

Wetropolis'  
Flood  
Demonstrator

O. Bokhove,  
T. Kent & T.  
Goodfellow

Wetropolis

Boxing Day  
floods

Origin

Simulator

Playing

# Wetropolis' Flood Demonstrator: mathematical design & drowning by numbers

O. Bokhove, T. Kent & T. Goodfellow

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EPSRC-UK Network *Maths Foresees* with Zweers, Hinxman & Borman  
(“Drowning by numbers”: 1988 movie)



EGU General Assembly, Games for Geoscience, 11-04-2018

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## 1 Wetropolis

## 2 Boxing Day floods

## 3 Origin

## 4 Simulator

## 5 Playing

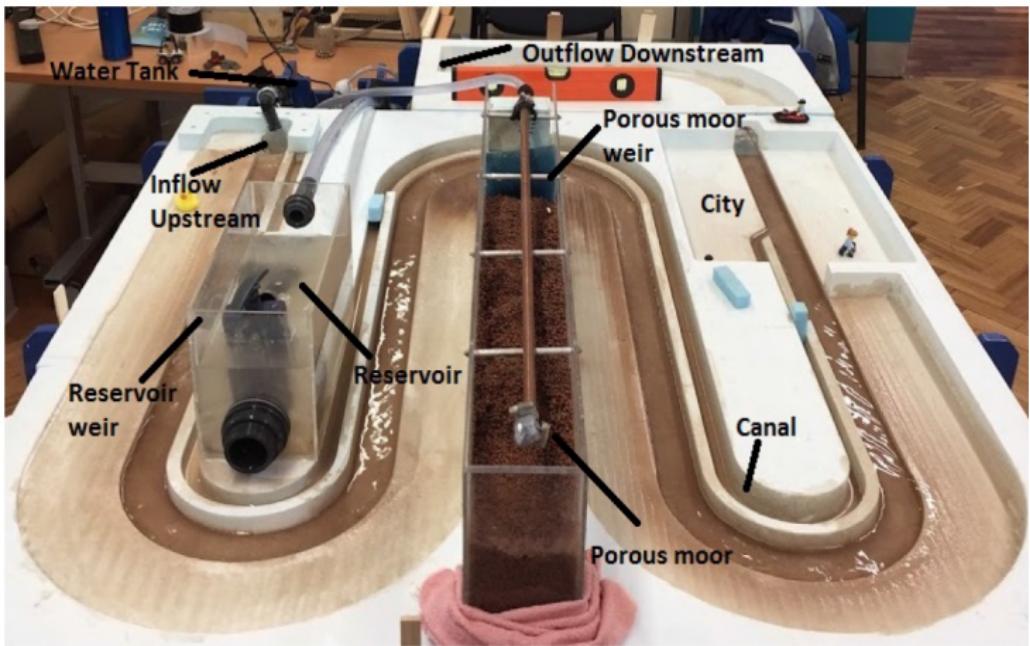
## 1. Wetropolis extreme flood & rainfall demo

## Wetropolis' Flood Demonstrator

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## Wetropolis Boxing Day floods

## Mathematical design (01-06-'16) led to *set-up*:



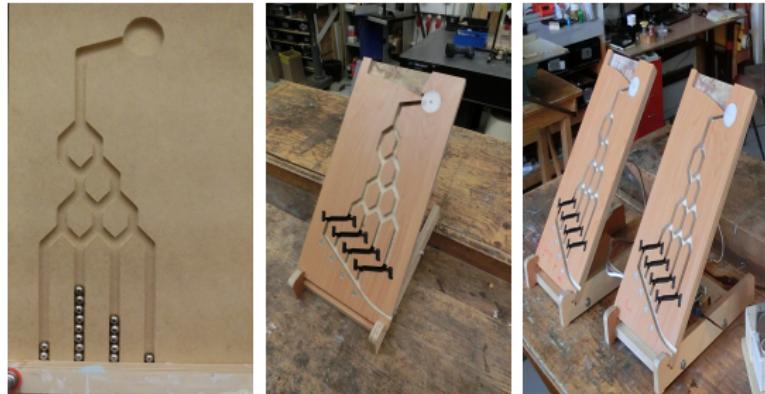
# High impact weather

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Draws from asymmetric Galton board(s):



- Rainfall amounts:  $(1, 2, 4, 8, 9, 18)r_0$  with extremes (on average 2.73%), coinciding with flood peaks.
- Rainfall location: in reservoir, both, moor or nowhere.

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## Discretise rainfall events (risk):

- Rainfall is discretized. We discretise rainfall into 2 category sets: location & rain amount.
- Our Wetropolis Day wd is *TUs*.
- Rain location has 4 categories: rain in reservoir, moor & reservoir, moor, or no rain in the catchment.
- Rain amount has 4 categories per location  $(1, 2, 4, 9)r_0/\text{wd}$ , gauged such that there is no flooding for  $(1, 2, 4)r_0/\text{wd}$  rainfall, with limited flooding for  $(8, 9)r_0/\text{wd}$  rain & flooding for  $18r_0/\text{wd}$  rain in moor & reservoir.

# High impact weather/rainfall

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- The probabilities for **rain amount** are “binomially” distributed physically using a half/stepped 7-pins Galton board:  $\frac{3}{16}, \frac{7}{16}, \frac{5}{16}, \frac{1}{16}$  (risk).
- The probabilities for **rain location** are determined using another 7-pins Galton board as  $\frac{3}{16}, \frac{7}{16}, \frac{5}{16}, \frac{1}{16}$ .
- There are therefore **6 rainfall outcomes** possible per wd.
- Rain amount per wd = 10s determined by **gauging**, such that there is no flooding with rain amounts  $(1, 2, 4)r_0$ , moderate flooding possible when  $(8, 9)r_0$  & **massive flooding** for  $18r_0$ .

# High impact weather/rainfall

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- Table of rainfall amount/TU versus rain location:

Table : Probability matrix times 256.

	$r_0$	$2r_0$	$4r_0$	$9r_0$
reservoir	9	21	15	3
both	21	49	35	7
moor	15	35	25	5
no rain	3	7	5	1

- Accumulated rainfall amounts per wd in catchment:

$0 : 0.0625 = 1/16$ ,  $r_0 : 0.0938 = 24/256$ ,  $2r_0 : 0.3008 = 77/256$ ,  $4r_0 : 0.3477 = 89/256$ ,  $8r_0 : 0.1367 = 35/256$ ,  $9r_0 : 0.0469 = 8/256$ ,  $18r_0 : 0.0273 = 7/256$ .

# Wetropolis Boxing Day flooding

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- 2-wd-day consecutive rainfall –0.07.5% (1 : 1334wd's)  
–induced *Boxing Day floods*:



- Wetropolis (*simulator*) led to definition of **excess flood volume**.

## 2. Boxing Day floods Dec. 2015 in Yorkshire UK

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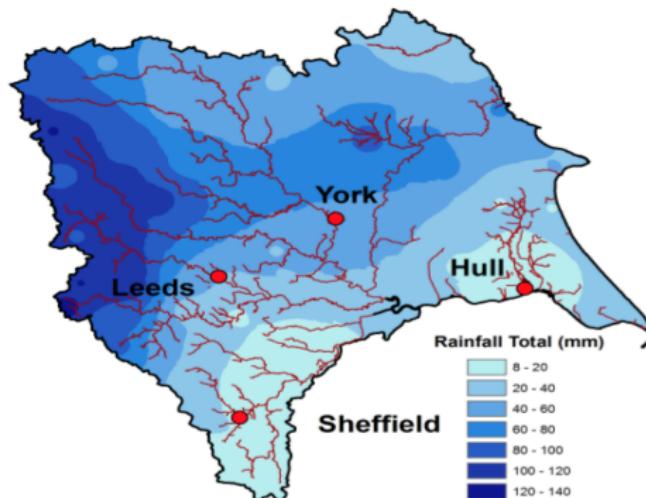
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Extreme rainfall over 48hrs preceded by 3rd wettest Nov. &  
wettest Dec. (report Environment Agency 2016):

- *Leeds' Aire River Flood* & *Aire River Kirkstall The Forge*
- Mytholmroyd's Calder River.
- Extreme event return period: 1:100<sup>+</sup> & 1:200<sup>+</sup> years.



# Boxing Day floods: excess flood volume

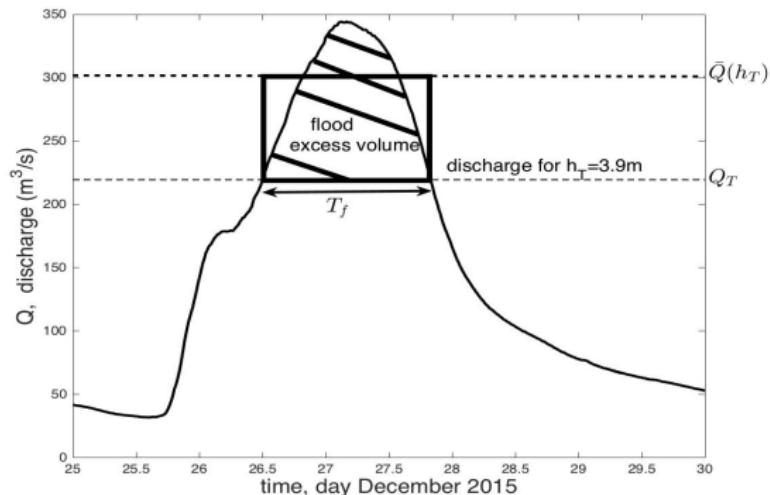
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- Analysis of Aire River level data  $h(x_0, t)$  per 15min using rating curve  $C(h - a)^b$  (EA-data) yields **flood excess volume**  $9.29 \text{Mm}^3 \approx 2150 \times 2150 \times 2 \text{m}^3$  or square lake
- *Rather than drowning by numbers base flood mitigation strategies on FEV.*



### 3. Origin of Wetropolis

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In Hebden Bridge ("Science of floods") & Churchtown (Flood Action Group), towns in Yorkshire & Lancashire that have seen a lot of sustained and flash floods over the last decade, I addressed the following questions for *flood victims*:

- Is it going to **rain more** in the future?  
No, but ....
- Can we define **extreme precipitation & flooding events?**  
Yes, but ....
- How (well) **can we predict** heavy precipitation & floods?  
Yes & no.
- How (well) can we mitigate and **control flooding?**  
Yes but ....

# Wetropolis: conceptual table-top experiment

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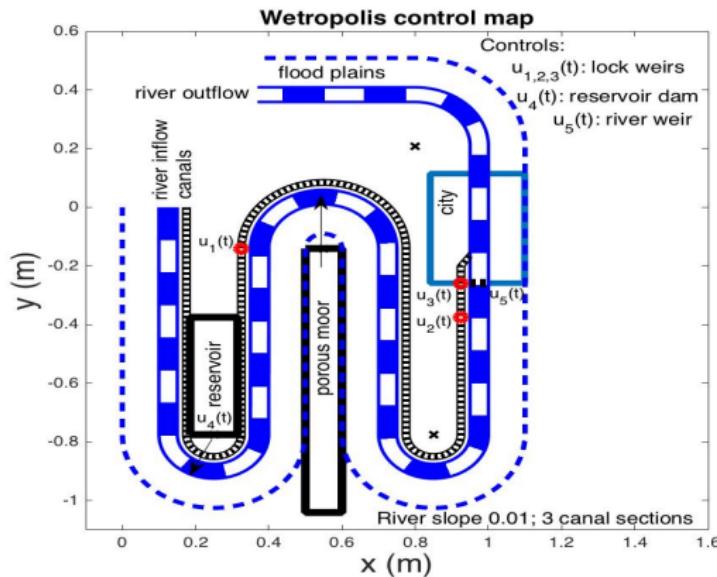
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Playing

- Plan-view, *mathematical design* before construction:



- <https://blogs.reading.ac.uk/dare/2017/07/25/wetropolis-flood-demonstrator/>

## 4. Design hydro- & meteorological simulator

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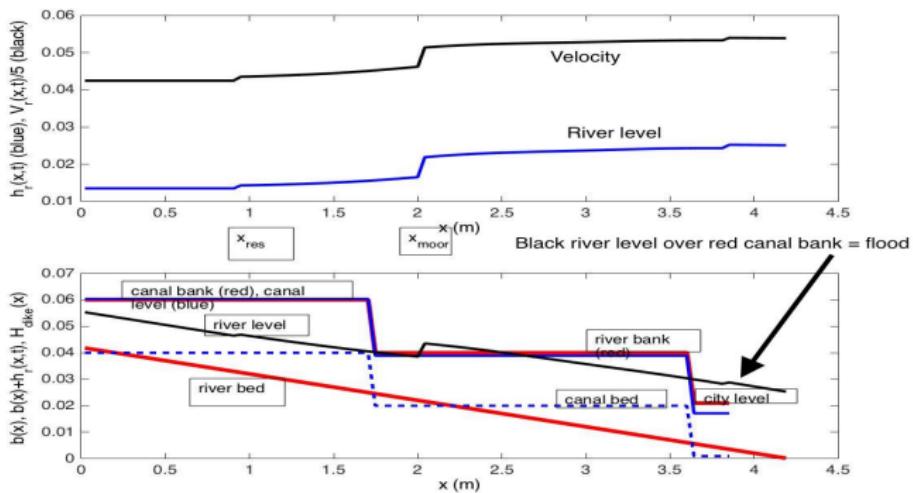
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Side view of canals & river and their bed & waterlevel profiles:



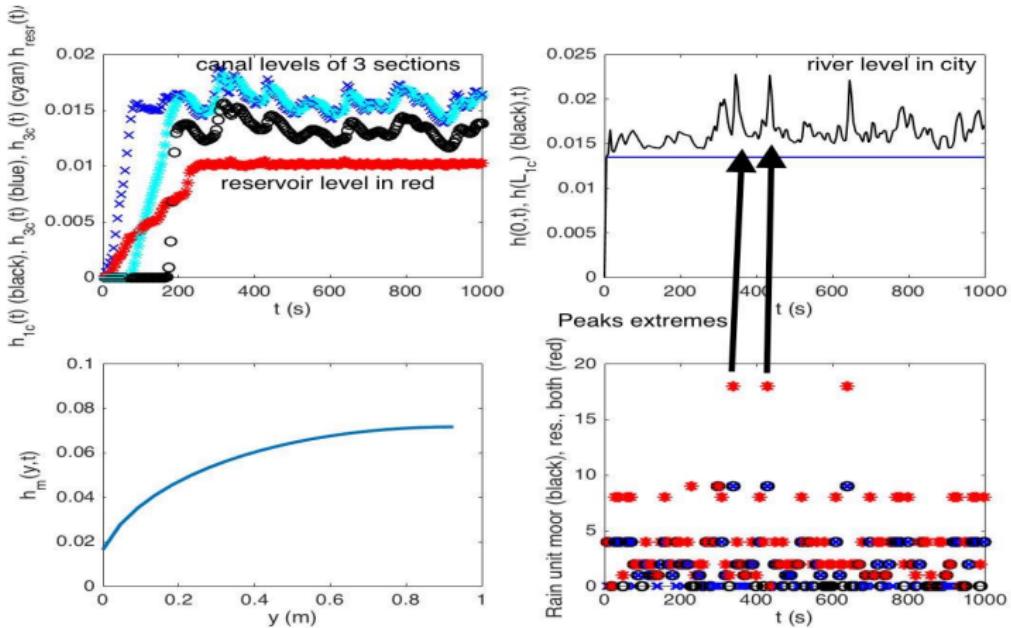
# Sample simulation

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At  $t = 0$ : canals, moor and reservoir empty.  $wd = 10s$ ,  
 $r_0 = 0.18 \text{ l}/\text{wd}$ : *simulation*



## 5. Playing with Wetropolis

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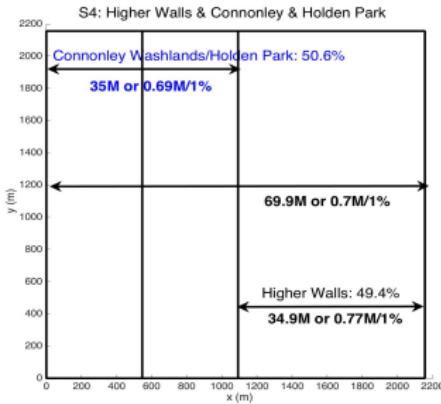
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Playing

- **Maths design:** let public experience flood risk.
- Led to rarely used concept: **FEV** Boxing Day flood  
 $V_e(h_T = 3.9m) = 9.29\text{Mm}^3 = 2150^2 \times 2\text{m}^3$ :



- **Playing:** board game with real consequences, teaching plans on risk, make/assess histograms/PDFs . . . .
- Dutch ERDF EU proposal . . . *policy, outreach & education*.

# Wetropolis NFM

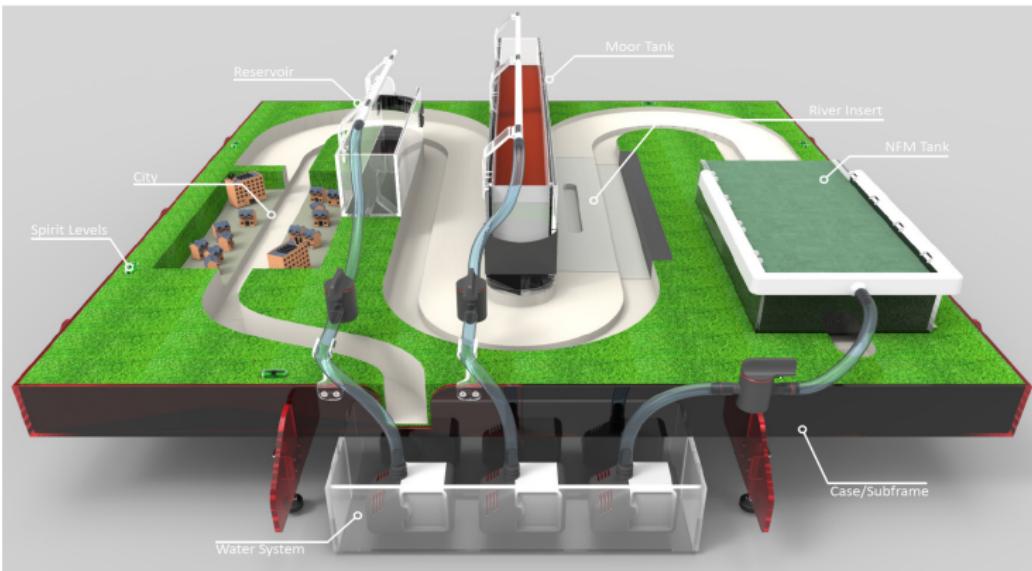
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New version illustrating Natural Flood Management in *progress*:

## Design Changes & Improvements



# Wetropolis very busy schematic

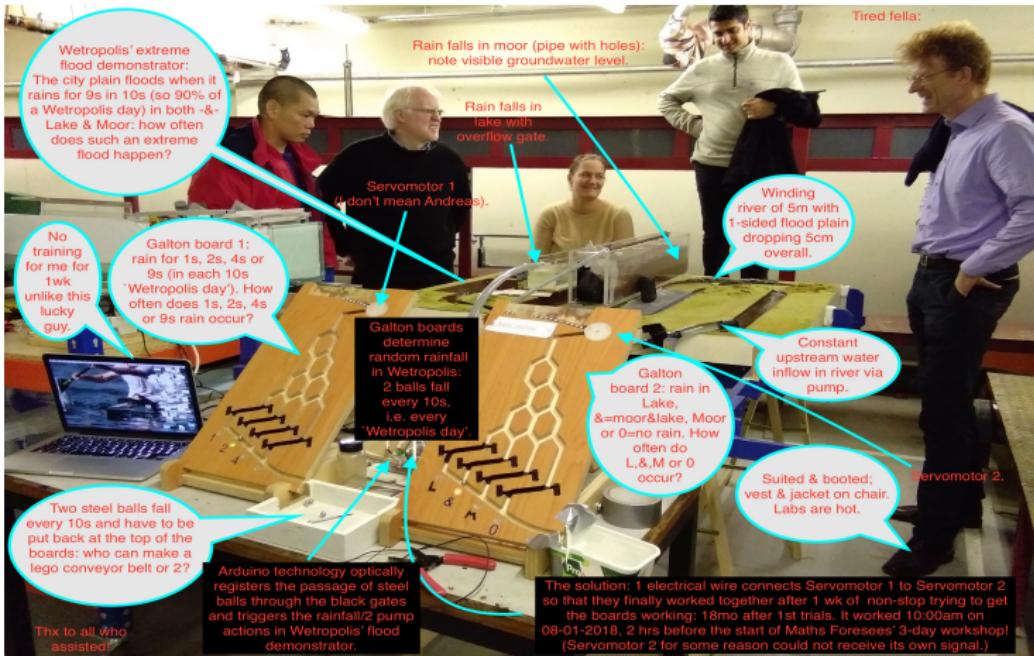
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## Cartoon:



# Wetropolis: conceptual flood demo

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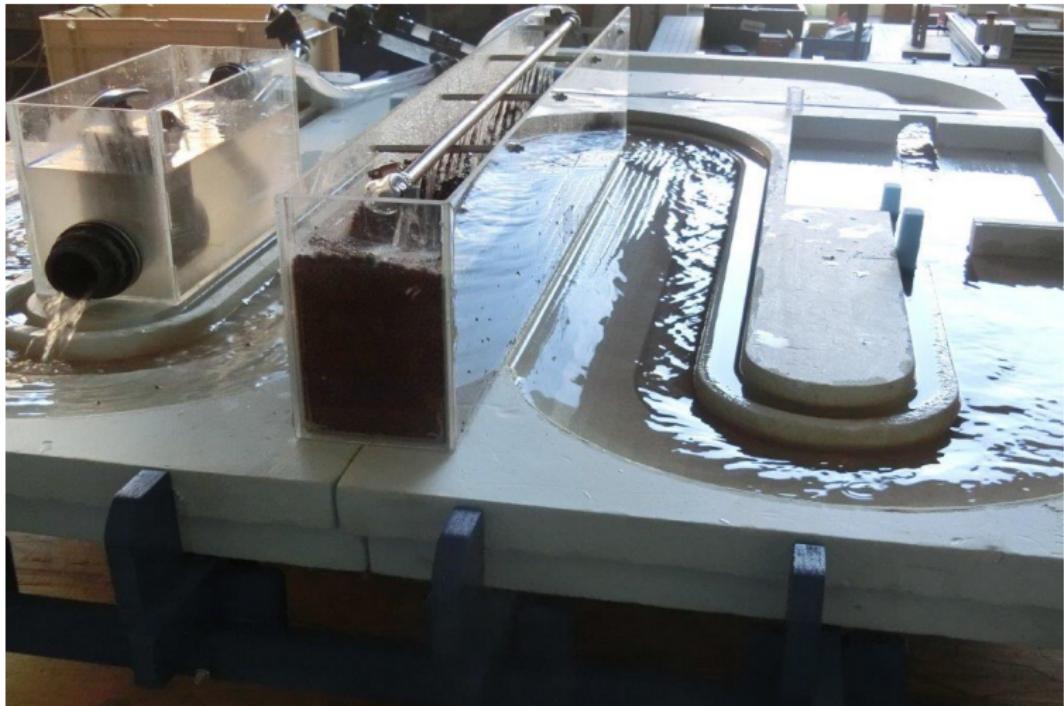
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