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MODELLING SEDIMENT BED AGGRADATION IN STORM WATER/COMBINED SEWERS

A. Campisano, *C. Modica*
Department of Civil and Environmental Engineering
University of Catania

INTRODUCTION

- Drainage systems serving peri-urban catchments are often plagued by the entrance of large amounts of sediments

- The existing mismatch between catchments sediment input rate and the channel sediment transport capacity can determine **deposition** and bed **aggradation**

- Deposition phenomena in channels can assume troblesome sizes in systems without inlet protection (i.e. **open** **drains** or storm water channels)

- Aggradation processes can be responsible for flow capacity **restrictions**, increased overall hydraulic **roughness** of the channel/drain and increased risks of **overflow**, depending on geometrical and hydraulic characteristics of the channel

INTRODUCTION

- Data on aggradation processes available by **laboratory experiments** in flumes

- Experimental campaign at SAFL (Saint Anthony Falls Laboratory), University of Minnesota (Seal et al., 1997), monitoring **bed profile evolution** and sediment transport in rectangular flumes

- On the other side, **lots of approaches** to model aggradation process, mainly with regard to river engineering (models for uniform sediments, for sediment mixtures, 1D and 2D modelling)

- Also different approaches have been adopted to solve the equations governing flow and sediment (uncoupled, semi-coupled and fully coupled models) and to describe the **mutual interactions** between water flow and sediment bed within each simulation time step

MODEL DESCRIPTION

- Based on the semi-coupled solution of the 1D - De Saint Venant equations

- Full coupling is accomplished only if governing equations are solved in a **not conservative** form, then producing **numerical errors** in correspondence to high gradients in water flow variables (i.e. hydraulic jumps, deposition fronts, etc.)

- No need of using 2D modelling to describe aggradation processes in open drains

- Moreover, the description of the evolution of the bed deposit profile is often **sufficient** for such systems to evaluate restrictions or risks of overflows

MODEL DESCRIPTION

- Fully dynamic 1D-De Saint Venant Equations written in conservative form:

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}(\mathbf{U})}{\partial x} = \mathbf{D}(\mathbf{U})$$

$$\mathbf{U} = \begin{bmatrix} A \\ Q \\ A_s \end{bmatrix} \qquad \mathbf{F}(\mathbf{U}) = \begin{bmatrix} Q \\ V \cdot Q + \dfrac{F_h}{\rho} \\ \dfrac{1}{1-p} \cdot Q_s \end{bmatrix} \qquad \mathbf{D}(\mathbf{U}) = \begin{bmatrix} 0 \\ \dfrac{F_h}{\rho} + g \cdot A \cdot (i - J) \\ \dfrac{1}{1-p} \cdot q_{ls} \end{bmatrix}$$

- The solution of such equation requires to use a **sediment transport formula** to estimate the sediment discharge Q_s

MODEL DESCRIPTION

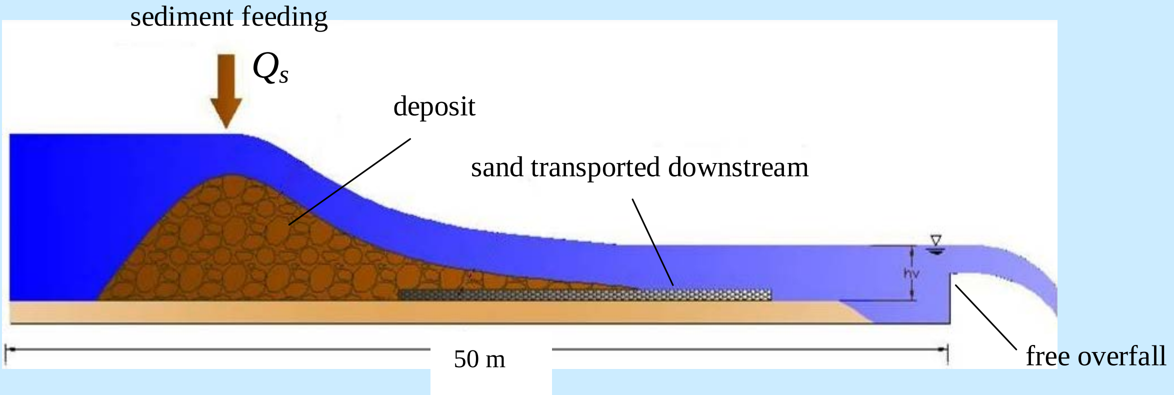
- Three well known bed load transport formulas were implemented in the model to simulate the SAFL experiments:
  - Meyer-Peter-Muller, 1948
  - Suszka, 1991
  - Ackers, 1984
- The finite difference scheme of TVD-MacCormack was used for the numerical solution, since it is a "**shock-capturing**" scheme able to describe discontinuities such as hydraulic jumps and steep mobile bed fronts, then **suitable** for the analysis of aggradation process.
- The sediment input into the flume was simulated as **lateral sediment inflow** q_{ls} per unit of flume length to overcome numerical problems experienced in literature and to obtain a realistic description of the experimental feeding conditions at SAFL

SAFL EXPERIMENTS

- Six aggradation experiments (runs 1-6) were performed at SAFL using a 55 m long laboratory flume with rectangular cross section

Run	Duration T [h]	Flume width B [m]	Bottom slope i [%]	Water discharge Q [m³/s]	Sediment discharge Q_s [m³/s]	Downstream water level h_v [m]
1	16.83	0.305	0.2	0.049	$4.762\ 10^{-5}$	0.40
2	32.40	0.305	0.2	0.049	$2.381\ 10^{-5}$	0.45
3	64.00	0.305	0.2	0.049	$1.193\ 10^{-5}$	0.50
4	24.00	2.700	1.0	0.440	$10.62\ 10^{-5}$	0.50
5	17.00	2.700	1.0	0.110	$3.669\ 10^{-5}$	0.15
6	27.00	0.305	1.0	0.122	$7.887\ 10^{-5}$	0.15

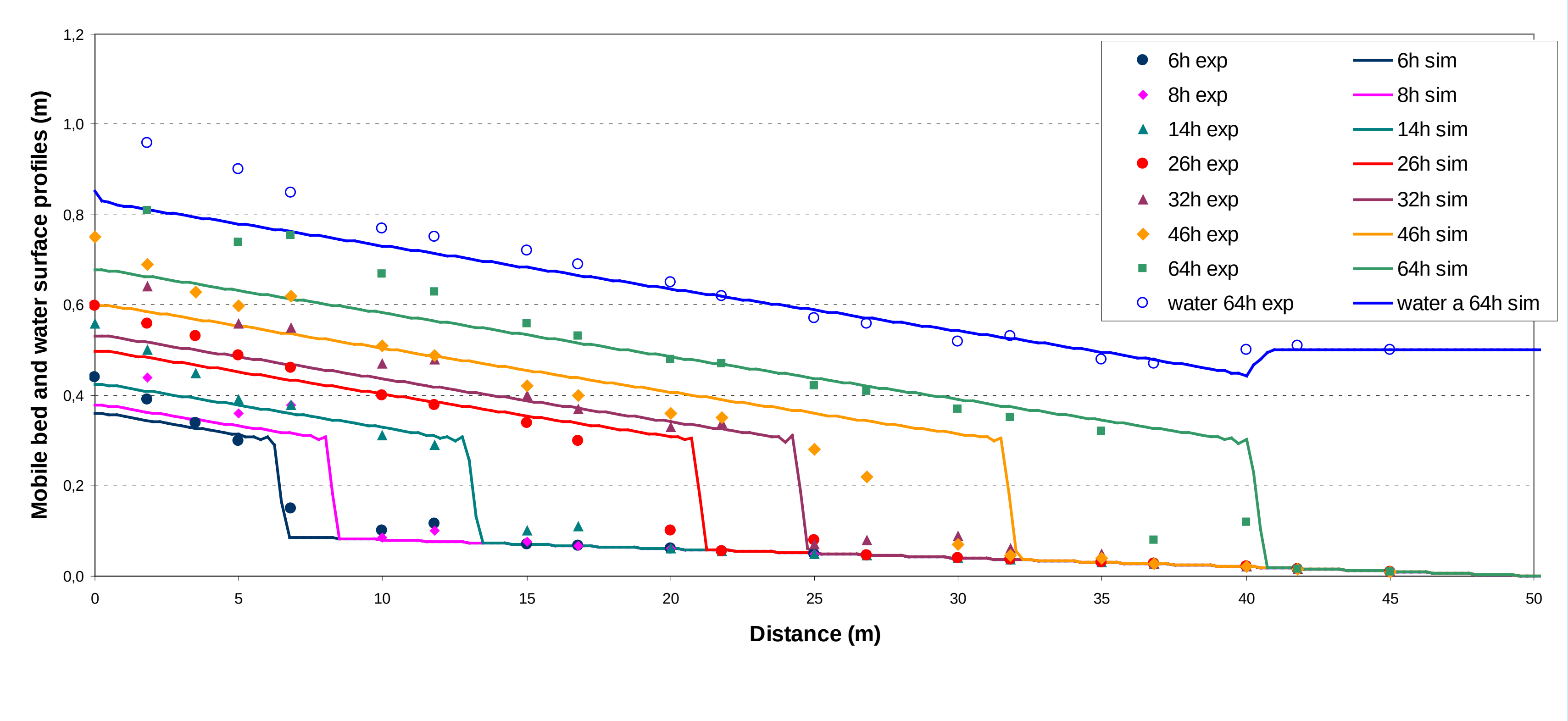
- The sediment has:
- ρ_s=2650 kg/m³
- d_{50}=4.63 mm
- σ=5.57 mm
- typical of the coarser part of deposits.



RESULTS

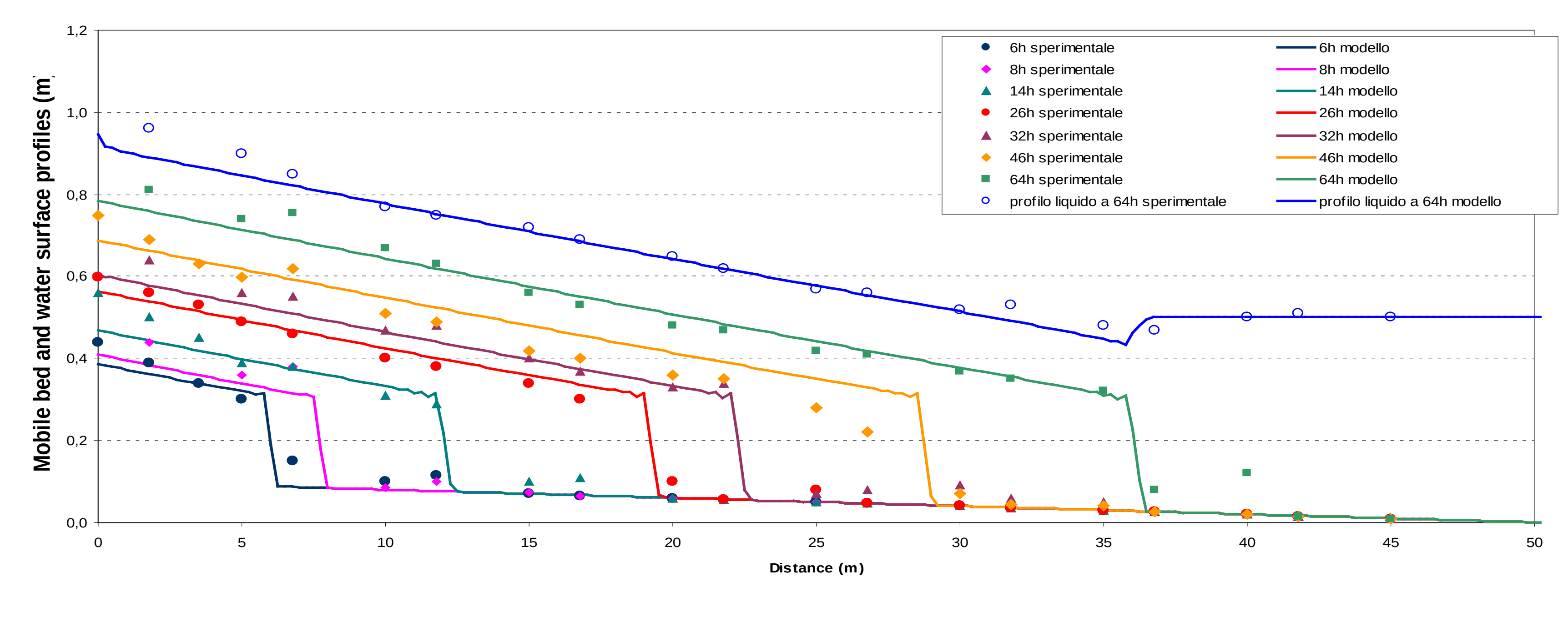
Focus to run 3, with lots of measurements.

Meyer-Peter-Muller (1948)



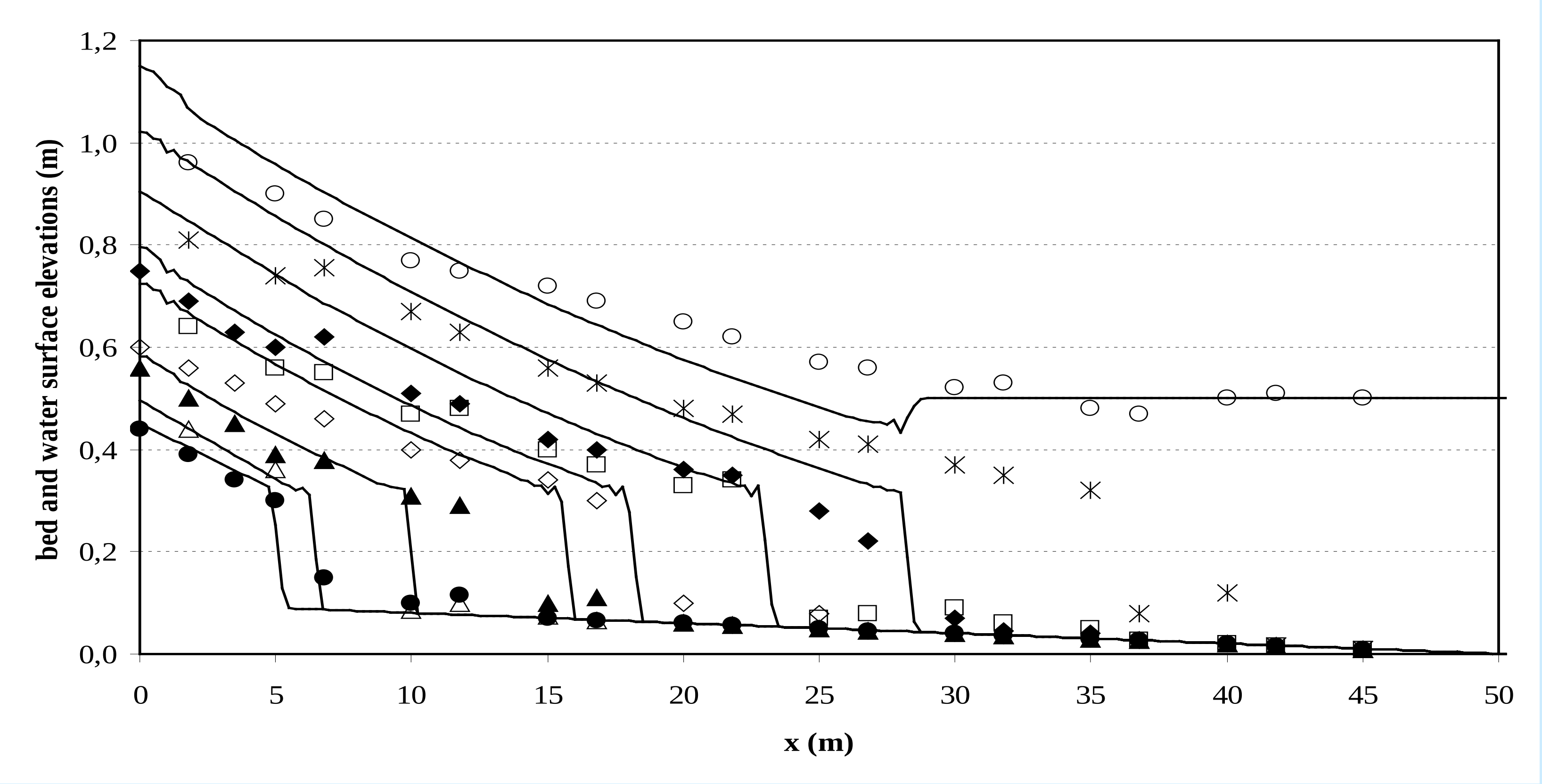
RESULTS

Suszka (1991)

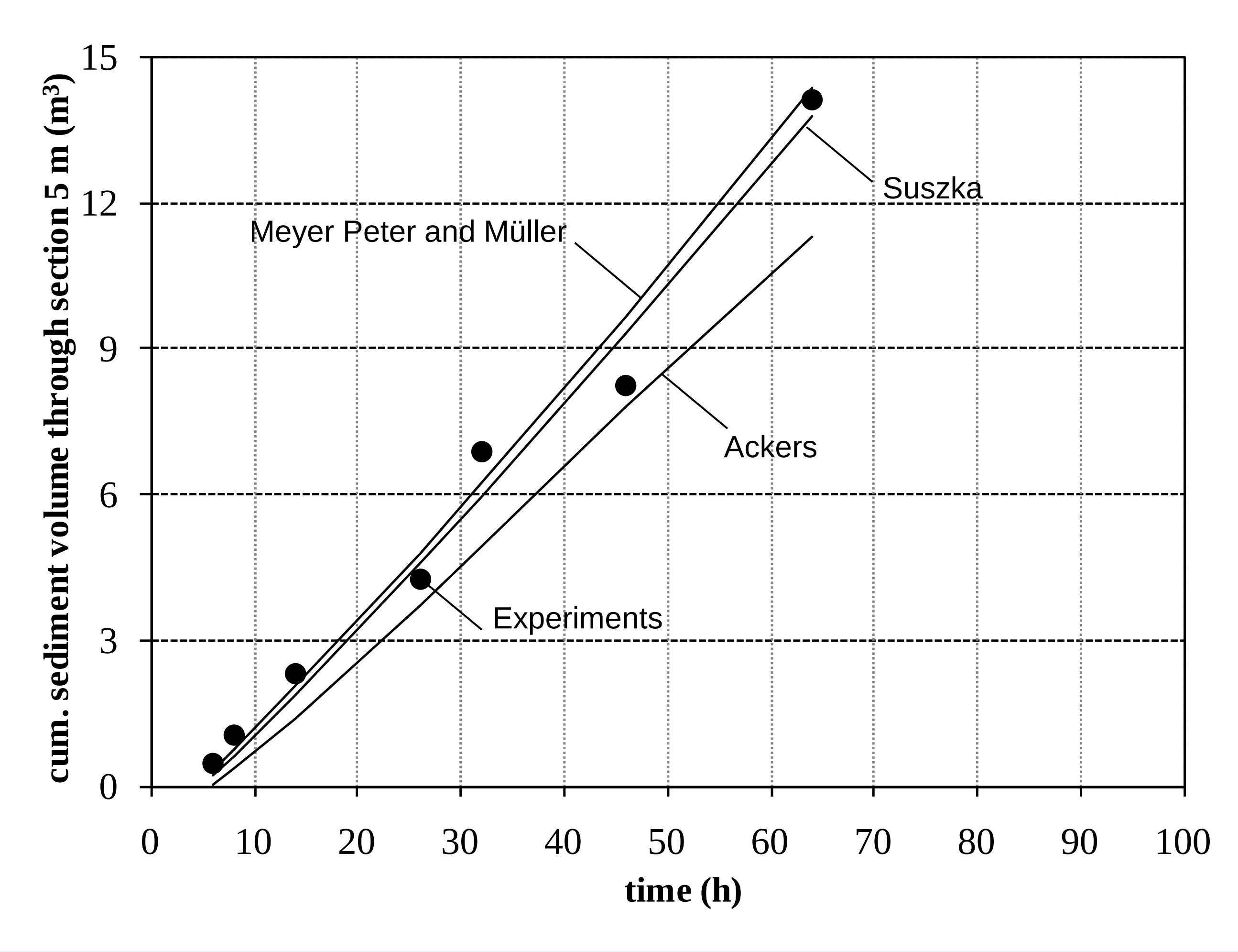


RESULTS

Ackers (1984)



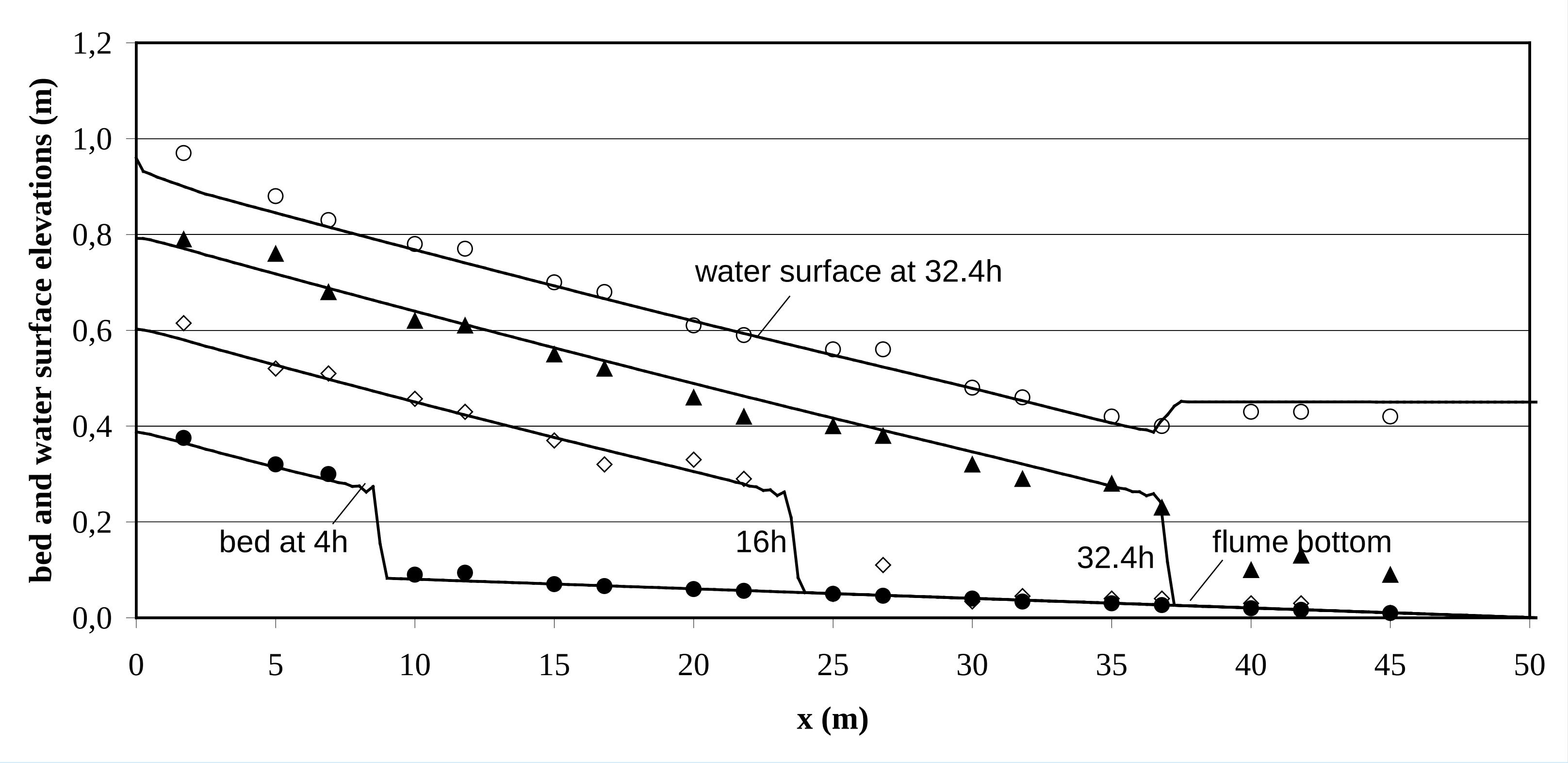
RESULTS



cum. sediment volume through section 5 m (m³)
15
12
9
6
3
0
0
10
20
30
40
50
60
70
80
90
100
time (h)
Meyer Peter and Müller
Suszka
Ackers
Experiments

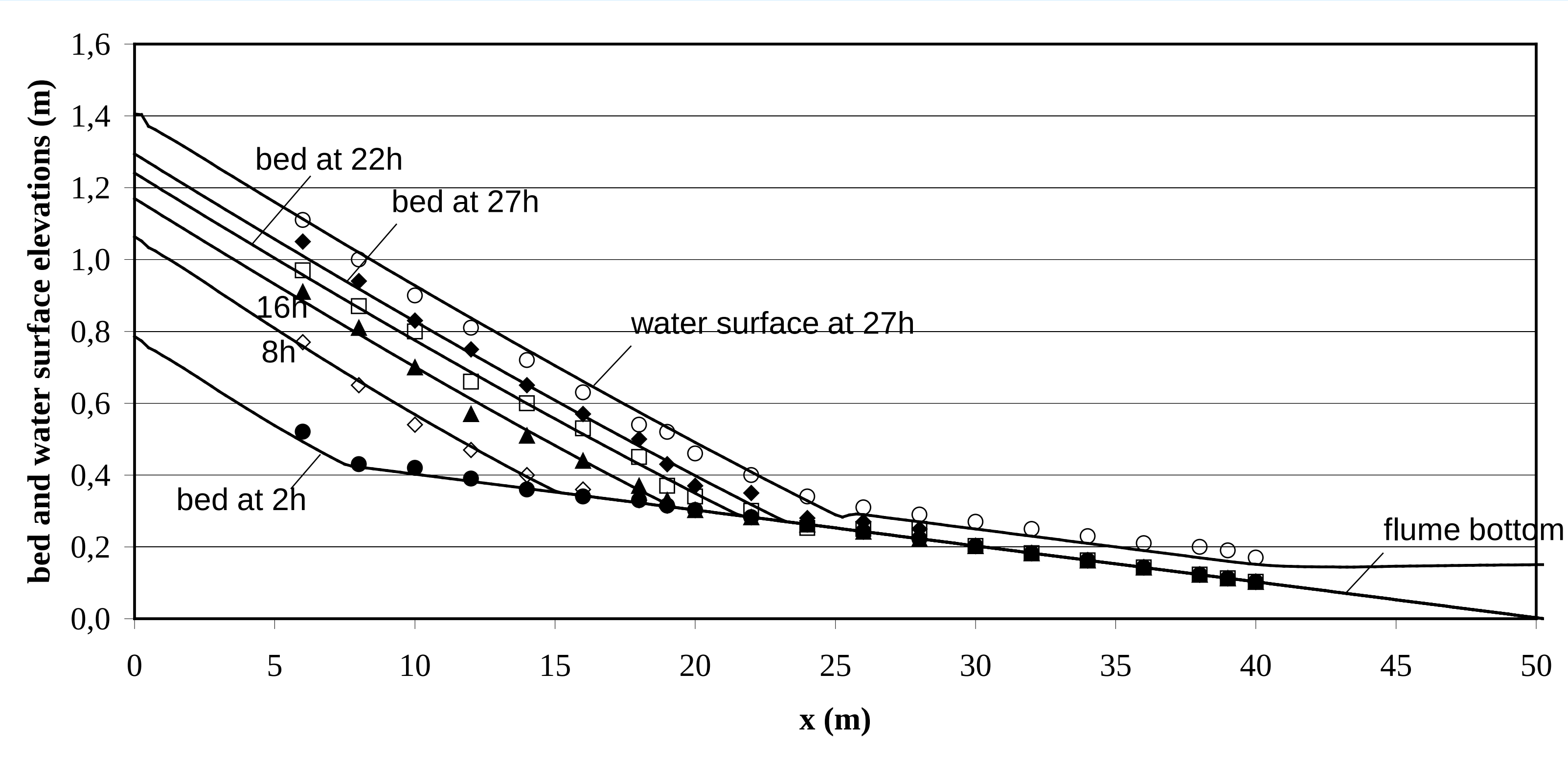
RESULTS

RUN 2 - Suszka (1991)



RESULTS

RUN 6 - Suszka (1991)



RESULTS

Values of RMSE for bed elevations and water elevations

	Run 1		Run 2		Run 3		Run 4		Run 5		Run 6	
Formula	**BE**	**WE**	**BE**	**WE**	**BE**	**WE**	**BE**	**WE**	**BE**	**WE**	**BE**	**WE**
Meyer-Peter and Müller (1948)	0.042	0.037	0.033	0.037	0.061	0.053	0.015	0.013	0.015	-	0.016	0.021
Suszka (1991)	0.020	0.026	0.028	0.040	0.029	0.036	0.016	0.014	0.015	-	0.012	0.012
Ackers (1984)	0.012	0.022	0.034	0.040	0.058	0.065	0.012	0.022	0.160	-	0.018	0.024

CONCLUSIONS

- Numerical investigation to model sediment bed aggradation in open drains /stormwater channels
- Well known bed load transport formulas used to describe the sediment transport process
- Model comparison with experimental results at SAFL concerning temporal evolution of the deposit
- Model **globally able** to successfully describe the process with some **differences** depending on the used sediment transport formula
- According to the size of the SAFL sediment, results are **limited** to the coarser portion of sediments forming deposits in drains

Thank you for your attention