ML Applications for Hydraulic

Conventional hydrodynamic numerical models and issues

- Solving water engineering problems typically requires flow characterization, including the prediction of space-time variation of flow depth and flow velocity.
- Physically-based models: NS equations considering external forces with suitable initial-boundary conditions can be used to describe flow characteristics.

- Applying an accurate numerical method
- Observed data and expert knowledge are required for
  - Empirical formulae
  - Model calibration and validation.

⇒ Computation time consuming

⇒ Mostly impossible for large scale modelling

ML models

- Trained on dataset can be obtained from
  - Observation,
  - Results of calibrated numerical models.

⇒ Provide
  - Non-linear relationship between flow parameters
  - Predicted results in the short term.

Water Supply

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Predicting submerged hydraulic jump characteristics using machine learning methods

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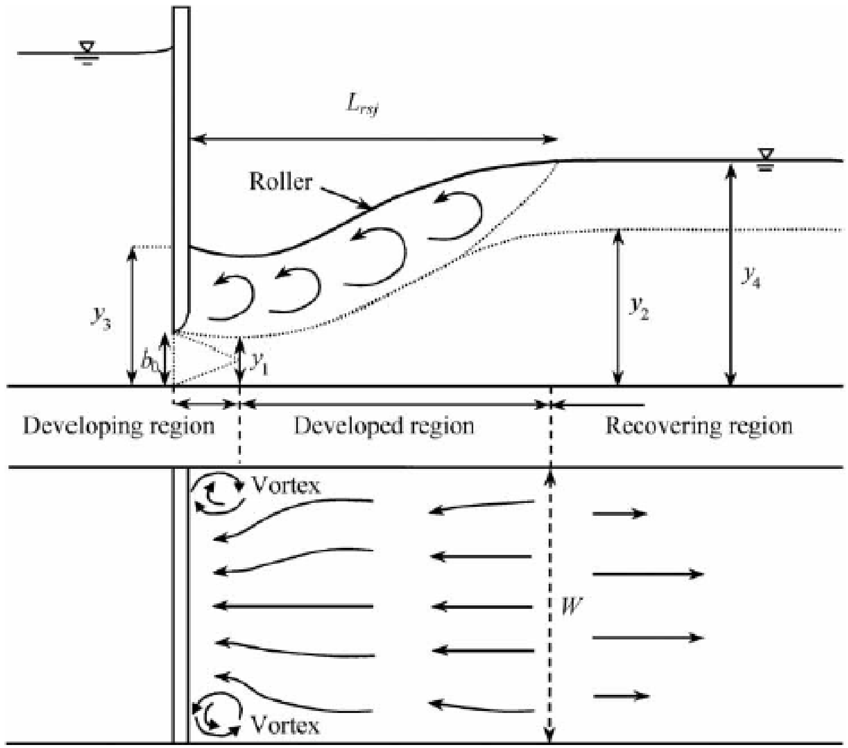
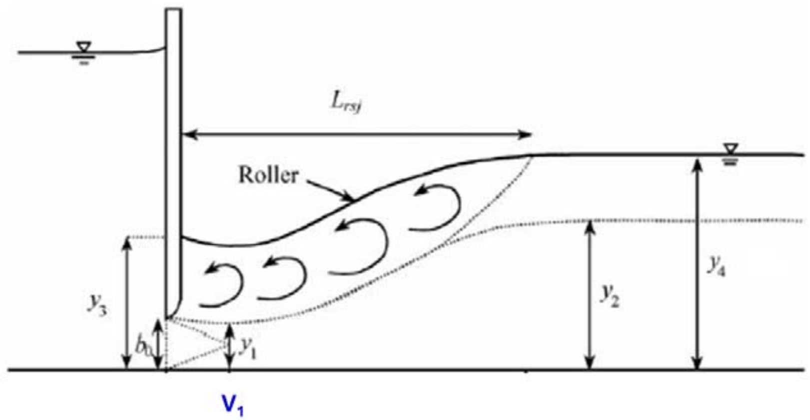
- Hydraulic jump occurs by converting the supercritical to subcritical flow regimes downstream of hydraulic structures.
  - High energy to erode the channel and river bed.
  - Submerged hydraulic jump downstream of a sluice gate can disperse flow energy.
  - Jump length plays an important role in the economic design of stilling basins and the length of the protection downstream
- Non-linear relationship between the relative energy loss, jump length, Froude number and submergence ratio.



- Submerged hydraulic jump in a smooth bed channel

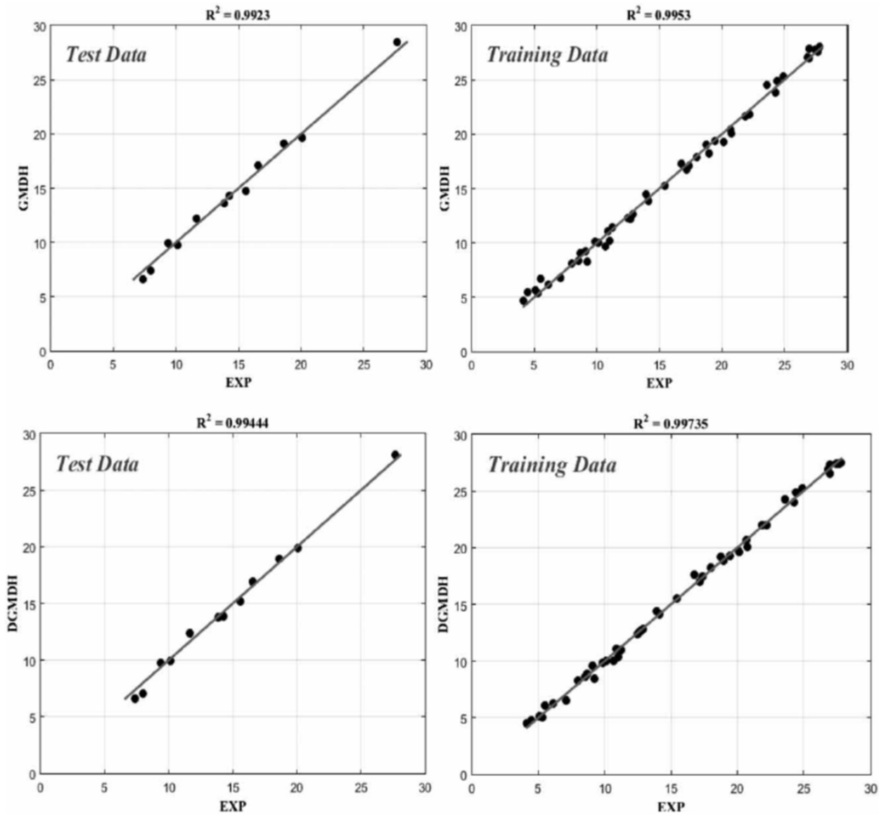


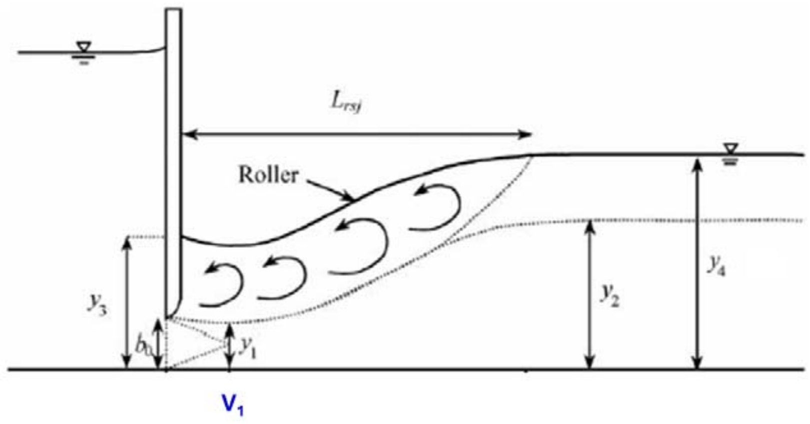
- Relative submergence depth based on Buckingham theory:

$$\frac{y_3}{y_1} = \Im_1\left(Fr_1, S\right)$$

$$S = \frac{y_4 - y_2}{y_2}$$

Researcher/method	MAPE	R^2
Rao & Rajaratnam (1963)	0.1026	0.9921
Abdel-Aal (2004)	0.0540	0.9715
GMDH	0.043	0.9923
DGMDH	0.038	0.9944



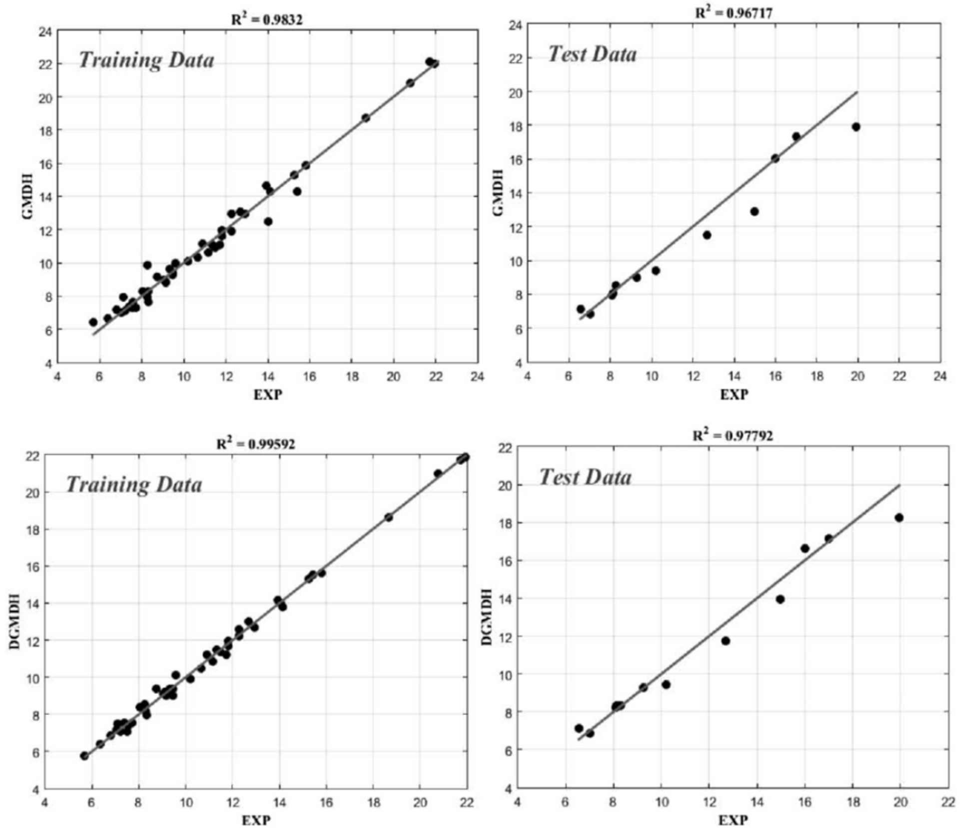


- Submerged jump length:

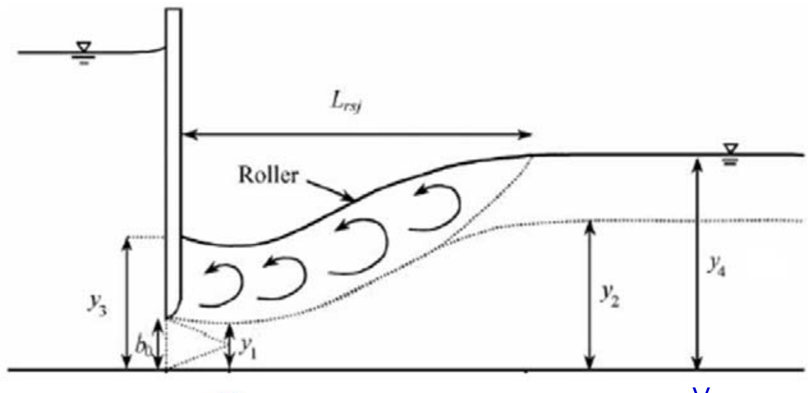
$$\frac{L_{rsj}}{y_2} = \Im_2\left(Fr_1, S\right)$$

$$S = \frac{y_4 - y_2}{y_2}$$

Researcher/method	MAPE	R^2
Rao & Rajaratnam (1963)	0.0926	0.9505
Abdel-Aal (2004)	0.0569	0.9478
GMDH	0.0527	0.9671
DGMDH	0.0387	0.9779



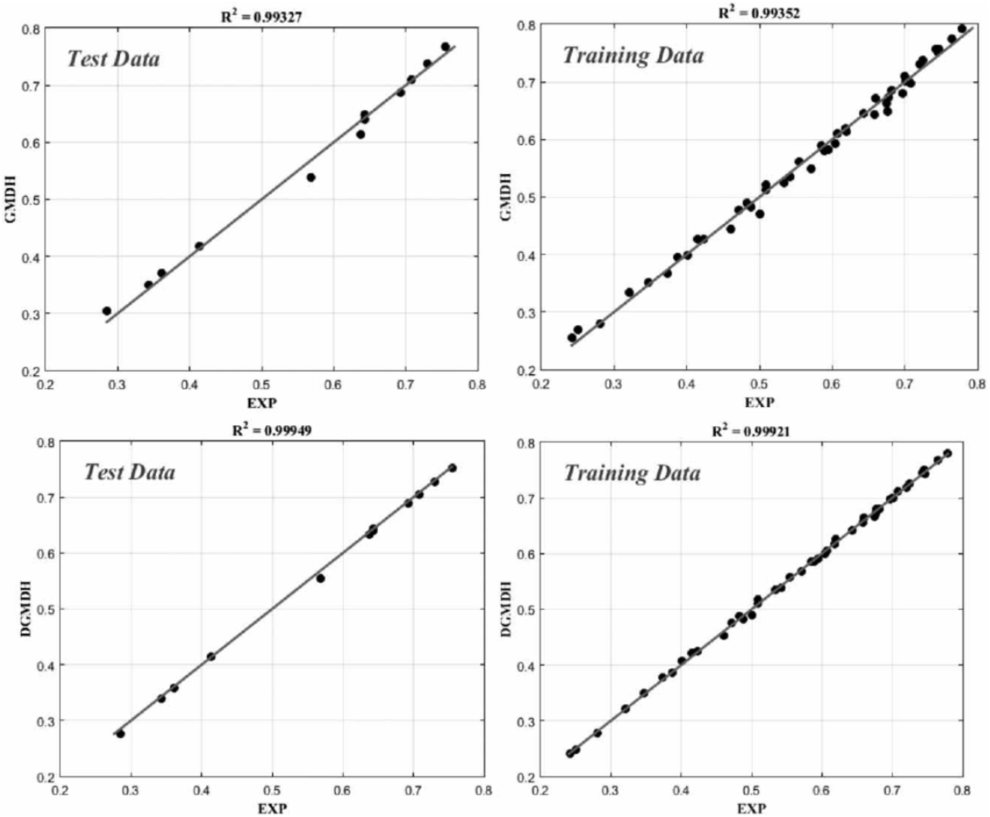
- Relative energy loss



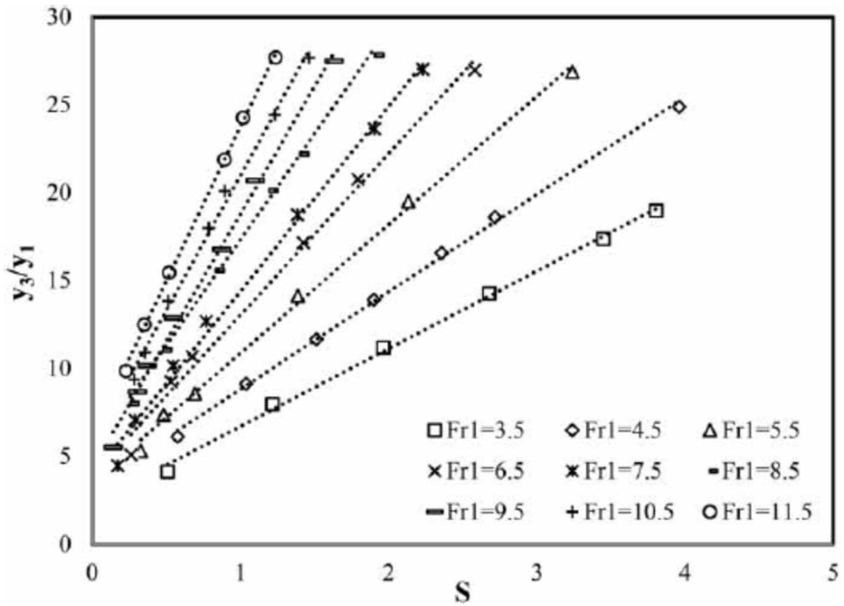
$$\frac{\Delta E}{E_1} = \frac{E_1 - E_2}{E_1} = \Im_2\left(Fr_1, S\right)$$

$$E_1 = y_3 + \frac{V_1^2}{2g}$$

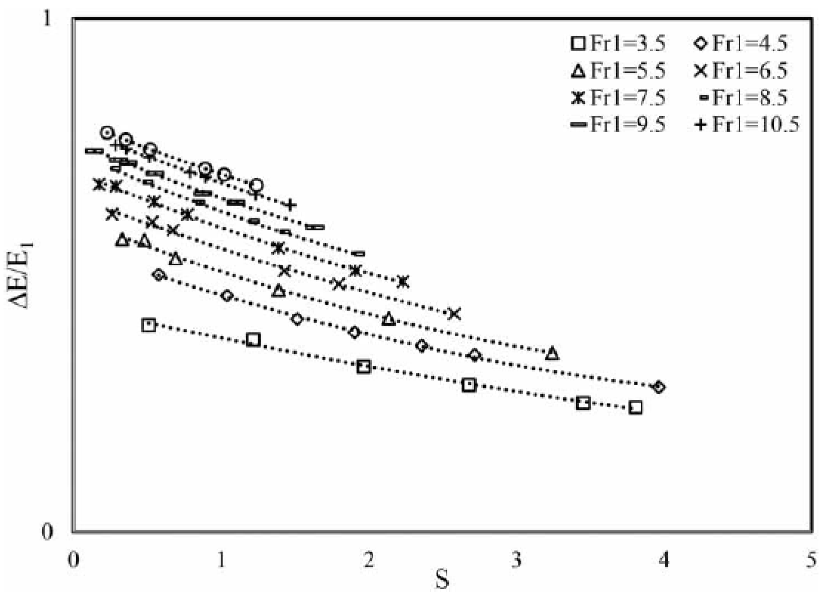
$$E_2 = y_4 + \frac{V_4^2}{2g}$$



Researcher/method	MAPE	R^2
Rao & Rajaratnam (1963)	0.1251	0.9980
Abdel-Aal (2004)	0.0403	0.9972
GMDH	0.0192	0.9932
DGMDH	0.0093	0.9994



Changes in relative submergence depth (y_3/y_1) versus the submergence ratio (S) for different Froude numbers



Changes in the relative energy loss of the submerged hydraulic jump ($\Delta E/E_1$) versus the submergence ratio (S) for different Froude numbers

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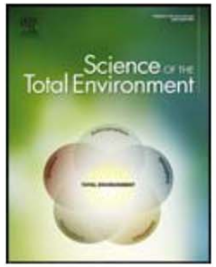
journal homepage: www.elsevier.com/locate/scitotenv



Influence of urban pattern on inundation flow in floodplains of lowland rivers

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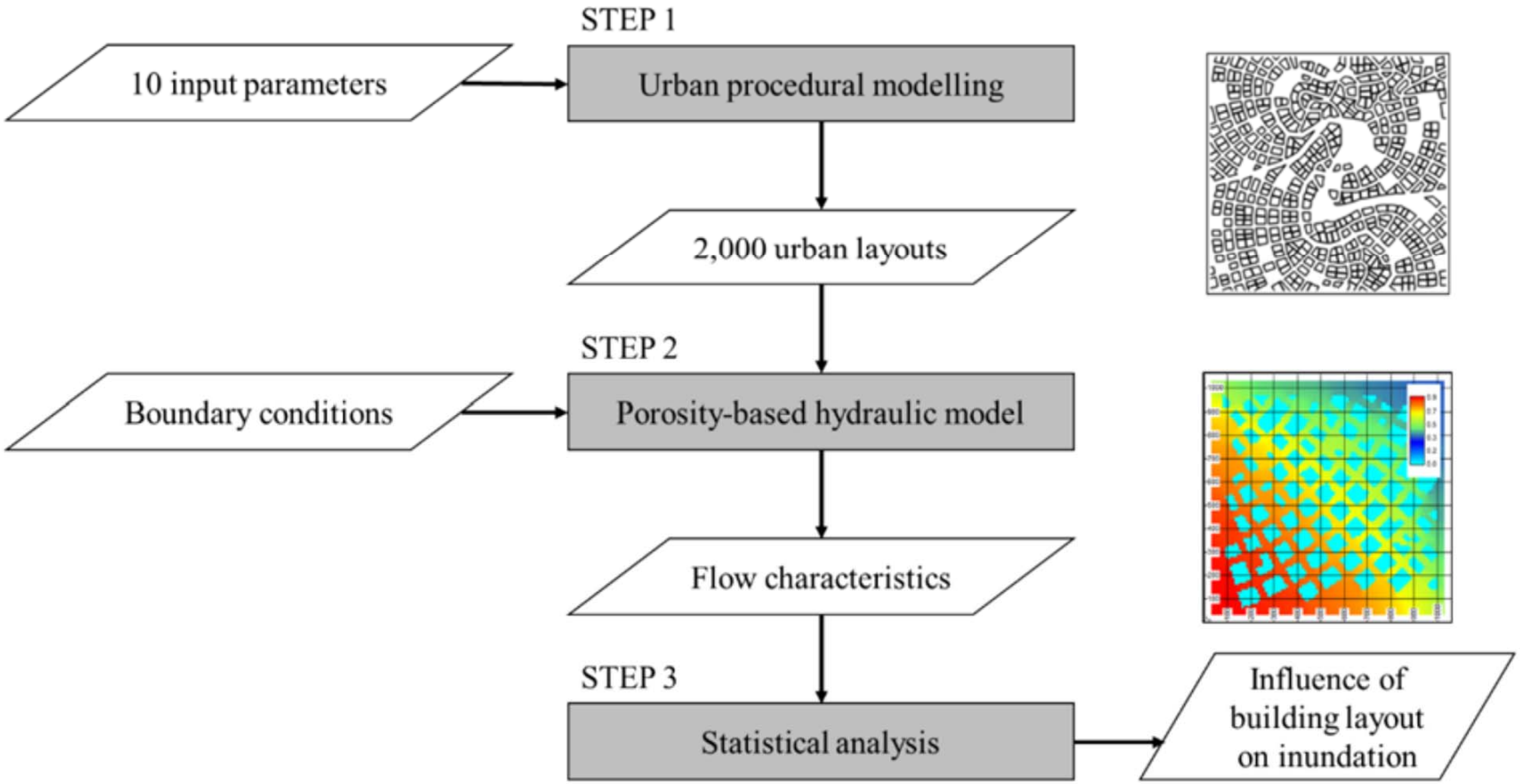
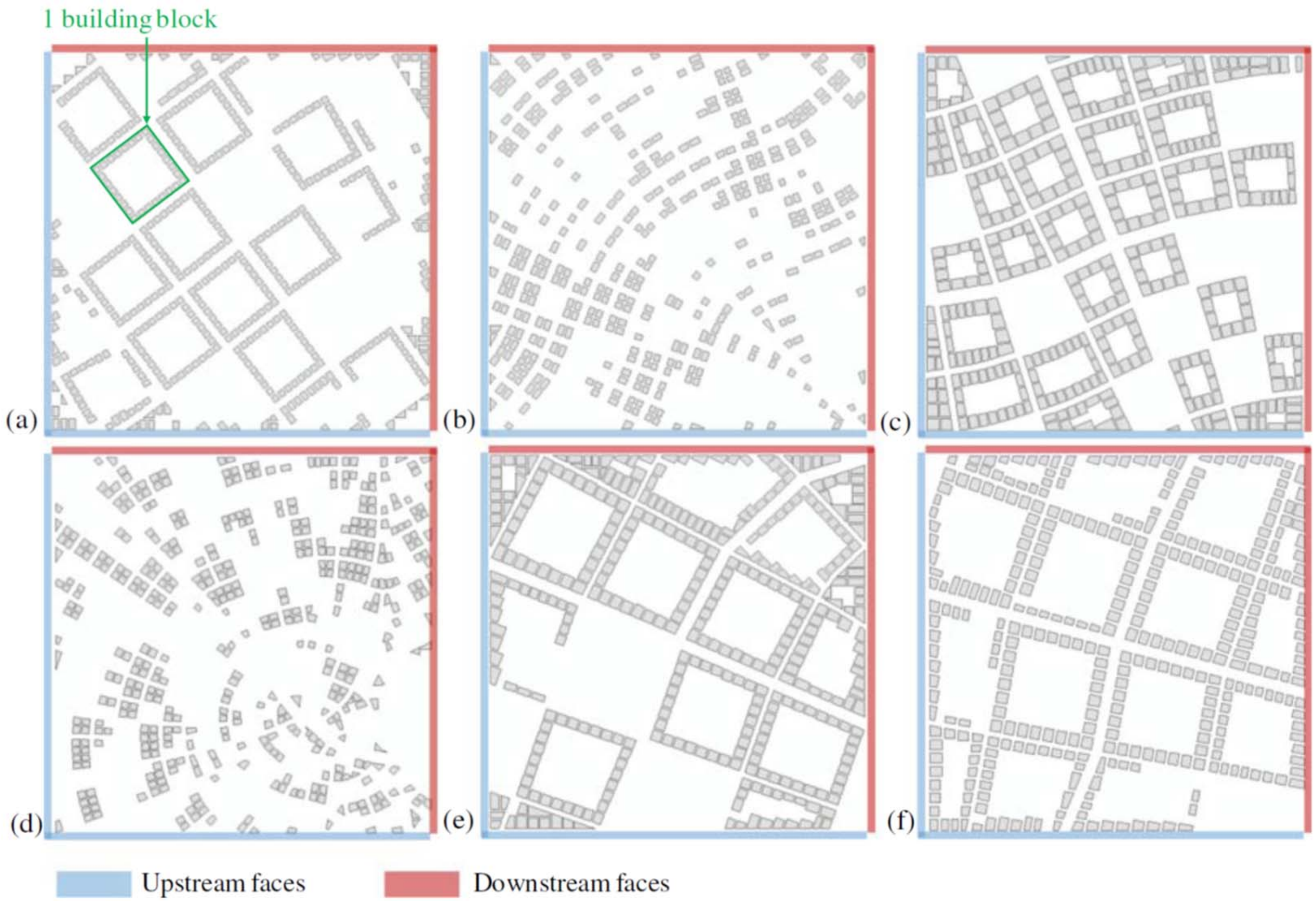
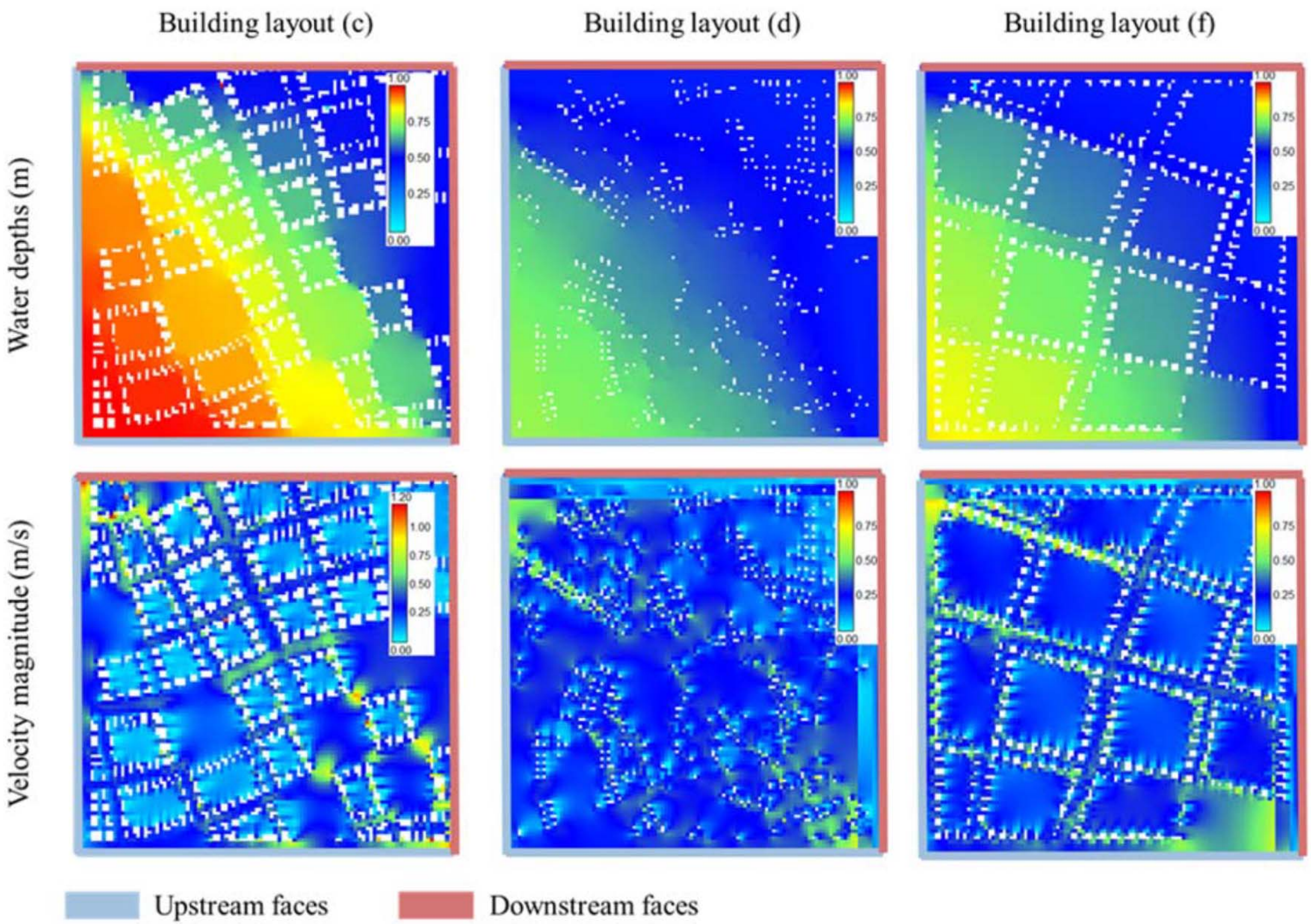
- To investigate the respective influence of various urban pattern characteristics on inundation flow by applying:
  - **Steady two-dimensional hydraulic computations** for over a set of 2000 synthetic urban patterns (locations and shapes of streets and buildings over a square domain of 1 × 1 km^2) with identical hydraulic boundary conditions.
  - **Multiple linear regressions** for relationships between urban characteristics and the computed inundation water depths.
- This study gives guidelines for more flood-proof urban planning.



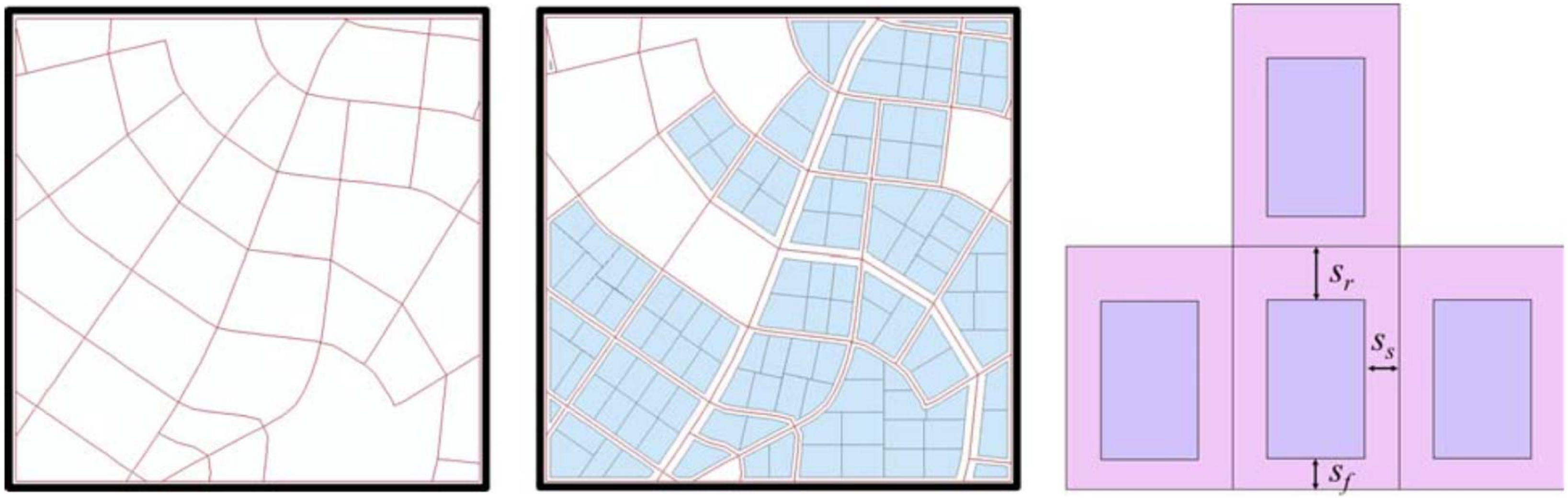
Methodology for the determination of the influence of building layout on inundation characteristics



Building footprints for six out of the 2000 layouts used for simulations



Representation of water depths and flow fields for some urban patterns



Definition of the tensor field of the streets, the parcels and building footprint in each parcel.

	Urban parameter	Minimum	Maximum
L_s	Average street length	40 m	400 m
α	Street orientation	0°	180°
χ	Street curvature	0 km^{-1}	10 km^{-1}.
W	Major street width	16 m	33 m
w	Minor street width	8 m	16 m
P_c	Park coverage	5%	40%
A_p	Mean parcel area	350 m^2	1100 m^2
s_f	Building front setback	1 m	5 m
s_r	Building rear setback	1 m	5 m
s_s	Building side setback	1 m	5 m

Urban parameters

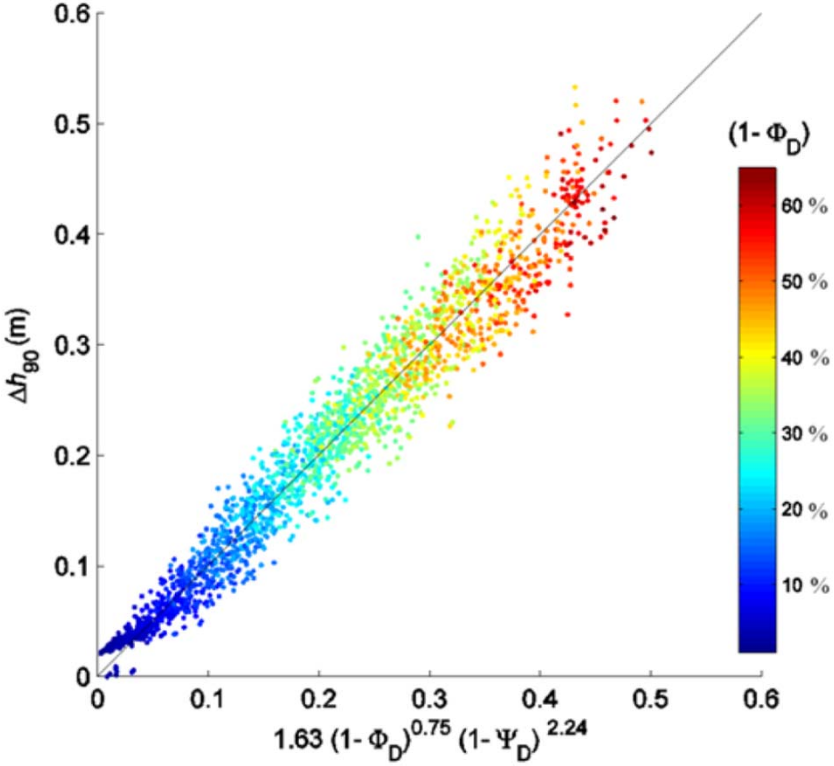
Results

$$\Phi_D = 1 - x_9$$

$$\Psi_b = 2\left(\frac{s_s}{\sqrt{A_p}} + \frac{s_f - s_s}{L_s}\right)$$

$$\Psi_D = \frac{\Psi_b L_s + w}{L_s + w} + \frac{w}{L_D}\left(\frac{W}{w} - 1\right)\left(1 - \frac{\Psi_b L_s + w}{L_s + w}\right)$$

$$\Delta h_{90} = a\ (1-\Phi_D)^b\ (1-\Psi_D)^c$$



The 90th percentile of the computed water depths along the upstream boundary of the domain is defined based on the district-scale storage Φ_D and conveyance porosities Ψ_D.

Data preprocessing

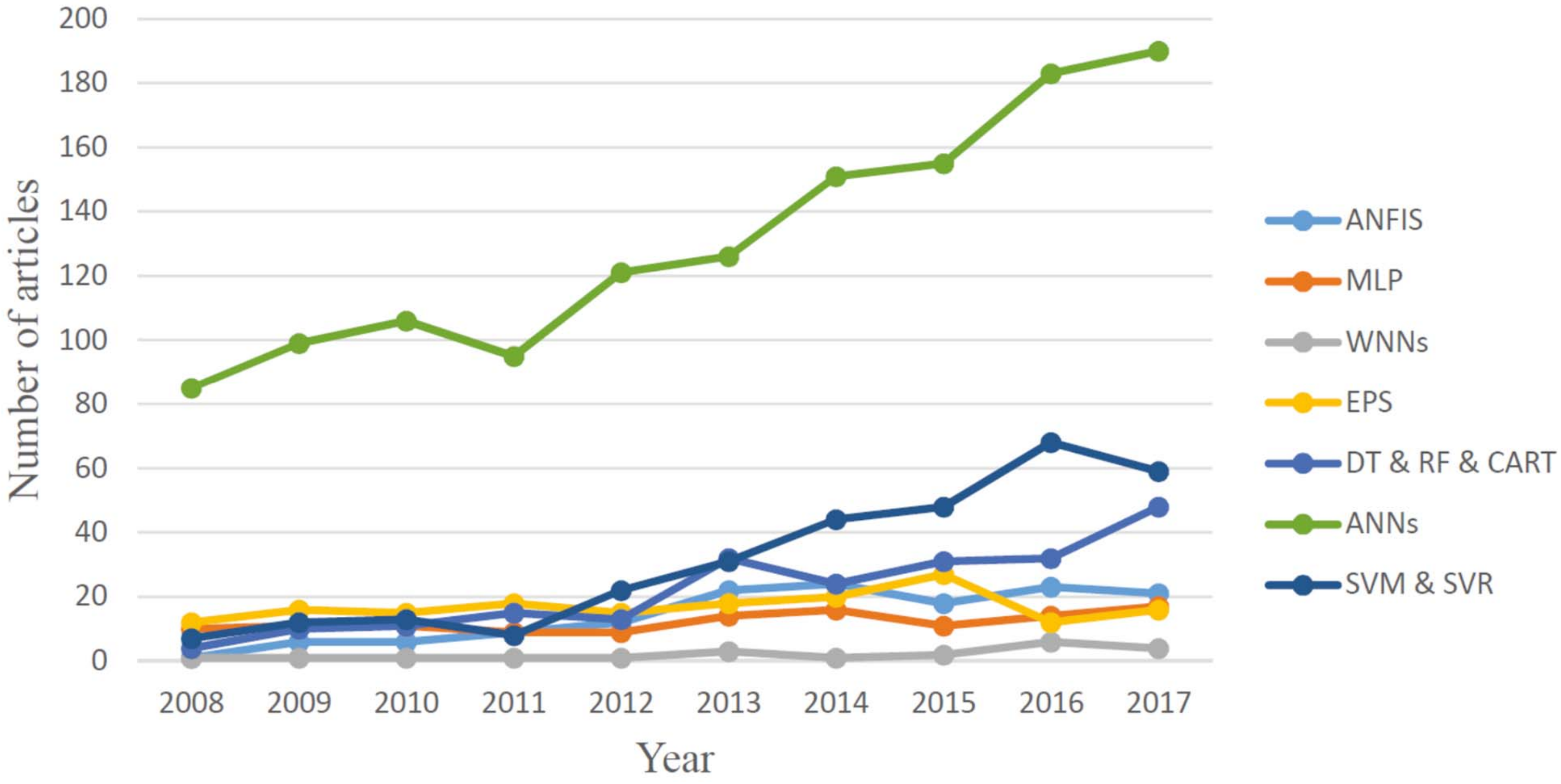
- 9 urban input parameters

Variable definition	Minimum	Maximum
$x_1 = L_s$	40 m	400 m
$x_2 = \|\sin(2(\alpha - 45^\circ))\|$	0	1
$x_3 = \chi$	0 km^{-1}	10 km^{-1}
$x_4 = W + 2\, s_f$	18 m	38 m
$x_5 = w + 2\, s_f$	10 m	21 m
$x_6 = A_p$	350 m^2	1100 m^2
$x_7 = s_r$	1 m	5 m
$x_8 = s_s$	1 m	5 m
$x_9 = f(L_s, \alpha, \chi, W, w, P_c, A_p, s_r, s_f, s_s)$	0%	43%

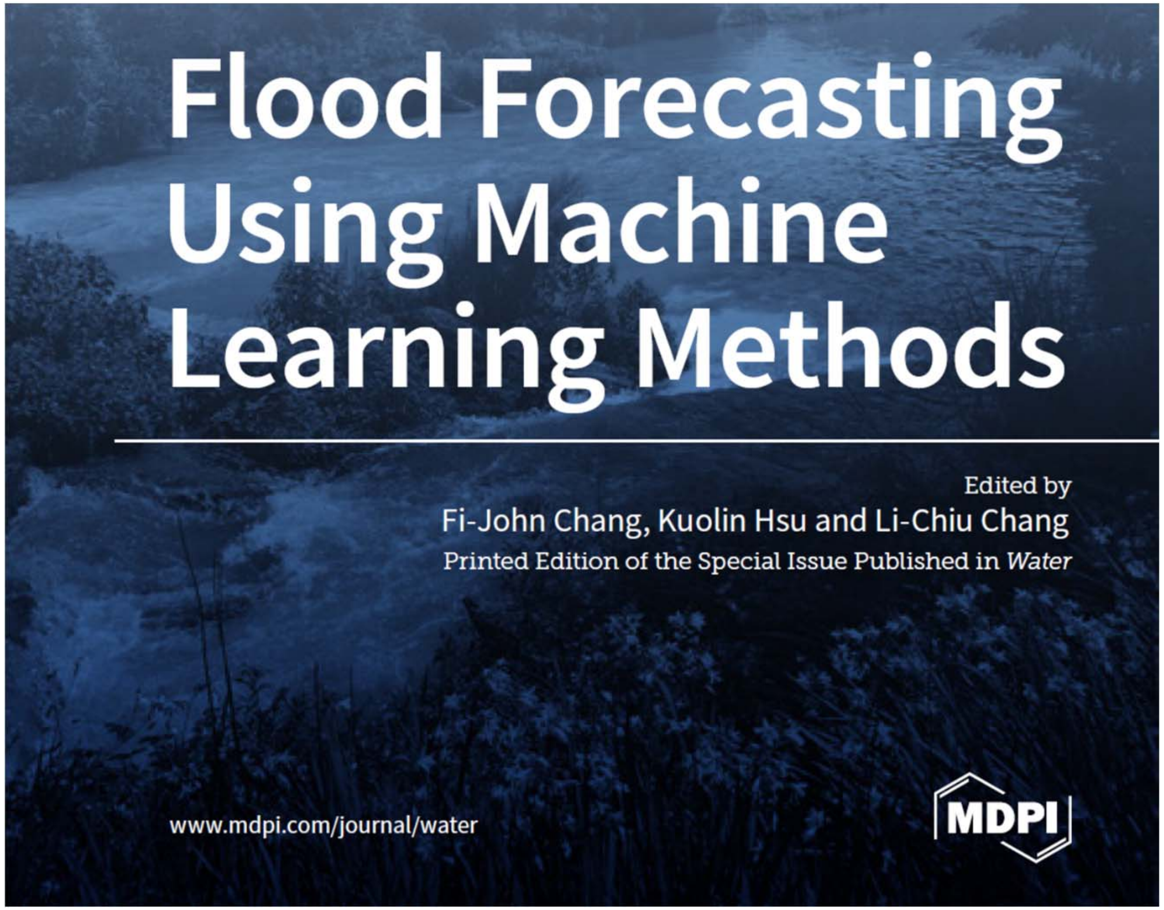
- Inundation output: the 90^{th} percentile of the computed water depths along the upstream boundary of the domain (noted Δh_{90}).

MATLAB - Exercise 8.1

1. Import Data: Urban_Inundation.xlsx
2. Normalize variables
3. Divide into 3 datasets: Training (70%); Validation (15%); Testing (15%)
4. Design MLP networks with
   - 9 inputs: x_1,.., x_9
   - 1 output: Δh_{90}
5. Train and test the networks by applying
   - Case1: one hidden layer and different number of hidden neuron, different activation and training functions
   - Case 2: two hidden layers
6. Evaluate network performance and chose the “best” results.

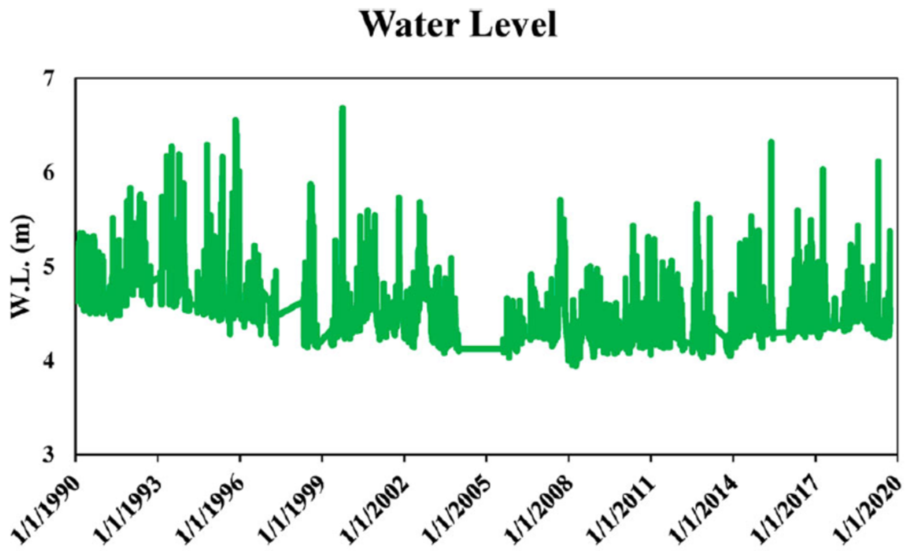


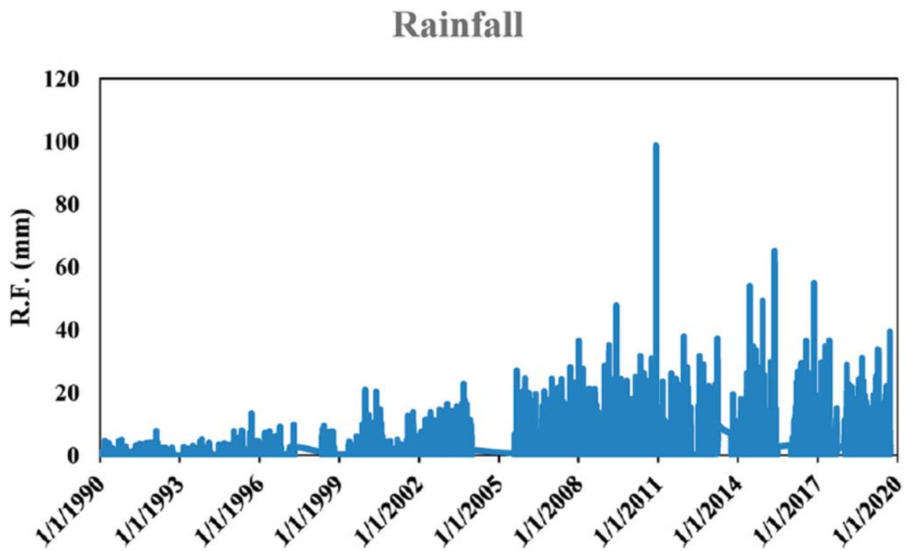
Major ML methods used for flood prediction in the literature.
Reference year: 2008 (source: Scopus)

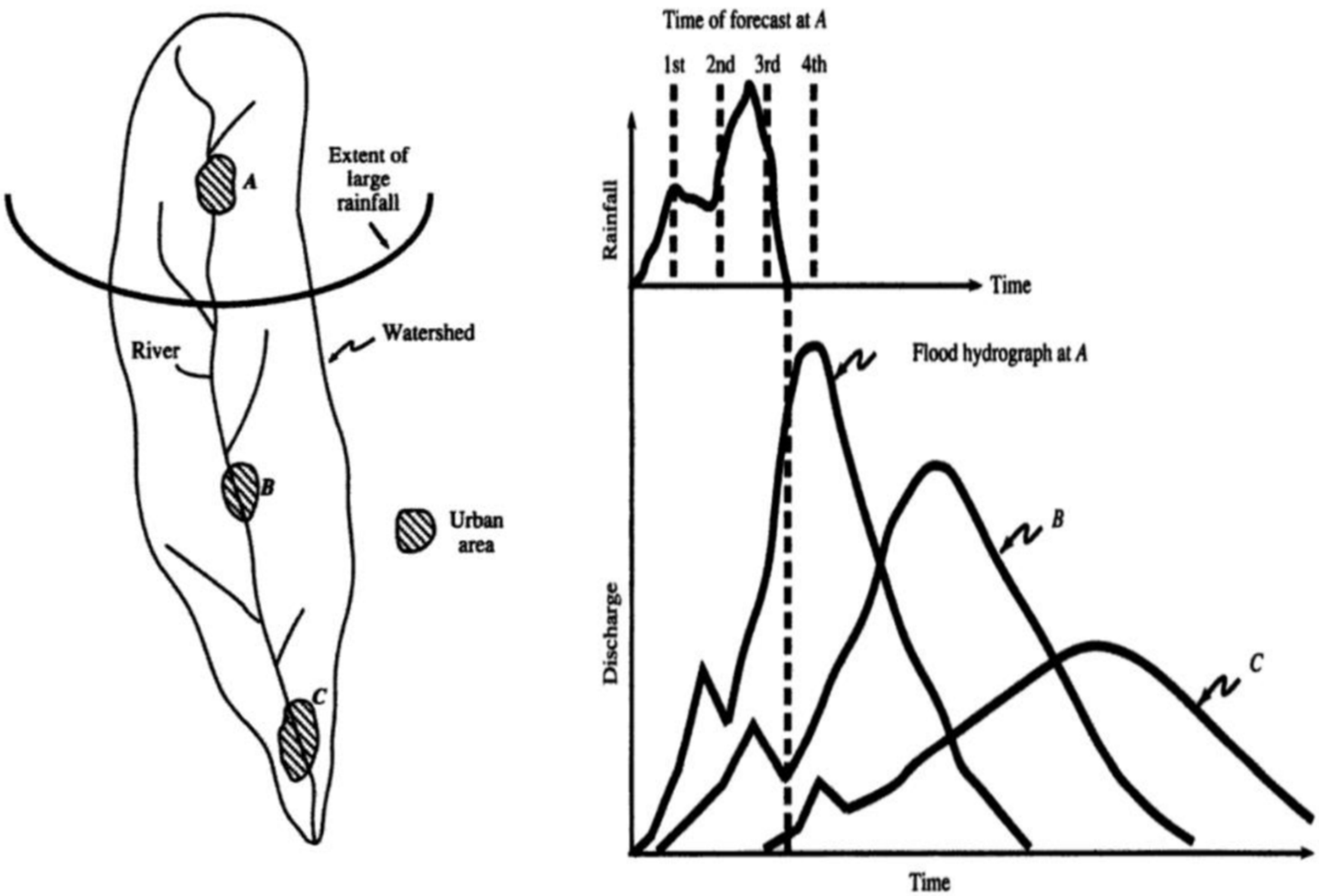


https://gigamove.rwth-aachen.de/de/download/b7292e4400ba6aecefcc320552c2d0f7

Among other, time series of rainfall as important inputs affecting the water level / flow discharge

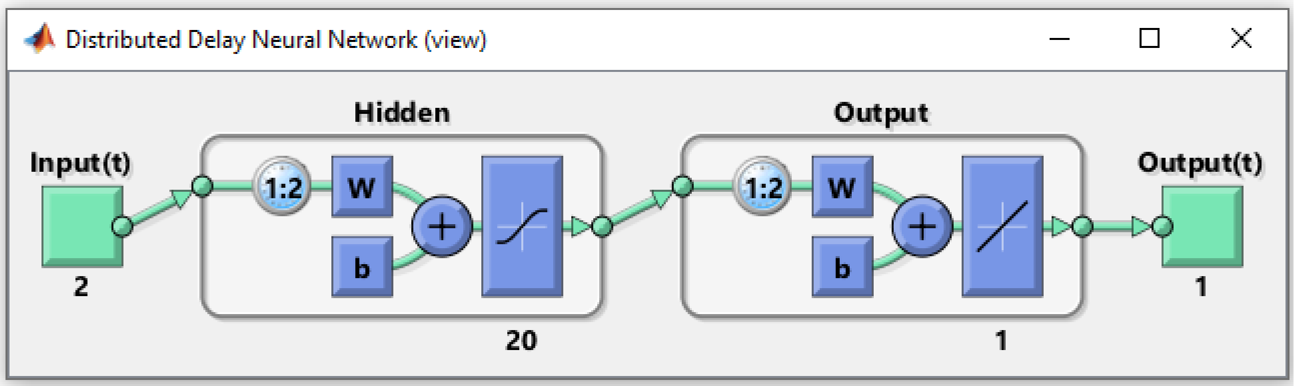






Effect of Lead Time and Flood hydrograph at Downstream Location in a Watershed (L. Mays & Tung, 1992)

Time Series Distributed Delay Networks




```
nnet = distdelaynet({1:2,1:2},20);
[Xs,Xi,Ai,Ts] = preparets(nnet,Input,Target);
```

Nonlinear Autoregressive Network with External Input

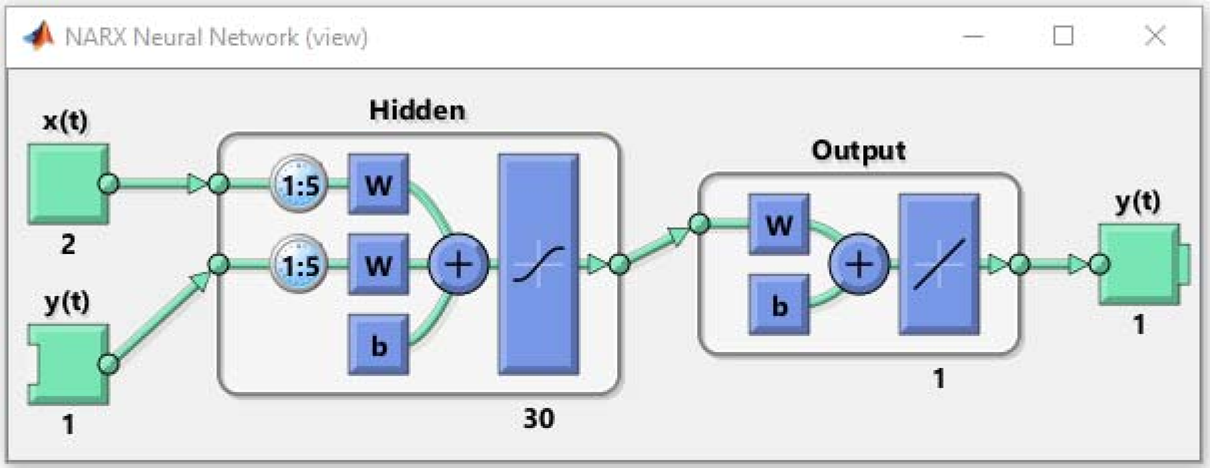
Open

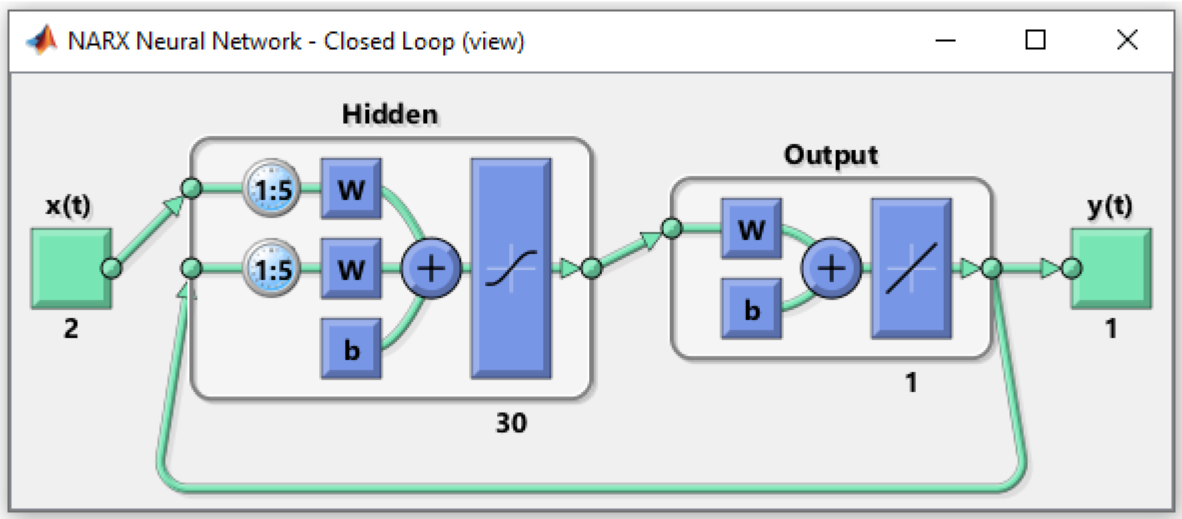
nnet = narxnet(inputDelays, feedbackDelays, hiddenLayerSize, 'open')

Closed

nnet = narxnet(inputDelays, feedbackDelays, hiddenLayerSize, ‘closed')

[Xs,Xi,Ai,Ts] = preparets(nnet,Input,{}, Target)





MATLAB - Exercise 8.2

1. Import time series data: Flood_Data.xlsx
2. Impute the missing data
3. Normalize variables
4. Design, train and test two following networks
   I. TS-ANN (Time Series Distributed Delay Networks) with 4 inputs (flow discharge and precipitation at two former time steps) and one output (flow discharge) at the present time.
   II. Nonlinear Autoregressive Network with External Input

5. View the networks and evaluate the results.

Data for your project

1. Germany

https://www.gkd.bayern.de/de/fluesse/abfluss/isar/grafrath-16603000/download?zr=gesamt&beginn=01.07.2019&ende=23.07.2019&wertart=ezw

2. USA

https://www.sciencebase.gov/catalog/items?q=&filter=tags%3Dsuspended+material+%28water%29

https://waterdata.usgs.gov/co/nwis/uv/?site_no=06708690&PARAmeter_cd=00045,72192