Integrated Water Resources Management for Bathing Water Compliance

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Water Security - Typical Challenges

Source: http://water.org/learn-about-the-water-crisis/

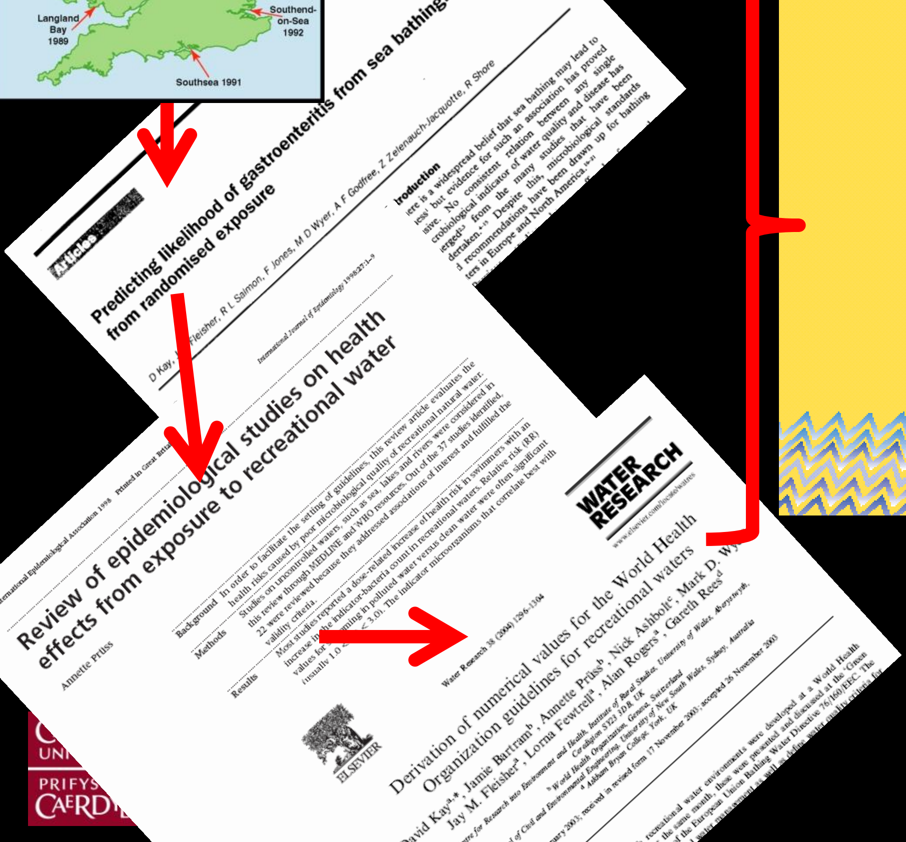
General Challenges

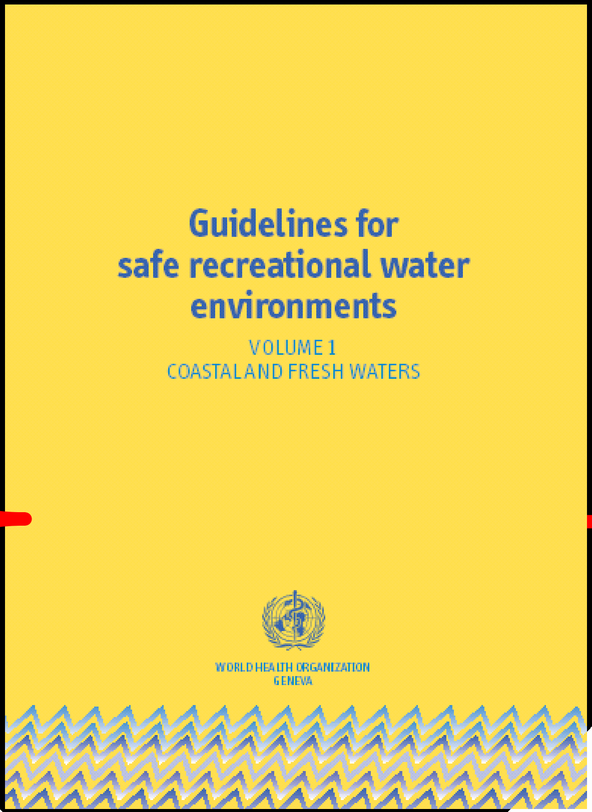
- Security of clean water supply will become an increasing challenge over the next 30 years
- Concern about water quality in river, estuarine and coastal basins is increasing worldwide
- Traditionally hydraulic engineers and researchers have focused attention on hydraulics & hydrology
- Increasing emphasis now also being focused on epidemiological process modelling etc. in hydro-environmental impact assessment studies

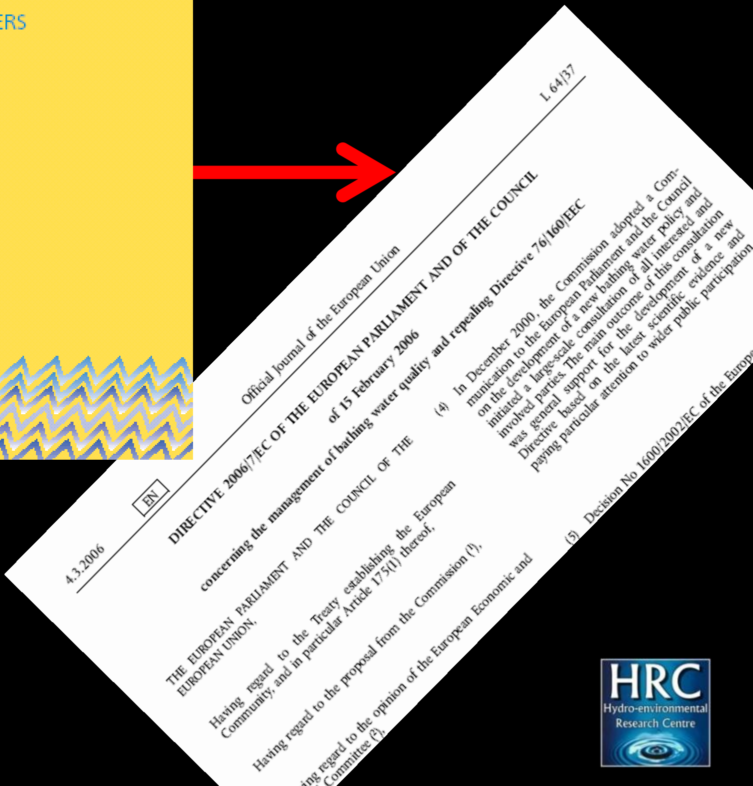
Some Specific Challenges

- Many widely used water quality model systems:-
  - Treat 1-D and 2-D models as independent
  - Treat dispersion and diffusion as constants
  - Treat bacterial decay as a constant
  - Assume mean hourly or daily load inputs
  - Ignore bacteria $\leftrightarrow$ sediment interactions
  - Treat FIO-sediment partitioning as a constant
  - Ignore organic content of sediments

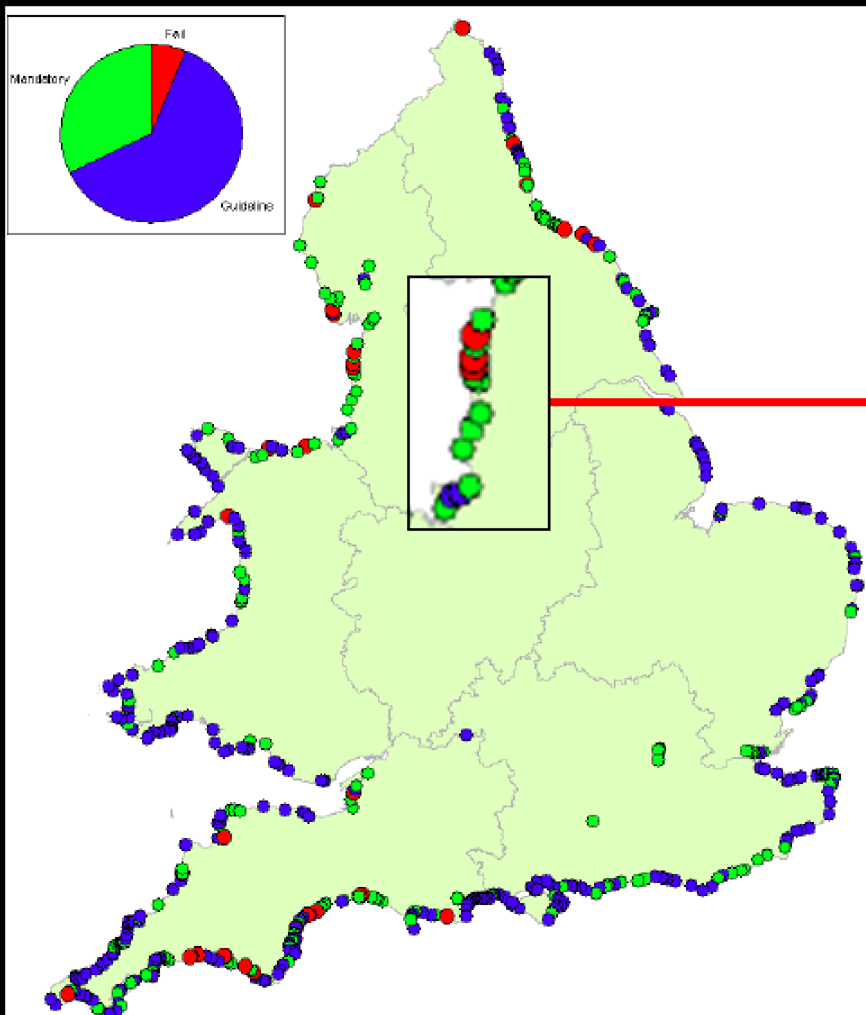
Legislative Drivers

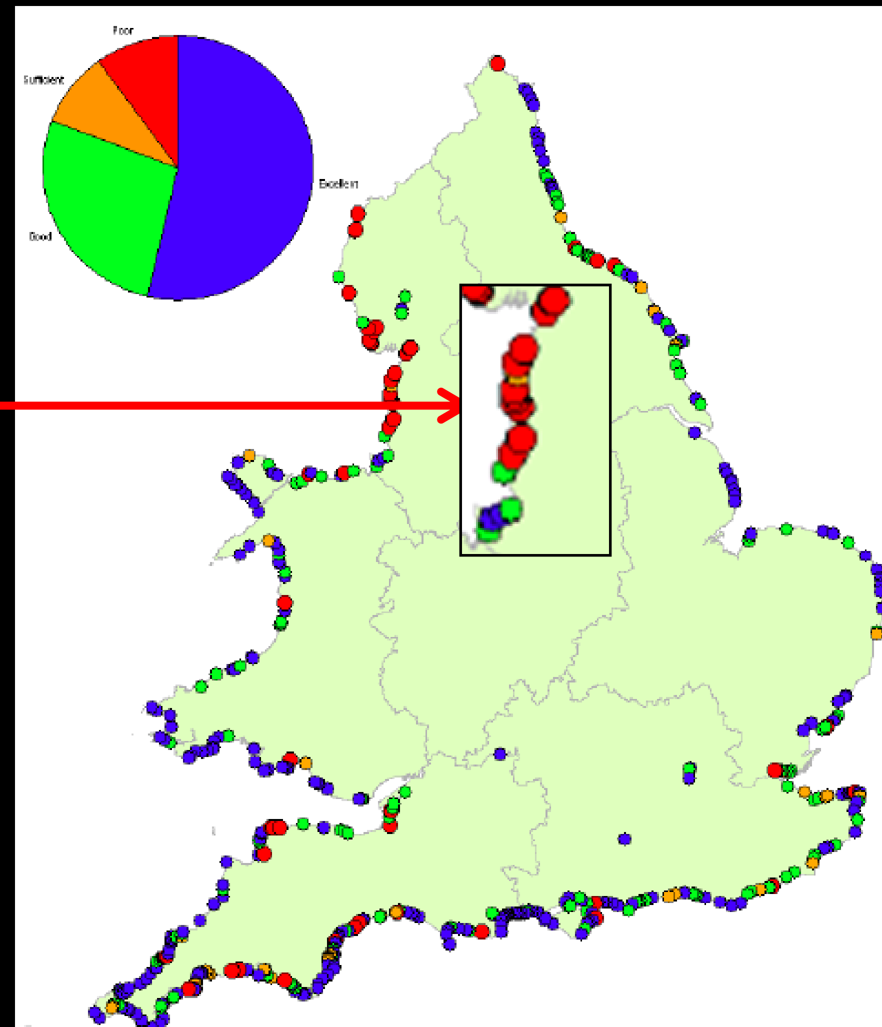






50% Loss in UK Blue Flag Beaches

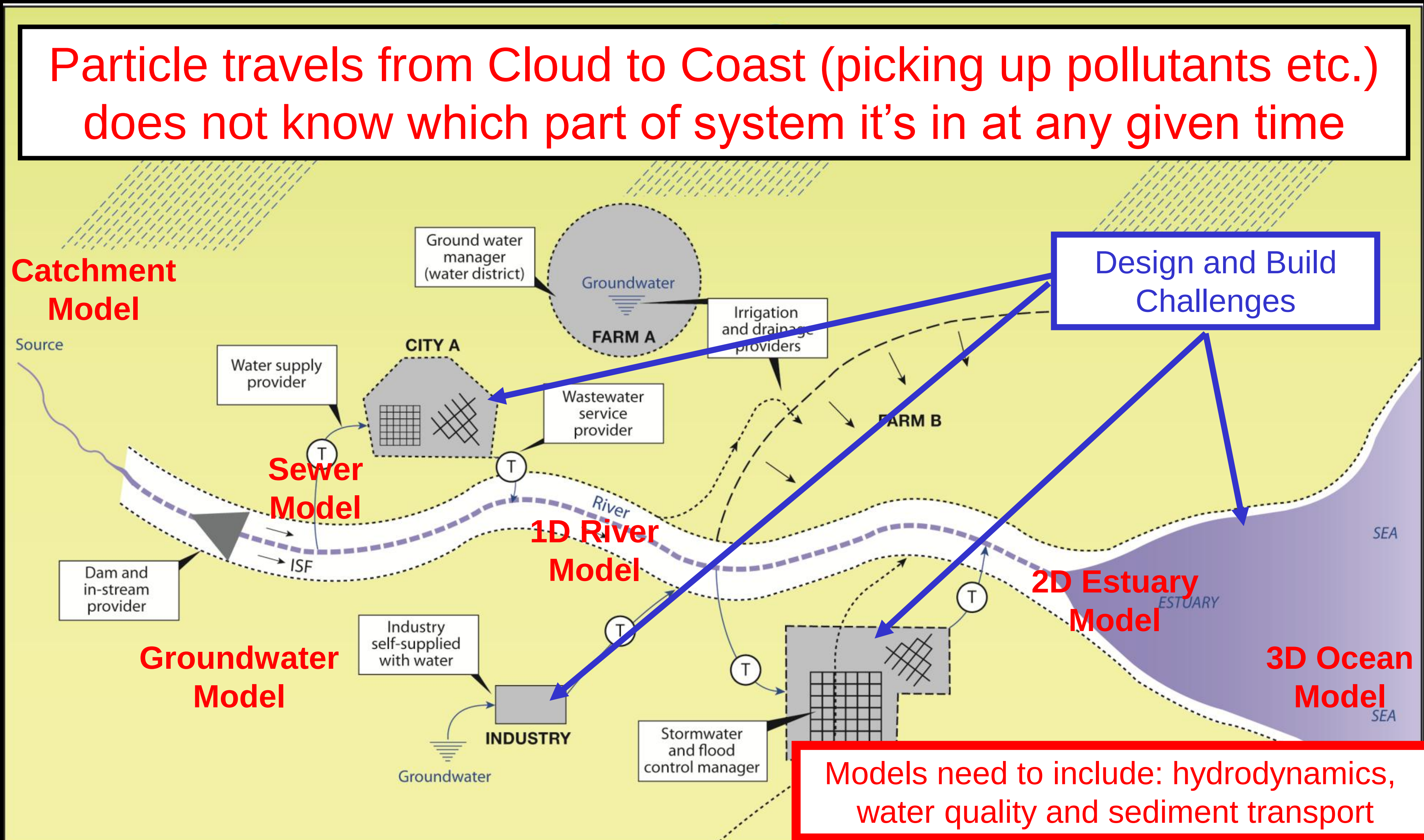




Historical Approaches

- Simplistic environmental understanding
  - Uniform bathing day water quality
  - Uniform quality of inputs from rivers etc.
  - Diffuse catchment sources poorly characterised
  - Intermittent discharges poorly quantified
- Models poorly parameterised
  - Bathing water compliance used for calibration
  - Inputs from catchments poorly characterised
  - Log_{10} order accuracy often regarded acceptable

Cloud to Coast System and Services



Ribble River Basin and Fylde Coast U.K.

Acknowledgements

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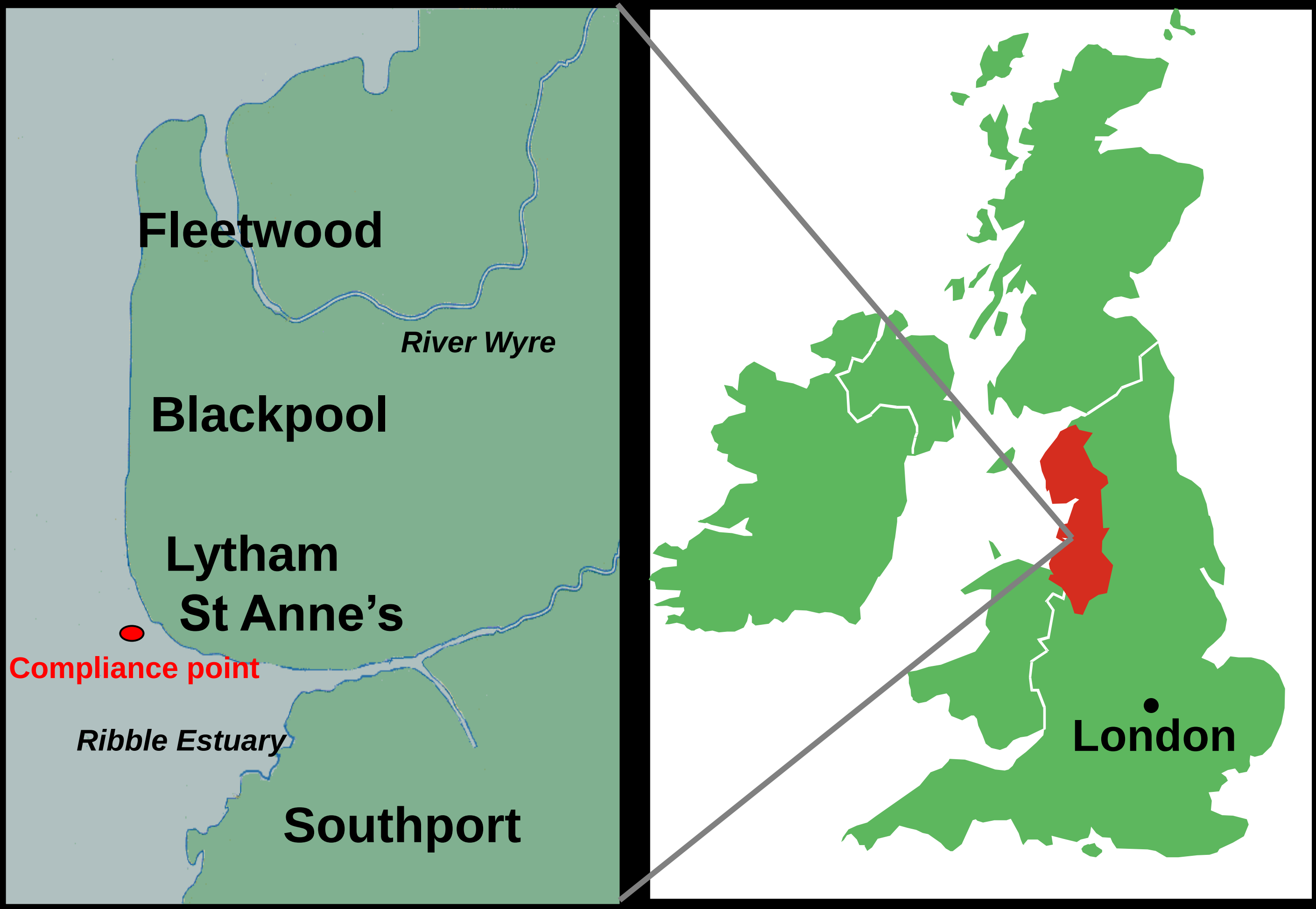
Reference: NE/I008306/1

Partners: Environment Agency; United Utilities; CH2MHILL; defra; Lancaster University; NFU; Ribble Rivers Trust

www.shef.ac.uk/c2c

Ribble and Fylde Coast - NW England



Background in 1990s

- Failure to meet EU Bathing Water standards
- Storm sewers and sewage works discharging along coast thought to be main problem
- Combined storm water and sewer overflows discharging into water courses and rivers
- Field surveys undertaken to establish inputs and failure levels at compliance points
  - Surveys unable to provide definitive conclusions
  - Data could not allow for impact of future proposed capital improvements to works to be assessed

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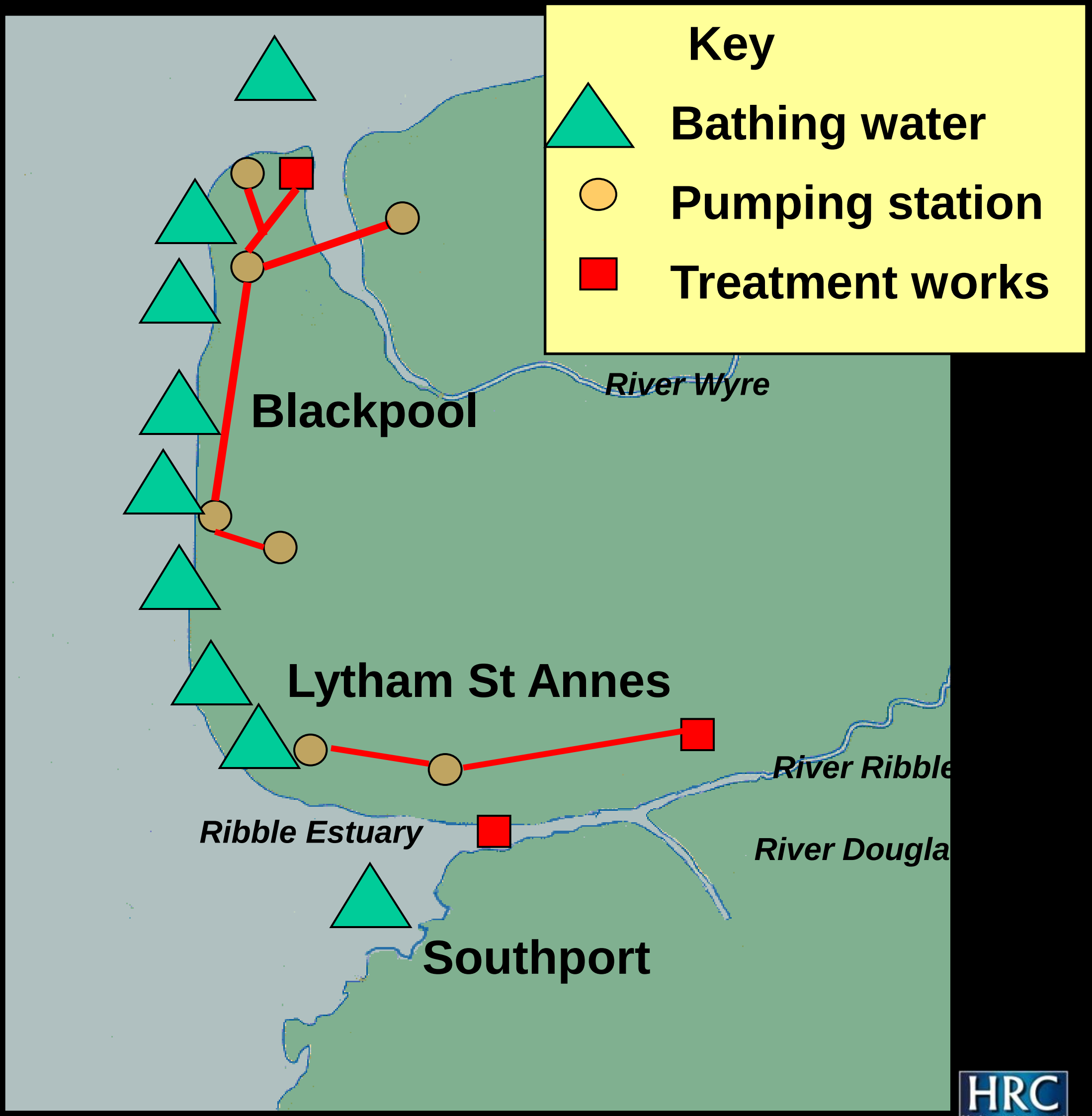
Water Asset - Investments in 1990s

- $800 million invested from 1993 – 1996
- 3 major sewage treatment works
- 5 pumping stations with storm outfalls along coast



Objectives

- Refine HRC hydro-environmental modelling tools
- Quantify impact of sewage inputs into Ribble basin on coastal bathing water quality
- Investigate influence of various parameters such as wind, tides, river discharge, etc
- Allow for continuous and intermittent inputs
- Incorporate land use changes and diffuse source inputs as boundary fluxes when data available
- Propose management strategies for basin

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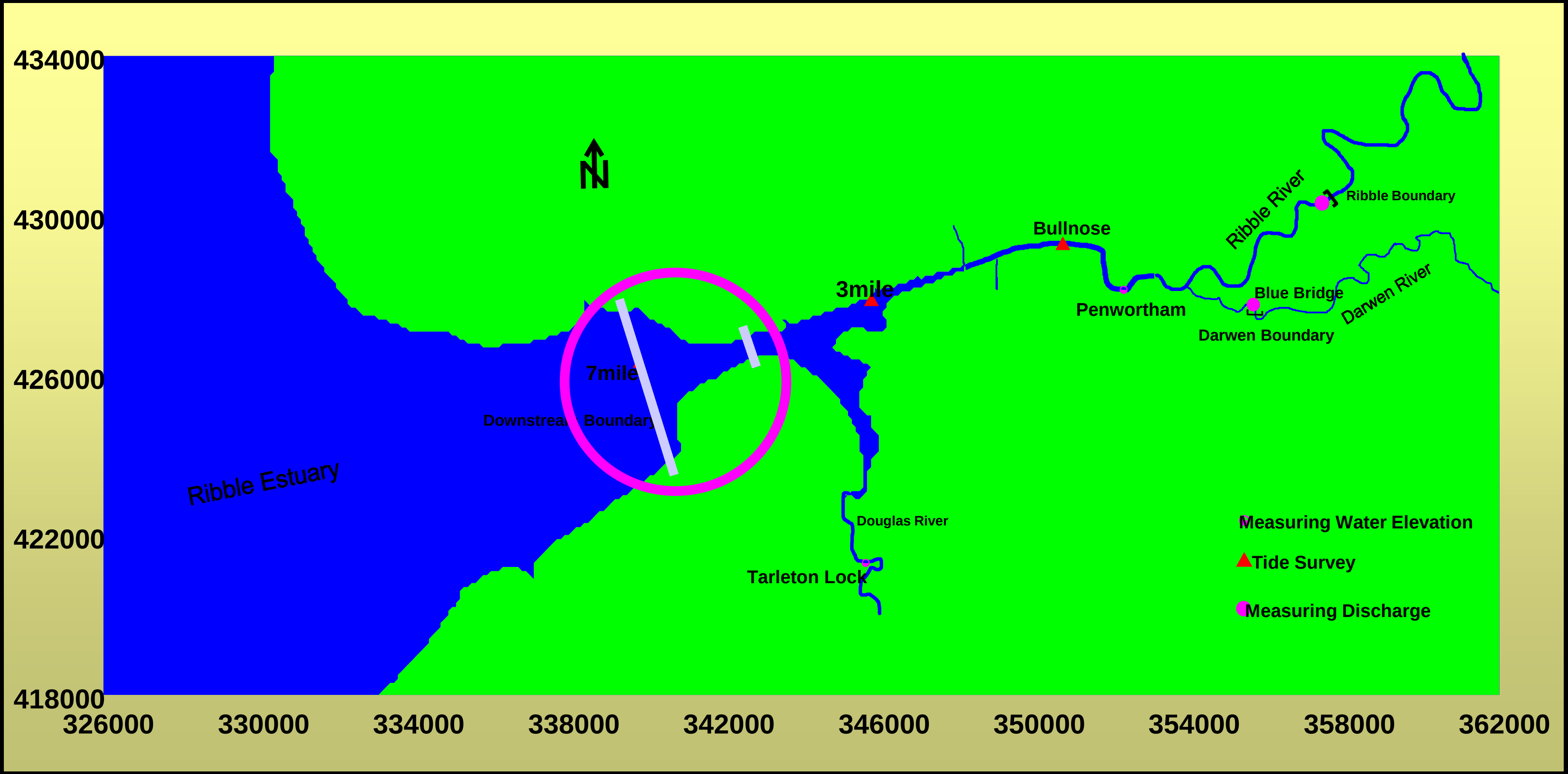
Study Area

- Tidal limit for rivers Ribble, Darwen and Douglas
- Seaward boundary close to 25m contour in Irish Sea
- Narrow rivers feed into wide estuary and coastal zone
  - Riverine boundary limit < 10m
  - Coastal boundary limit > 40km
- Many effluent discharges occur along river reaches
- Complex hydrodynamic processes in estuarine zone

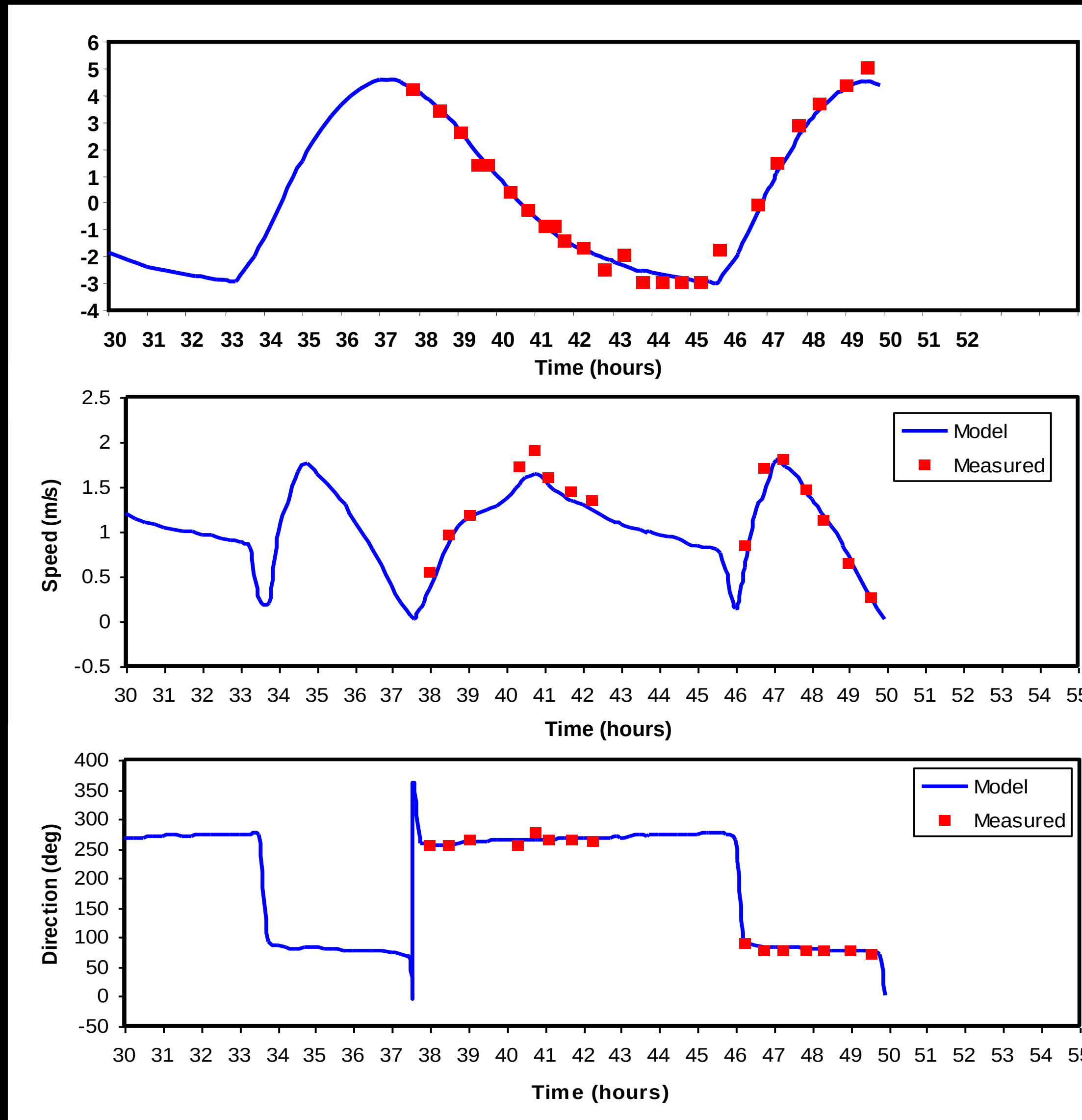

Linked 2-D and 1-D Models



Current Calibration

11 Milepost

3/12/98



***E*$_{max}$=4.7%**

***E*$_{min}$=1.9%**

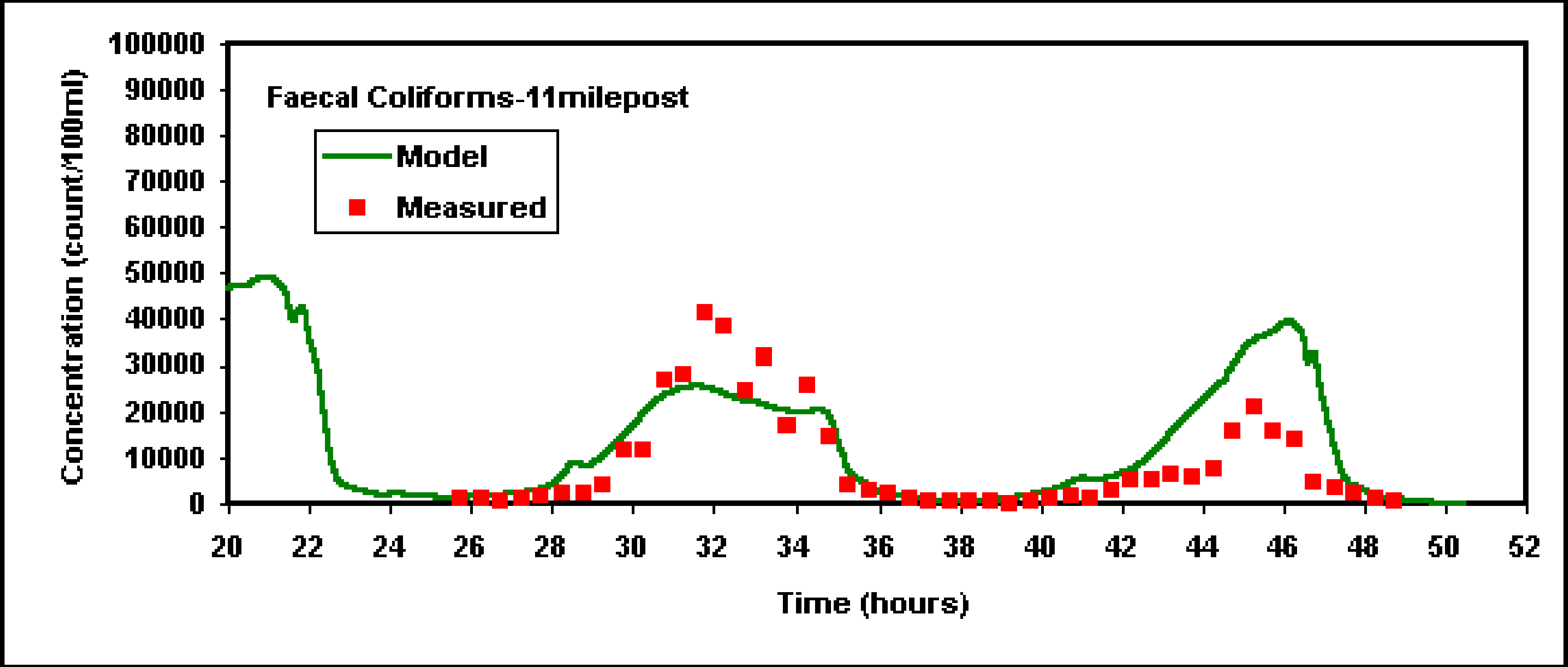
***E*$_{max}$=13.0%**

***E*$_{min}$=9.7%**

***E*$_{min}$=2.2%**

Ribble Estuary

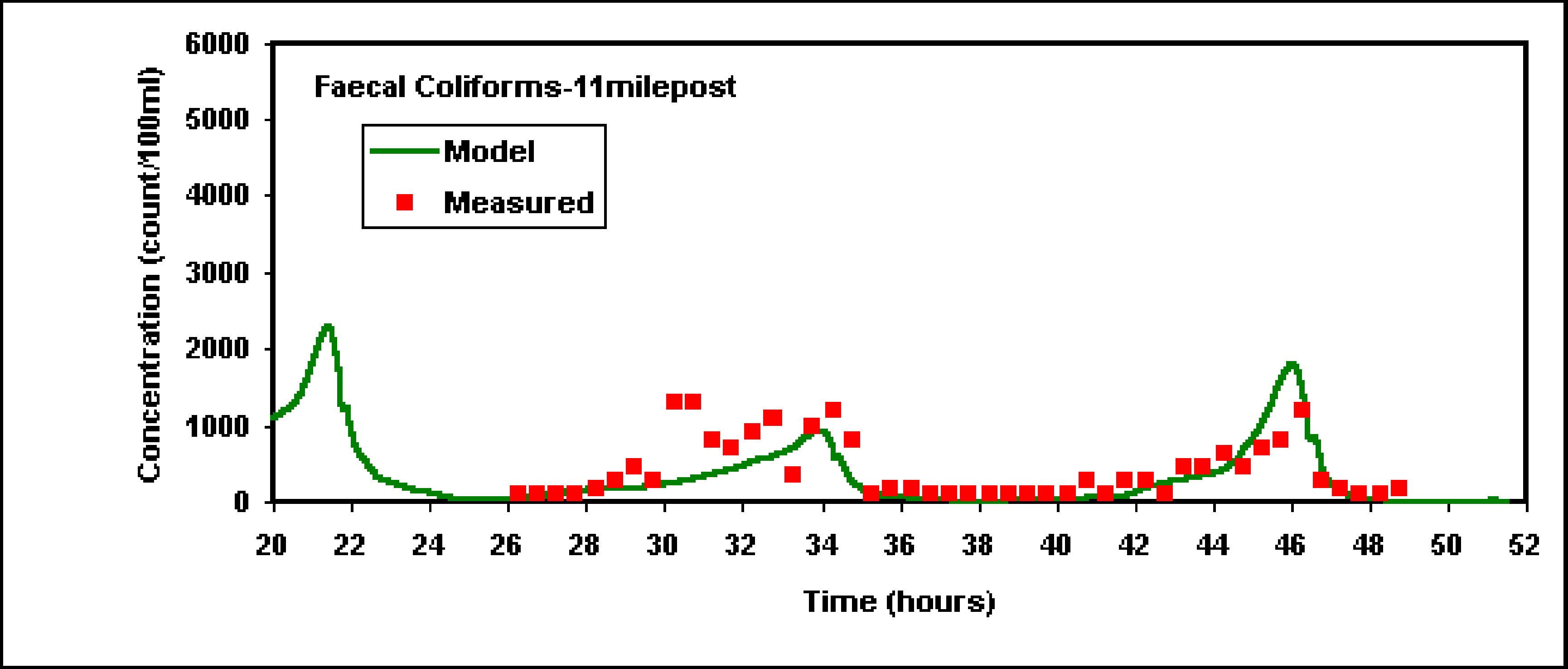
Model Calibration
11 milepost



11 May 1999 Wet Weather Neap Tide

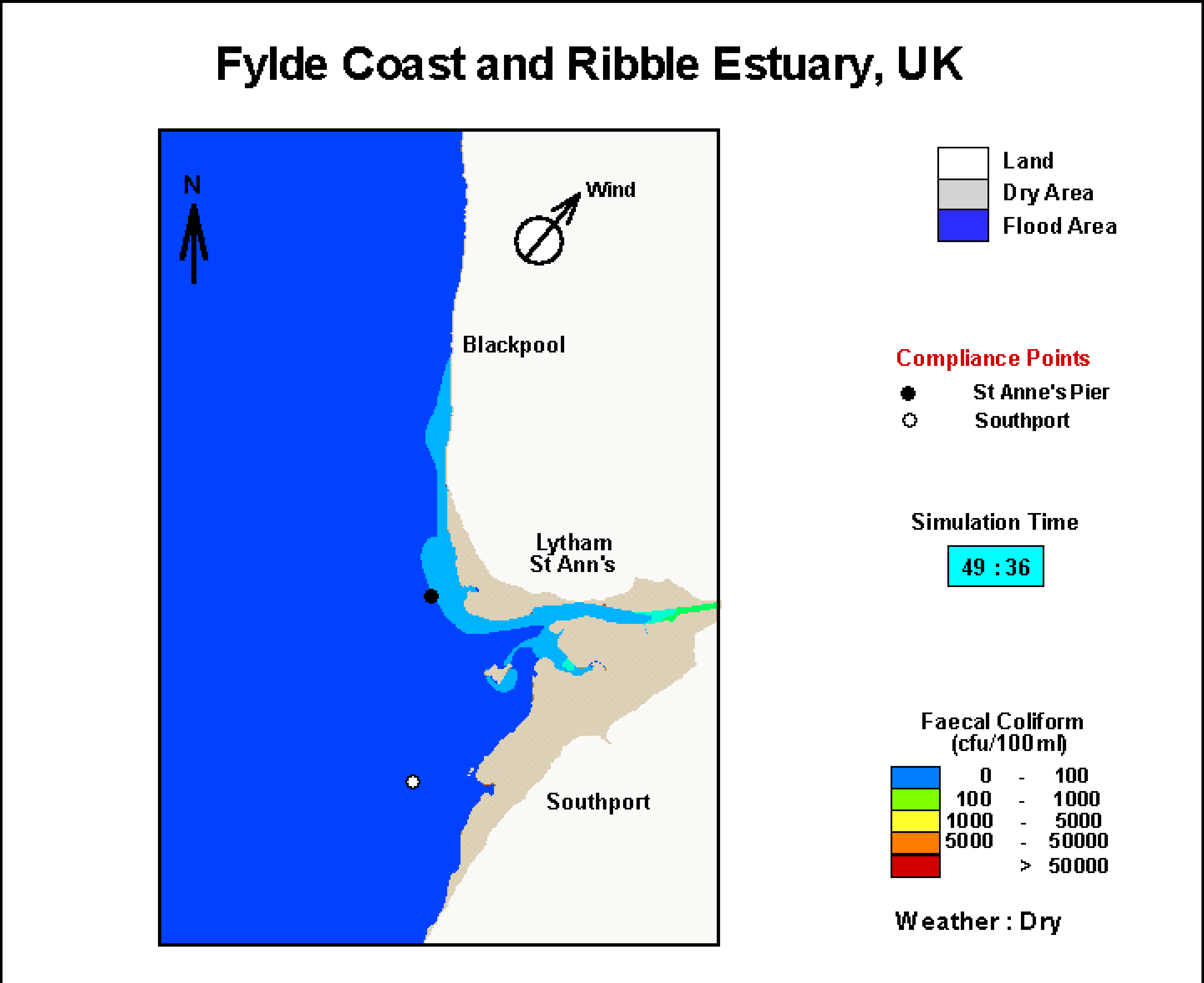
Ribble Estuary

Model Calibration
11 milepost

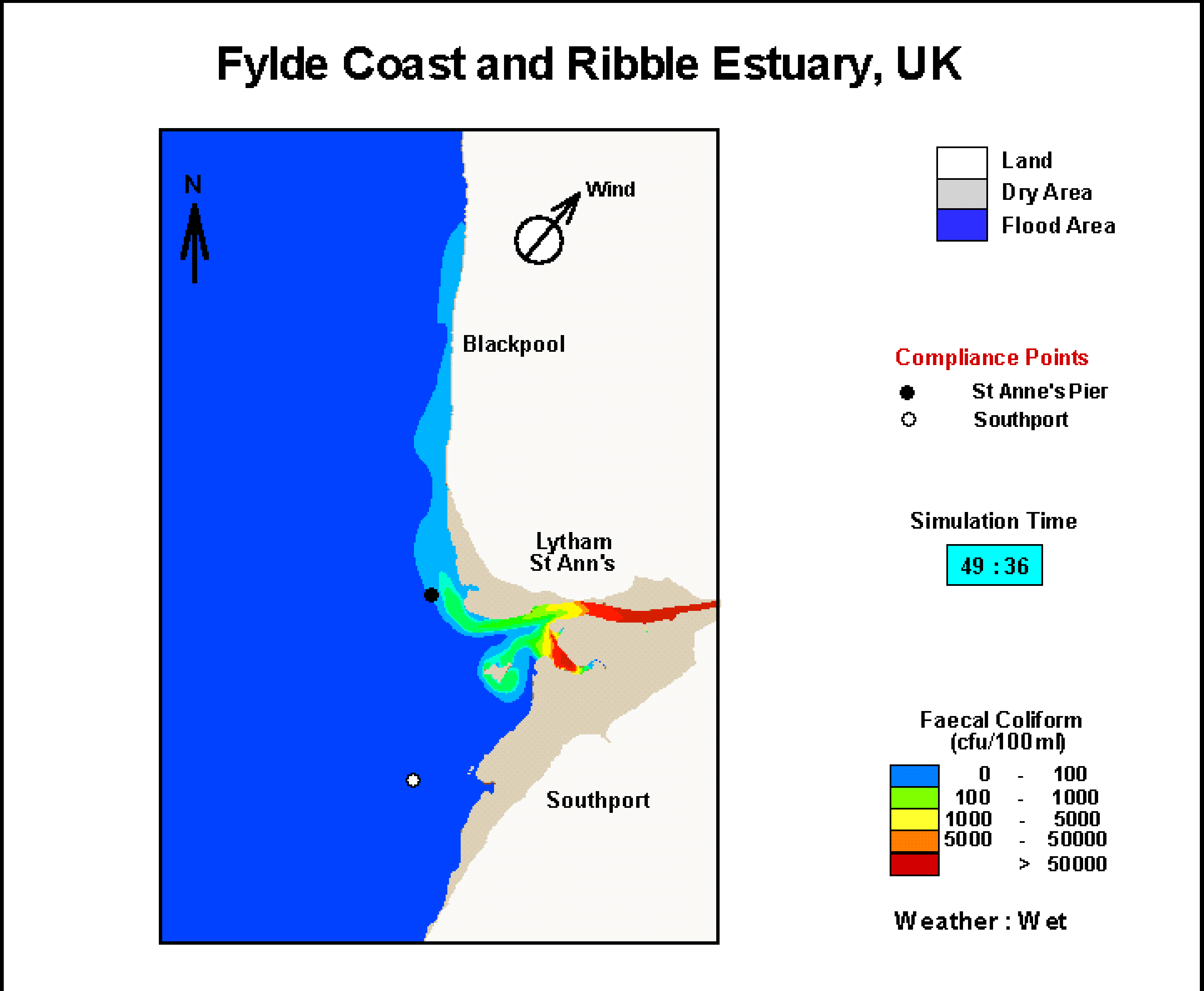


19 May 1999 Dry Weather Spring Tide

Coliform Predictions



Coliform Predictions



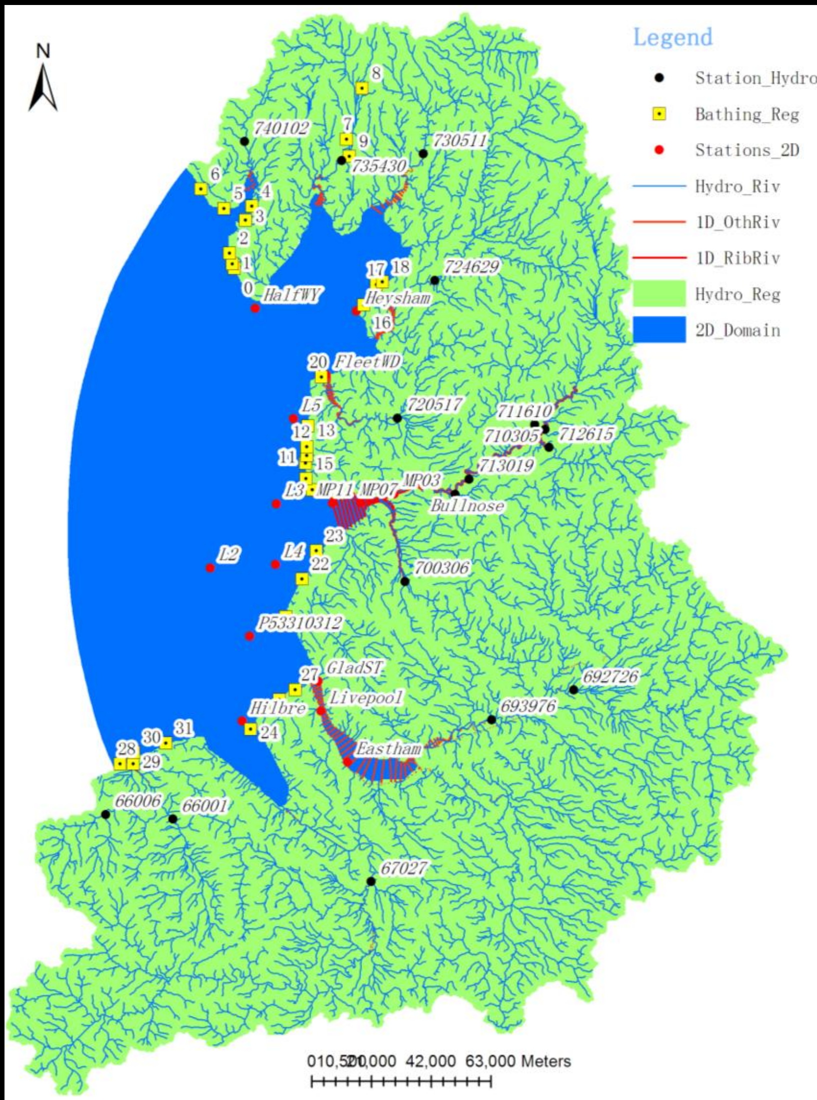
Motivation for Re-Visiting Study

- Growing concern about impact of recent land use changes on estuary and coastal water quality
- Re-occurrence of non-compliance of EU BWD
- Needed to include model of catchments into linked model - C2C holistic approach
- Needed to model both rural and urban catchment inputs - together with land use changes
- Significantly improve ability to predict exposure to, and health impact of, pathogens in coastal waters

Objectives of New Study

- Develop an integrated Cloud-to-Coast model
- Estimate urban point and diffuse loads of FIOs
- Collect new data on FIO loads and fluxes
- Calibrate and validate overall process models
- Produce qualitative health impact assessment
- Create an emulator of model - “Predict & Protect”
- Produce recommendations for policy and make: models, data, formulae available to stakeholders

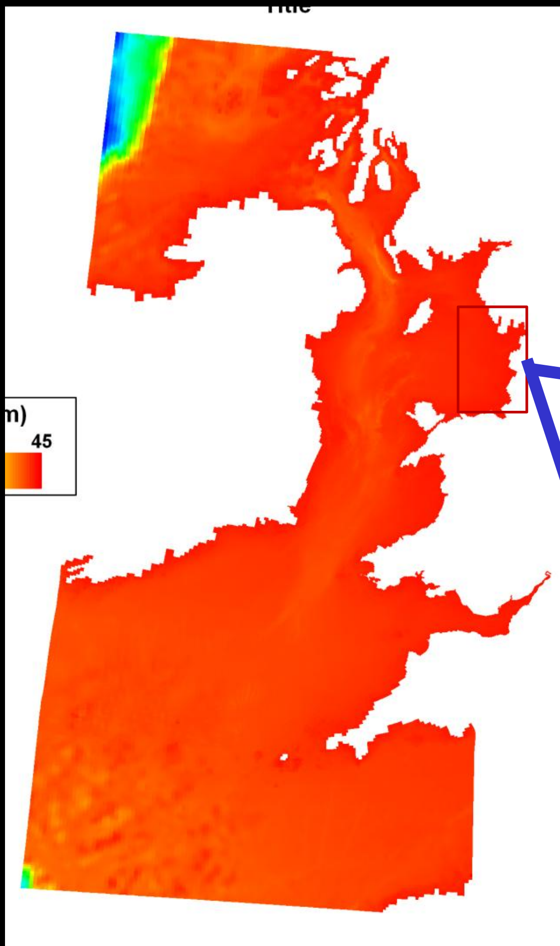
C2C: Integrated Modelling Domain



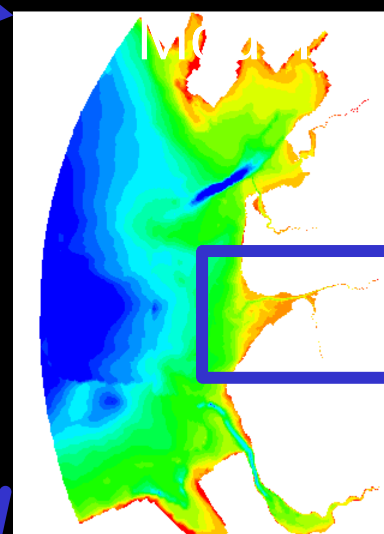
- Includes: catchment, river, & coastal models of flow, sediment & FIO processes
- Includes: extended coastal domain around Ribble with tides, waves, sediment and FIO processes
- Includes: climate and land use changes + urban point sources to assess bathing water compliance

C2C: Integrated Model Set Up

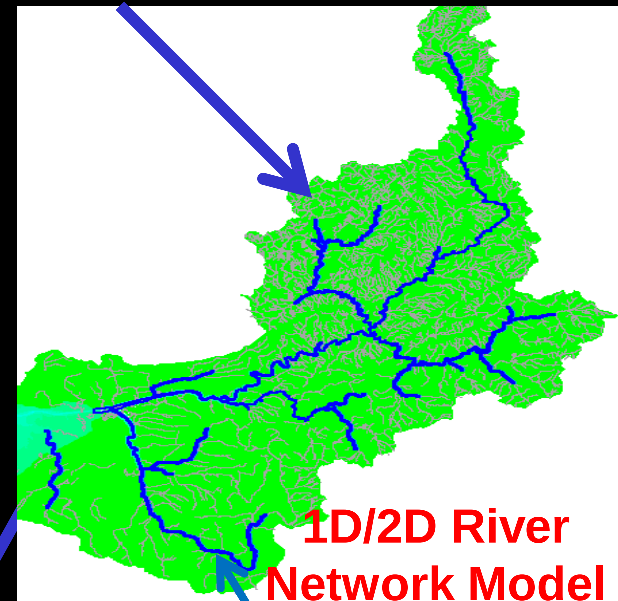
2D/3D Irish Sea Model



2D/3D Coastal Estuary Model

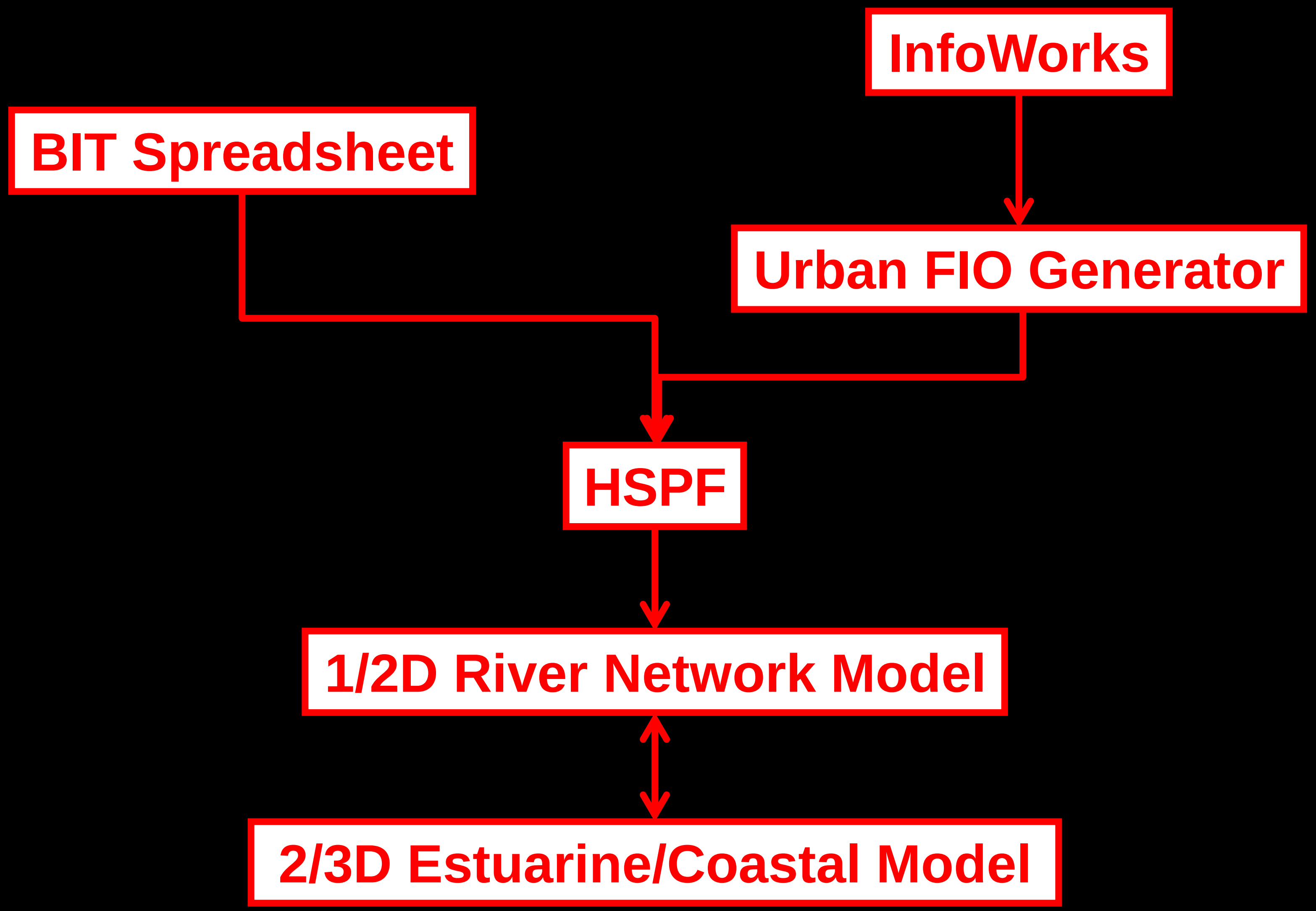


HSPF Catchment Model



InfoWorks Model

C2C: Integrated Model Configuration



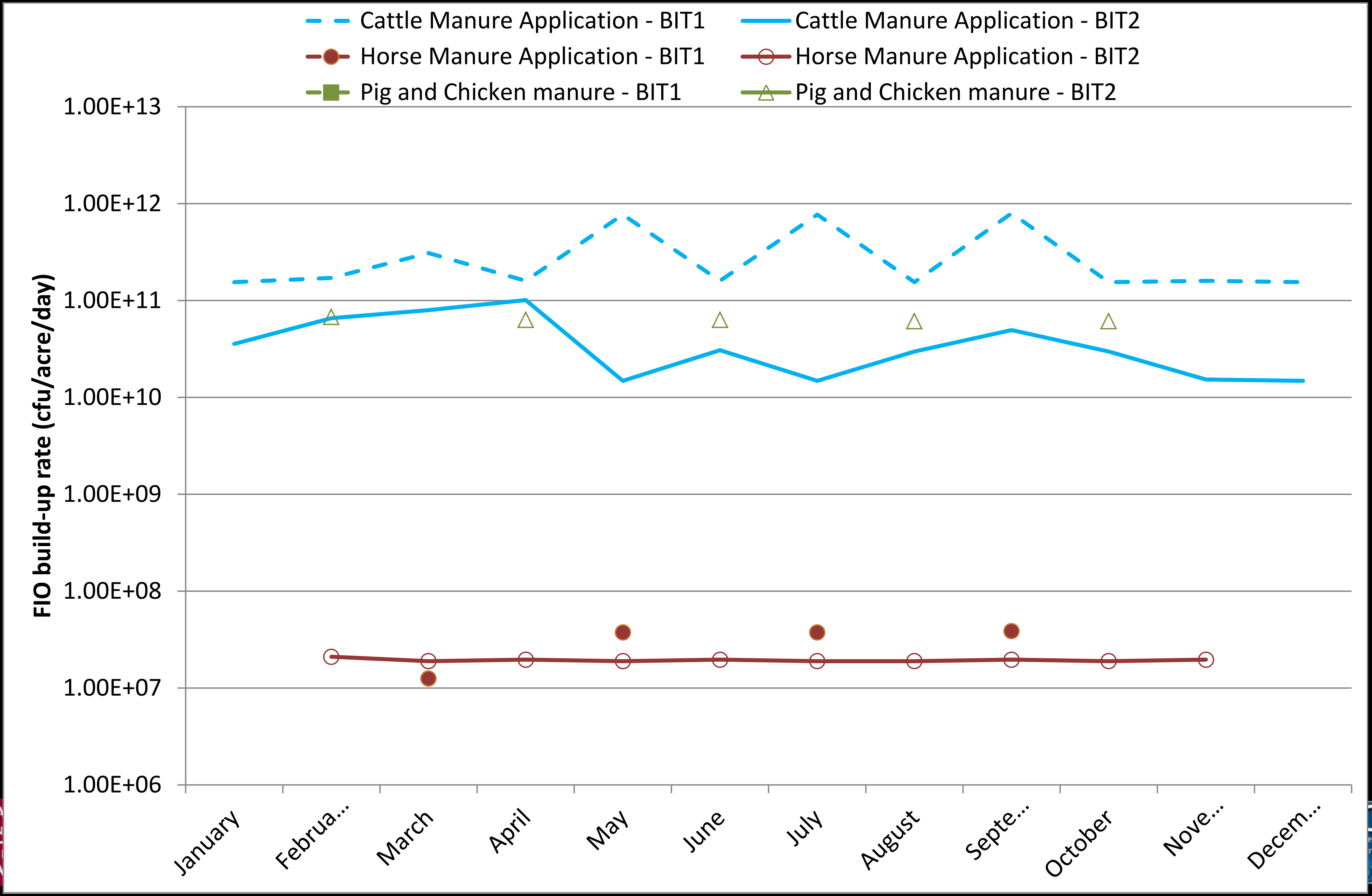
HSPF Catchments

- 28 very different catchments, including: rural & urban, steep & mild slope, arable & pasture and forested land use etc.

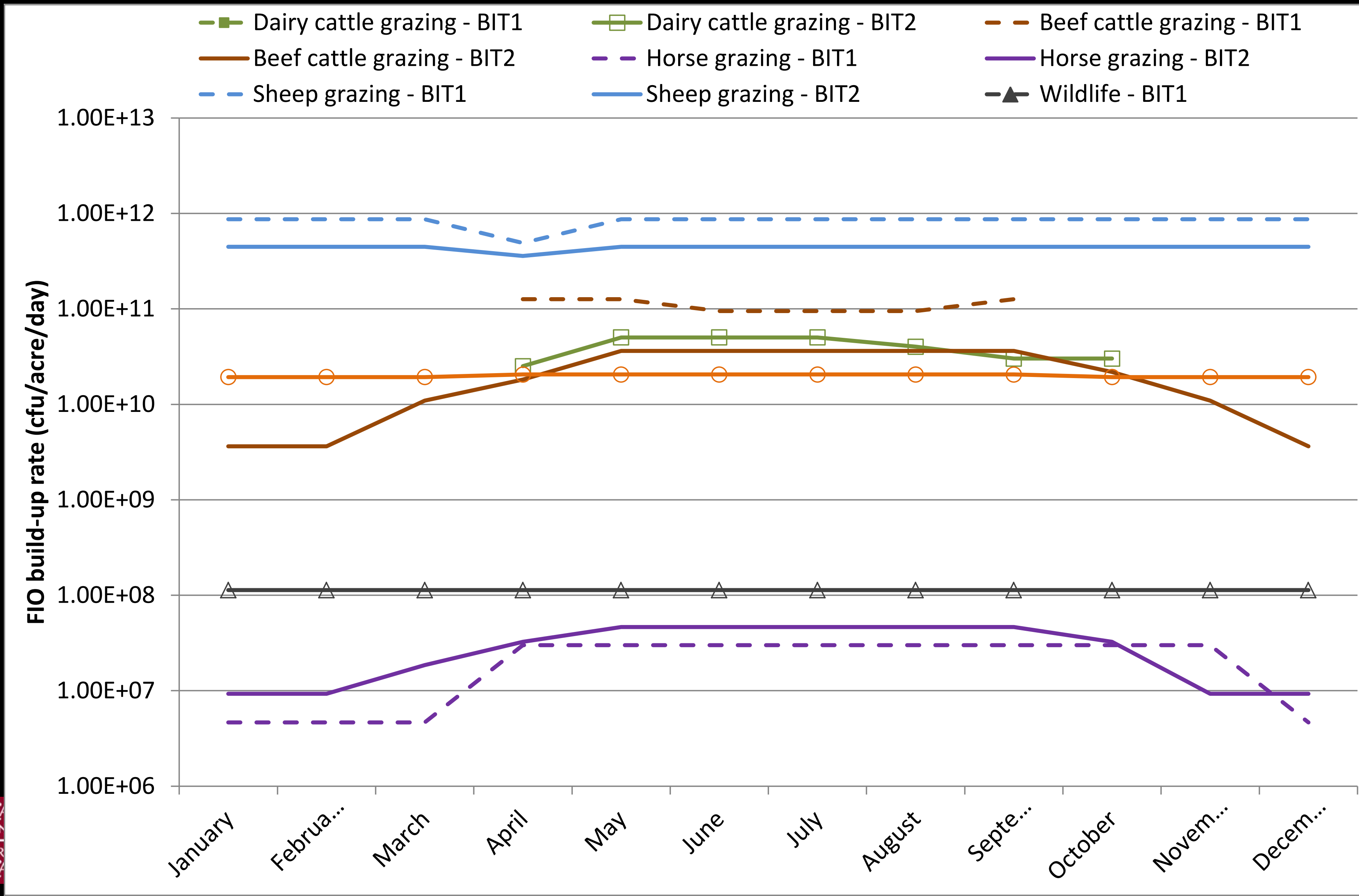
US EPA Bacterial Indicator Tool (BIT)

- Splits sub-catchments by land use: mountainous, heath, bog, pastureland, forest, built-up areas, cropland and water
- Accounts for: stocking densities, FIO production rates, decay, manure application, wildlife, etc.
- Includes continuous point sources: septic tanks, cattle in streams etc.
- Washoff: applied manure, grazing, wildlife
- Other default values chosen from stakeholder engagement - ensuring appropriate values

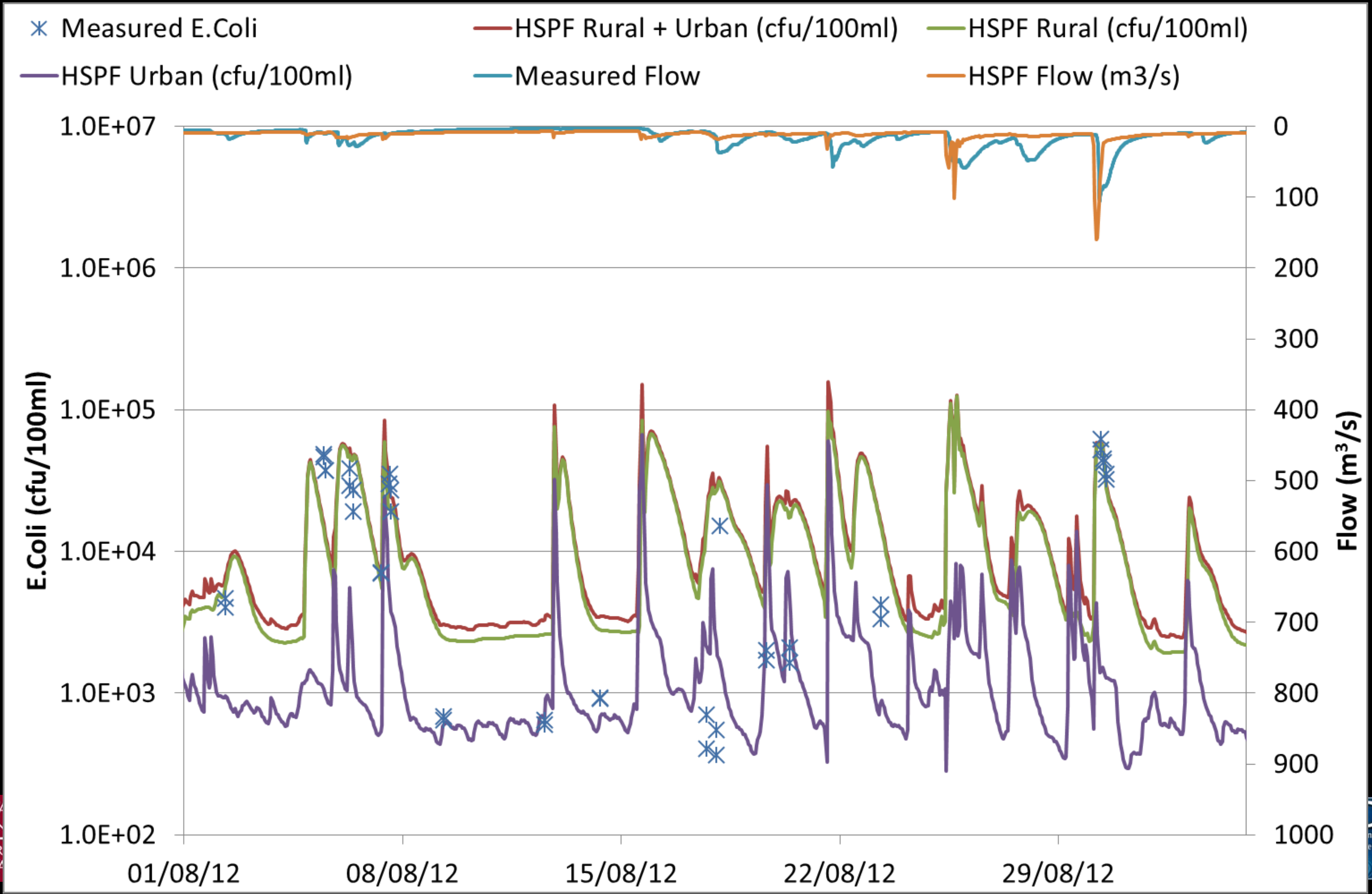
Catchment 2 - BIT Manure Application



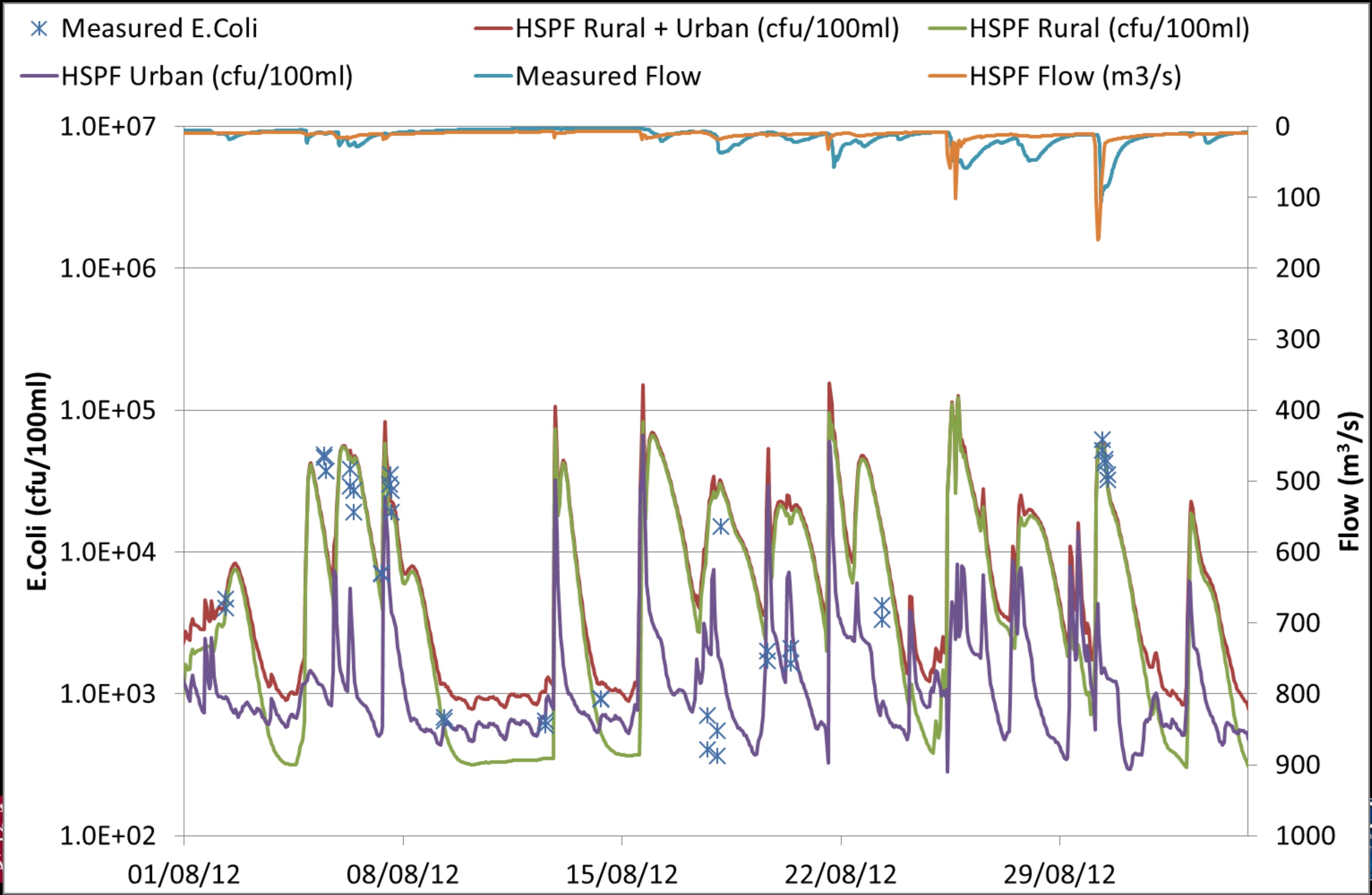
Catchment 2 - BIT Pasture Grazing



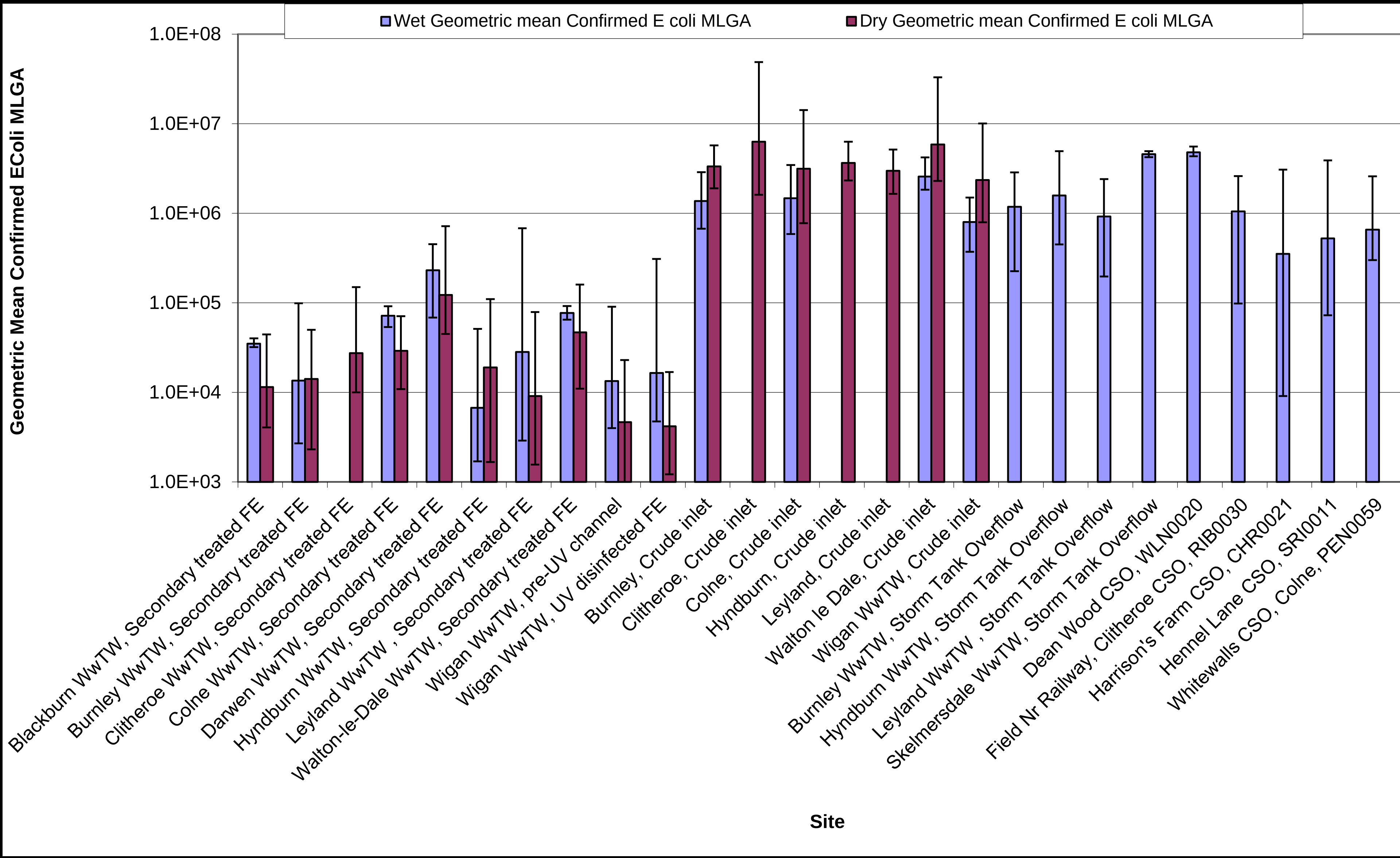
Catchment 2 - Verification Rural+Urban



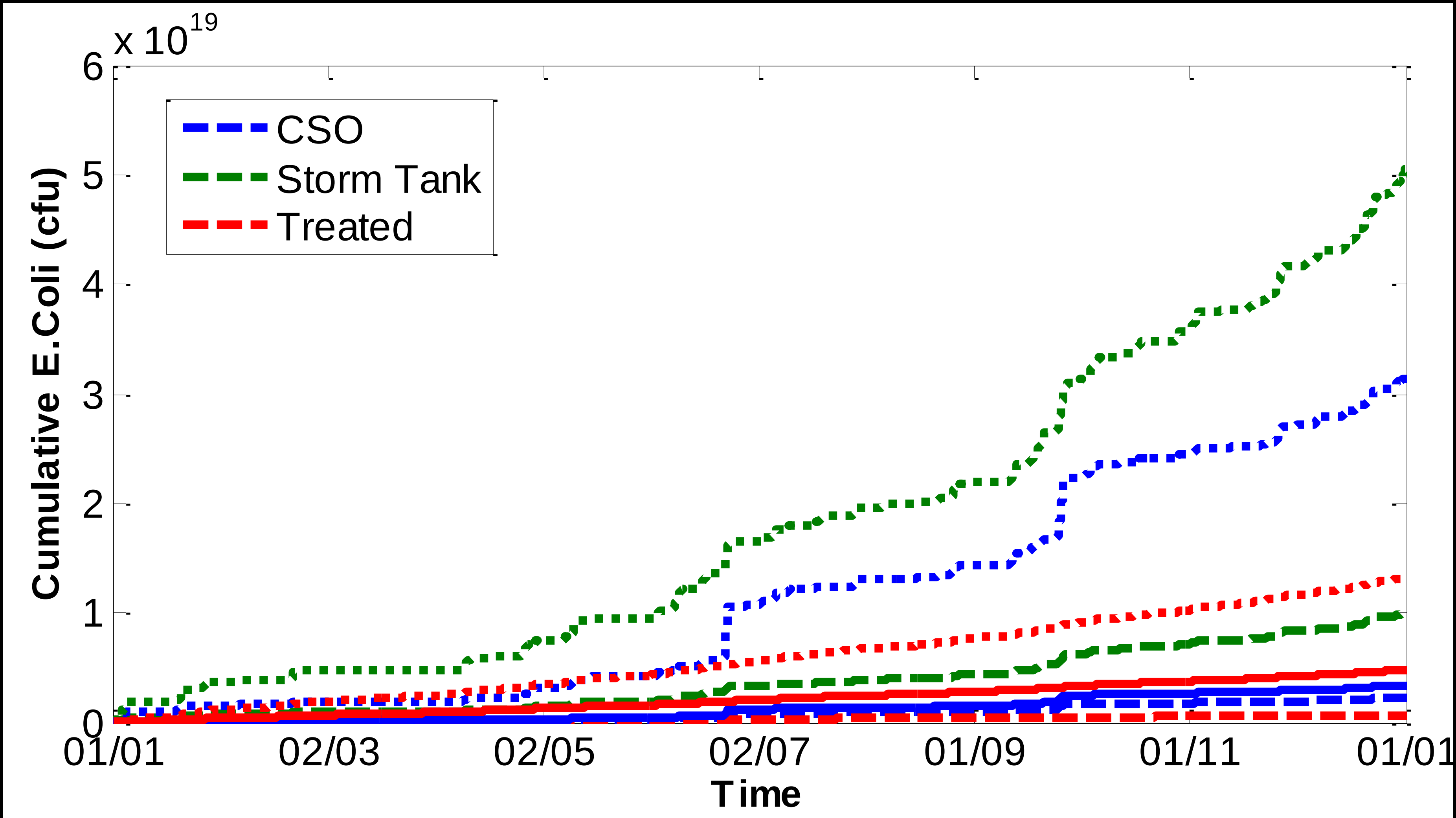
Catchment 2 - Septic Tanks Removed



Urban Inputs - E.coli Data Summary



Urban Inputs - E.coli Annual Loads

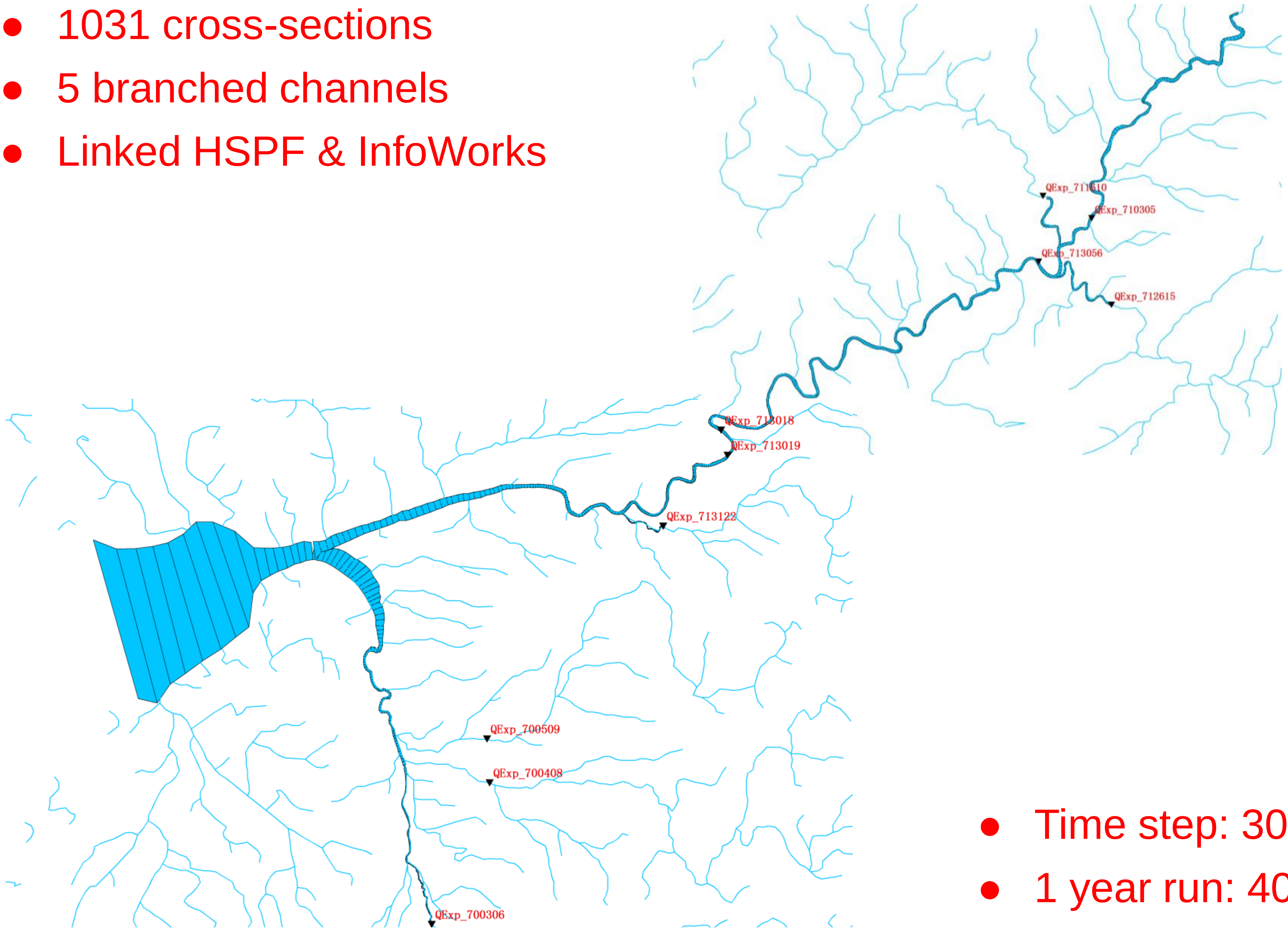


Dotted lines = Max Geo Mean; Dashed Lines = Min Geo Mean; Solid Line = Local Geo Mean

Local value not available for storm tank cons for this network

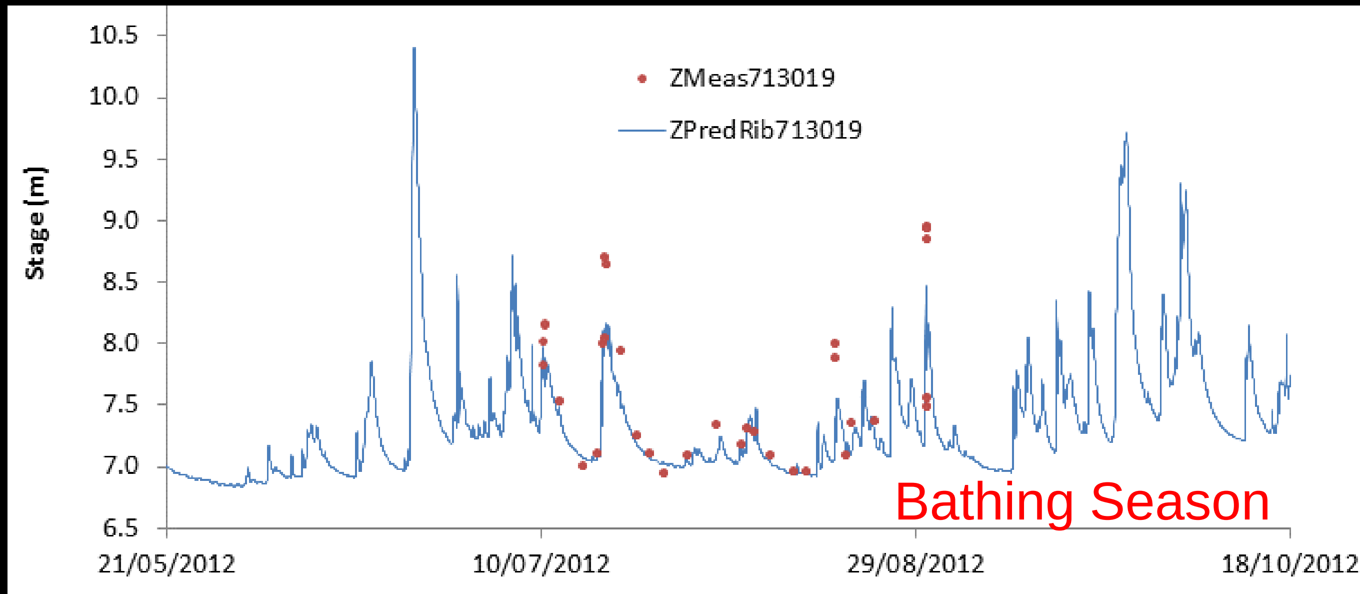
1D RNM - Model Configuration

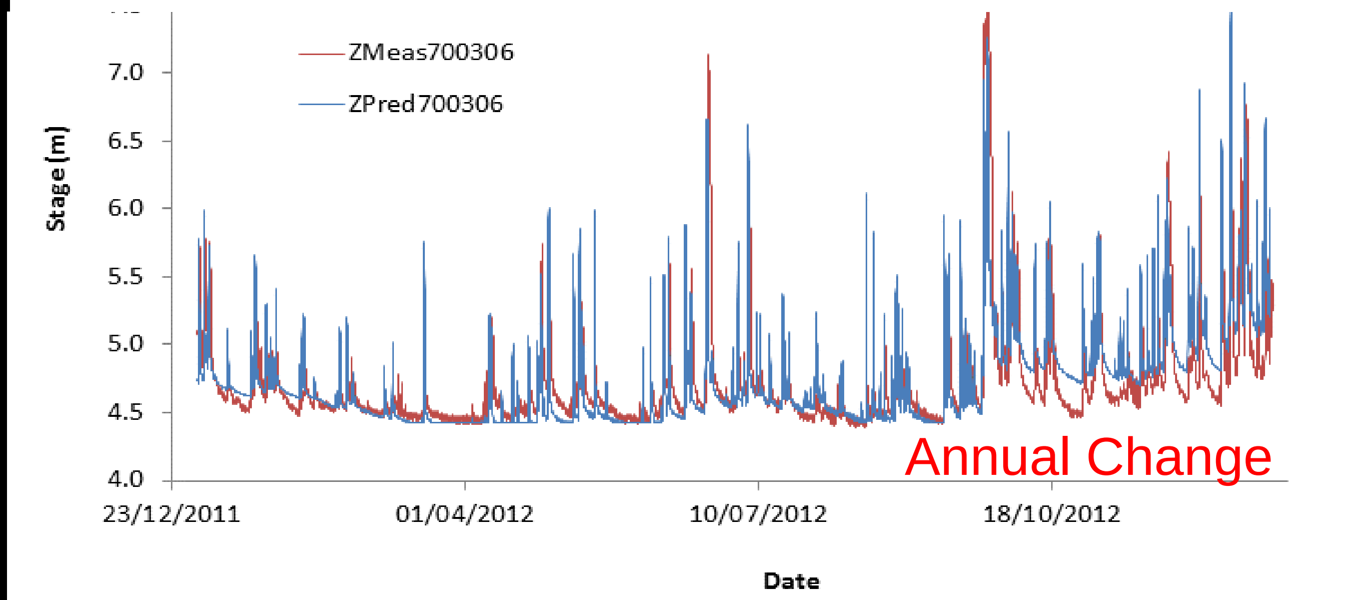
- 1031 cross-sections
- 5 branched channels
- Linked HSPF & InfoWorks



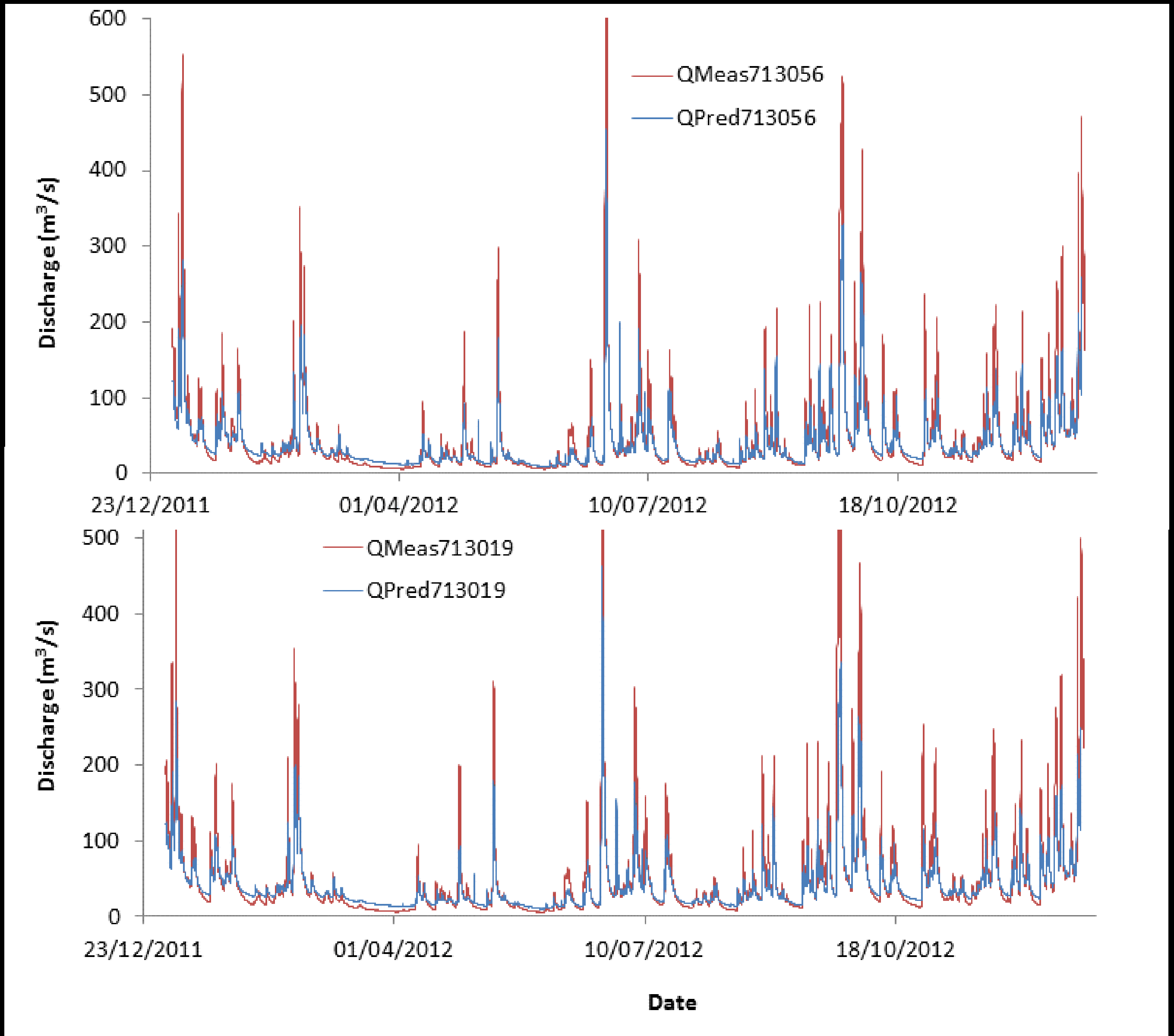
- Time step: 30s
- 1 year run: 40m

1D RNM - Stage Verification

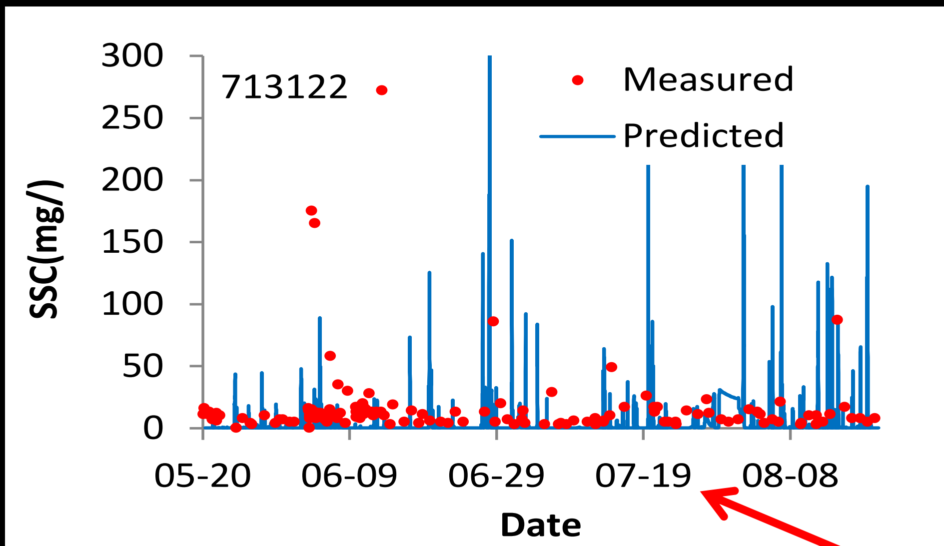


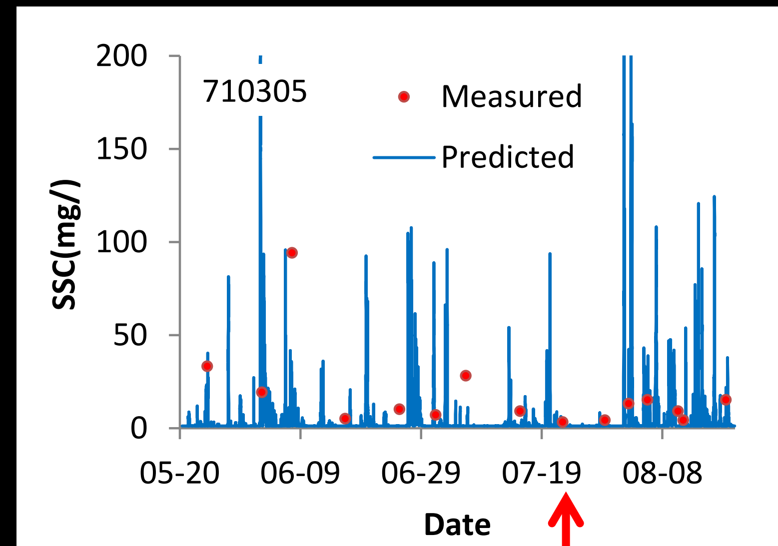


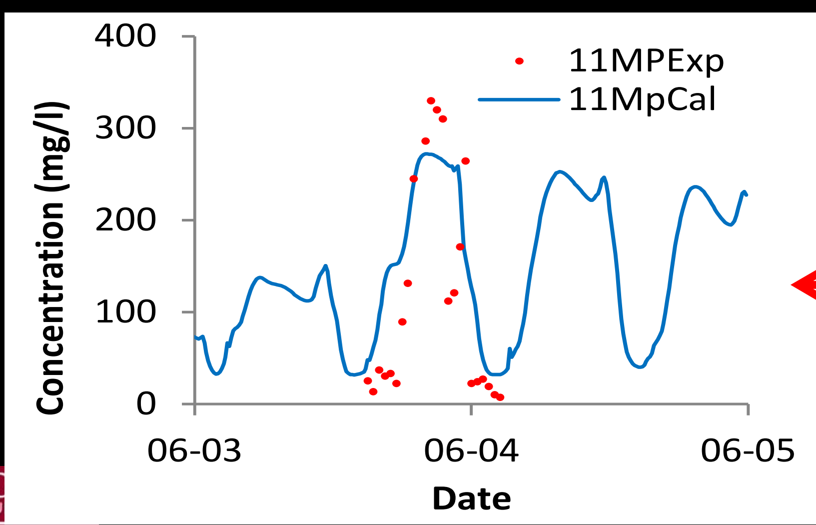
1D RNM - Discharge Verification

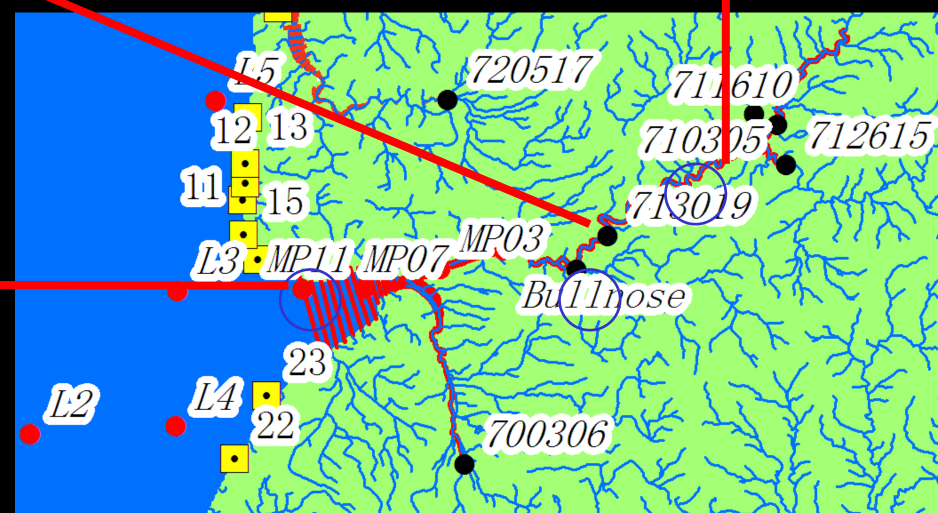


1D RNM - SSC Verification

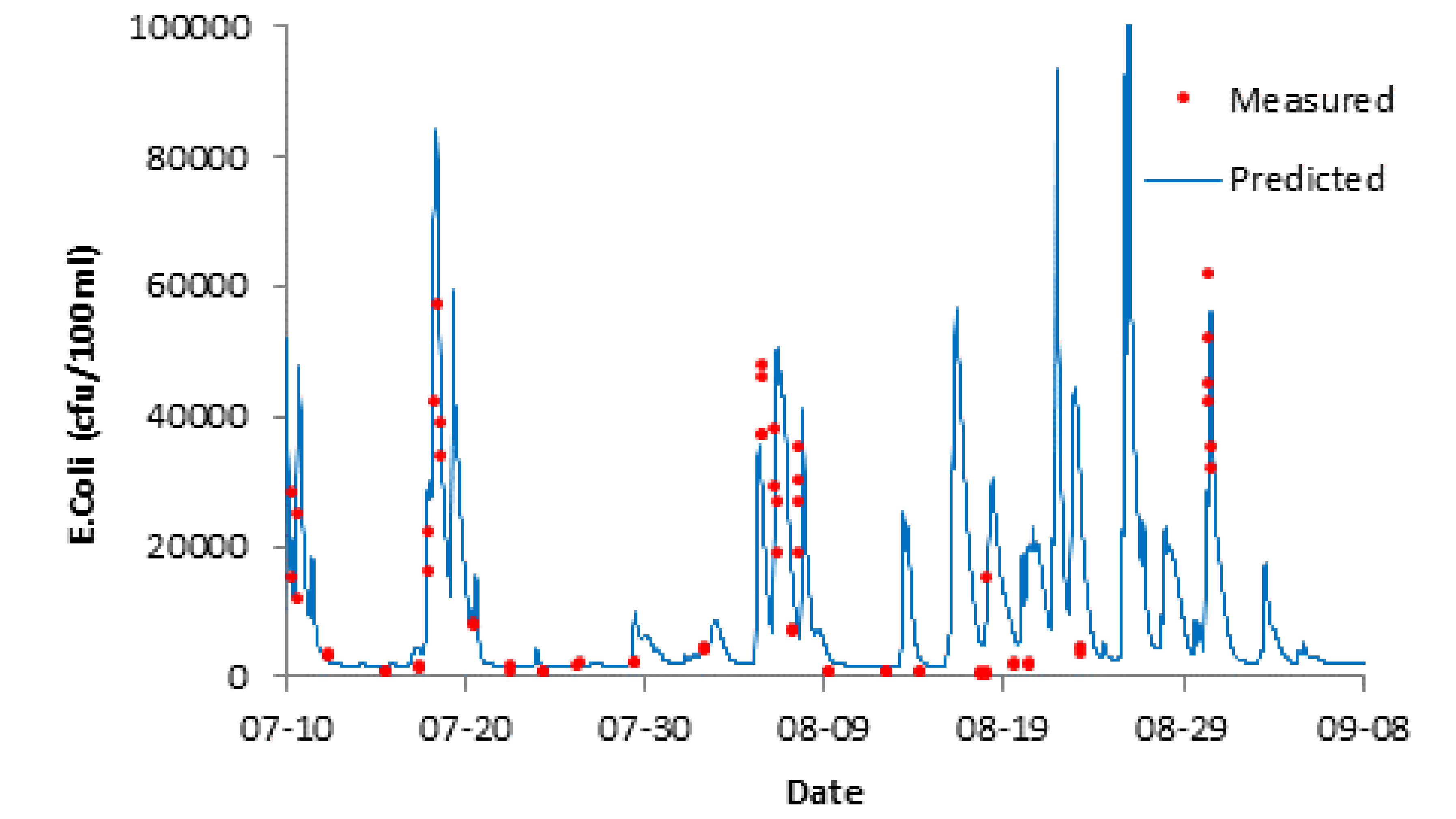






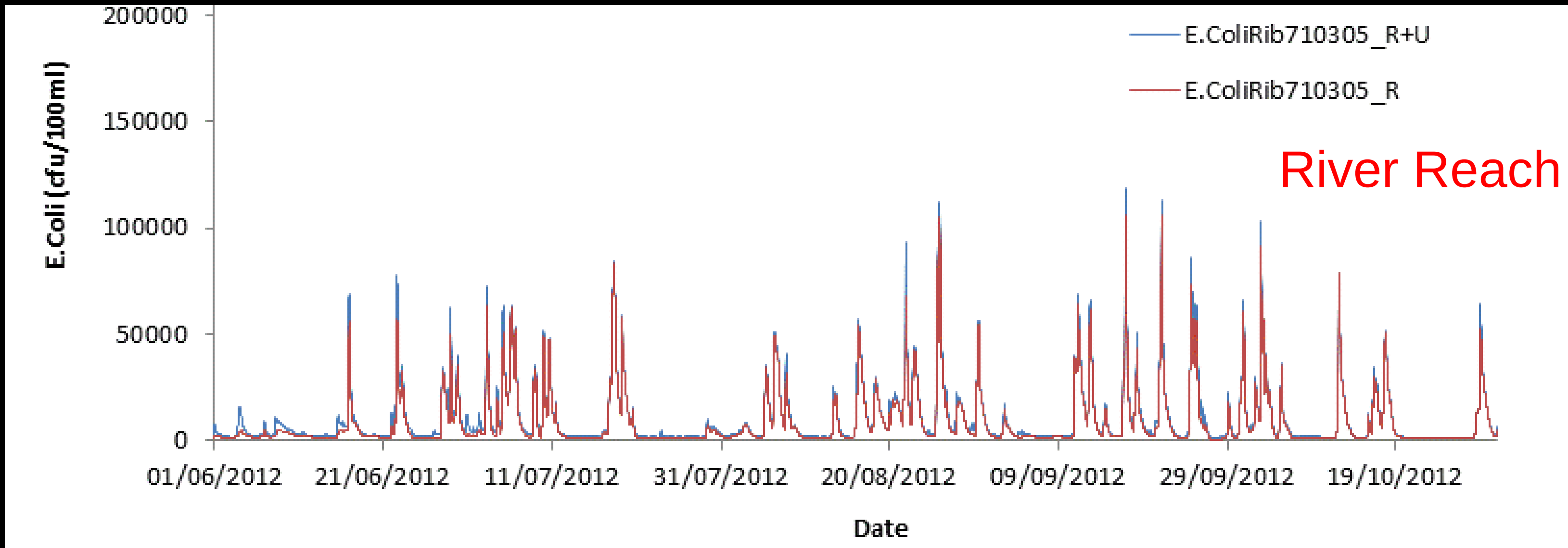


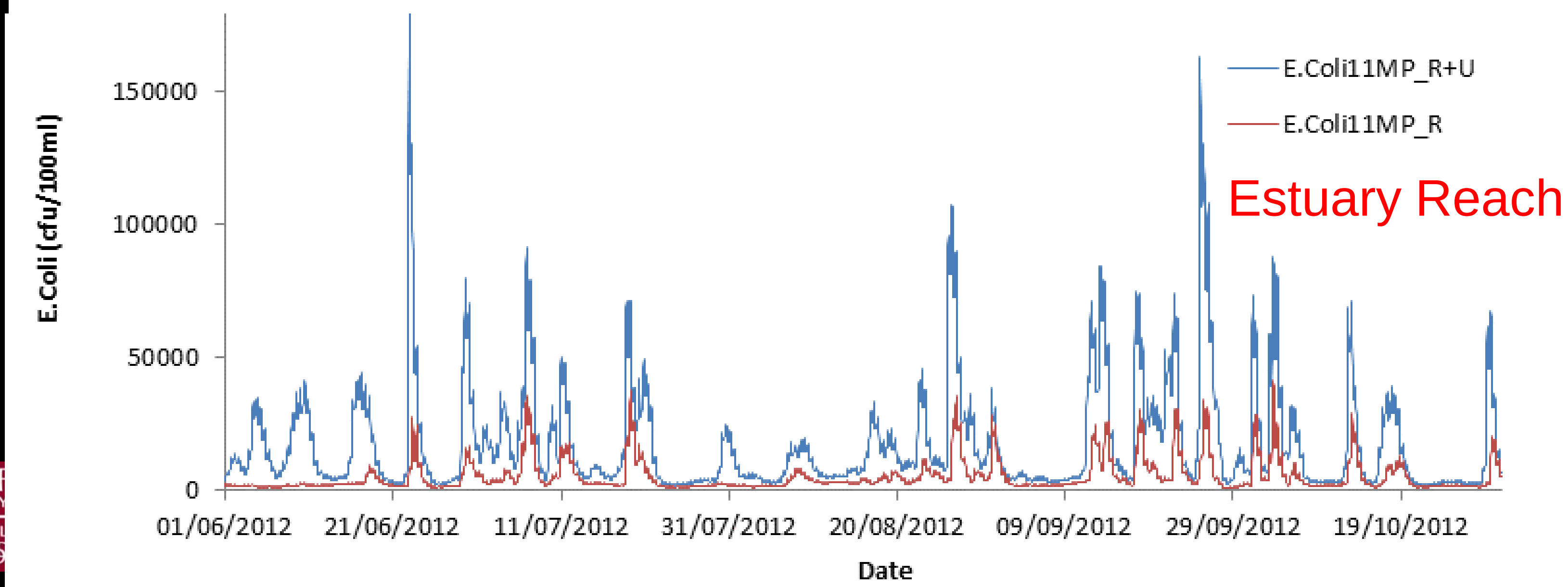
1D RNM - Typical E.coli Verification



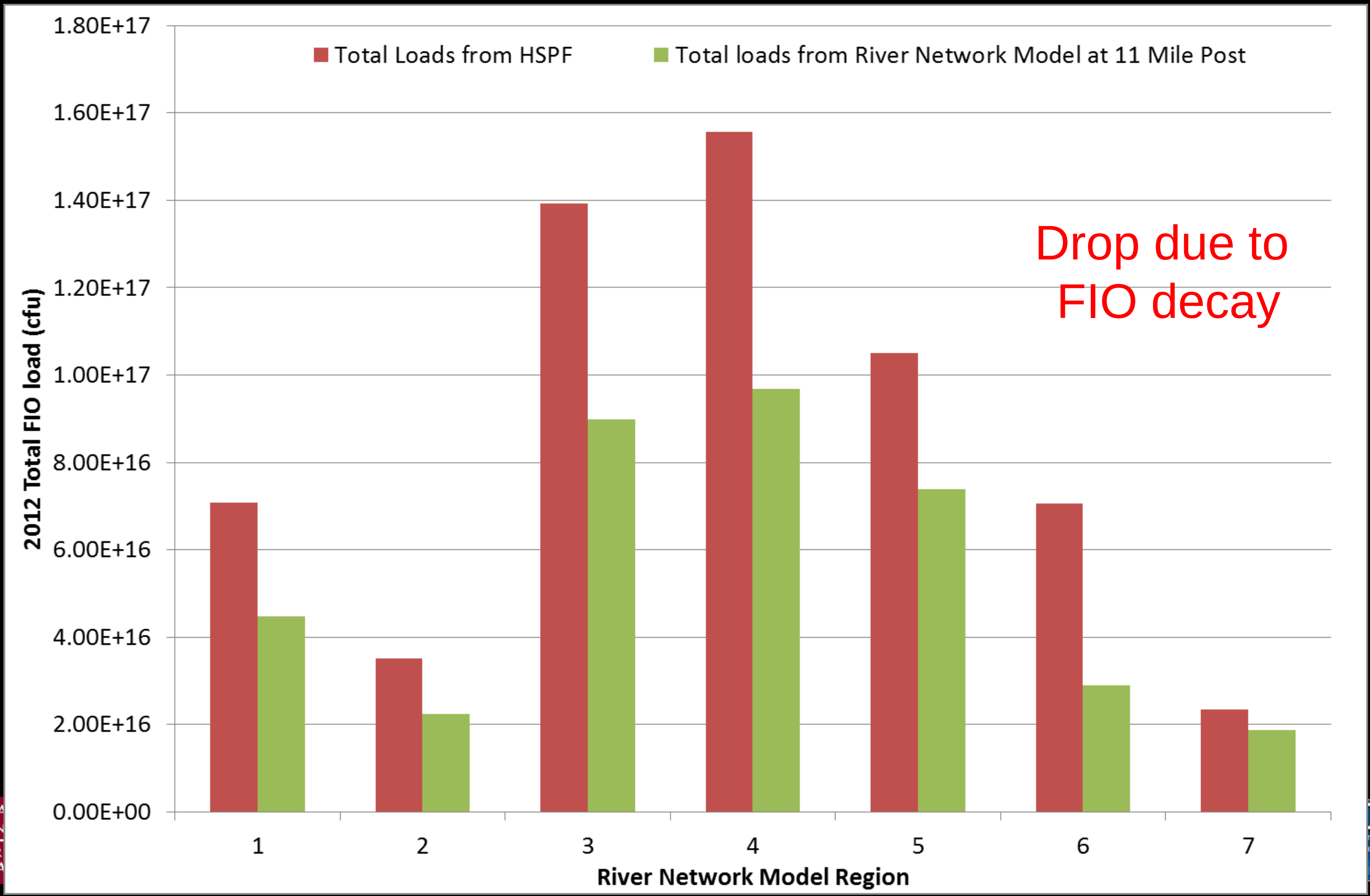
103: Ribble, Mitton Bridge

1D RNM - Typical Scenario Predictions

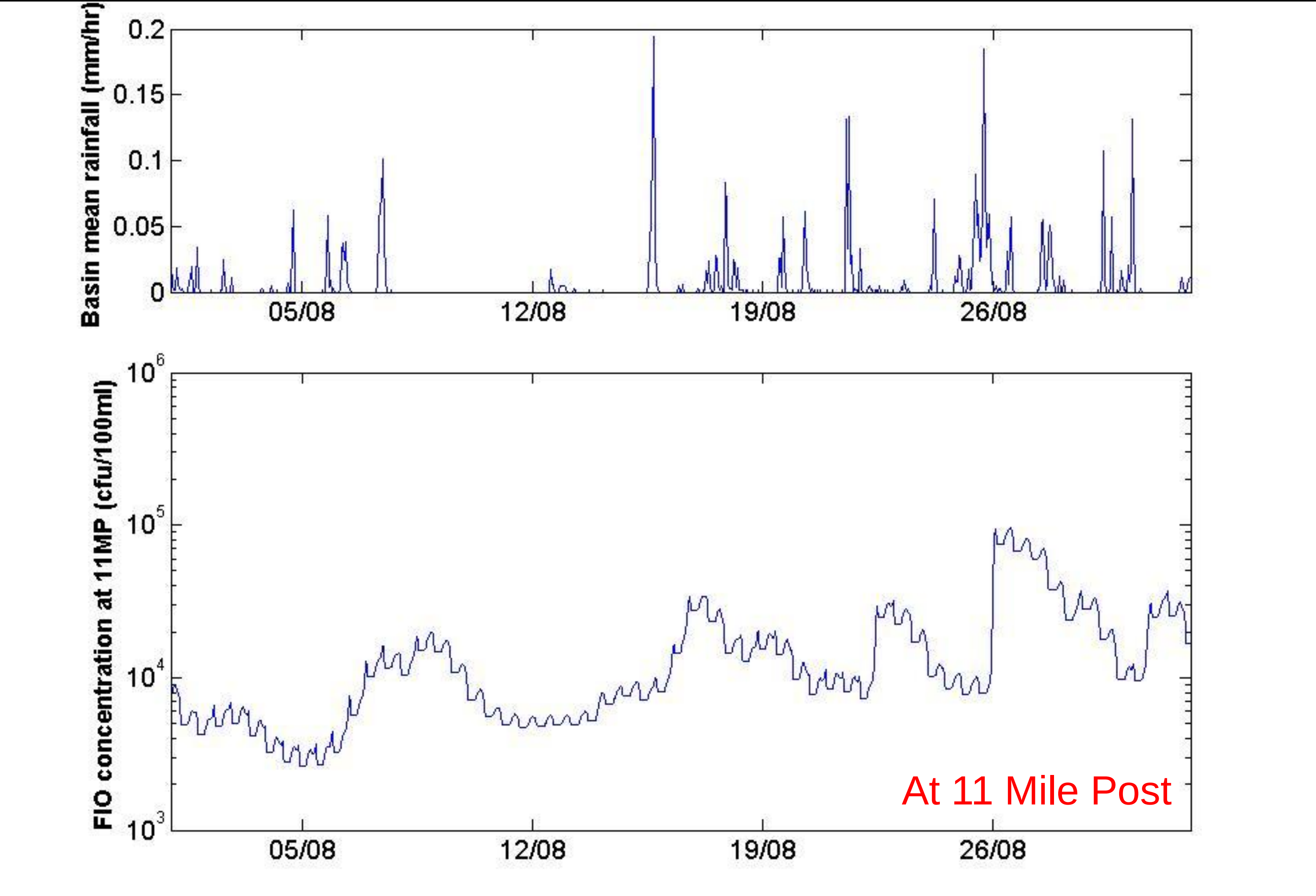




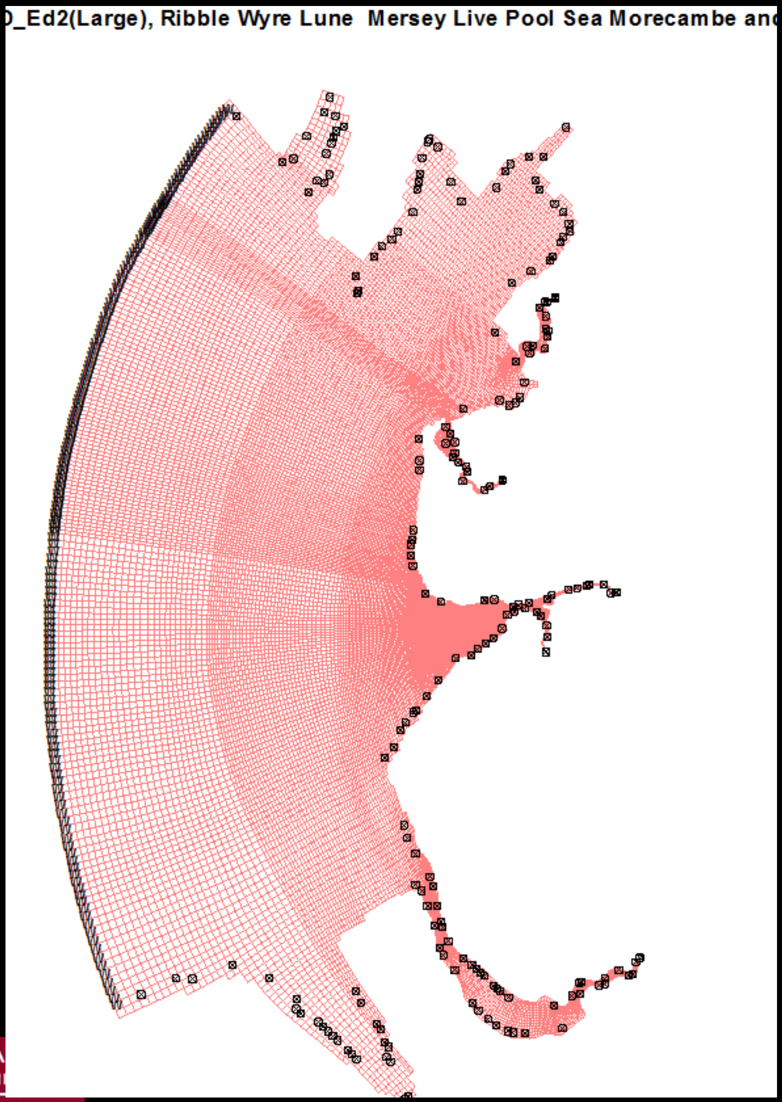
Annual Loads of FIO into Estuary



Predicted FIO - Estuary for Aug/2008



Boundary Inputs for Coastal Model



- 203 river boundary inputs around coastal model
- Discharges and sediment flux data from catchment and river network models
- Offshore tidal boundary data from EFDC Irish Sea model and MIKE Global
- EFDC refined for dynamic decay & ad/desorption

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Field Data Monitoring

- Continuous offshore data sampling for elevations currents, meteorological and FIO data
- ADCP deployment at 6 sites
- 2 tracer surveys for source apportionment
- Continued processing of catchment data
- T_{90} experiments from samples to determine day and night time decay rates
- Virus sampling and analysis

Offshore Boat Surveys

- Comprehensive estuarine and offshore surveys
- Drogue tracking, WQ and irradiance depth profiles, and sediment samples

Tracer Studies in Estuary and Coast

Measured T_{90} Values (Kay *et al*.)

	n	Mean T_{90} (Hours) Irradiated	Mean T_{90} (Hours) Dark	Mean Total Irradiation D_{90} (MJ m^{-2}) (Visible+UVA+UVB)
E. coli				
Freshwater	68	13.61	**355.51	6.65
Estuarine	32	8.56	*30.64	5.17
Saline	20	2.33	33.77	1.41
Confirmed Enterococci				
Freshwater	68	14.87	65.70	8.99
Estuarine†	32	11.08	84.63	6.70
Saline	20	4.98	57.39	3.01

* Excludes one experiment where no decay was observed

** Excludes two experiments where no decay was observed

† Estuarine data includes a wide range of salinity (1-30 ppt)

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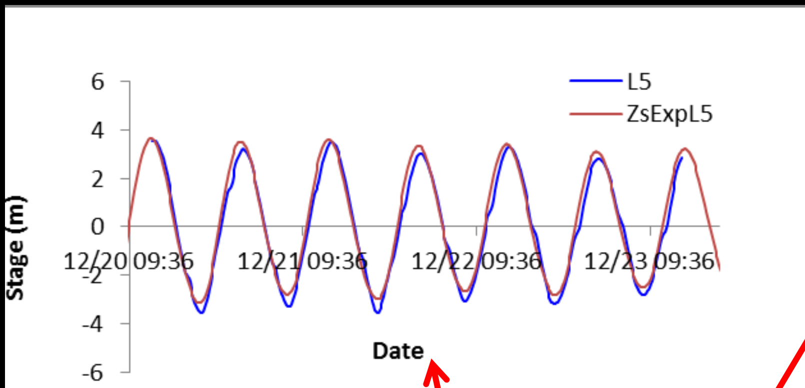
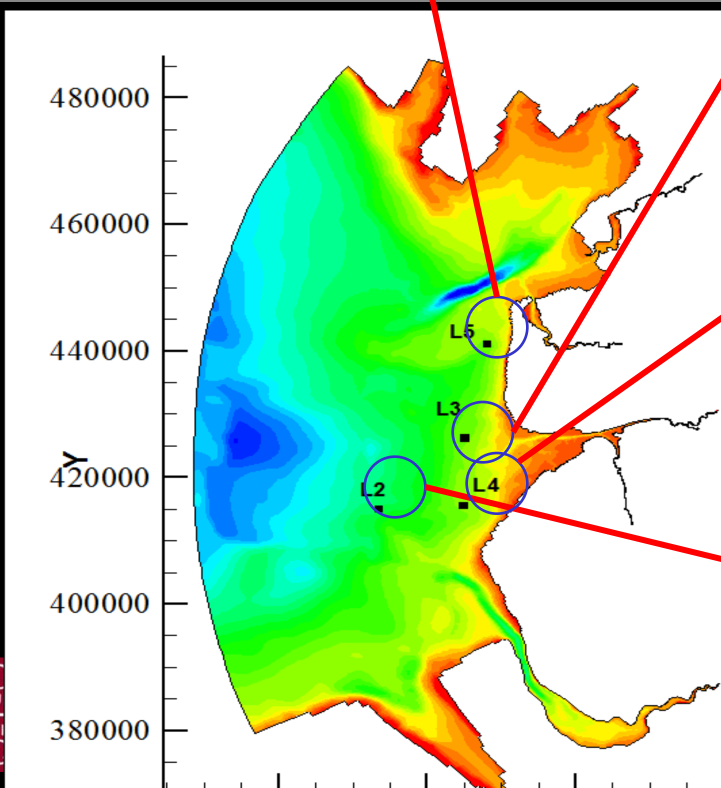
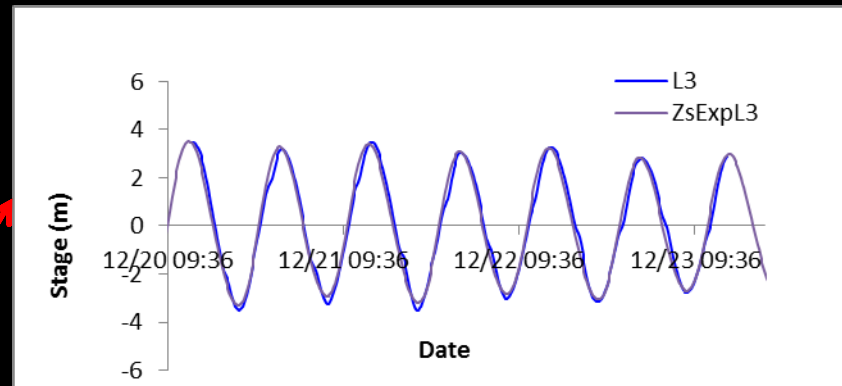
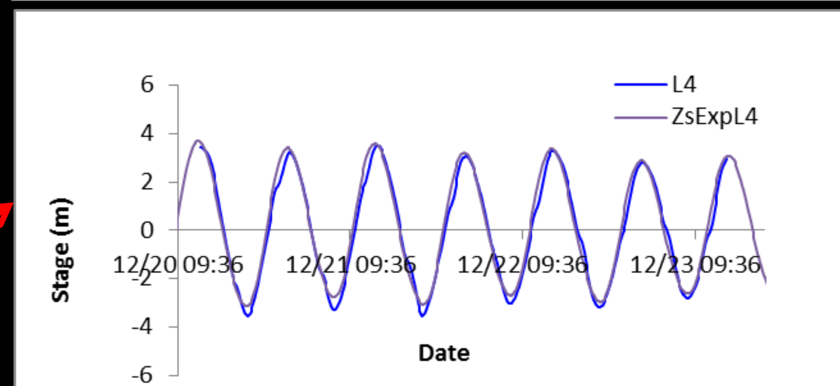
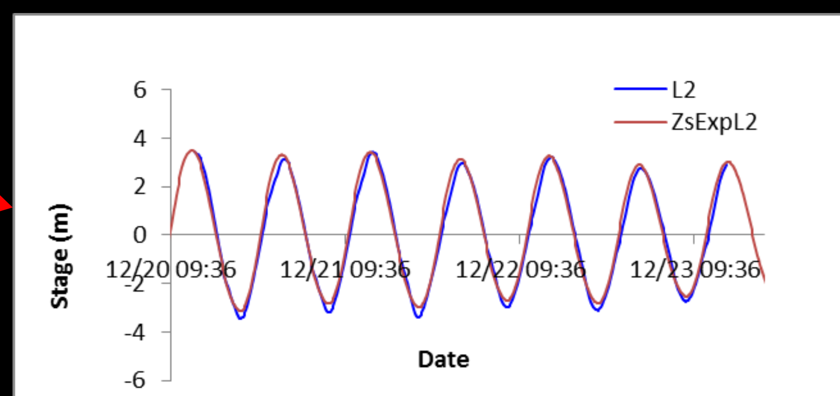
EFDC - Verification of Tidal Elevations



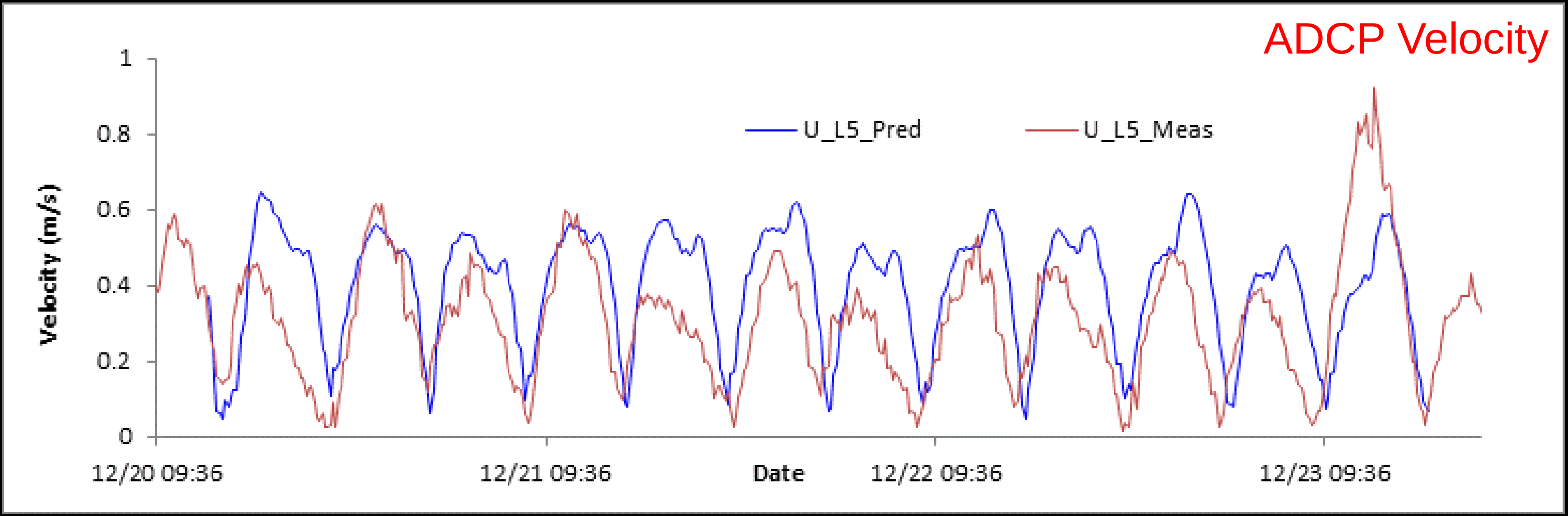


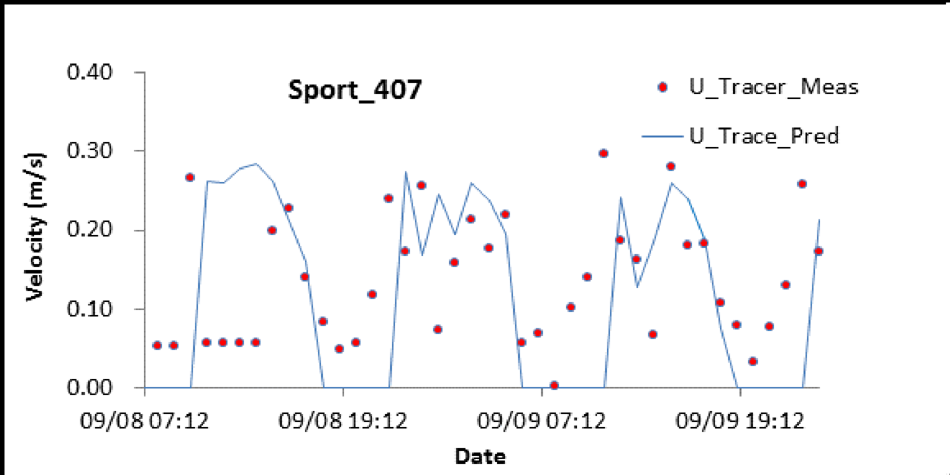


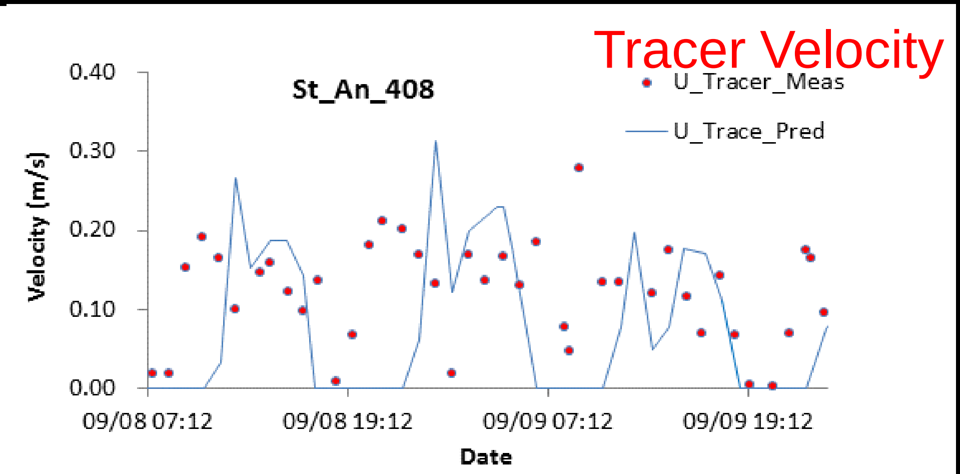




EFDC - Verification of Tidal Currents







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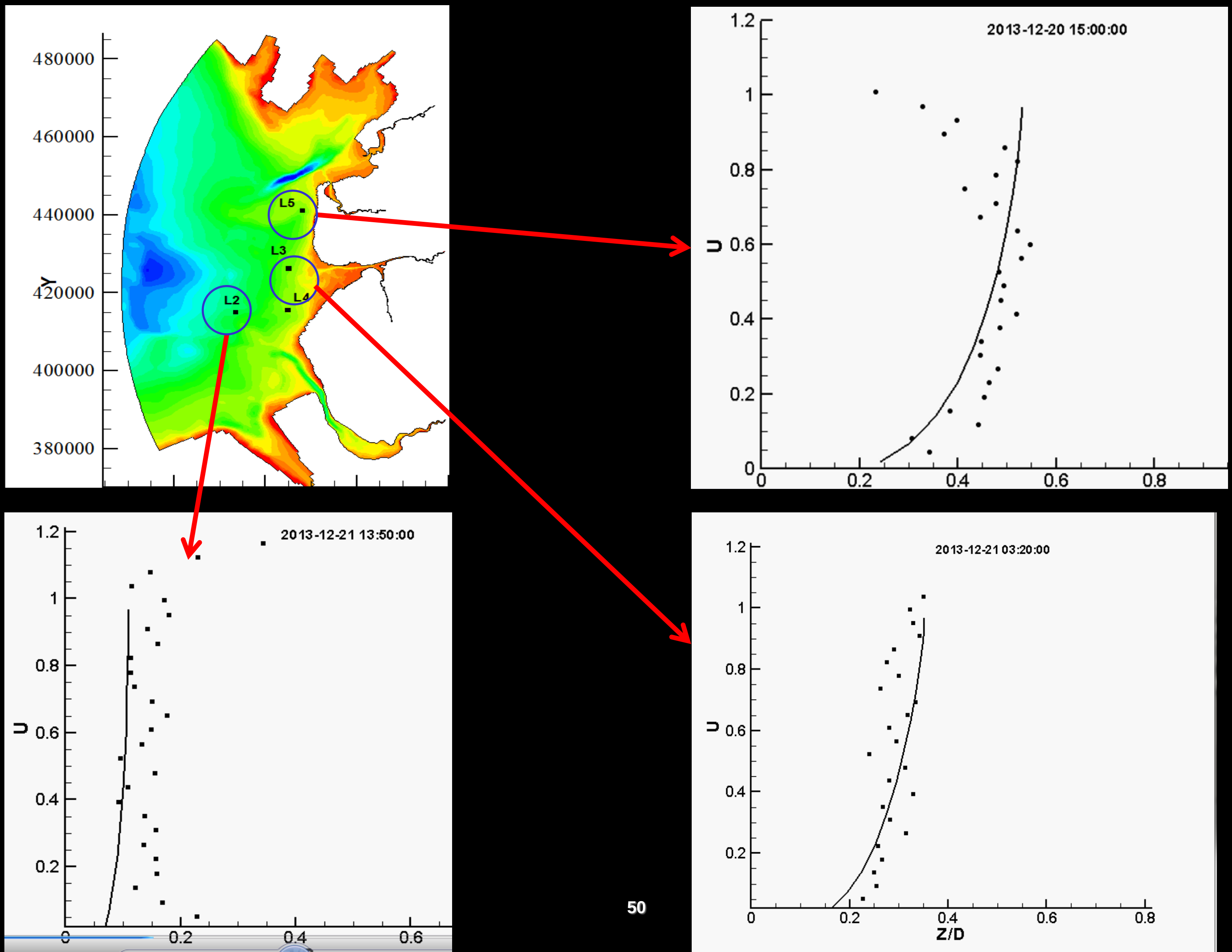
EFDC - Verification of Current Profiles



Dispersion Coefficient

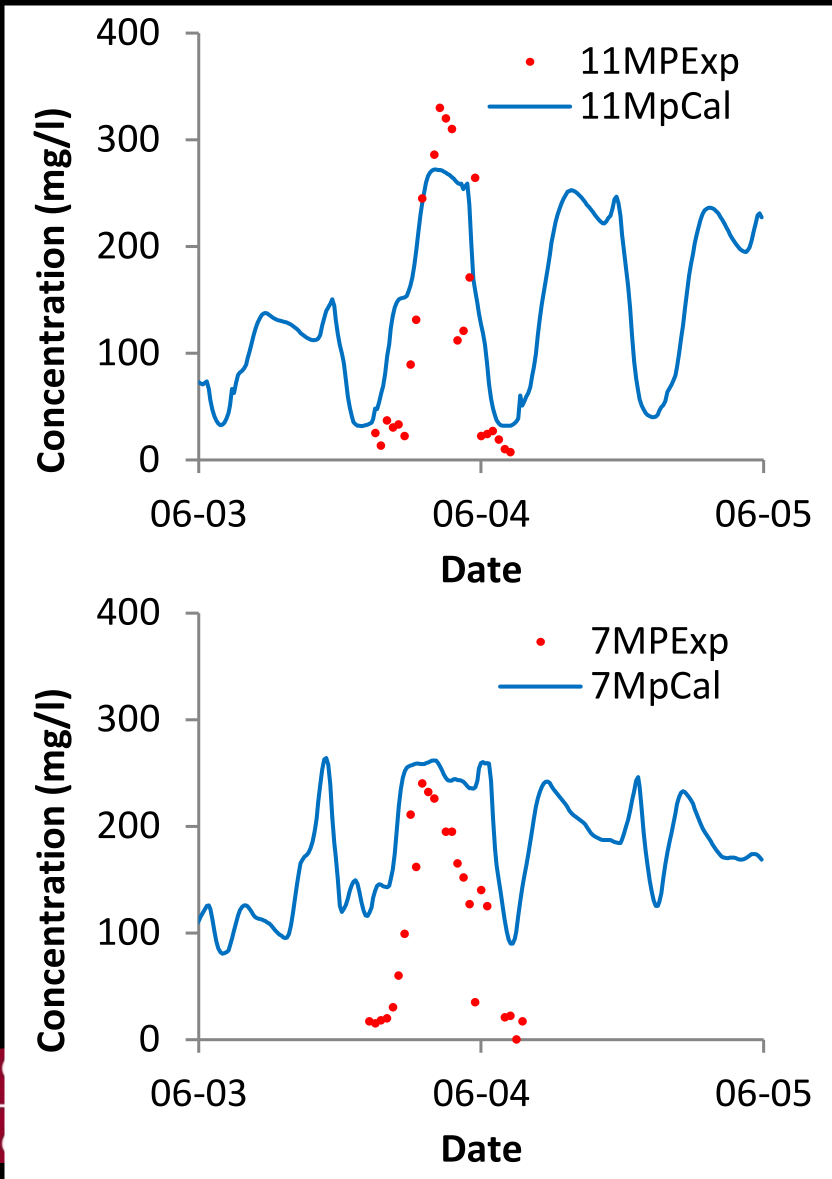
- 1D River network (Fischer *et al.* 1979):

$$D_x = 0.007 \cdot (W / H)^{2.1} \cdot \left(\frac{U}{U_*}\right)^{0.7} H.U_* \quad (1)$$

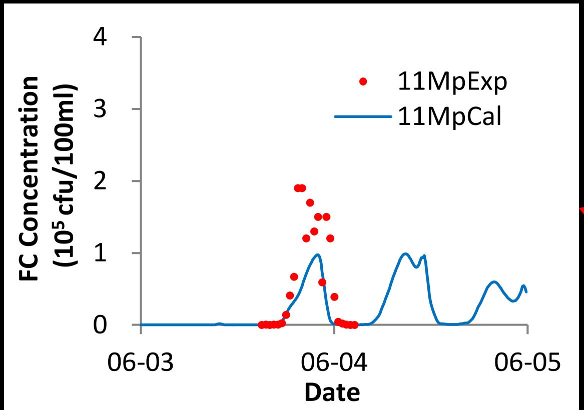
$$U_* = \sqrt{gHJ} \quad (2)$$

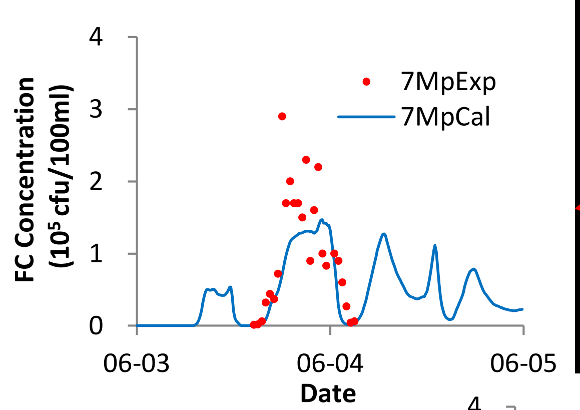
- River Network dispersion coefficients ranged from:- 1 - 10 m^2/s in upper and middle reaches - governed by flow
- Estuary dispersion coefficients much larger than rivers:- with range of: 1 - 500 m^2/s

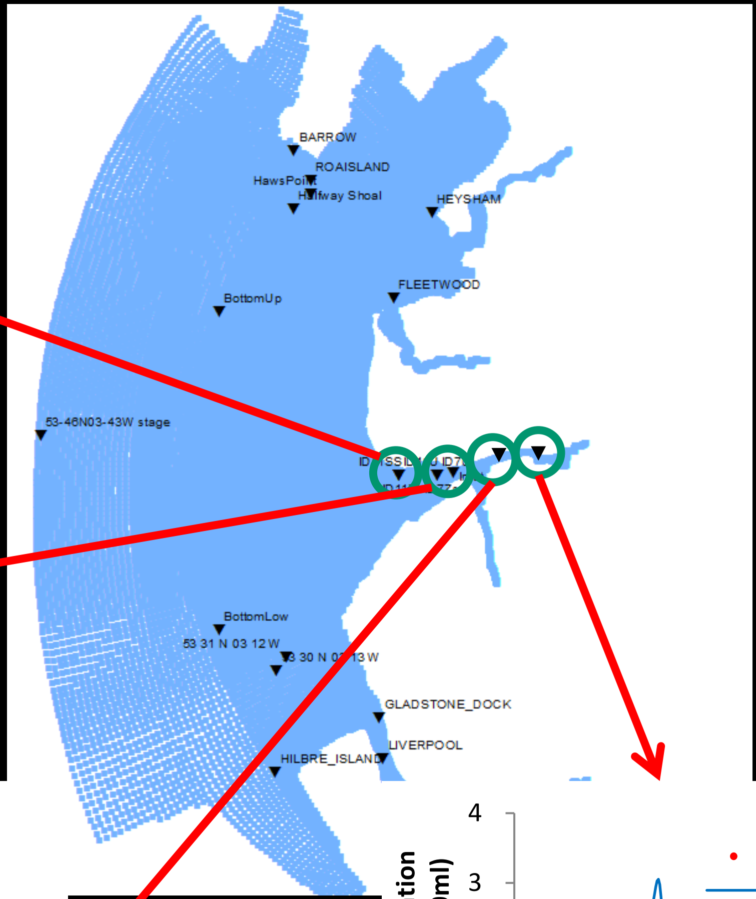
EFDC - SSC Verification

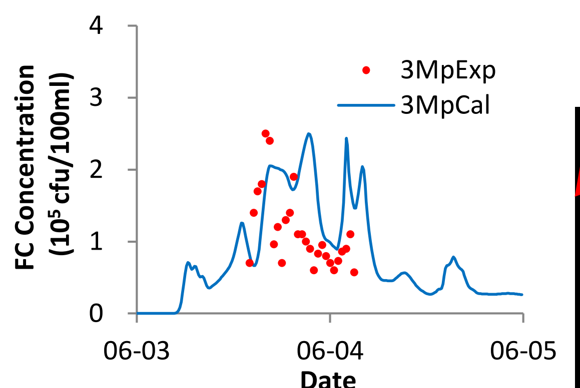


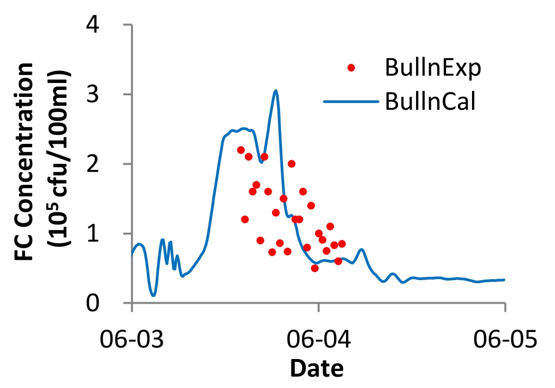
EFDC - E.coli Verification











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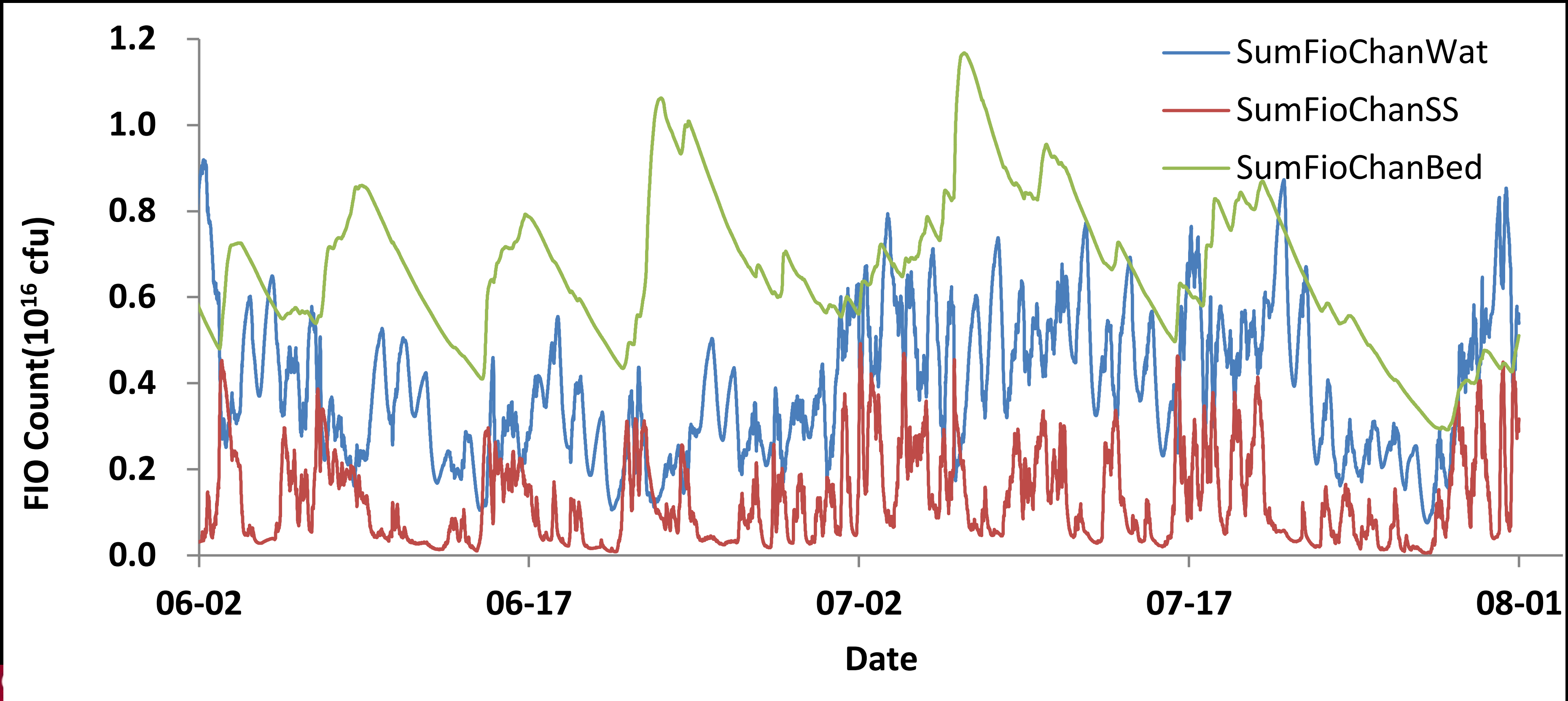
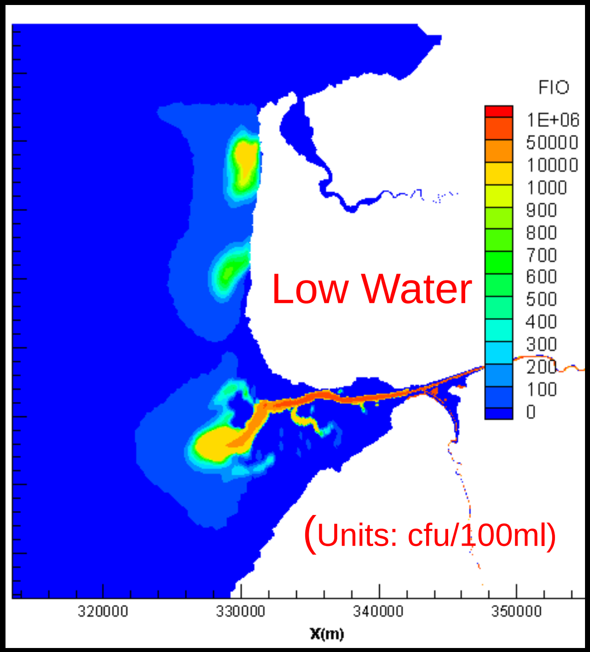
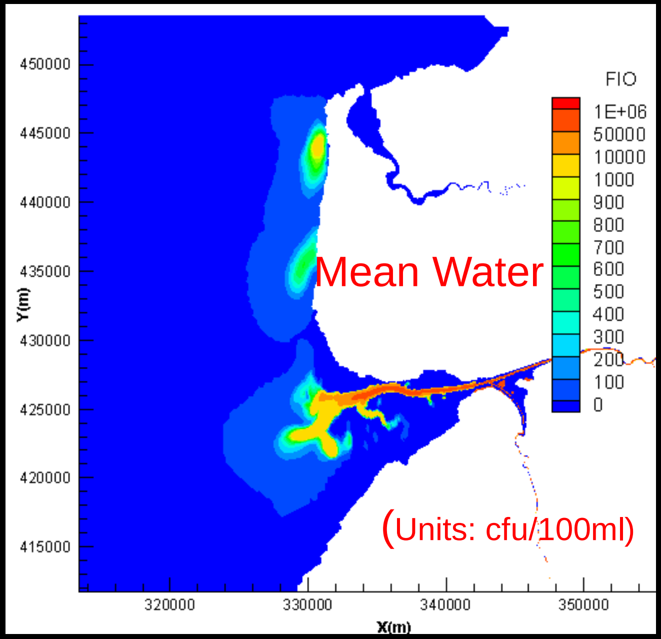
FIO in River Column, SSC and Bed

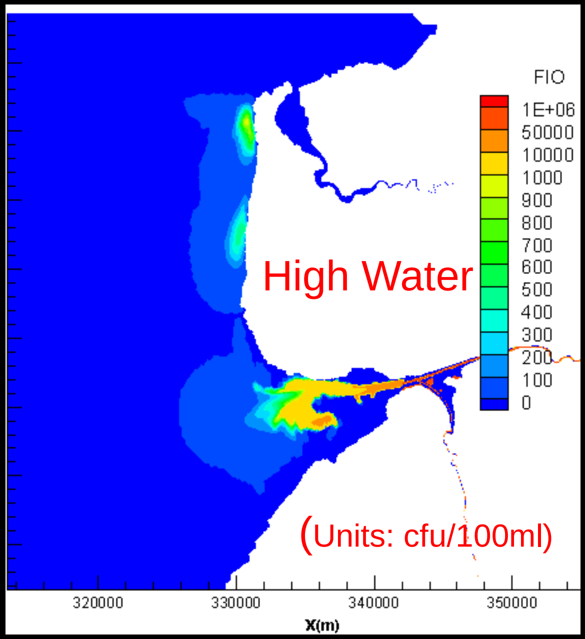
- FIO distribution in river water, on suspended sediments and on bed sediments



FIO Levels for Different Tides







- High Faecal Concentration Region (HFCR), from 1,000 to 10,000 cfu/100ml, located mainly in river region and salt marshes in Ribble

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Health Risk Analysis (Continued)

- Daily Swimming Risk of GI from FIOs:

$$P(ill)_{FC,day} = 1 - \left[1 + \left(D_{FC,oral} / N_{50}\right) \times \left(2^{1/\alpha} - 1\right)\right]^{-\alpha}$$

P(ill) = daily GI probability associated with FIOs, $D_{FC.oral}$ = number of FIOs ingested, N_{50} = median infective dose that causes half of population to be infected, and α = slope parameter

N_{50} and α set to 5.96×10^5 and 0.49 respectively

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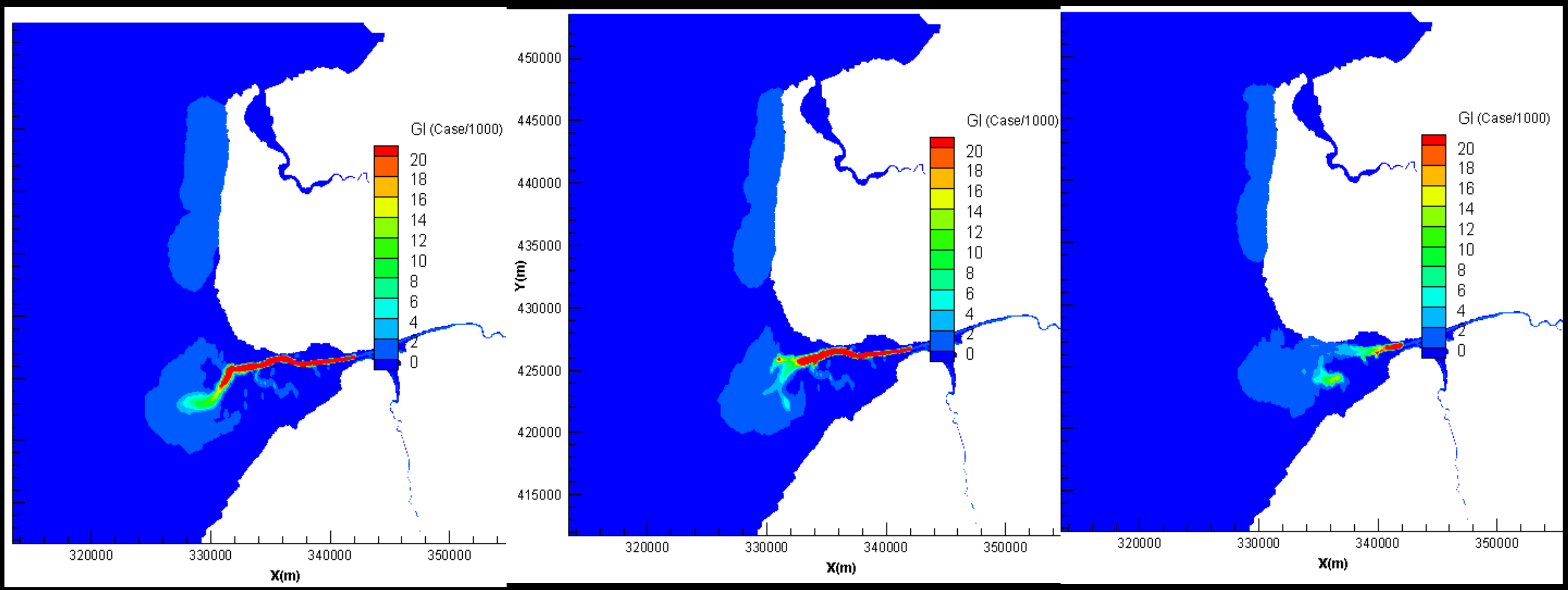
Health Risk Analysis (Continued)



- Spatial & temporal distribution of risk of acquiring GI per 1000 swimmers predicted for various tides
- FIO levels acceptable for compliance against UK & US criteria for bathing water beaches

General Conclusions

- Hydro-environment Engineering and Research is a subject of increasing global significance
- Integrated Water Resources Management needs holistic C2C solutions and integrated CFD models
- Many water quality process models include crude representations of biochemical/kinetic processes
- Considerable scope for further experimental and field studies to improve hydro-bio/geochemistry
- Considerable scope for improved FIO and health risk assessment in river and coastal waters

Specific Conclusions

- FIO levels in Ribble Estuary and Fylde Coast highly dependent on inputs from catchments
- Adsorbed FIO levels on SSC is an important mechanism for transport of FIOs with flow
- FIO levels very highly dependent upon dispersion coefficients and particularly dynamic decay rates
- Extensive synchronous data are vital for proper model calibration and validation
- Storm water and CSO inputs are generally less critical in non-compliance than diffuse inputs

Thank You

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