PROGRESS AND PERSPECTIVES ON THE USE OF DYE STUDIES IN WASTEWATER DISCHARGE IMPACT ASSESSMENTS

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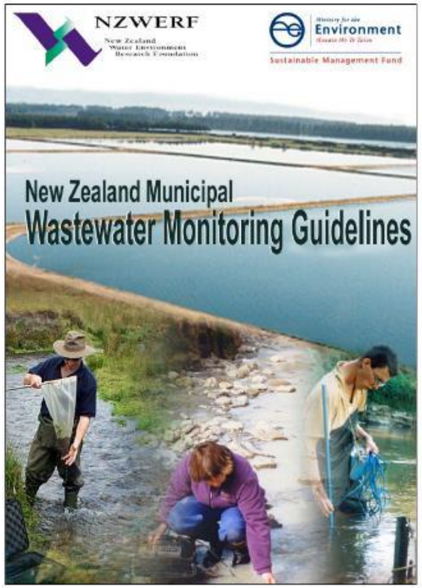
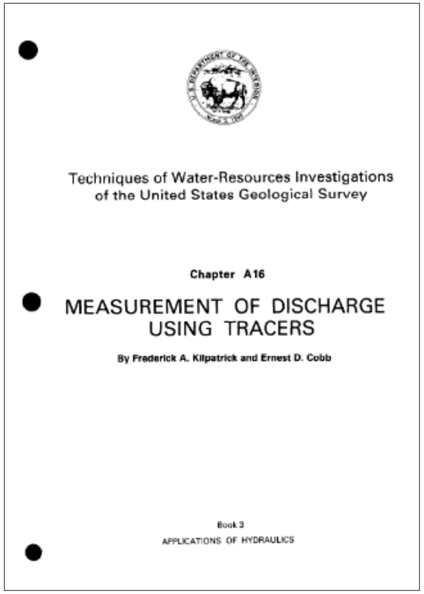
DYE STUDIES AND WASTEWATER DISCHARGE MONITORING

- Types of monitoring programmes:
  - Baseline monitoring to understand the state of the receiving environment before commencement of the discharge. As part of an AEE.
  - Monitoring to verify compliance with resource consent conditions/limits.
  - Investigative monitoring to determine the nature and cause of the problem.



- Applications of dye tracing studies:
  - Discharge measurements
  - Discharge retention, buildup and flushing
  - Time of travel
  - Dispersion studies


Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A16

MEASUREMENT OF DISCHARGE USING TRACERS

By Frederick A. Kilpatrick and Ernest D. Cobb

Book 3

APPLICATIONS OF HYDRAULICS

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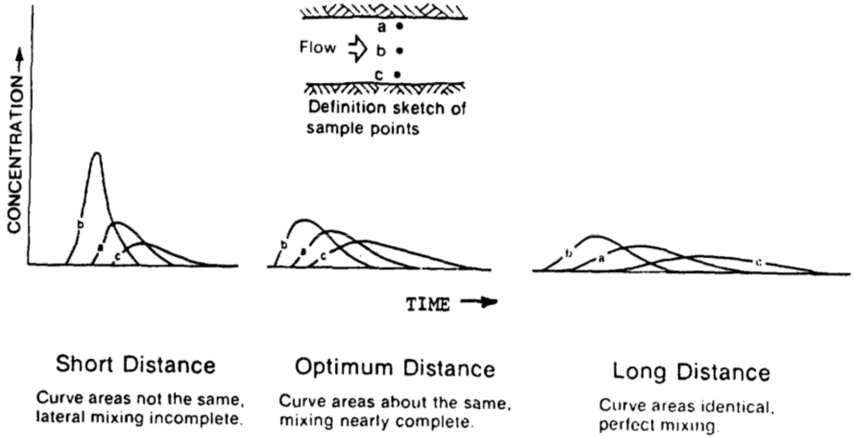
FUNDAMENTAL AND PRACTICAL ASPECTS

- Dye is introduced into a discharge/waterbody and subsequently tracked in the receiving waters over time.
- Tracking can be done visually or by measuring dye concentrations with a fluorometer (*in situ* or in the laboratory).
- Duration of dye release:
  - Batch/slug
  - Single tide
  - One-half tidal day
  - Whole tidal day

  (these can't be done simultaneously)

Typical dye response curves:



Source: Kilpatrick & Cobb (1985)

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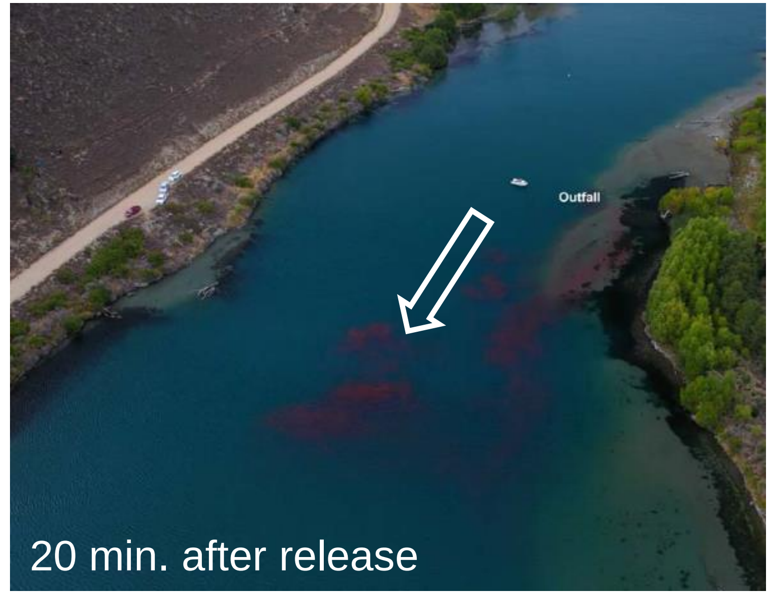
BATCH/SLUG DYE RELEASE


5 min. after release

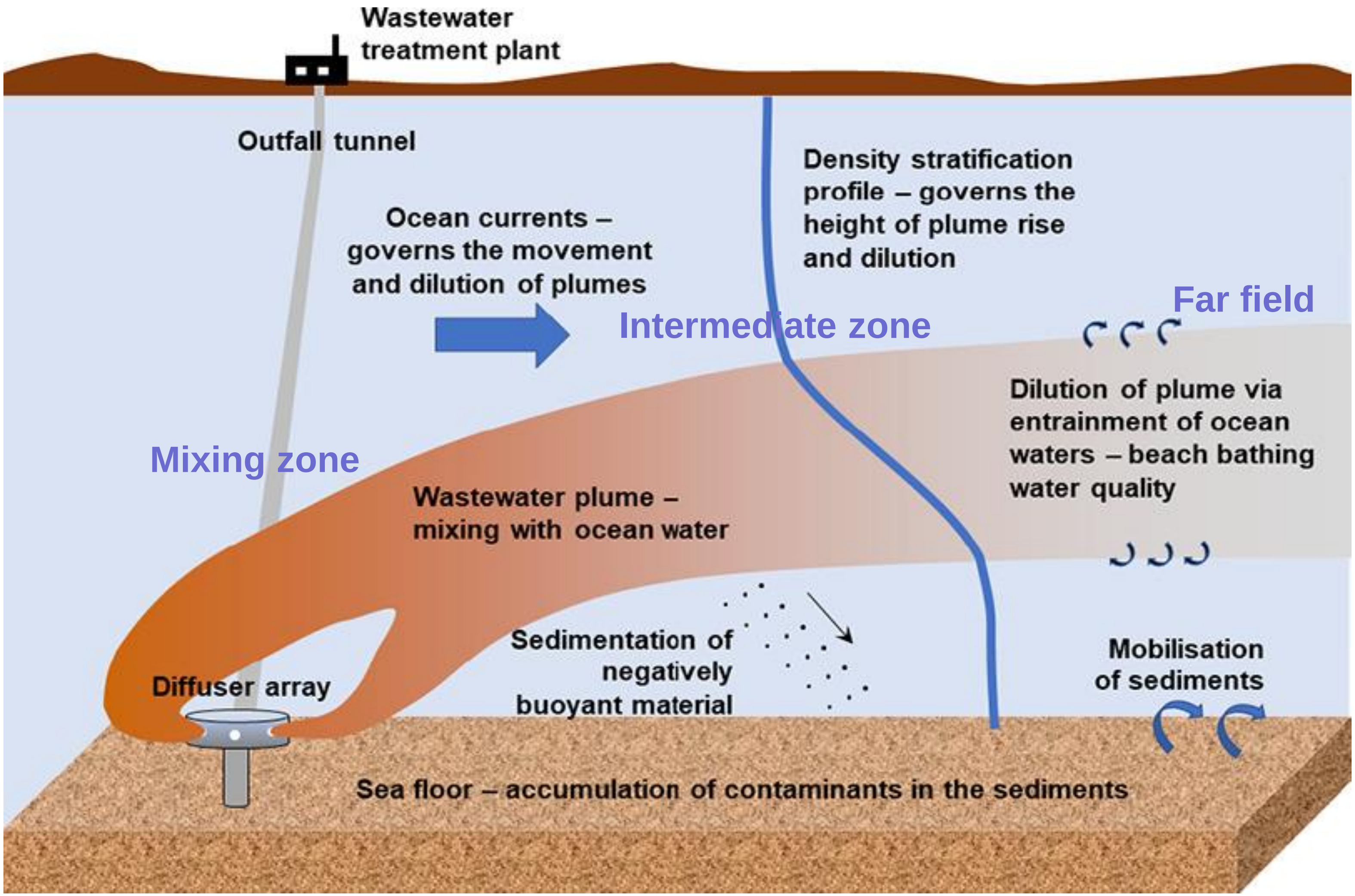


20 min. after release

40 min. after release

50 min. after release

WASTEWATER MIXING AND DISPERSION



Modified from Tate et al. (2019)

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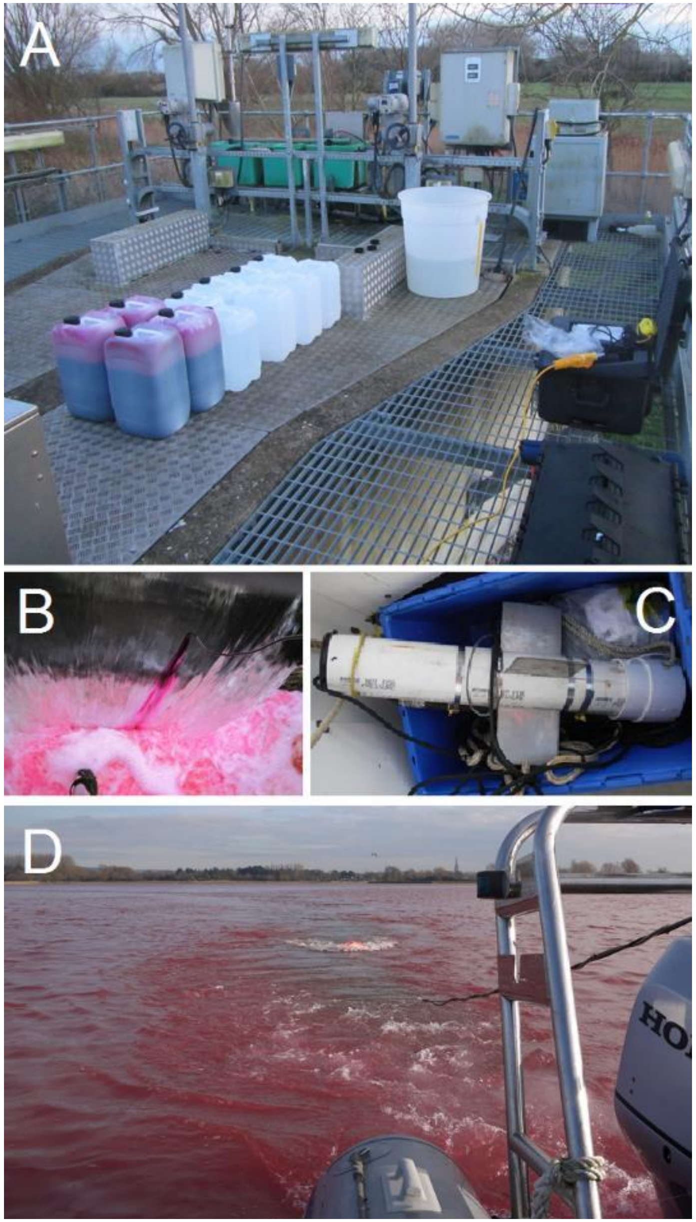
CONTINUOUS/FLOW PROPORTIONAL DYE RELEASE

- Example dye injection setup up and approach for studying buildup and dispersion of effluent from UV disinfection plant in estuary:
  - 60 L dye mixed with deionised water (A).
  - Dye mixture injected continuously over 12.4h following disinfection (B).
  - Dye fluorescence measured by submersible fluorometer inside torpedo (C).
  - Dye concentrations and edges of the plume tracked in the estuary via boat (D). Dye conc. plotted in real-time on GIS map.



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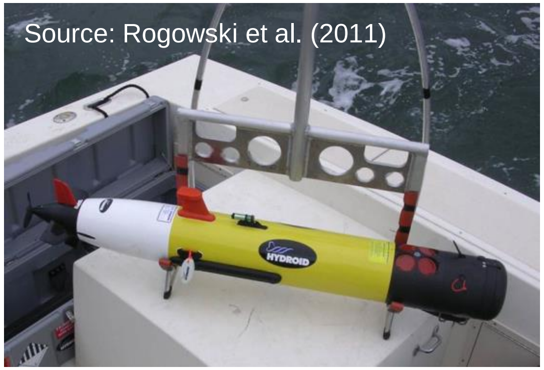
MONITORING INSTRUMENTATION

Compact, high-performance, low power fluorometers

Frame with temperature sensor and current meter; jet ski with fluorometer

Source: Scripps IO

AUV with ADCP, CTD and fluorometer



Source: Rogowski et al. (2011)

UAV with camera

Aircraft with multispectral dye fluorescence camera and hyperspectral pushbroom visible-to-NIR imager

Source: Clark et al. (2014)

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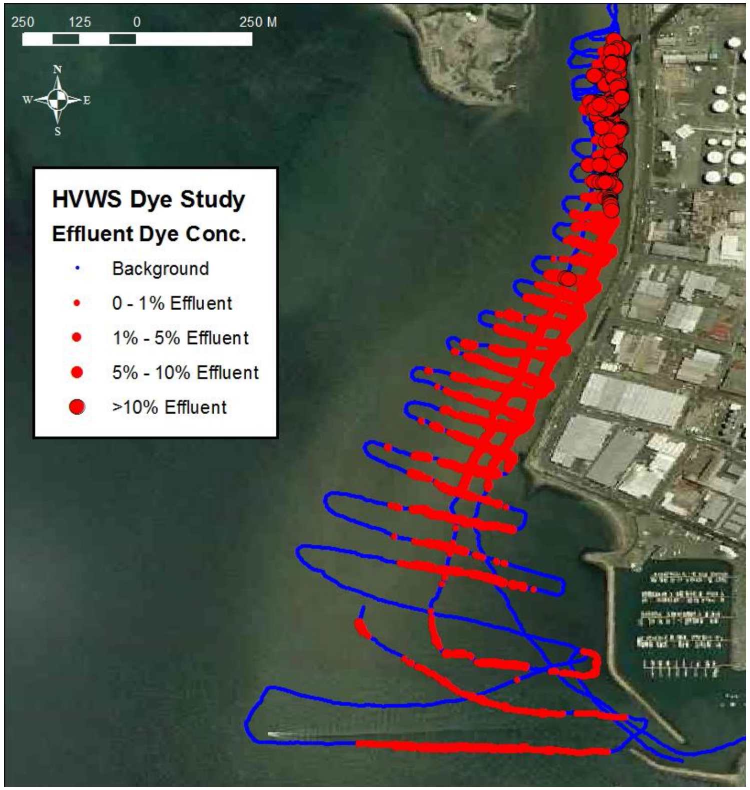
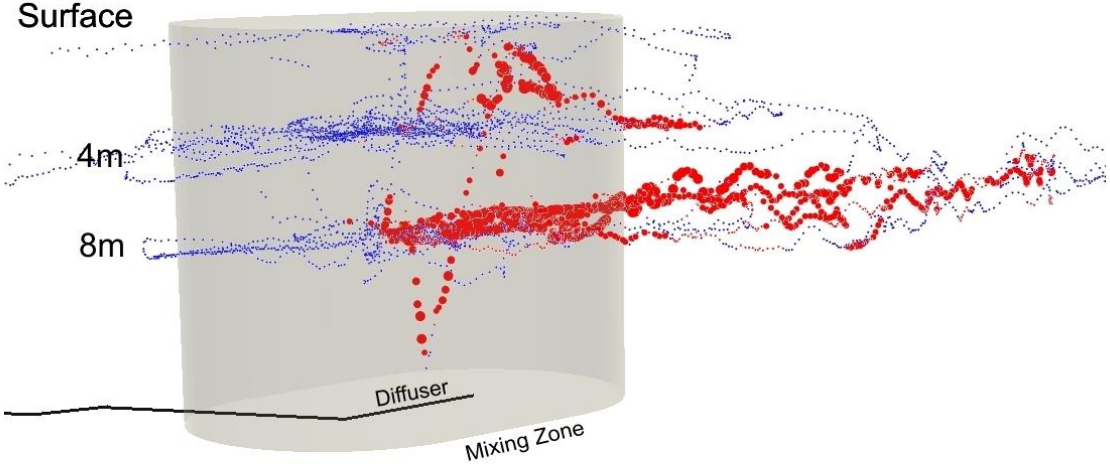
KEY CONSIDERATIONS

- Tracer selection. Depends on the objectives of the study and characteristics of the study site.
- Characteristics/design of the discharge
- Freshwater flows
- Bathymetry
- Tidal flows/wind effects
- Physical structures





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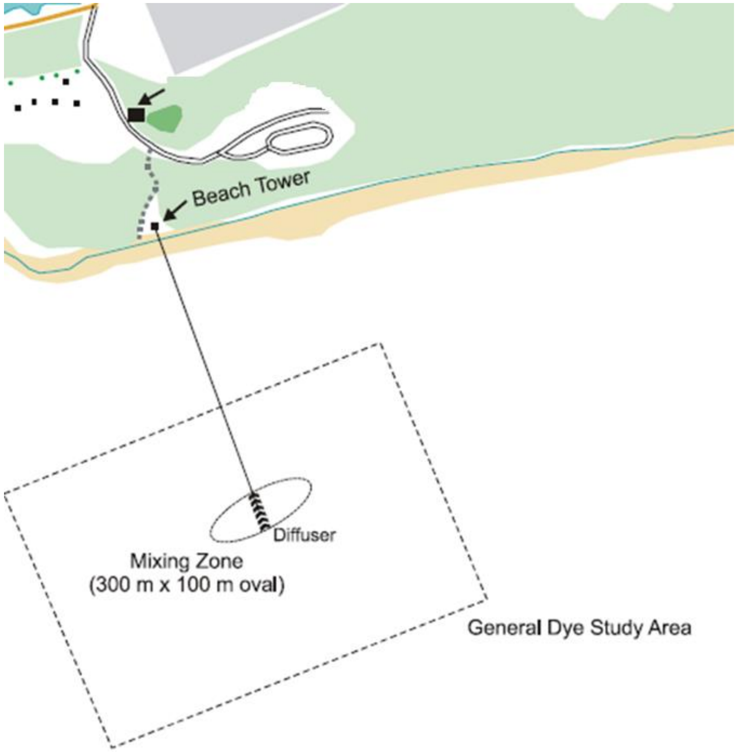
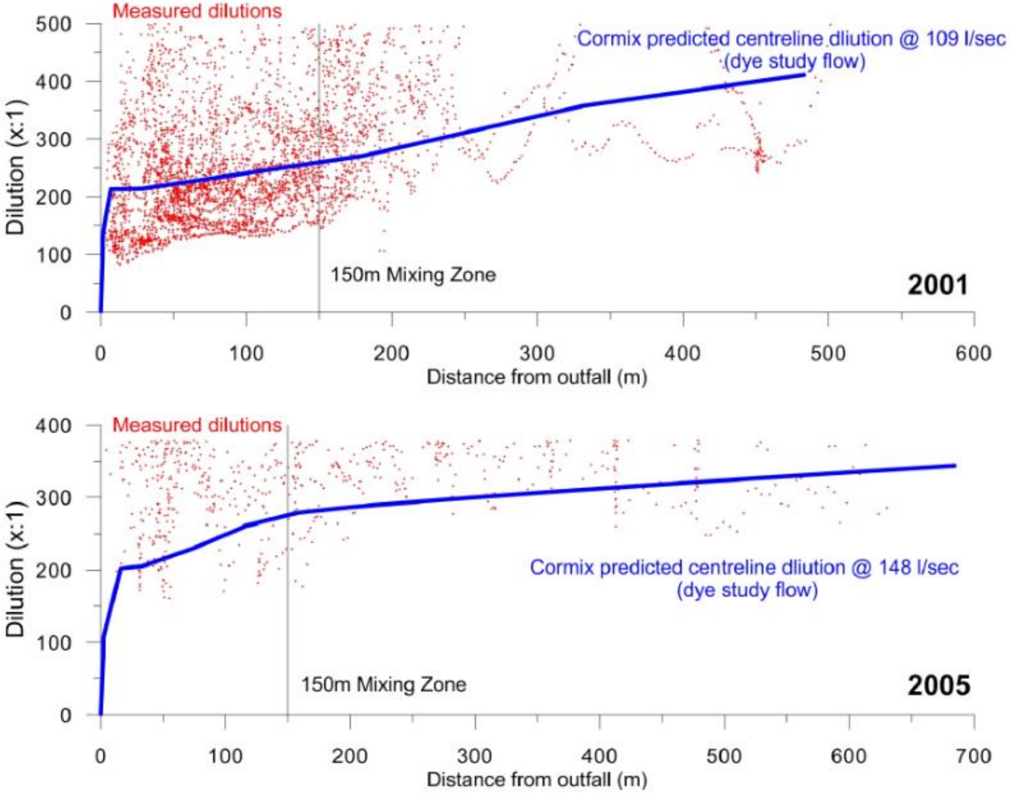
VALIDATION OF MIXING ZONE MODELS

- Field-verified dilutions from continuous dye releases to improve prediction of effluent dilution under reduced/increased flow conditions.



Comparison of modelled and observed dilutions:



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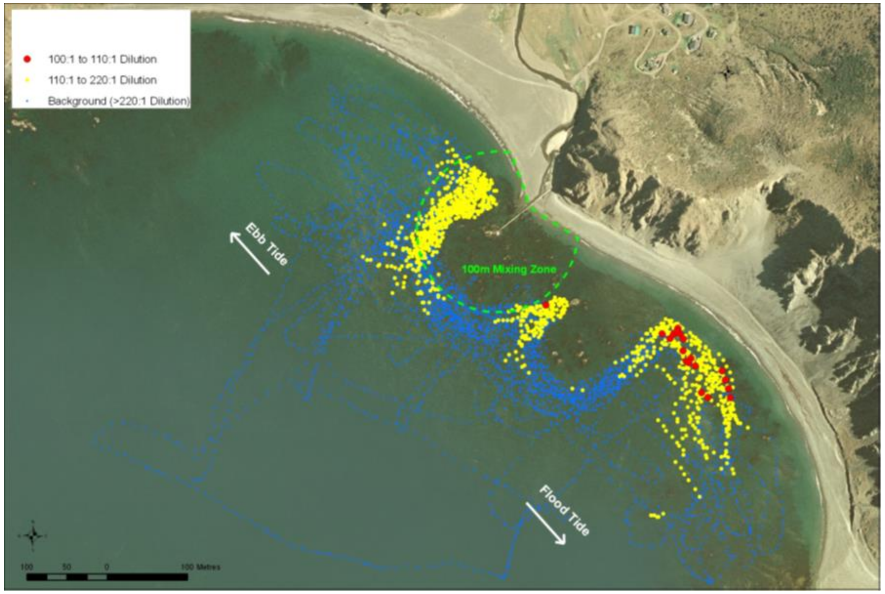
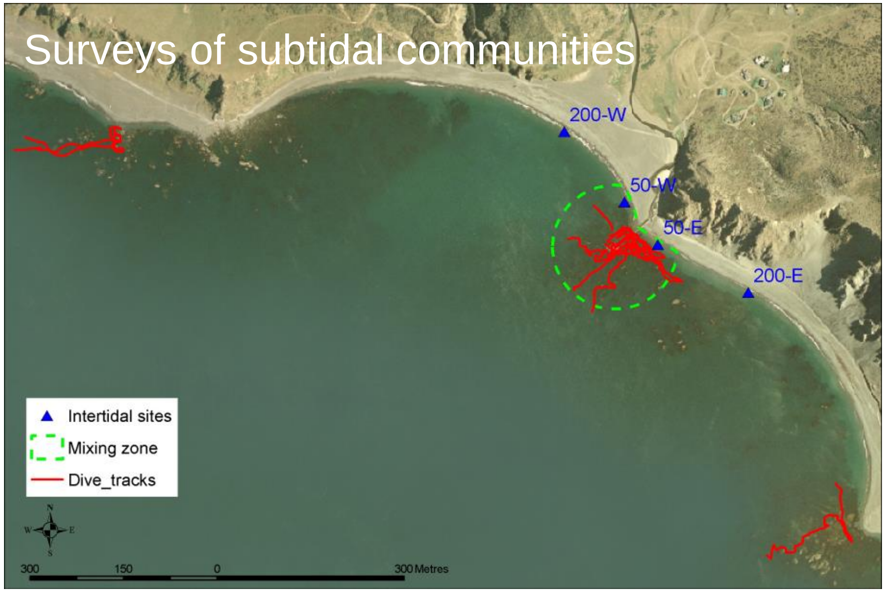
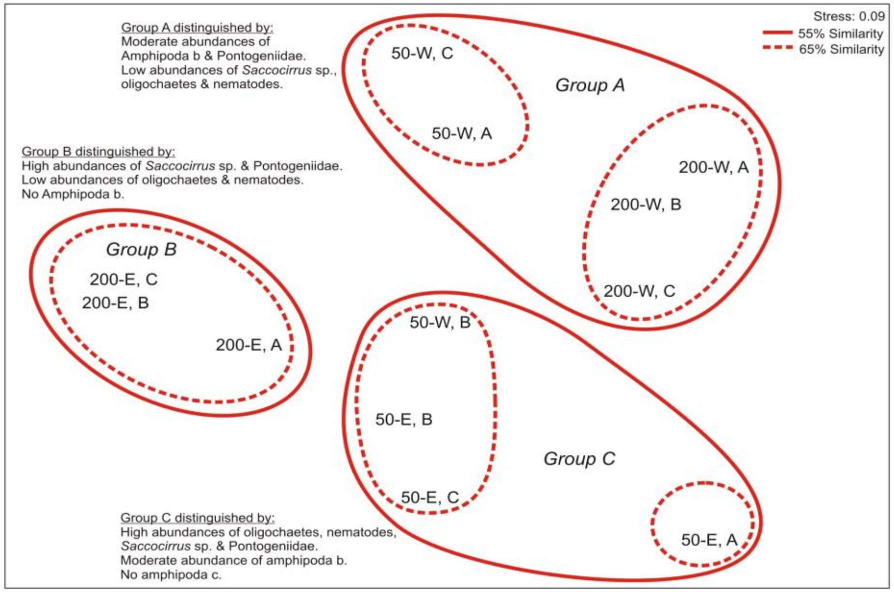
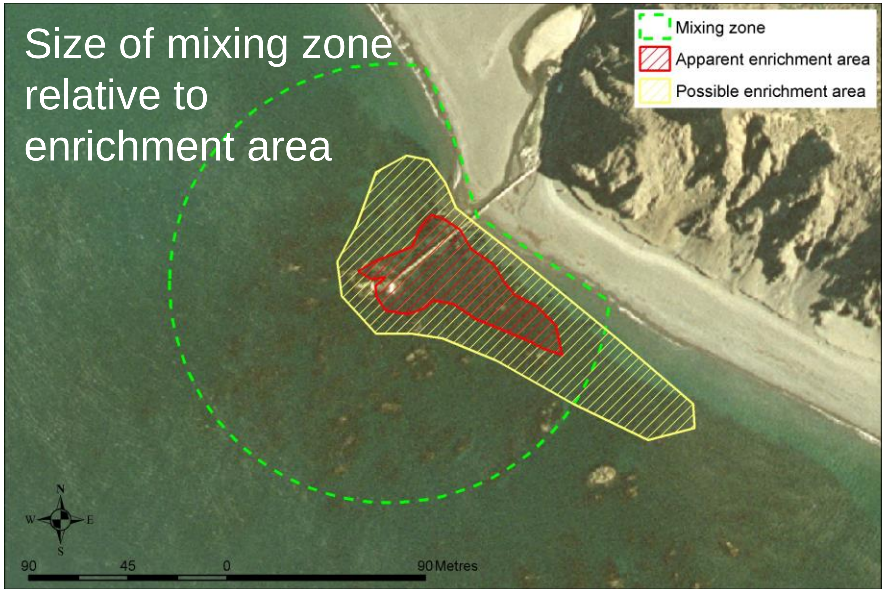
MIXING ZONE AND ECOLOGICAL EFFECTS



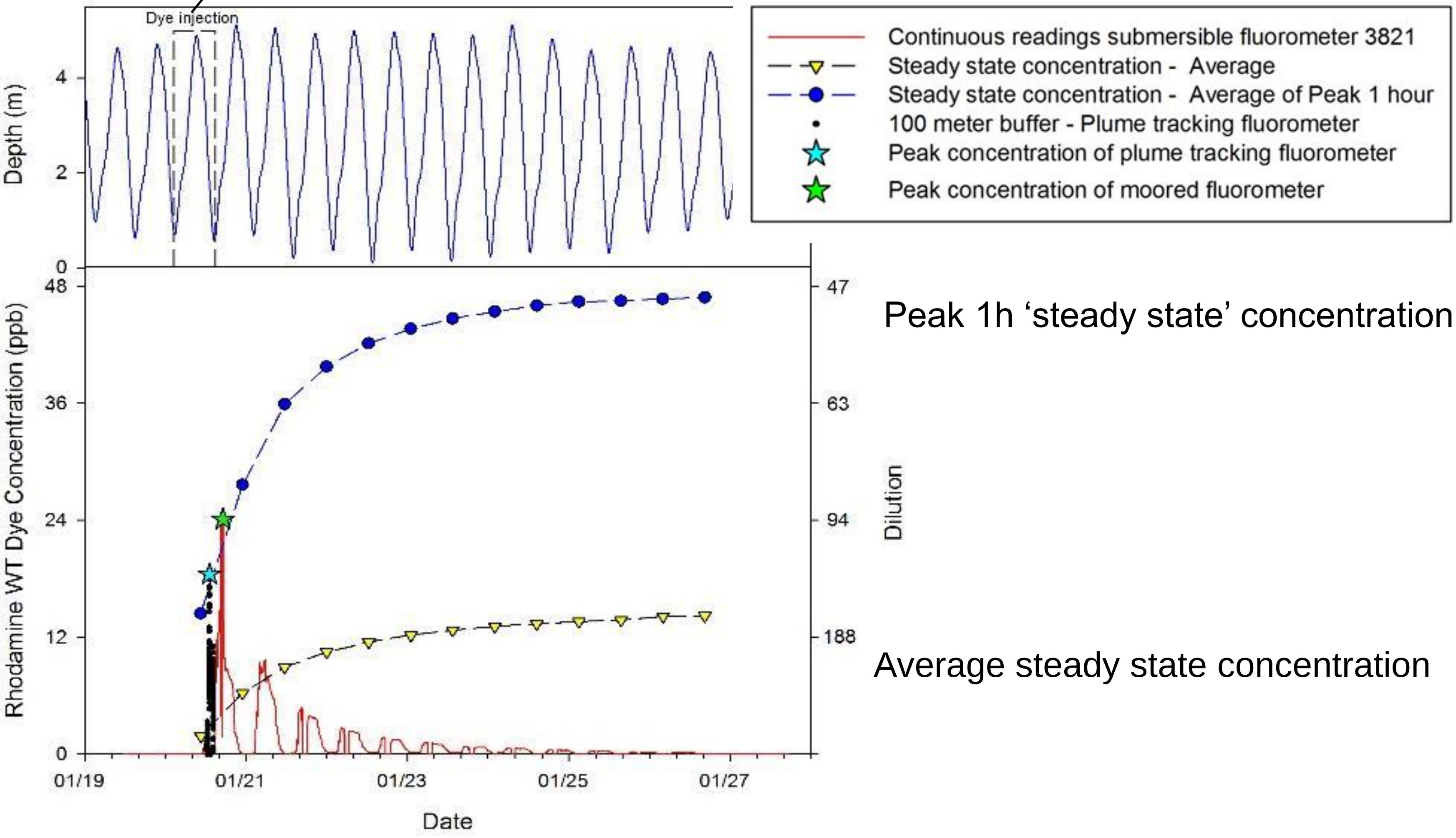






STEADY-STATE DILUTION OF WASTEWATER EFFLUENT

Dye injected over 12.4h



Peak 1h 'steady state' concentration

Average steady state concentration

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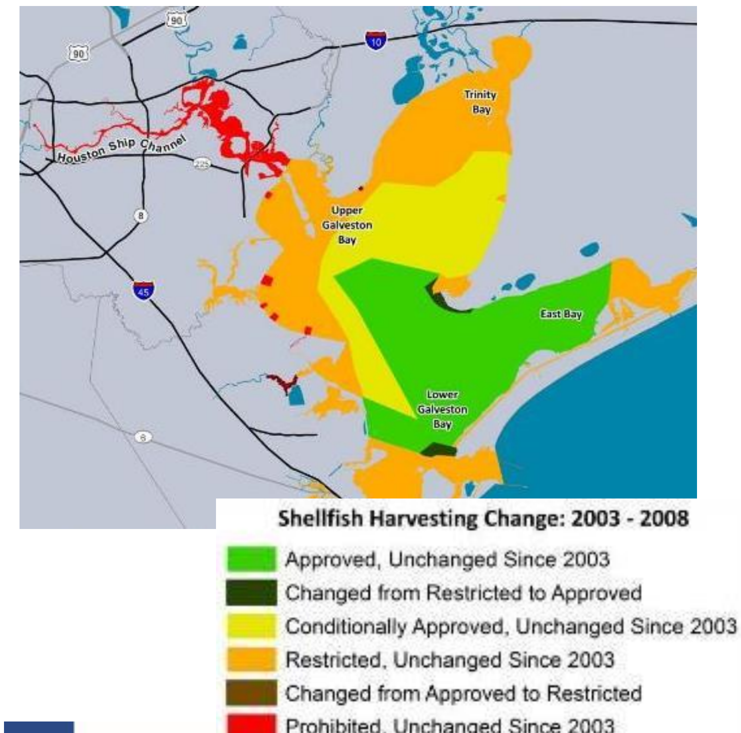
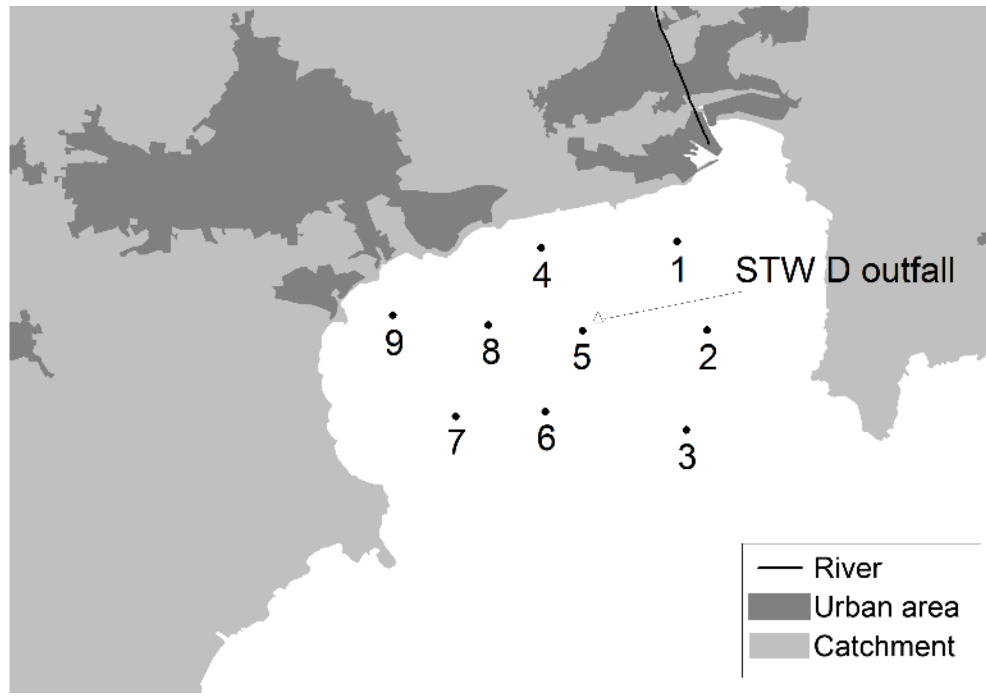
MICROBIOLOGICAL IMPACTS IN SHELLFISH GROWING AREAS

- Exclusion/buffer zones around WWTP outfalls are increasingly required to mitigate risk of human exposure to pathogenic viruses.

Example buffer zone in a US oyster growing area:



Experimental site: deep, well flushed coastal embayment with mussel aquaculture site.



Secondary-treated effluent discharged at site 5 via long sea outfall.

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MICROBIOLOGICAL IMPACTS IN SHELLFISH GROWING AREAS

Microbiological monitoring

- Norovirus and *E. coli* quantified in oysters (*C. gigas*) and mussels (*Mytilus* spp.) using ISO/TS15216-1 (RT-PCR) and ISO16649-3 (MPN), respectively.

Hydrographic studies

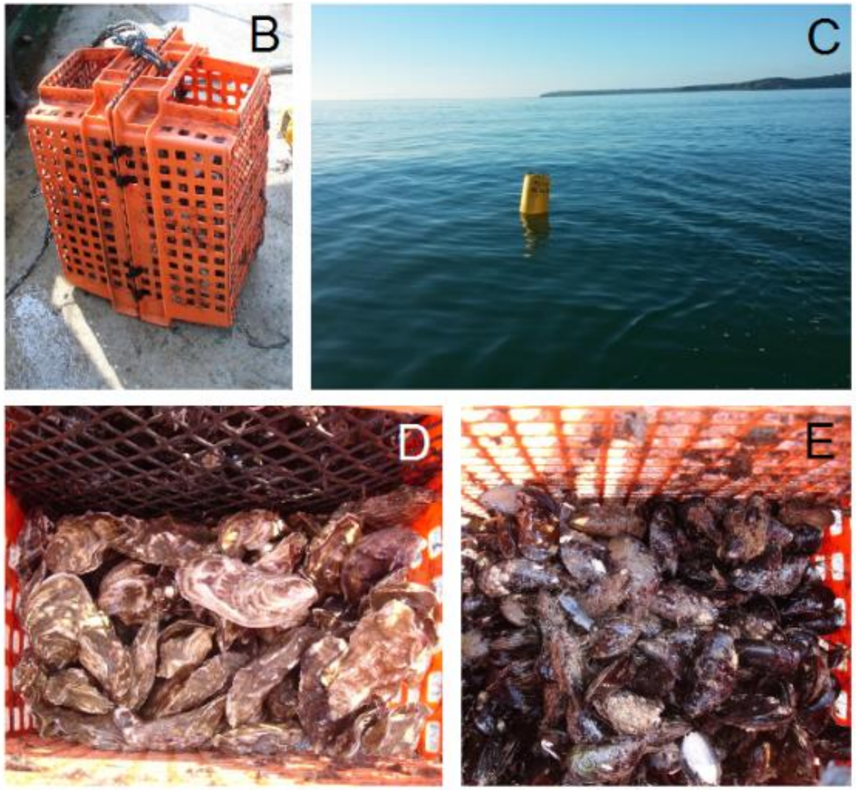
- Dye tracing to study dispersion, dilution and time of travel of secondary treated effluent in the growing area.
- Drogues with Globalstar satellite modems and GPS released at shellfish cage sites to study surface water movements.

Satellite remote sensing

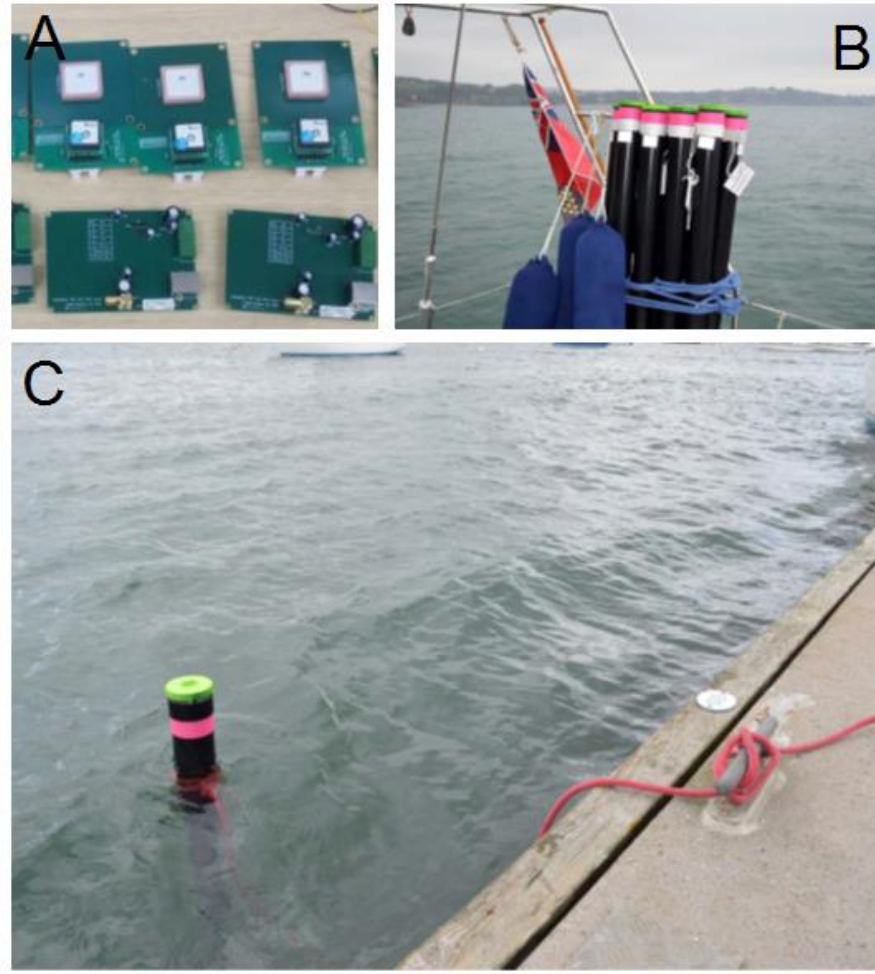
- Landsat 8 imagery to describe water circulation processes (mainly river plumes).

MICROBIOLOGICAL IMPACTS IN SHELLFISH GROWING AREAS

Shellfish in cages deployed at 3 m depth to capture buoyant plume:



Satellite tracking drogues:



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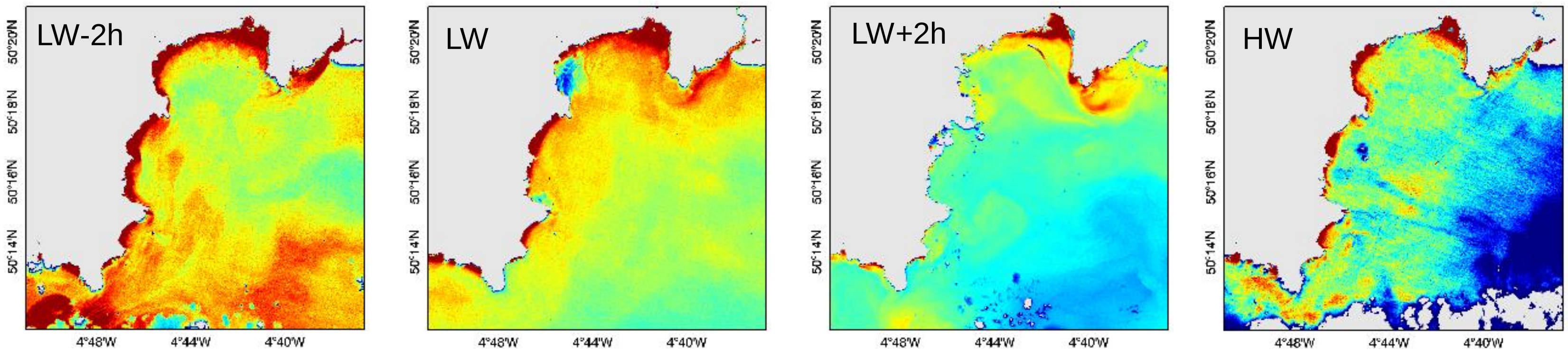
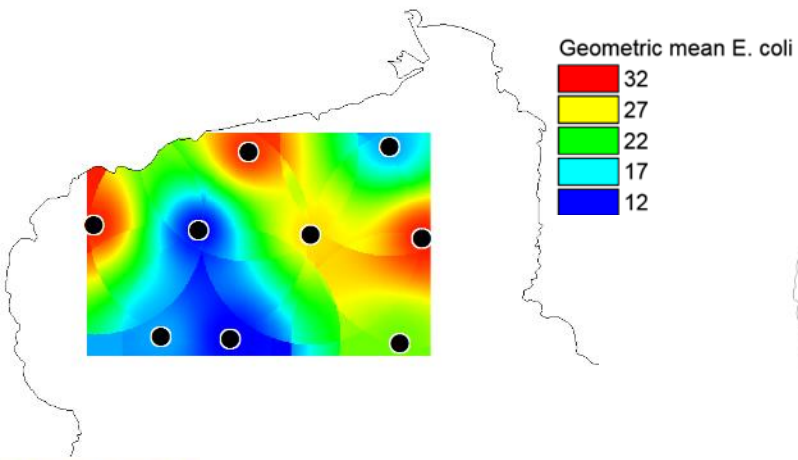
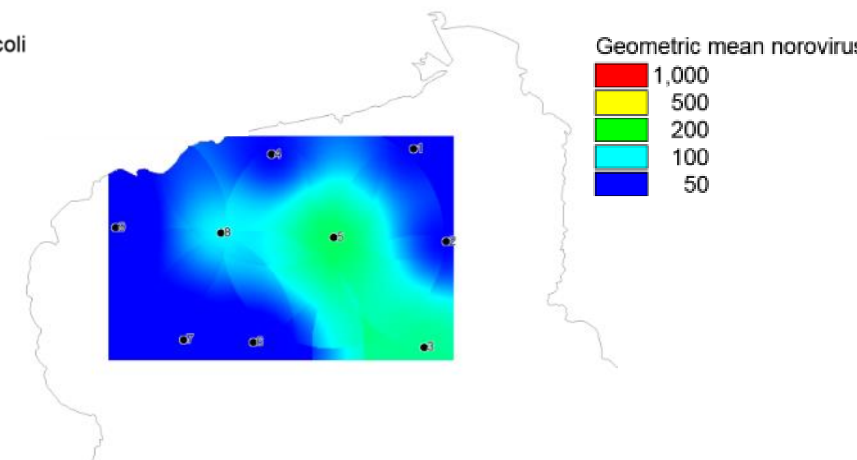
SATELLITE REMOTE SENSING

- Turbidity fields derived from Landsat 8 imagery provided high-resolution information on small scale river plume structures.



- Microbial source attribution: *E. coli* primarily associated with river discharges.





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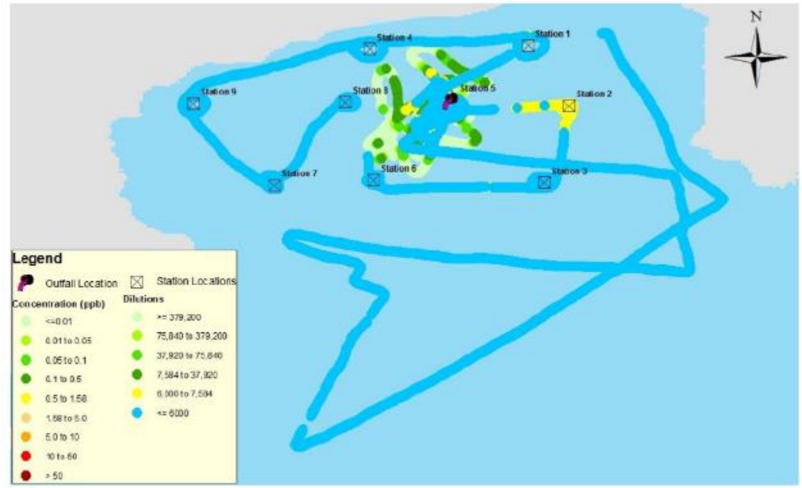
MODELLED DISCHARGE BUFFER ZONE SCENARIOS

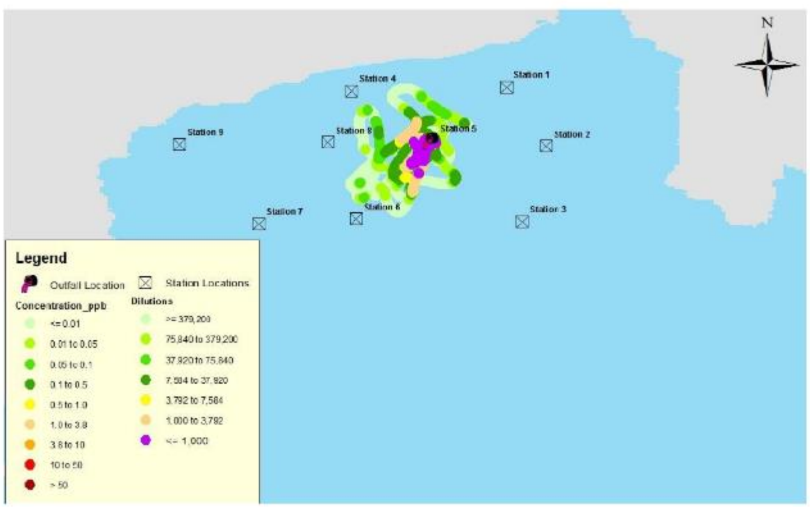
GIS mapping of dye tracking data to illustrate:

6,000:1 dilution

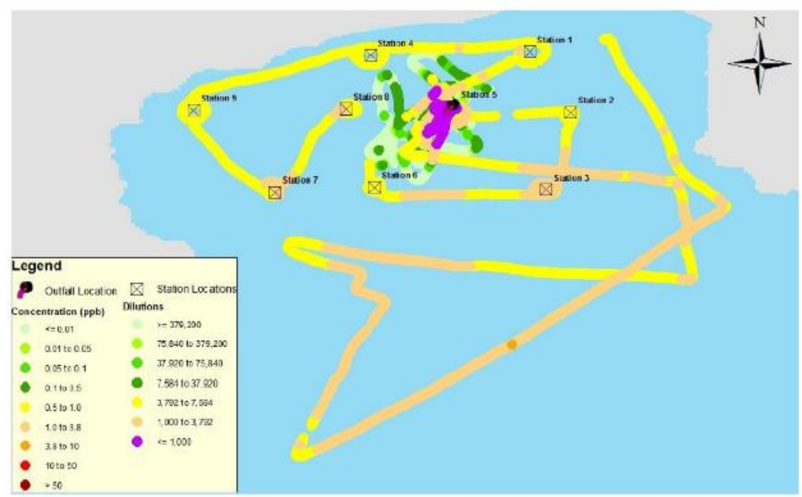
6,000:1 dilution for 90th percentile WWTP flows



1,000:1 dilution

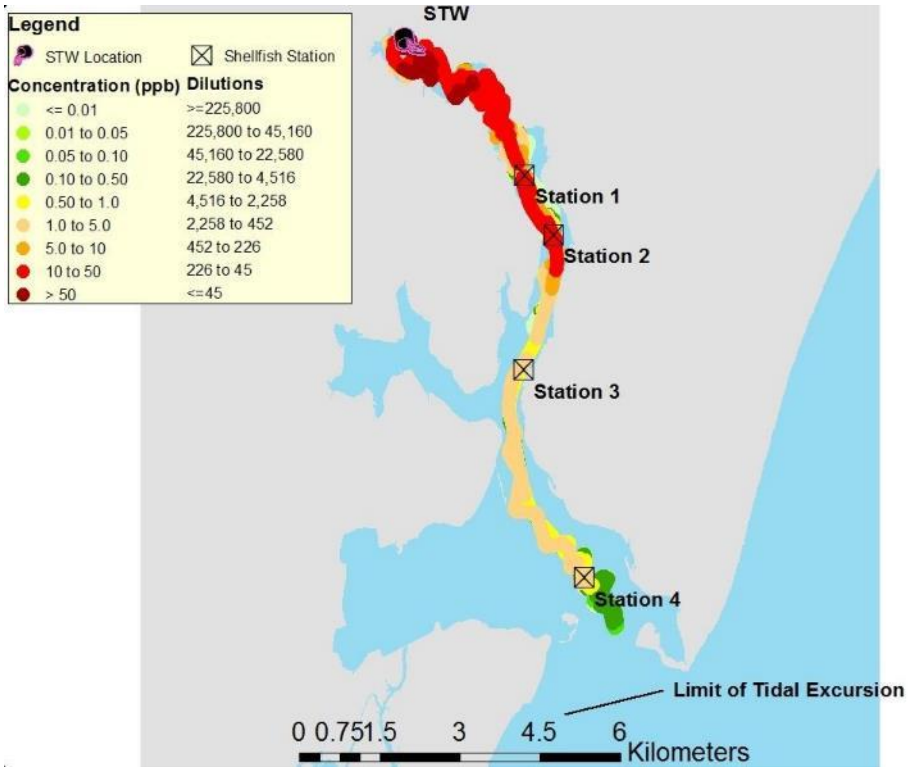


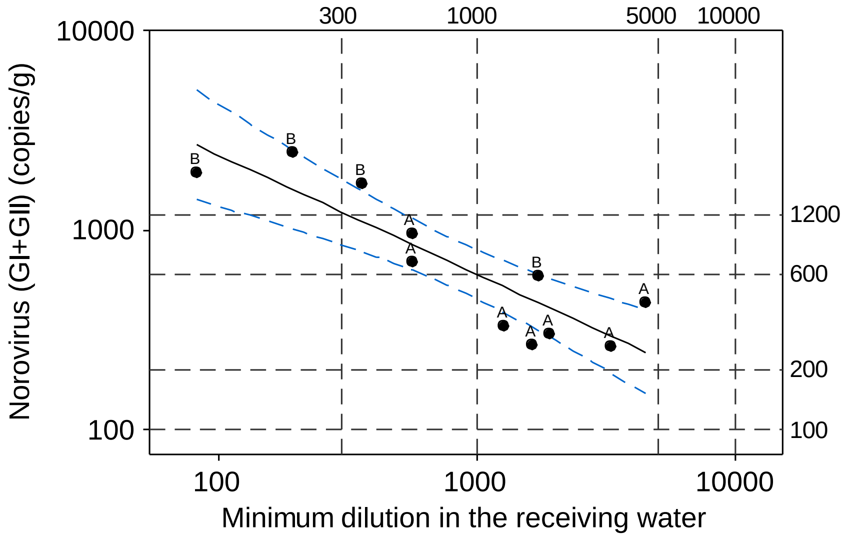
1,000:1 dilutionfor 90th percentile WWTP flows



MICROBIOLOGICAL IMPACTS OF SEWER OVERFLOWS

- Dye study to determine time of travel of effluent from combined sewer overflow
- ToT considered as part of protocol to manage norovirus contamination in designated oyster growing water and bathing waters.





Dilution ratio	Mean concentration of norovirus (copies/g)	Mean concentration of *E. coli* (MPN/100g)
300:1	1,200	260
1,000:1	600	100
5,000:1	200	30
10,000:1	100	15

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SUMMARY

- Integration of dye fluorescence measurements with data from sensor technology, underwater vehicles and remote sensing improves understanding of the fate and behavior of effluent plumes.

- New marine monitoring instrumentation provides more comprehensive modelling outputs to assist planning/design of outfalls and impact assessment of effluent discharges.

- An initial concept of effluent plume behavior should be developed prior to conducting the field studies. This includes characterisation of 'background' fluorescence levels.

- Multiple dye studies performed under different conditions may be needed to adequately characterise both initial (near field) dilution and far-field vertical and horizontal processes.

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