Wetropolis Game: City Guardians

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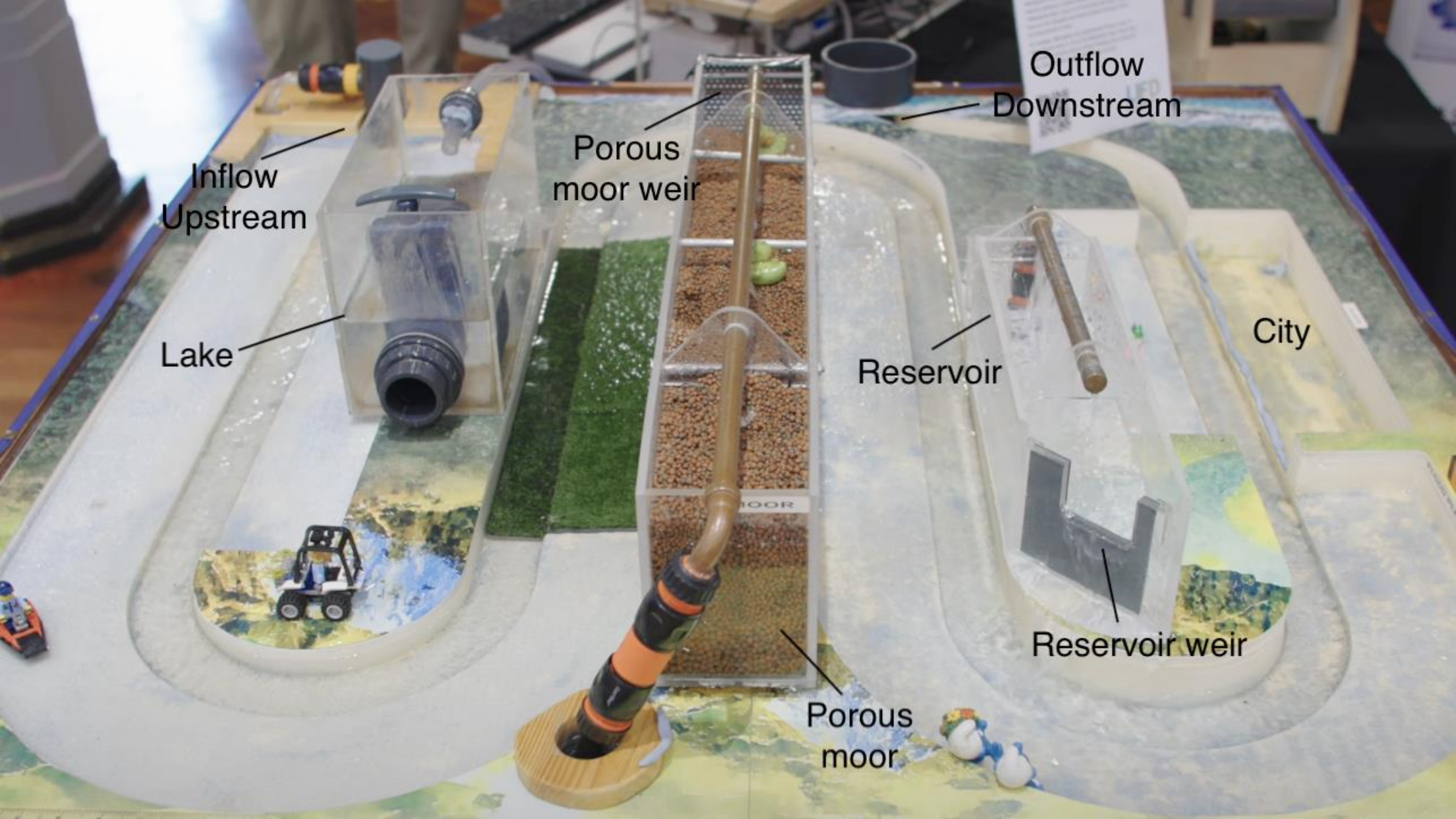
Introduction to Wetropolis

A physical and conceptual demonstrator of extreme rainfall and flooding

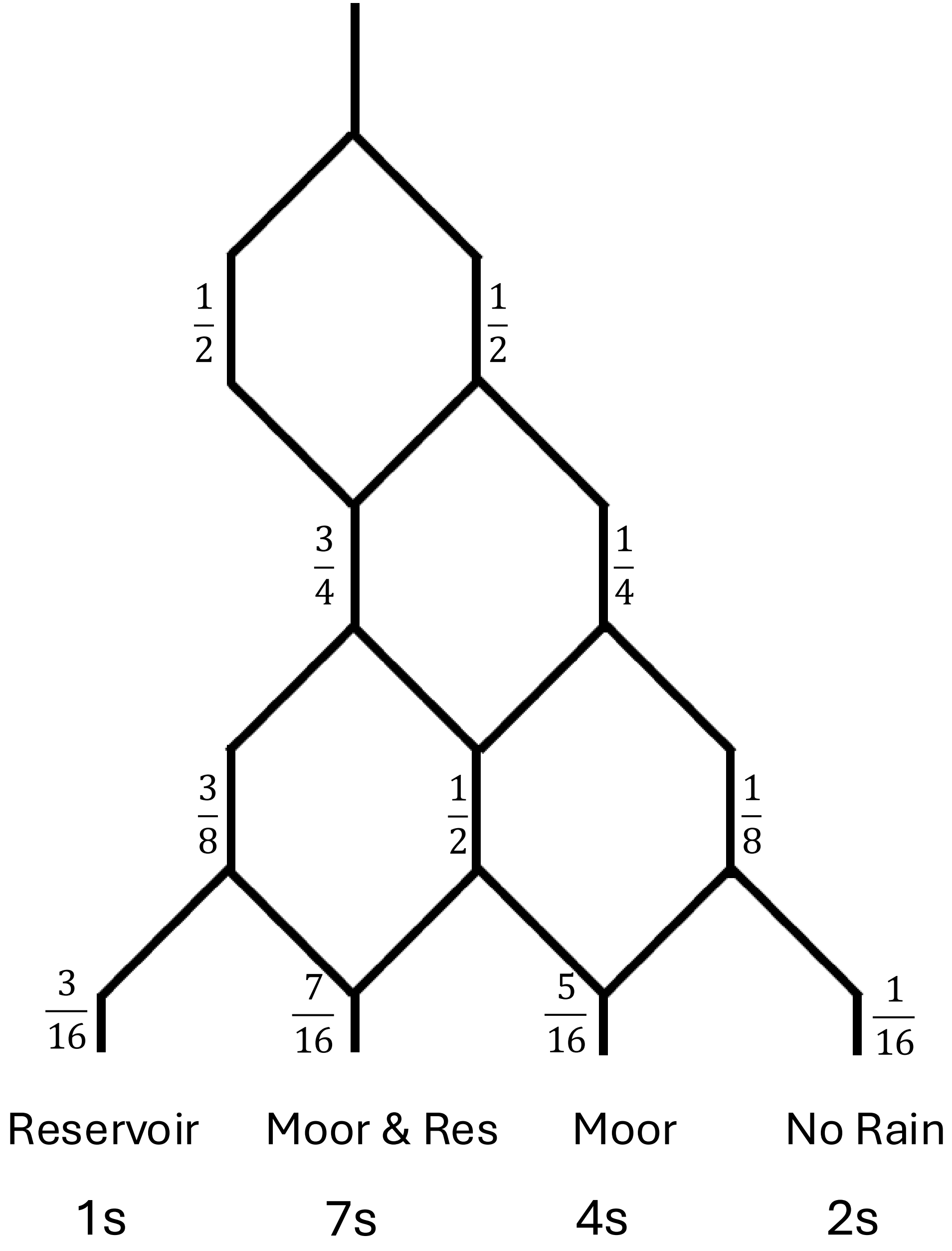
References:
Bokhove, O., Hicks, T., Zweers, W. and Kent, T. Wetropolis extreme rainfall and flood demonstrator: from mathematical design to outreach. *Hydrology and Earth System Sciences*. [Online]. 2020, 24(5), pp.2483-2503. [Accessed 1 October 2024]. Available from: https://doi.org/10.5194/hess-24-2483-2020
Kent, T. and Bokhove, O. Wetropolis rainfall and flood demonstrator: towards real-time simulations with data assimilation. University of Leeds. [Online]. 2020. [Accessed 1 October 2024]. Available from: https://github.com/tkent198/hydraulic_wetro/blob/master/Wetropolis_Au_modelv2.pdf

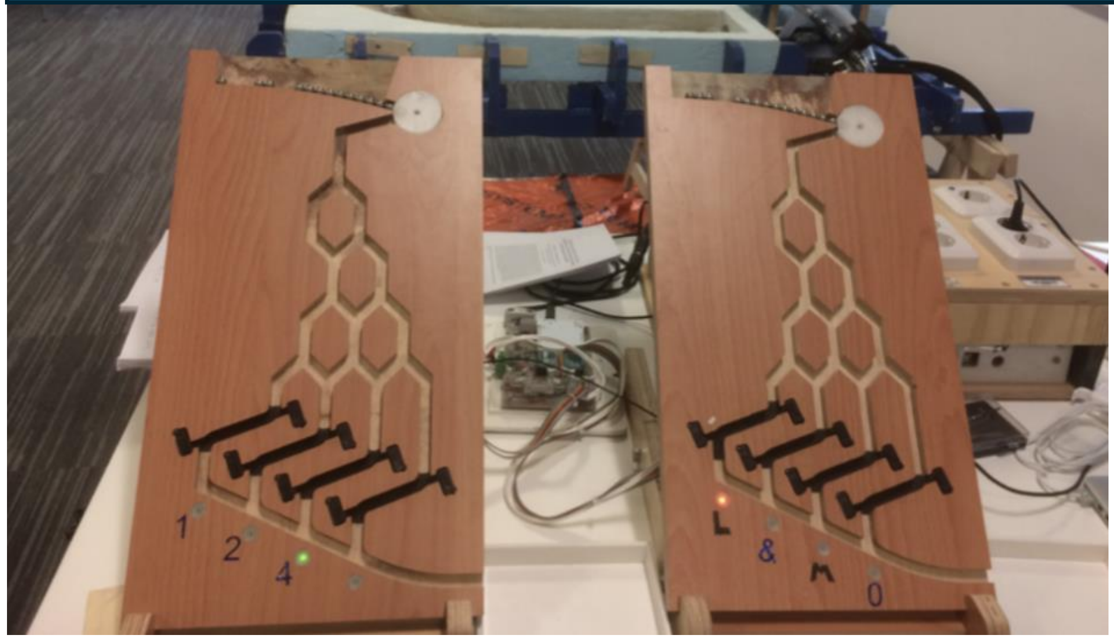

Outflow
Downstream
Porous
moor weir
Inflow
Upstream
Lake
City
Reservoir
Reservoir weir
Porous
moor
MOOR

Mathematical Design in Wetropolis

- Random Rainfall
- River Dynamics
- Groundwater Flow
- Reservoir

Random Rainfall





	r_0	$2r_0$	$4r_0$	$7r_0$
Reservoir	9	3	15	21
Both	21	7	35	49
Moor	15	5	25	35
No Rain	3	1	5	7

River Model

Saint-Venant equations

Model variables: cross-sectional area $A = A(s,t)$ and velocity $u = u(s,t)$, both functions of the along-channel spatial coordinate s and time t.

$$\partial_t A + \partial_s (Au) = S_A(s,t)$$
$$\underline{\partial_t u + u\partial_s u + g\partial_s h} - g(S_o - S_f) = 0$$

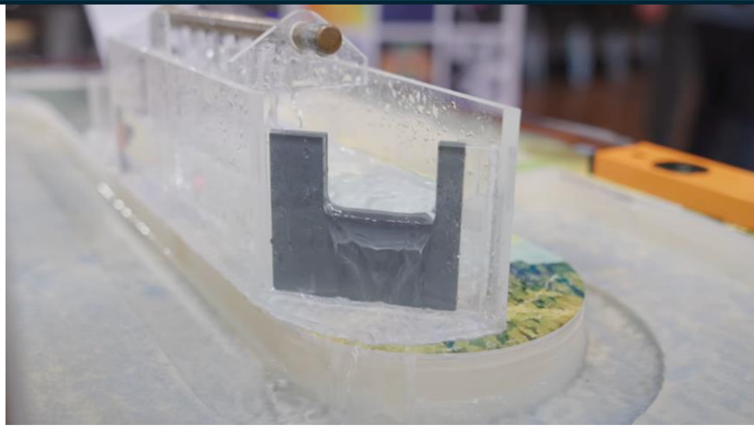
$S_A(s,t)$ is the mass source term $[\mathrm{m}^2\mathrm{s}^{-1}]$
$S_o = -\partial_s b$ is the bed slope
S_f is the friction term
g is the gravitational acceleration

The Manning relation for friction:

$$S_f = \frac{C_m^2}{R^{4/3}} u|u|, \qquad \Rightarrow u = \frac{R^{2/3}}{C_m}\sqrt{-\partial_s b}$$

$R = R(h) = \dfrac{\text{wetted area}}{\text{wetted perimeter}}$ is the hydraulic radius
C_m is the Manning friction coefficient

Reservoir



The reservoir stores rainfall and releases water into the river via a weir.

Weir relation: describes how water discharges across a weir that controls flow by imposing a certain height difference between upstream and downstream water levels.

$$w_{\mathrm{res}} L_{\mathrm{res}} \frac{\mathrm{d}h_{\mathrm{res}}}{\mathrm{d}t} = w_{\mathrm{res}} L_{\mathrm{res}} R_{\mathrm{res}}(t) - Q_{\mathrm{res}},$$

$$\text{with} \quad Q_{\mathrm{res}} = C_f \sqrt{g}\, w_{\mathrm{res}} \max(h_{\mathrm{res}} - P_{\mathrm{wr}}, 0)^{3/2}$$

$w_{\mathrm{res}} L_{\mathrm{res}}$: area of the reservoir
h_{res}: time-dependent water level in reservoir
C_f: Weir coefficient [dimensionless]
P_{wr}: overflow height of the weir
Q_{res}: flux down into the river
$R_{\mathrm{res}}(t)$: reservoir rainfall

Moor

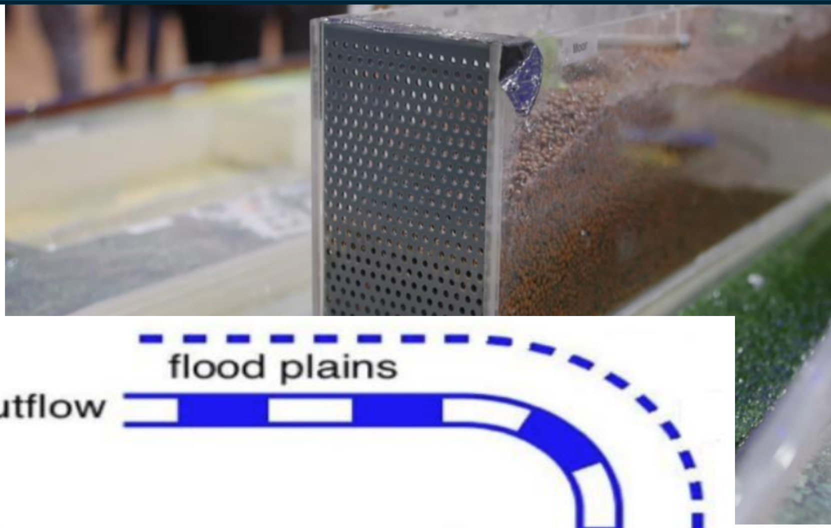
The nonlinear diffusion equation:

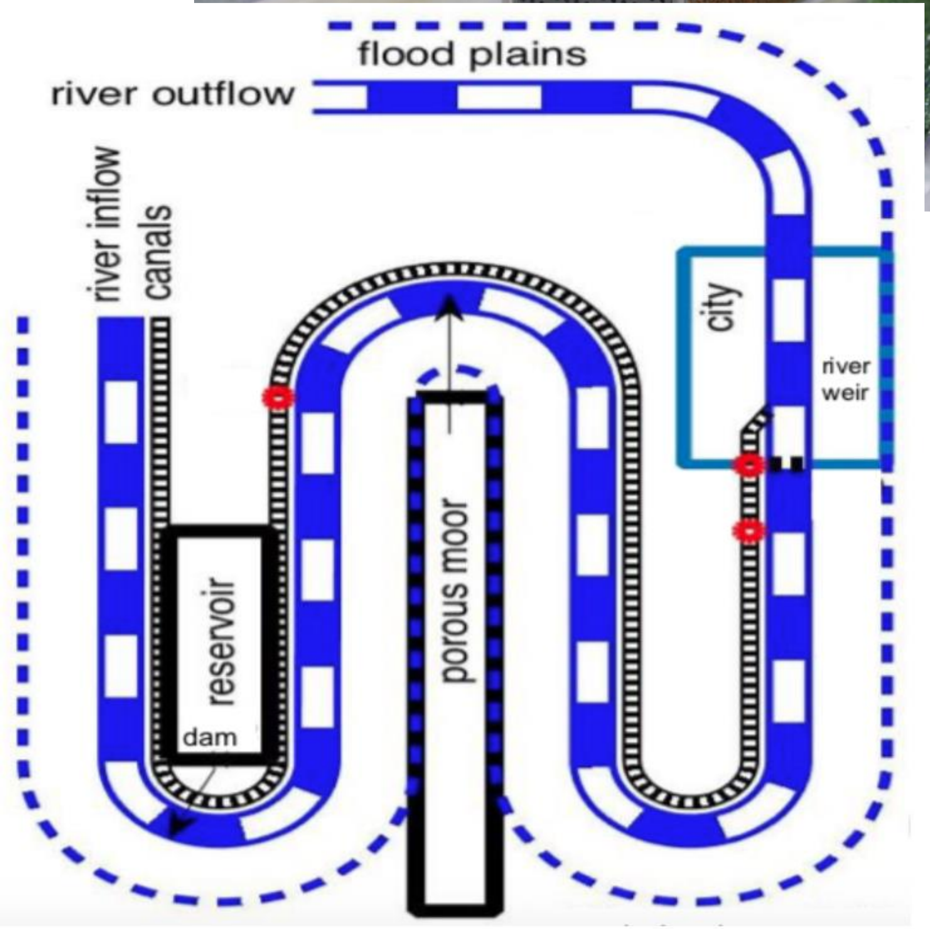
$$\partial_t(w_v h_{\mathrm{m}}) - \alpha g \partial_y\left(w_v h_{\mathrm{m}} \partial_y h_{\mathrm{m}}\right) = \frac{w_v R_{\mathrm{m}}(t)}{m_{\mathrm{por}}\sigma_e}$$

The mass flux of moor water running in the river:

$$Q_{\mathrm{m}}(t) = \cancel{(1-\gamma)}\frac{1}{2} m_{\mathrm{por}}\sigma_e w_v \alpha g (\partial_y h_{\mathrm{m}})^2|_{y=0}$$

w_v is the width, L_y is the length
$y \in [0, L_y]$ is the horizontal direction across the moor
$h_{\mathrm{m}}(y,t)$ is the local groundwater depth in the porous layer
$R_{\mathrm{m}}(y,t) = R_{\mathrm{m}}(t)$ is the moor rainfall
m_{por} is the porosity
σ_e is the fraction of pores filled with water
$\alpha = k/(\nu m_{\mathrm{por}}\sigma_e)$ with permeability k and viscosity ν





Climate change

In the latest version of Wetropolis, an additional lake has been incorporated upstream of the river to illustrate the impact of climate change.

Source term:

$$S_A(s,t) = Q_{\mathrm{lake}}(t)\delta(s - s_{\mathrm{lake}}) + Q_{\mathrm{res}}(t)\delta(s - s_{\mathrm{res}}) + Q_{\mathrm{moor}}(t)\delta(s - s_{\mathrm{moor}})$$

$Q_{\mathrm{lake}}, Q_{\mathrm{res}}, Q_{\mathrm{moor}}$ are the time-dependent inflows at their respective locations
$\delta(\cdot)$ is a Dirac delta representing pointwise inflow

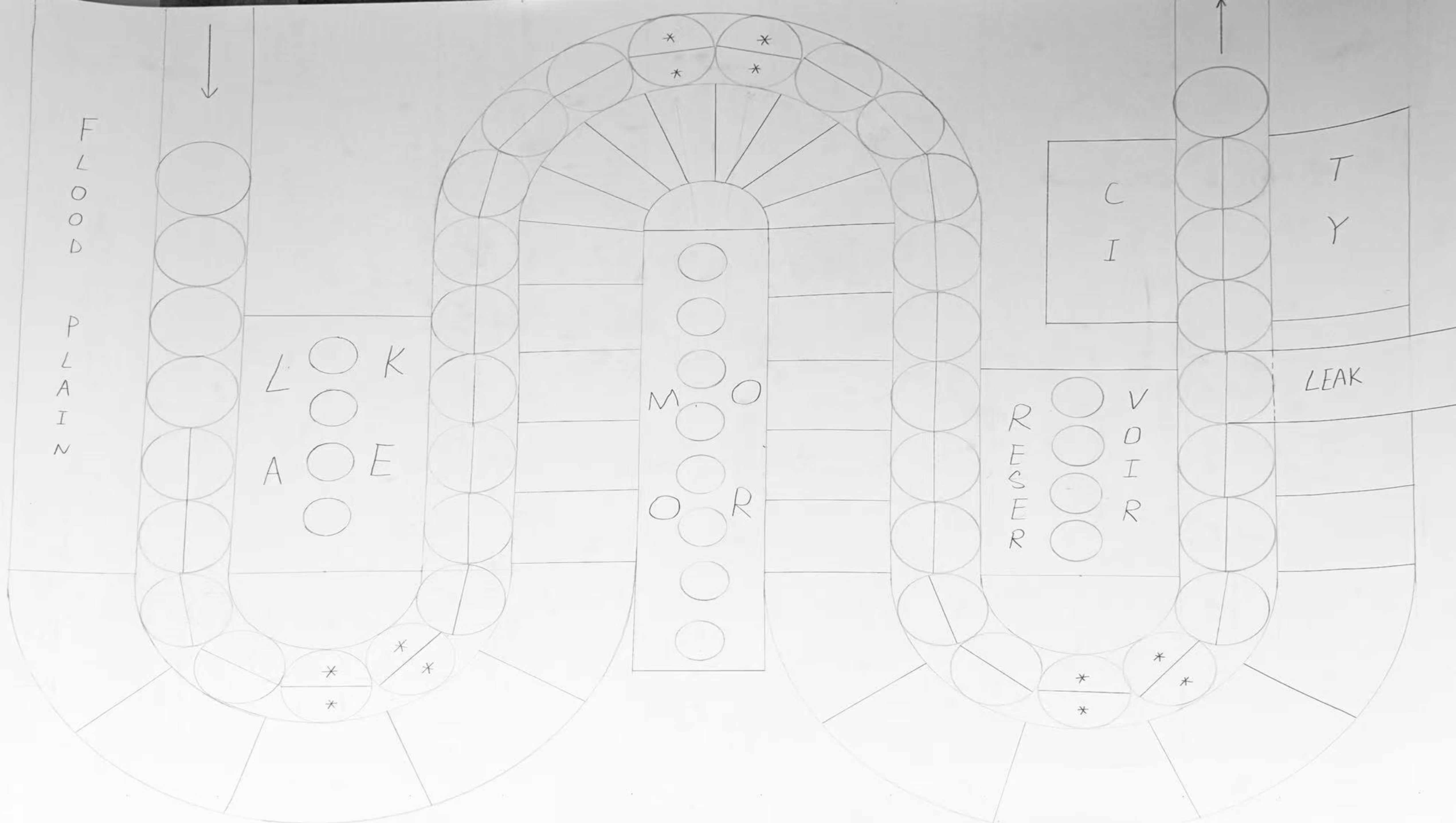
In the context of climate change, the combined inflows from the lake, reservoir and moor result in the generation of larger and faster flood waves downstream. This phenomenon serves to illustrate how changes at the catchment scale can intensify urban flooding.

Game Overview

- Cooperative
- Role-playing
- Strategy
- Water management

Key Components

- Game board
- Blue chips
- Dice mechanics
- Role cards


FLOOD PLAIN
LAKE
MOOR
RESERVOIR
CITY
LEAK

Game Rules (Basic)

- Rainfall:

Outcome	1	2-4	5-9	10-16
Amount (chips)	2	1	4	7
Location	No rain	Reservoir	Moor	Moor & Reservoir

- River Flow:

$$\begin{cases} 0 < h \leq 3, \text{moves 1 spot} \\ 4 \leq h \leq 6, \text{moves 2 spots} \\ h \geq 7, \text{moves 3 spots} \end{cases}$$

- Outflow

- Collapse of Weirs

Advanced Play

CLIMATE CHANGE

FLOOD PLAIN

Further Refinements

- Backwater Effects
- Location Change
- Climate Change Enhancement
- More Educational

Thank you and any questions?