Using dye tracing techniques to validate CFD models of urban drainage structures

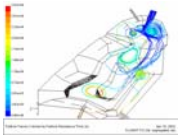
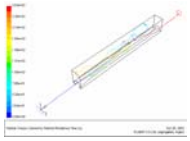
Virginia Stovin
The University of Sheffield

Introduction

- Solute (and sediment) transport processes affect the performance of a wide range of water engineering structures
- Urban drainage – impact of pollutants associated with CSOs


- Storm events – time-dependent hydraulics and pollutant concentrations, e.g. first foul flush
- Complex three-dimensional flow fields
- Computational Fluid Dynamics (CFD) modelling tools increasingly used to aid understanding/design

CFD Modelling

- CFD facilitates solution of complex time-dependent three-dimensional flow fields that control the transport of dissolved or suspended pollutants
- Alternative structures may be compared rapidly, and with a broader range of input conditions than is generally feasible in the laboratory, thus facilitating interpretation of the structure's performance and optimisation of design for pollution control
- Validation? Fitness for purpose?

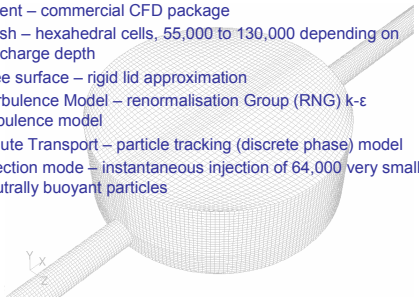
Surcharged Manhole


Two distinctly-different hydraulic regimes separated by a threshold surcharge level:

- Low surcharge – fully mixed, chaotic flow, asymmetric jet
- High surcharge – upper dead zone, symmetrical jet short-circuits straight through the manhole

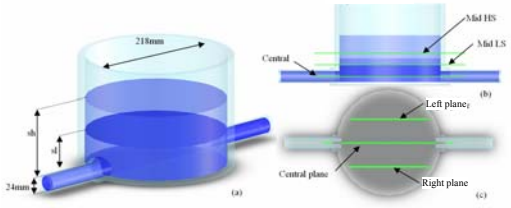
CFD Model

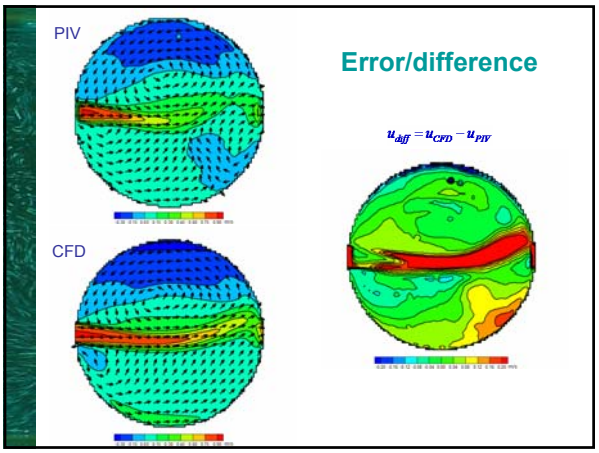
- Fluent – commercial CFD package
- Mesh – hexahedral cells, 55,000 to 130,000 depending on surcharge depth
- Free surface – rigid lid approximation
- Turbulence Model – renormalisation Group (RNG) k-ε turbulence model
- Solute Transport – particle tracking (discrete phase) model
- Injection mode – instantaneous injection of 64,000 very small neutrally buoyant particles

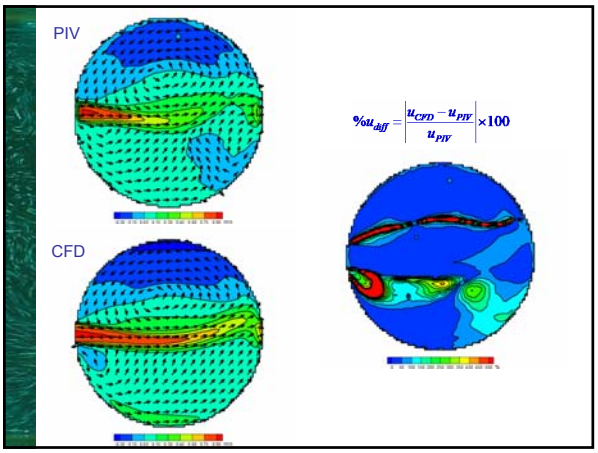


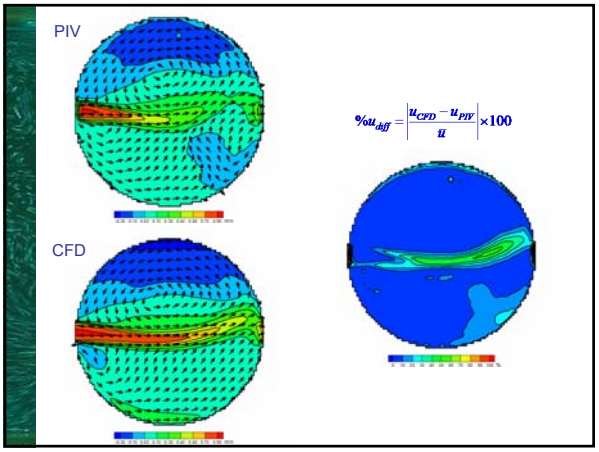
Validation using Particle Image Velocimetry (PIV)

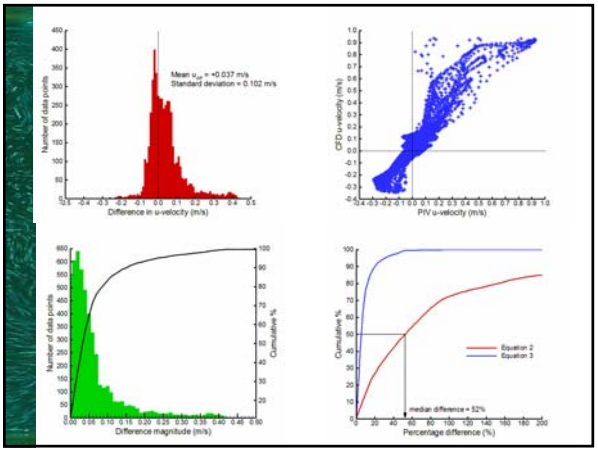
- 2D mapping of flow field on selected planes
- Light sheet to illuminate the plane
- Seeding of the flow with small neutrally-buoyant particles
- High speed camera (500 frames per second)







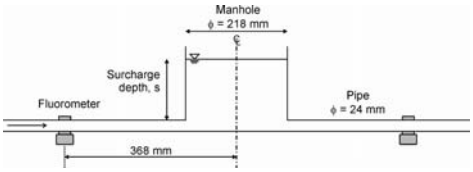




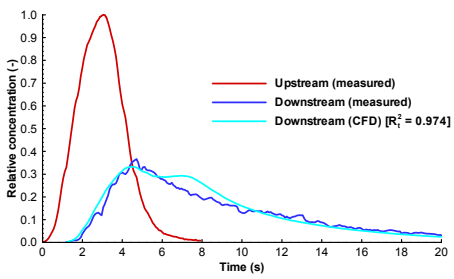
Interim validation conclusions

- High-resolution PIV data enables 2D validation over a plane of interest
- But:
  - Partial coverage:
    - 5 planes (only 1 considered here)
    - u-velocity component only
  - We don't really know what the numbers tell us – is the simulation *fit for purpose* or not?
- Our 'purpose' was to develop better understanding (and scaling laws) for solute transport
  - Compare CFD output with a dye trace

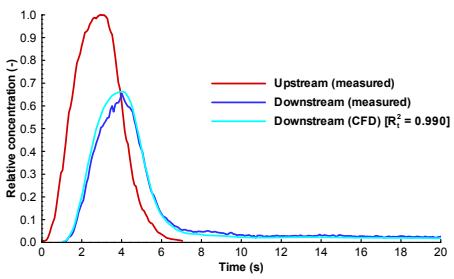
Laboratory Model Configuration



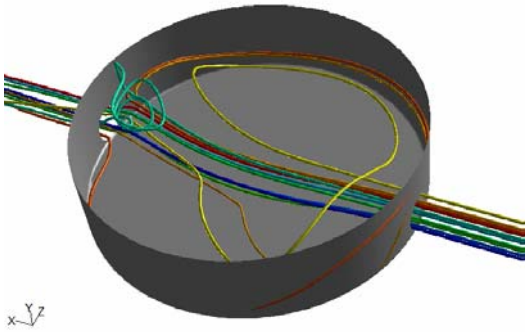
Dye trace comparison – low surcharge



Dye trace comparison – high surcharge

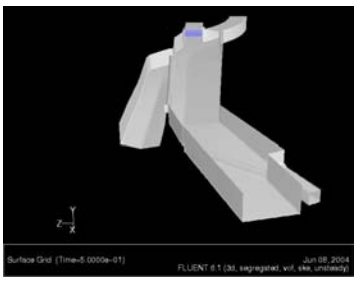


CFD Pathlines

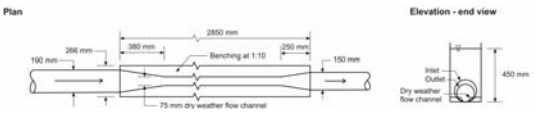


Littleborough CSO Storage Tank

Zurich CSO storage tank

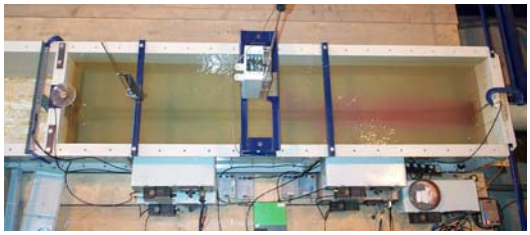


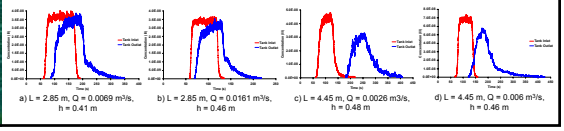
Laboratory storage tank



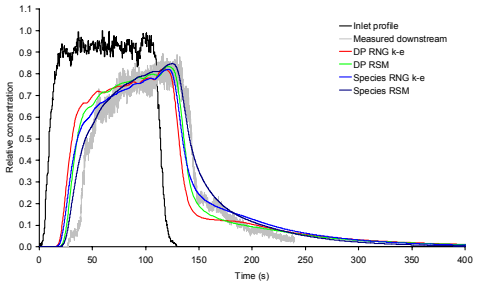
- Is it useful for CFD model validation?
- No flow field measurements ..

Dye tracing





Storage tank comparison



Conclusions

- Two urban drainage structures:
  - manhole;
  - storage tank
- Two flow regimes in the manhole (two short films):
  - Pre-threshold, well-mixed, high energy loss
  - Post-threshold, short-circuiting flow beneath upper dead zone, reduced energy loss
- Two approaches to validating a CFD model:
  - Particle Image Velocimetry (PIV)
  - Tracer test

Final Comment

- There are many practical situations in which full mapping of a drainage structure's flow field is neither feasible nor desirable, but where it would be possible to undertake a tracer test to characterise the longitudinal solute transport.
- It may be argued that – as solute transport characteristics represent the integration of all the hydrodynamic processes within the entire flow field – a close correlation between predicted and measured solute concentration profiles may provide confidence in the validity of the underlying flow field simulation.