSULTANTS S.A.

Funded by the European Union

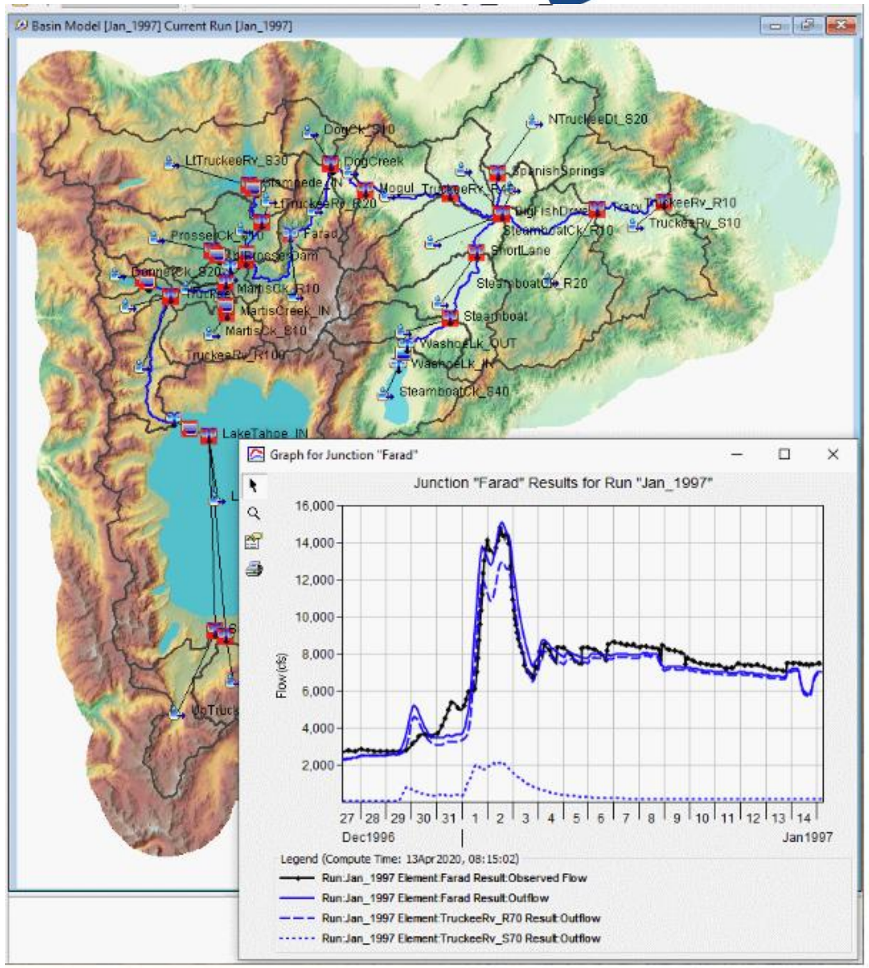
Hydrological Model Types

A hydrological model is a simplification of a real-world system that aids in understanding, predicting, and managing water resources.



HEC-HMS Hydrological Model

- Free hydrologic model developed by the U.S. Army Corps of Engineers for precipitation–runoff simulation
- Simulates rainfall–runoff, snowmelt and baseflow to estimate streamflow magnitude and timing
- Applicable to large river basins and small urban or natural watersheds
- Widely used for flood forecasting, water resources management and watershed analysis
- Particularly useful in Mediterranean semi-arid basins for event-based simulations and flash flood analysis, though sensitive to rainfall input quality
- Data requirements: Moderate: Requires meteorological, land use, soil data



https://www.hec.usace.army.mil/software/hec-hms/

LDK CONSULTANTS S.A.

Funded by the European Union

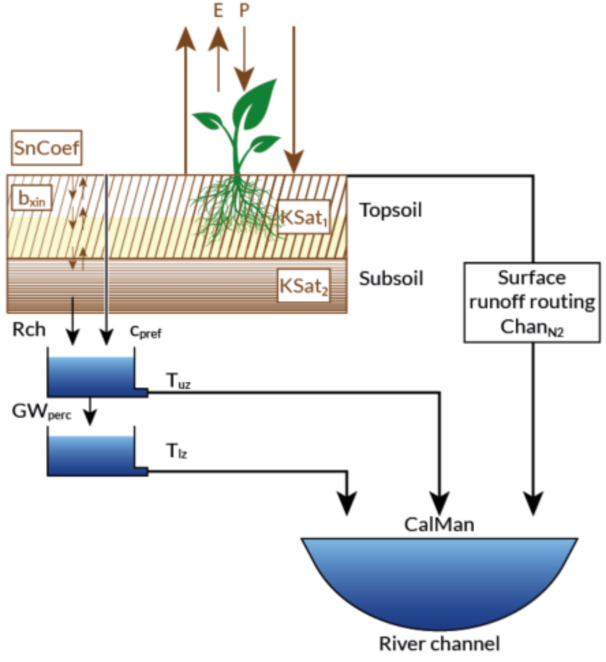
LISFLOOD Hydrological Model

Developed by the European Commission Joint Research Centre (JRC).
Grid-based rainfall–runoff model simulating the full water cycle
Simulates water movement from rainfall to rivers, lakes, soil and groundwater
Applied at large spatial scales: river basins, continents and global level
Model capabilities:

- Simulates hydrological processes
- Includes surface water, groundwater, lakes and reservoirs
- Includes water demand from sectors such as irrigated agriculture

Applications:

- Flood forecasting (EFAS, GloFAS)
- Drought monitoring (European Drought Observatory)
- Water resources and climate impact assessments
- Analysis of land-use change, climate change and water management Policies
- Data requirements: Very High: Needs extensive data (climate & weather, soil characteristics, topography, land cover)



https://ec-jrc.github.io/lisflood-model/

SWAT Hydrological Model

- SWAT (Soil and Water Assessment Tool) is a spatially distributed watershed-scale model used to simulate hydrological and environmental processes
- Simulates infiltration, surface runoff, evapotranspiration and groundwater flow typically at a daily time step
- Integrates water quantity, water quality, sediment transport and nutrient dynamics
- Widely used to assess land-use change, water management practices and climate variability impacts
- Extensively applied in Mediterranean basins (e.g., Greece, Italy, Spain) due to its ability to simulate seasonal climates, intense storms, erosion and complex land-use patterns
- Data requirements: High: Needs extensive data (weather, soil, topography)

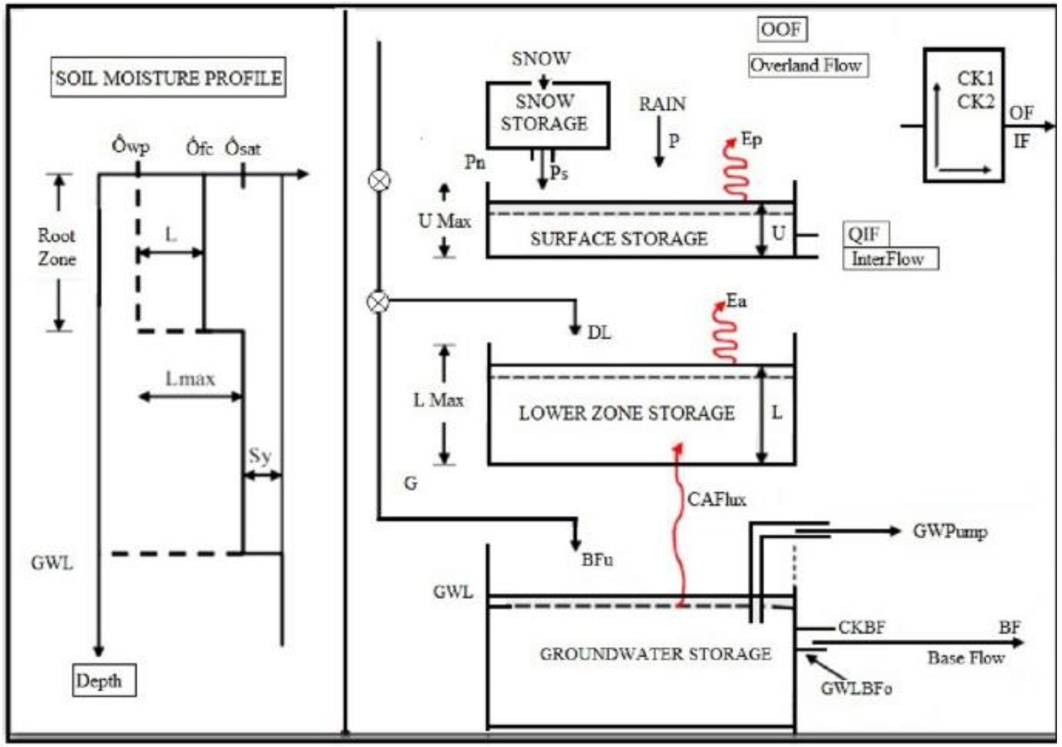
Soil & Water Assessment Tool | SWAT

WEAP Hydrologic Model

- WEAP (Water Evaluation And Planning System) is an integrated water resources planning model linking water supply, demand, quantity and quality
- Represents water use patterns, efficiencies, pricing, allocation rules and hydropower demand on the demand side
- Simulates streamflow, groundwater, reservoirs and water transfers on the supply side
- Widely used to evaluate water management strategies, policy scenarios and climate change impacts, particularly in water-scarce Mediterranean regions
- Allows integrated simulation of multiple water uses (irrigation, domestic supply, etc.), though it is data-intensive and less suited for flash flood or complex groundwater simulations
- Limited capability for flash flood simulation and complex groundwater processes
- Data-intensive model requiring extensive hydrological, demand and operational datasets for calibration.
- Data requirements: High: Needs extensive data (temperature time series, demand data, monthly river flows, surface water quality)

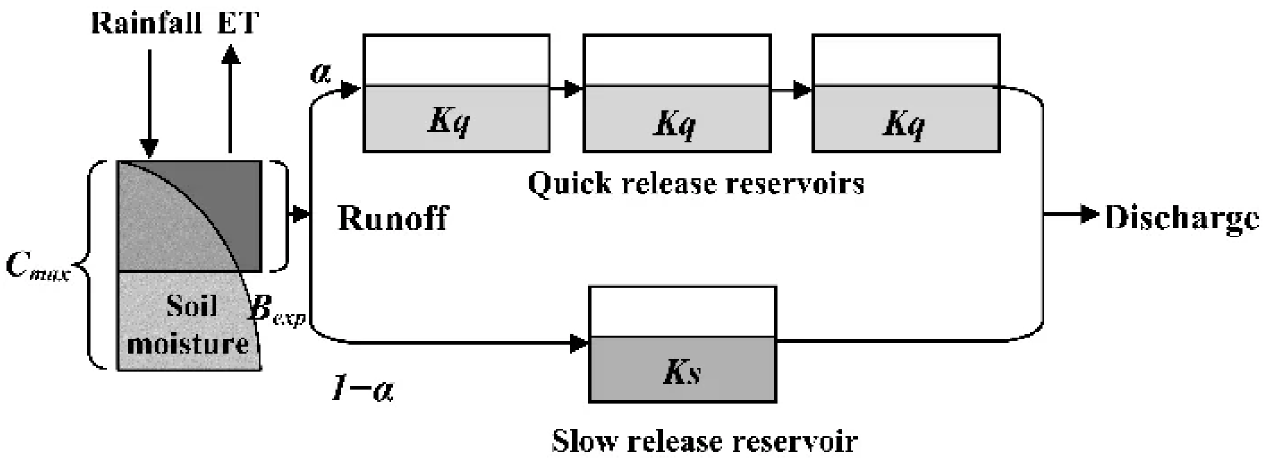
MIKE HYDRO Basin

- MIKE HYDRO Basin: Basin-scale water allocation model (reservoirs, transfers, system rules).
- Scenario analysis: infrastructure, demand, operations, climate. Outputs: maps, time series, indicators.
- Best for: multi-sector basin planning in water-scarce Mediterranean systems. Not for: small catchments (<20–30 km²) or flood modelling.
- Includes NAM: lumped rainfall–runoff model (4 storages, 3 flow components).
- Strength: data-scarce seasonal basins. Limitation: calibration-sensitive; weaker in steep or heterogeneous basins.
- Data requirements: runoff time series (if NAM is not used), meteorological time series (precipitation, evaporation) for NAM (RR Model); reservoir characteristics, diversion requirements, return flows, demand timeseries, real extractions



HYMOD Hydrologic model

• HYMOD is a simple conceptual rainfall–runoff model with five parameters, designed for daily hydrological simulation
• Represents key watershed processes including excess rainfall generation, soil storage, percolation and streamflow routing
• Requires limited input data, typically precipitation and potential evapotranspiration
• Demonstrates robust performance across diverse climates, including Mediterranean-type regions
• Limitations include simplified representation of complex processes and sensitivity to parameter regionalization, which may reduce performance in ungauged basins



DOI:10.5194/hessd-7-3803-2010

GR4J/GR5J/GR6J model

- Daily conceptual models with 4, 5, or 6 parameters, calibrated using observed streamflow data
- Require very limited input data, typically precipitation and potential evapotranspiration, making them suitable for data-scarce basins
- Widely applied in Mediterranean catchments for daily streamflow simulation and climate change impact studies
- Limitations include simplified groundwater representation and inability to capture strong spatial rainfall variability, typical of convective Mediterranean storms

Commonly used Hydrological Models (1/2)

WES-BCA
Water and Environment Support - Biodiversity and Climate Action
in the Neighbourhood South region

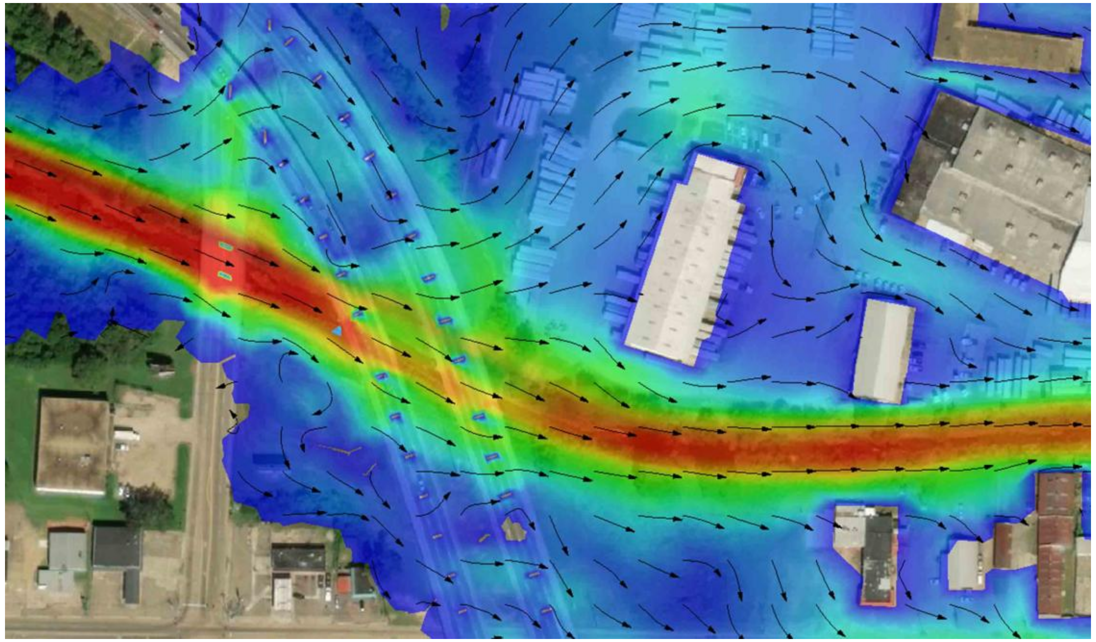
Model	Type	Strengths in Mediterranean Basins	Key Limitations	Ideal application
LISFLOOD	Fully distributed, process-based	Captures spatial rainfall gradients, flood/drought forecasting, climate-change impacts	Computationally heavy; limited karst representation	Flood forecasting, climate impact studies, basin-scale hydrology
HEC-HMS	Event-based & continuous rainfall–runoff	Excellent for flash floods, flexible loss/routing methods, works with limited data	Weak groundwater representation; sensitive to rainfall quality	Flash-flood modelling, storm events, semi-distributed hydrology
SWAT	Semi-distributed eco-hydrological	Simulating land-use, agriculture, sediment, climate scenarios	High parameterization; weaker for karst; rainfall-input sensitive	Agriculture, erosion, climate scenarios, water-quality modelling
MIKE HYDRO Basin	Integrated water-resources allocation	Simulating multi-sector allocation, reservoir operations, climate & policy scenarios	Not for flash floods; simplified groundwater unless coupled	Water allocation, reservoir planning, drought management
HBV	Conceptual rainfall–runoff	Strong seasonal simulation, low data needs, good for climate scenarios	Limited spatial detail; weak for karst; simple snow module	Climate-change studies, water-availability, seasonal hydrology

Commonly used Hydrological Models (2/2)

Model	Type	Strengths in Mediterranean Basins	Key Limitations	Ideal application
GR4J/5J/6J	Parsimonious conceptual	Very low data needs, robust calibration, GR6J strong for low flows	Lumped; limited flash-flood realism; no spatial detail	Daily runoff, drought analysis, ungauged basins
WEAP	Integrated water-resources planning	Demand–supply modelling, policy scenarios, irrigation & urban planning	Not a hydrological model; weak for floods; simplified hydrology	Allocation, drought planning, climate & socioeconomic scenarios
TOPMODEL	Conceptual, topography-based	Good for saturation-excess runoff, threshold behaviour, small steep basins	Poor for infiltration-excess floods; unsuitable for karst	Seasonal runoff, soil-moisture mapping, small mountainous basins
HYMOD	Parsimonious conceptual	Very low data needs, good for scenario ensembles, simple structure	Weak low-flow simulation; limited groundwater; lumped	Ungauged basins, sensitivity analysis, simple runoff modelling
NAM (MIKE NAM)	Conceptual rainfall–runoff	Strong seasonal performance, good for land-use/climate impacts, integrates with MIKE	Limited spatial detail; calibration sensitive; not ideal for karst	Continuous runoff, reservoir inflows, climate/land-use impacts

Hydraulic Models (Rivers)

A hydraulic model is a representation of how water flows and behaves in hydraulic systems such as rivers, canals, pipes, reservoirs, and floodplains. It is used to simulate water levels, flow velocities, discharge, and pressure under different conditions using the principles of fluid mechanics



- Used to simulate flow in rivers, channels, and floodplains
- Help estimate water depth, extent, and sometimes velocity
- Useful for flood hazard mapping and protection design
- Support evaluation of overflow and conveyance capacity
- Translate discharge into spatial flood consequences

✓ River Channel/Floodplain level

https://www.stantec.com/uk/ideas/content/blog/2021/completing-the-picture-the-future-of-hydraulic-modeling-is-two-dimensional

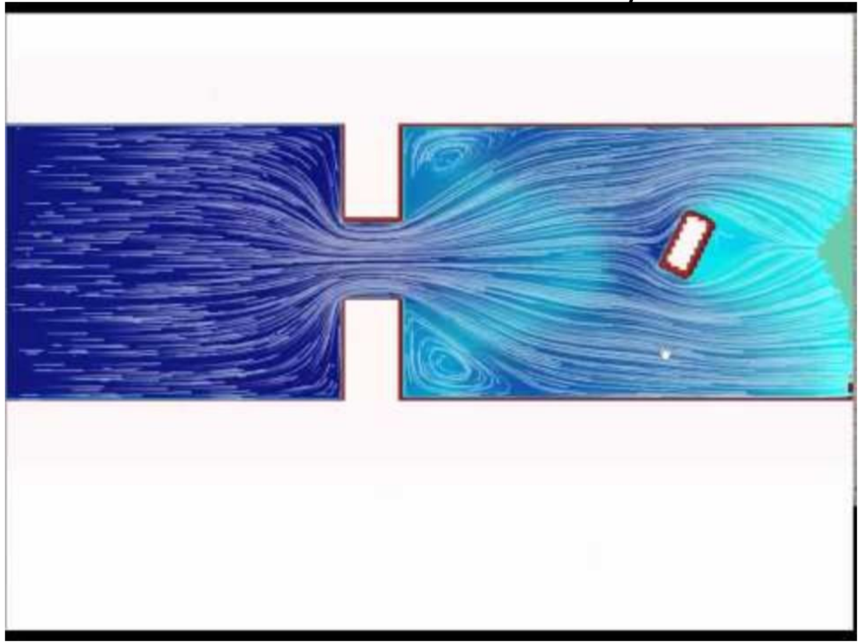
HEC-RAS Hydraulic Model

WES-BCA
Water and Environment Support - Biodiversity and Climate Action
in the Neighbourhood South region

- HEC-RAS (Hydrologic Engineering Center – River Analysis System) is a hydraulic model developed by the U.S. Army Corps of Engineers for river flow and floodplain analysis
- Simulates 1D steady flow, 1D/2D unsteady flow, sediment transport, and water quality processes
- Commonly used for river hydraulics, floodplain mapping, dam-break and levee-breach simulations
- Widely applied in Mediterranean regions for flash flood modeling, flood plain mapping, designing of hydraulic structures (check dams, levess, flood retention structures/ponds) river demarcations/delineations, evaluating the impact of flood, risk assessment studies

though less suited for reservoirs with complex circulation or advanced sediment dynamics

Data requirements: Inflow Hydrographs (discharge), precipitation, Topography (Cross Sections or Digital Elevation Model), Manning's roughness coefficient, boundary conditions



TUFLOW Hydraulic Model

WES-BCA
Water and Environment Support - Biodiversity and Climate Action in the Neighbourhood South region

• TUFLOW is a 1D/2D hydraulic modelling software designed to simulate free-surface flows in rivers, floodplains, urban areas, estuaries and coastal zones
• Widely used for flood risk assessment, urban drainage modelling, storm tide simulation and overland flow analysis
• Known for its robust 2D solver, rapid wetting and drying capability, and efficient simulation of large floodplain systems
• Strong GIS-centric workflow, allowing efficient data management, model setup and visualization of results
• Suitable for river flooding, urban flooding, estuarine and coastal hydraulics, including modelling of hydraulic structures, levees and embankments

Data requirements:
Bathymetry / Topography, timeseries, manning's roughness coefficient, boundary conditions

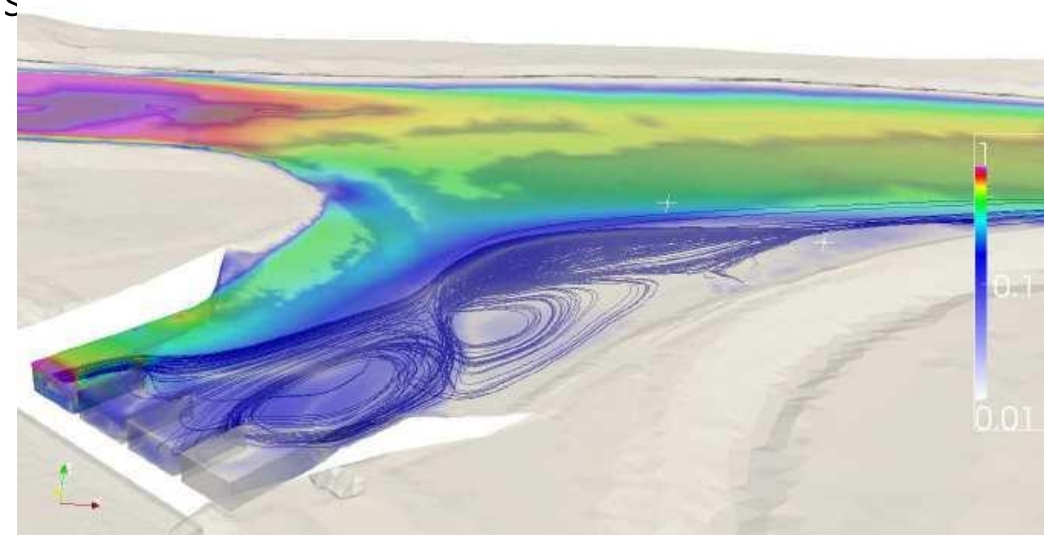
TUFLOW

Telemac Hydraulic Model

WES-BCA
Water and Environment Support - Biodiversity and Climate Action
in the Neighbourhood South region

- TELEMAC is an advanced open-source hydrodynamic modelling system used to simulate free-surface flows in rivers, lakes, estuaries, coastal zones and floodplains
- Widely applied for river hydraulics, floodplain modelling, tidal flows, storm surge and coastal flooding
- Capable of simulating complex geometries, sediment transport and morphodynamic processes
- Frequently used in Mediterranean studies for sediment transport, coastal morphology, flooding and water circulation
- Highly flexible and powerful, but computationally demanding and requiring advanced technical expertise (mesh generation, s

Data requirements: Bathymetry / Topography, Timeseries, manning's roughness coefficient, boundary conditions

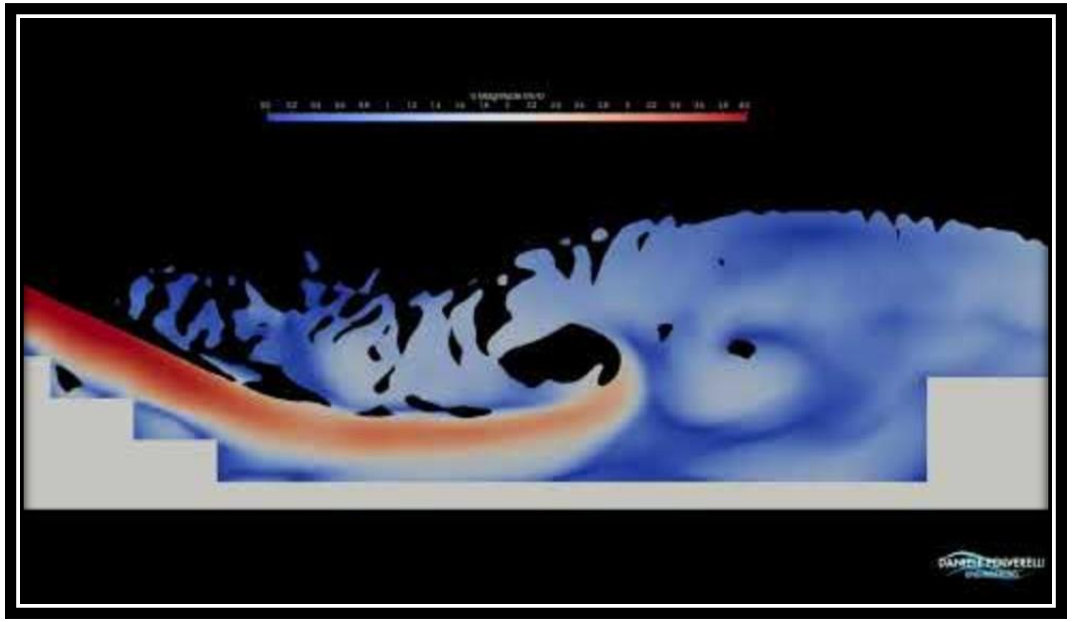


https://www.researchgate.net/figure/Overview-of-TELEMAC-3D-model_fig1_317721596

OpenFoam CFD Model

WES-BCA
Water and Environment Support - Biodiversity and Climate Action
in the Neighbourhood South region

- OpenFOAM is a fully open-source Computational Fluid Dynamics (CFD) platform used to simulate 3D fluid flow, turbulence, heat transfer and multiphase processes
- Solves the full 3D Navier–Stokes equations, enabling high-resolution simulations of complex hydraulic systems
- Widely used for hydraulic engineering, hydropower design, coastal engineering and environmental fluid dynamics
- Applied in Mediterranean studies for spillway design, breakwater overtopping, desalination intake hydraulics and wave–structure interactions
- Highly powerful and flexible, but computationally demanding and ideal only for specific cases. Requiring significant expertise, and not suited for basin-scale or long-duration hydraulic simulations



Commonly used Hydraulic Models

Model	Main Domain	Dimensions	Typical Scale	Cost	User facility	Mediterranean Application Examples
HEC-RAS	Rivers, floodplains, dams	1D / 2D	Reach–basin	Free	★★★★☆	Flash floods in Greece (Attica, Thessaly), Po & Ebro rivers, dam-break studies in Turkey
SWMM	Urban drainage & sewers	1D pipes + surface ponding	Urban districts	Free	★★★★☆	Pluvial flooding in Athens, Barcelona, Rome; CSO analysis in Istanbul
MIKE HYDRO / MIKE 11	River networks, basin management	1D	Basin–system	Commercial	★★★☆☆	Acheloos & Evinos (Greece), Ebro Basin (Spain), Po Basin (Italy), Seyhan–Ceyhan (Turkey)
TUFLOW	Floodplains, urban flooding, coasts	1D / 2D	Catchment–city	Commercial	★★★☆☆	Urban flooding in Liguria & Sicily, flash floods in Crete, coastal inundation in Spain
TELEMAC	Rivers, coasts, estuaries, morphology	1D / 2D / 3D	Reach–regional	Free (open-source)	★★☆☆☆	Ebro & Po deltas, Venice Lagoon, Izmir Bay, Greek estuaries (Axios–Aliakmonas)
OpenFOAM (CFD)	Detailed 3D hydraulics & structures	3D	Structure-scale	Free (open-source)	★☆☆☆☆	Spillways in Greece & Turkey, breakwaters in Italy & Spain, desalination outfalls in Cyprus

Urban Stormwater and Drainage Tools

https://www.autodesk.com/ca-en/products/infodrainage/free-trial

Urban Hydraulic Models
•Focus on runoff in built environments
•Represent pipes, inlets, storage, and overflow points
•Help assess drainage-system performance during intense rainfall
•Useful for pluvial flooding and urban adaptation design
•Support comparison of grey, green, and hybrid solutions

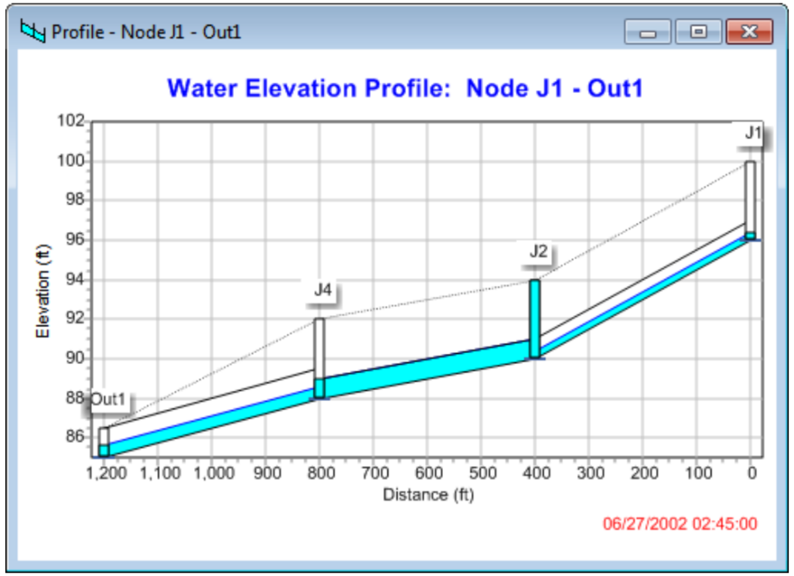
✓ City, neighborhood, or sewer-network level

Urban stormwater and river systems are often interconnected and should be analyzed as a coupled system

EPA-SWMM Model for Urban Water Management

• EPA-SWMM (Storm Water Management Model) is a free dynamic rainfall–runoff and urban drainage model developed by the U.S. Environmental Protection Agency (EPA)
• Simulates urban hydrology, hydraulics and water quality within stormwater, combined and sanitary sewer systems
• Models how rainfall becomes runoff and flows through pipes, channels, storage units, pumps and treatment systems
• Widely used in Mediterranean cities for urban flood modelling and stormwater management, especially for short-duration intense storms
• Not designed for large river basins, requires detailed urban infrastructure data, and can be computationally demanding for large networks

Data requirements: Rainfall time series (or design storm); subcatchment parameters (shape ,land use, soil); drainage network geometry, roughness coefficients; boundary conditions



SWMM Model for Urban Water Management

WES-BCA
Water and Environment Support - Biodiversity and Climate Action
in the Neighbourhood South region

- EPA-SWMM has a relatively simple and dated interface, with limited built-in visualization and workflow tools
- Does not explicitly support the SCS Curve Number method for rainfall–runoff calculations, commonly used in some regions
- Limited direct interoperability with design software such as Autodesk Civil 3D
- A large ecosystem of commercial platforms builds on the SWMM hydraulic and hydrologic solvers, adding advanced GUIs, GIS integration and modelling tools
- Major SWMM-based platforms include InfoWorks ICM, InfoDrainage, XPSWMM and PCSWMM

Emerging Digital And AI-supported Tools

WES-BCA
Water and Environment Support - Biodiversity and Climate Action
in the Neighbourhood South region

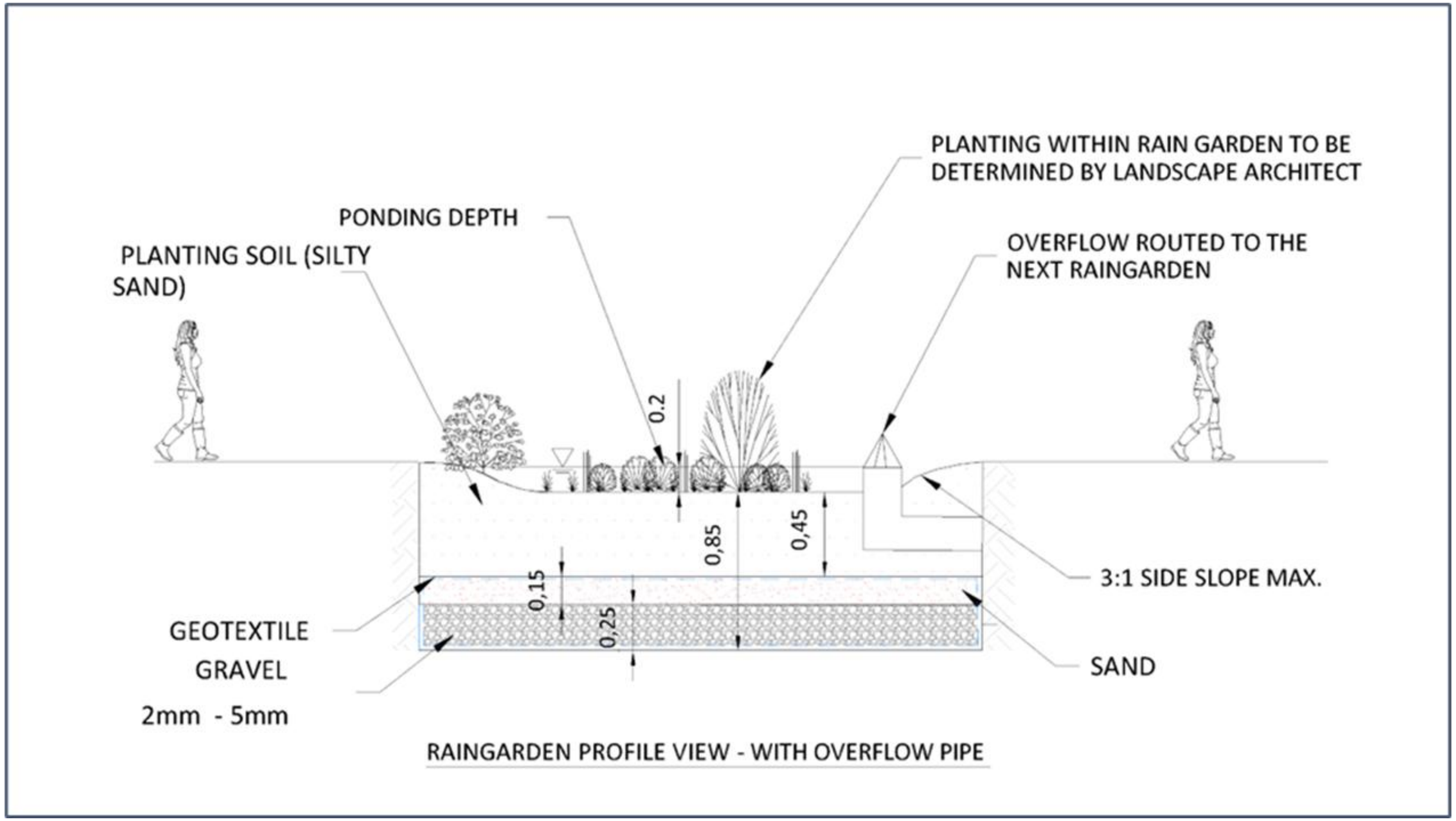
Regional/Large-scale Flood Risk And Forecasting Artificial Intelligence

- European Flood Awareness System (EFAS)
- Destination Earth (DestinE) Digital Twin Initiative
- Global Flood Awareness System (GloFAS)
- Google Flood Forecasting System

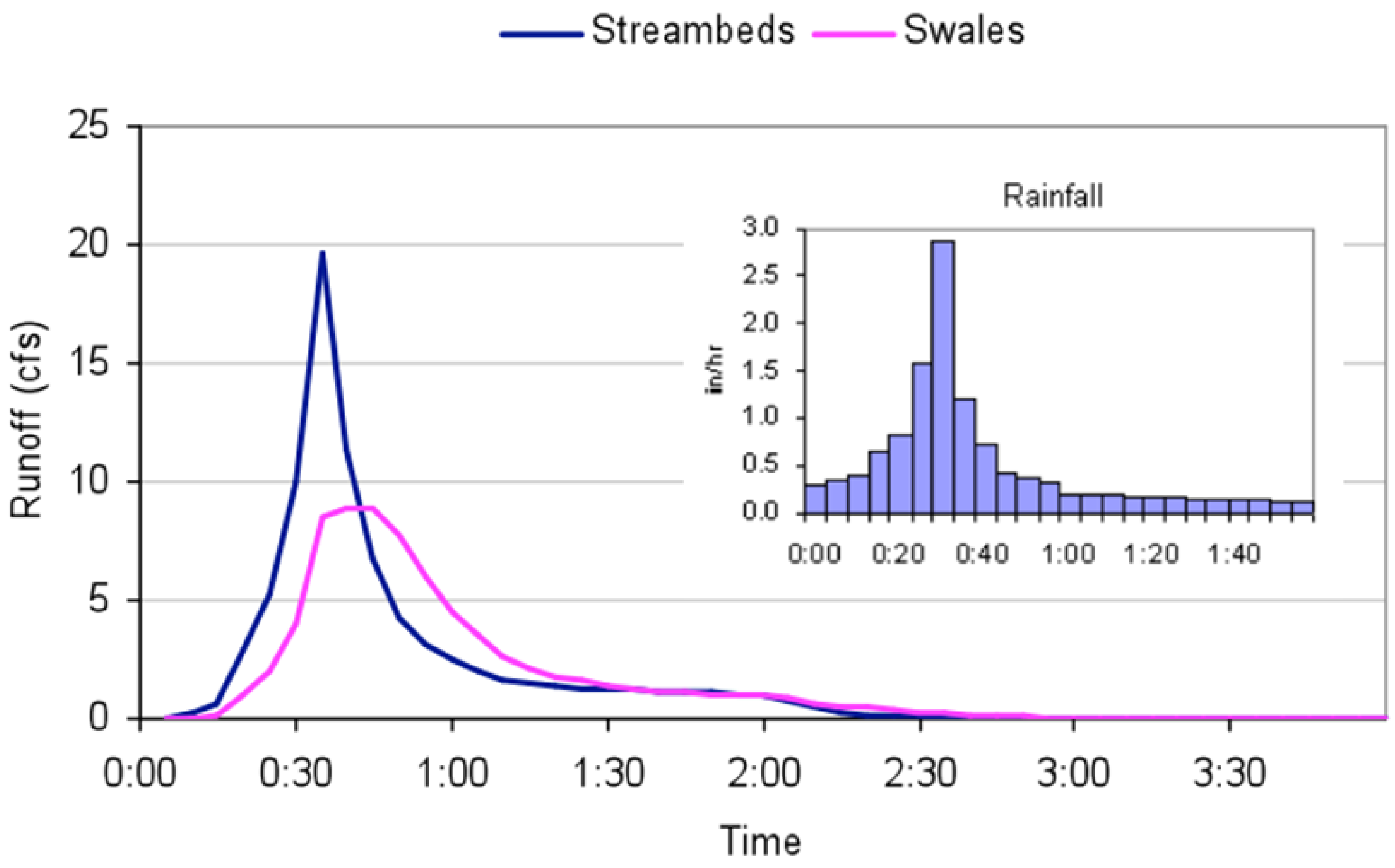
Local/Catchment-scale Nature-based Management

- Maintenance with Drone-based Inspection
- Satellite Remote Sensing and GIS-based Monitoring
- Digital Twins For Urban Flood Systems
- Real-time Control (RTC) Of “Smart” NBS

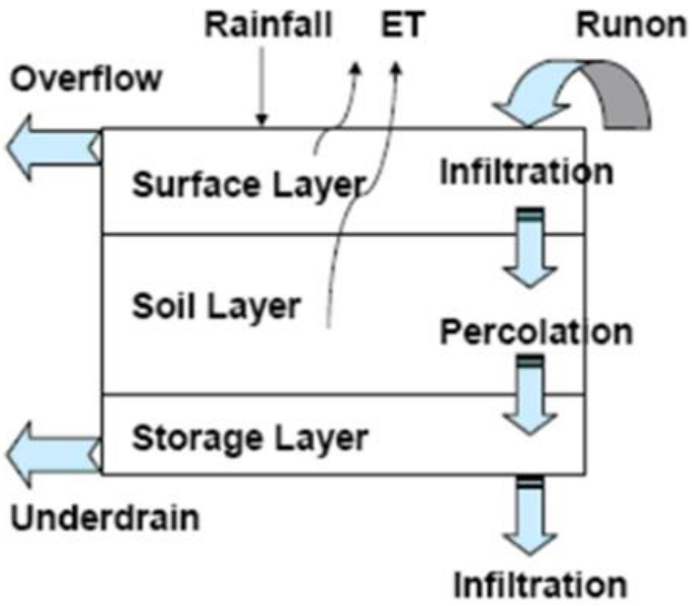
SWMM example: runoff reduction with rain gardens



SWMM example: runoff reduction with rain gardens



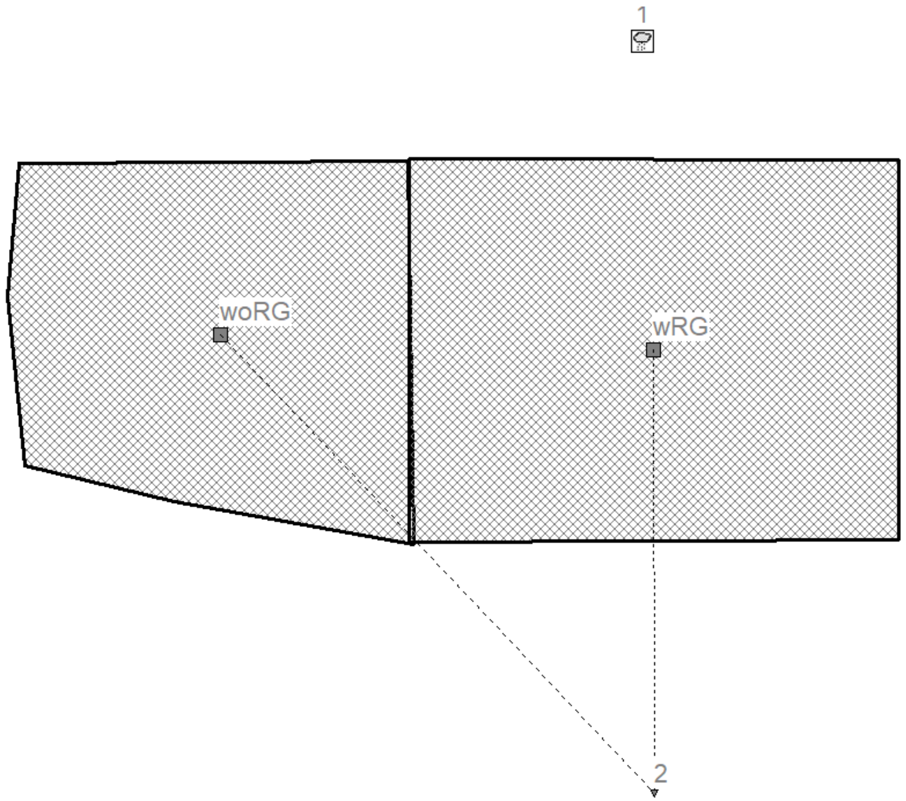
SWMM example: runoff reduction with rain gardens



LID Controls are low impact development practices designed to capture surface runoff and provide some combination of detention, infiltration, and evapotranspiration to it. They are considered as properties of a given subcatchment.. LID is the same notion like NWRMs to the SWMM terminology.
Conceptually, a generic LID unit can be represented by several vertical layers. Both direct rainfall and runoff from other locations fall on the surface layer. It loses water through evapotranspiration (ET) of any water held in depression storage and vegetative capture, through infiltration into the soil layer underneath it, and through any potential surface runoff. A modified soil mixture that can promote vegetative growth is present in the soil layer. It takes in water through infiltration from the top layer and loses it through percolation and ET into the storage layer below. Gravel or coarsely broken stone make up the storage layer. It gains water through percolation from the soil zone above it and loses it through infiltration.

SWMM example: runoff reduction with rain gardens

1. Two similar urban subcatchments under the same storm
2. woRG: without rain garden
3. wRG: with rain garden LID
4. Compare runoff response under identical conditions
5. Rain garden stores and infiltrates part of the runoff
6. Expected effect: lower runoff volume and lower peak runoff
7. Key message: LID can support flood adaptation by reducing runoff at the source



Discussion

WES-BCA
Water and Environment Support - Biodiversity and Climate Action
in the Neighbourhood South region

- Which types of tools are most used in your institution?
- What are your main challenges: data, calibration, capacity, or communication?
- Which applications matter most in your context: basins, rivers, cities, or mapping?
- How can software better support planning and decision-making in practice?

Funded by the European Union