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Drainage Services Department, 12 November 2014

Application of the WATERMAN Real Time Coastal Water Quality Management System to Environmental Engineering and Control

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Outline

1. Overview of Harbour Area Treatment Scheme
   - Disinfection Control and Dosage Optimization
2. WATERMAN real time beach water quality forecast system - setting of effluent discharge bacterial standard
3. Emergency response in pollution accidents
4. Disinfection performance and fluid mechanics of chlorine mixing by multiple dense jets
5. Conclusions

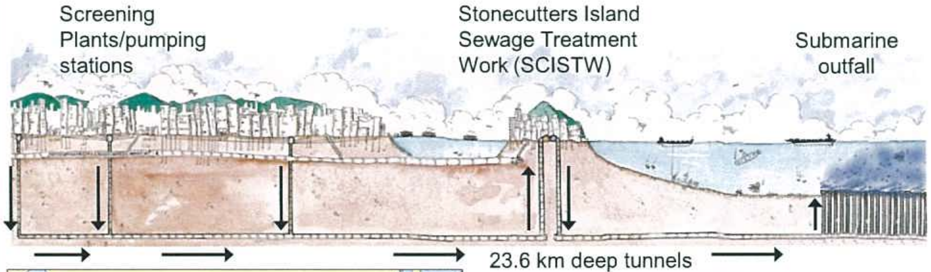
Overview of HATS and WATERMAN real time water quality forecasting system

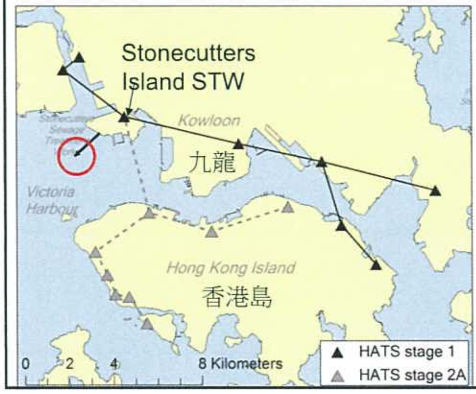
Hong Kong Special Administrative Region, China

Challenges of Coastal Water Quality Management

- Coastal water quality prediction is a challenging multi-scale and multi-disciplinary problem
- Pollution sources located in close proximity to sensitive receivers
- Dynamic marine environment with complex currents; highly nonlinear biochemical process
- Water quality data are typically sparse and costly
- Uncertainty in rate coefficients, loading and boundary conditions
- Need for public accountability and public engagement

Harbour Area Treatment Scheme (HATS)





Chemically Enhanced Primary Treatment (CEPT) since 2001; 23.6 km of deep tunnels; disinfection since March 2010

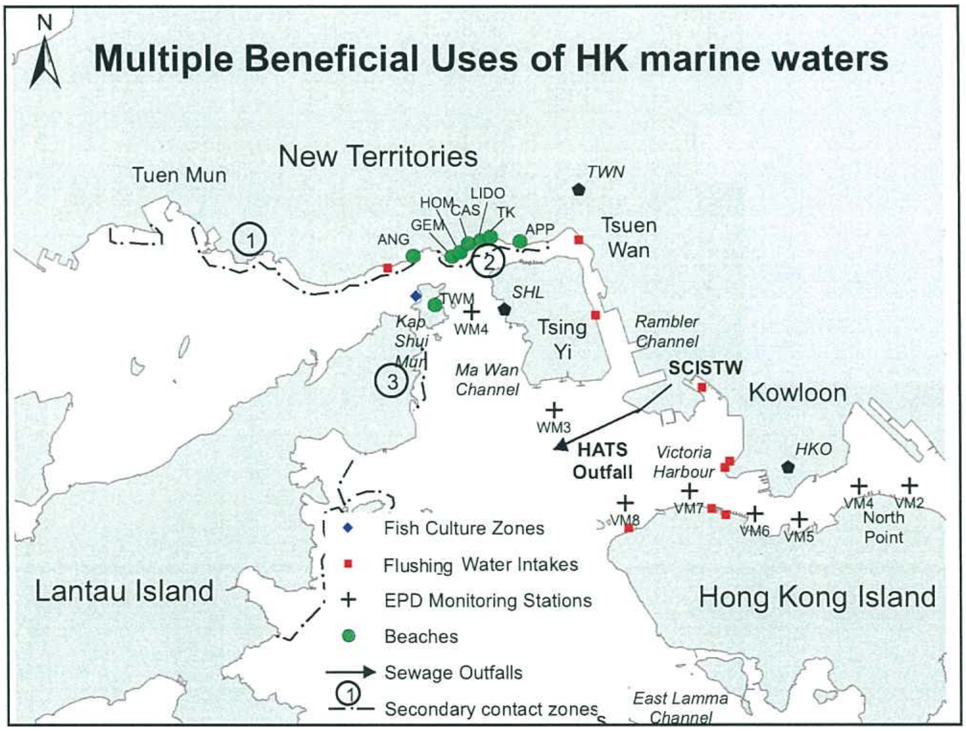
Stage 1: $Q = 1.4 \times 10^6 \ m^3/d$

Stage 2A: $Q = 1.8 \times 10^6 \ m^3/d$

HATS Stage 1

- Chemically-enhanced primary treatment at **Stonecutters Island STW**
- Stops 600 tonnes/yr of sludge from entering the harbour
- Pollutants removal rate:
  - 70% organics (BOD)
  - 80% suspended solids
  - 60% heavy metals
  - 25% total nitrogen
  - 50% phosphorus
  - *E.coli*:
    - ➢ before disinfection: 50%
    - ➢ after disinfection: $10^7 \rightarrow 10^5$ cnt/100mL

Multiple Beneficial Uses of HK marine waters



Hong Kong's beach grading system
香港海灘水質評級系統

Grading	Beach water quality 泳灘水質	*E. coli* * (counts /100 mL) 大腸桿菌	Minor illnesses rate ** (cases per 1000 swimmers) 發病率	Water Quality Objective Compliance/ Exceedance
1	Good	≤ 24	Undetectable	Compliance
2	Fair	25 - 180	≤ 10	
3	Poor	181 - 610	11 - 15	Exceedance
4	Very poor	> 610	> 15	

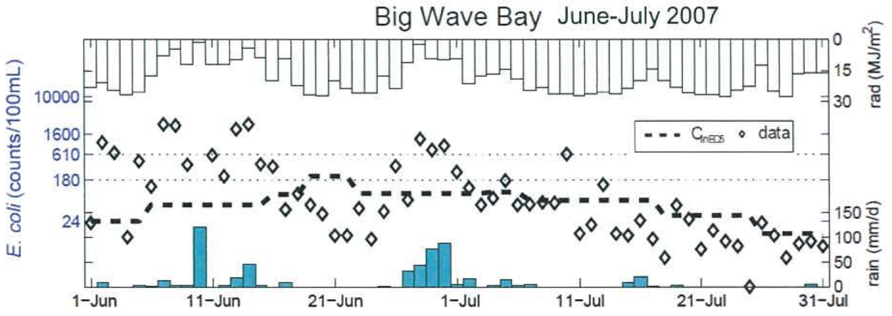
***Weekly Beach Grading**: G. Mean *E. coli* level of the 5 most recent data (C_{lnEC5})
Annual Beach Ranking: G. Mean *E. coli* level of all bathing season data (Mar-Oct)

** Skin and Gastrointestinal illnesses (Cheung et al. 1990)

Beach grading based purely on past sparsely sampled data

The need for a better beach WQ management system

- **Resource-intensive** for sampling and analysis of *E.coli* data (41 beaches x 4-5 times/month x 8 months per year)
- At least 24 hr to obtain *E. coli* measurement results – **delayed response** for pollution events
- Represents the average WQ over the past 1 month - **cannot capture the dynamic beach *E. coli* variation**; **no forecast ability!**



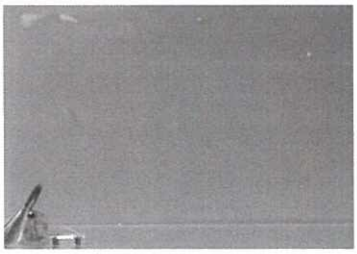
HK Water Quality Criteria for Sensitive Receivers

- Bathing beaches
  - *E.coli* < 610 counts/100mL for annual geometric mean
  - *E.coli* < 1600 counts/100mL for single sample
- Fish culture zone
  - *E.coli* < 610 counts/100mL for annual geometric mean
- Flushing sea water intakes
  - *E.coli* < 20,000 counts/100mL at any time
- Secondary Contact Zones
  - *E.coli* < 610 counts/100mL for annual geometric mean

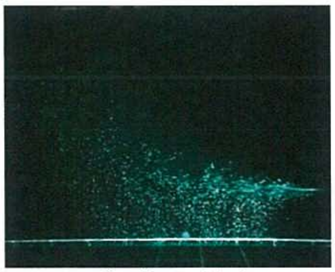
Environmental discharges in the form of buoyant jets

Single buoyant jet

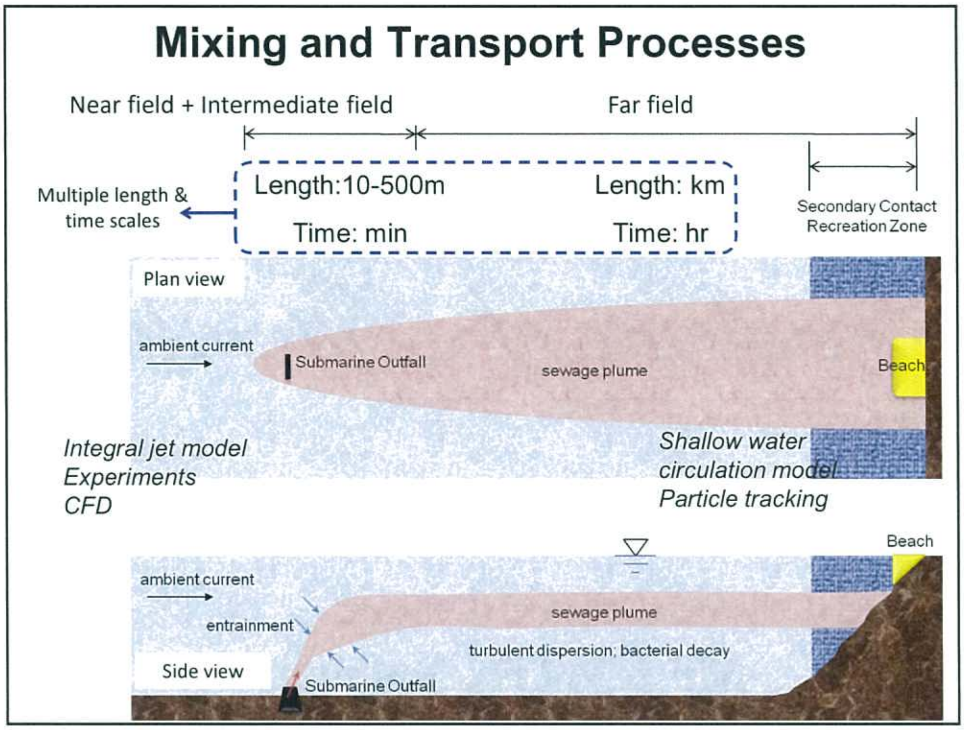
Rosette jet group



Dense jets



Sediment jets



Mixing and Transport Processes

Near field + Intermediate field

Far field

Multiple length & time scales

Length:10-500m

Time: min

Length: km

Time: hr

Secondary Contact Recreation Zone

Plan view

ambient current

Submarine Outfall

sewage plume

Beach

Integral jet model
Experiments
CFD

Shallow water circulation model
Particle tracking

Beach

ambient current

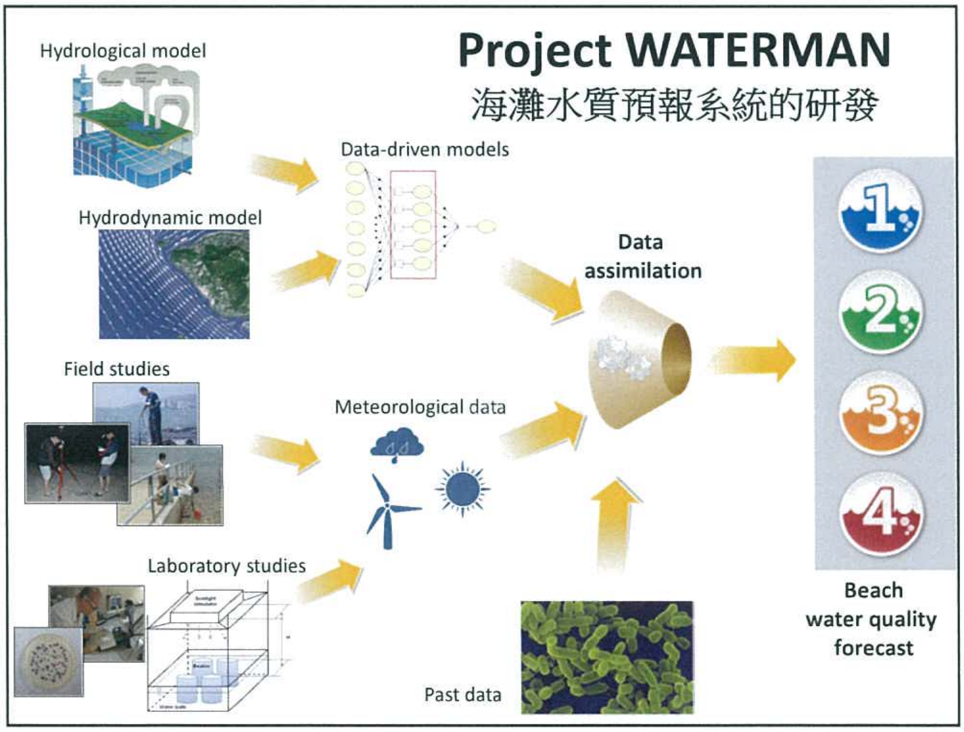
entrainment

sewage plume

turbulent dispersion; bacterial decay

Side view

Submarine Outfall



Project WATERMAN

海灘水質預報系統的研發

Hydrological model

Hydrodynamic model

Field studies

Laboratory studies

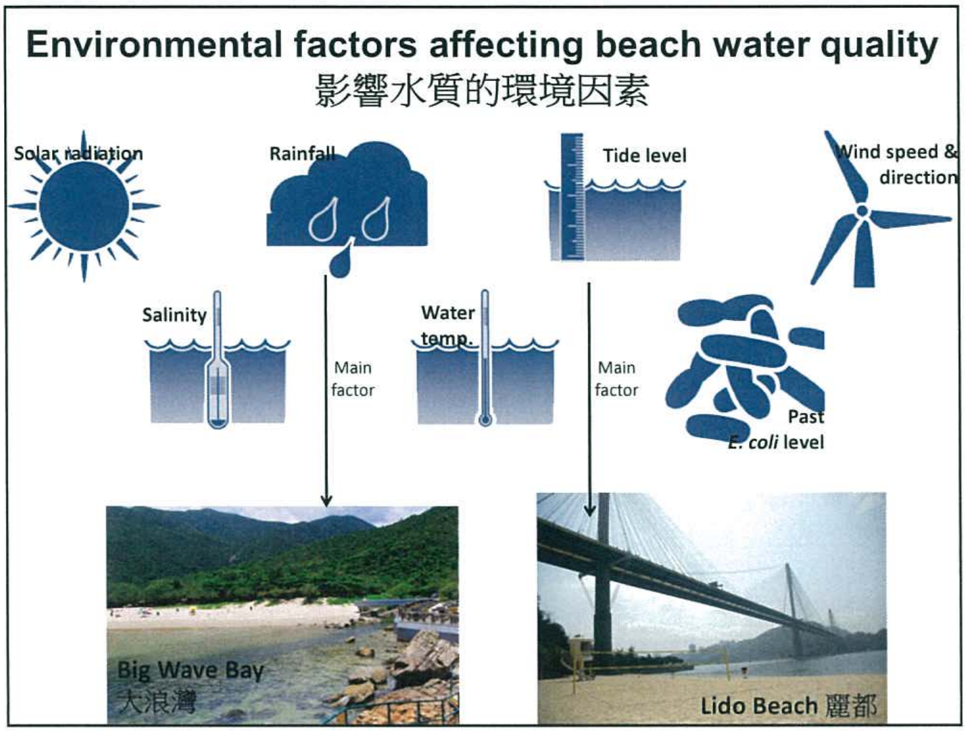
Data-driven models

Meteorological data

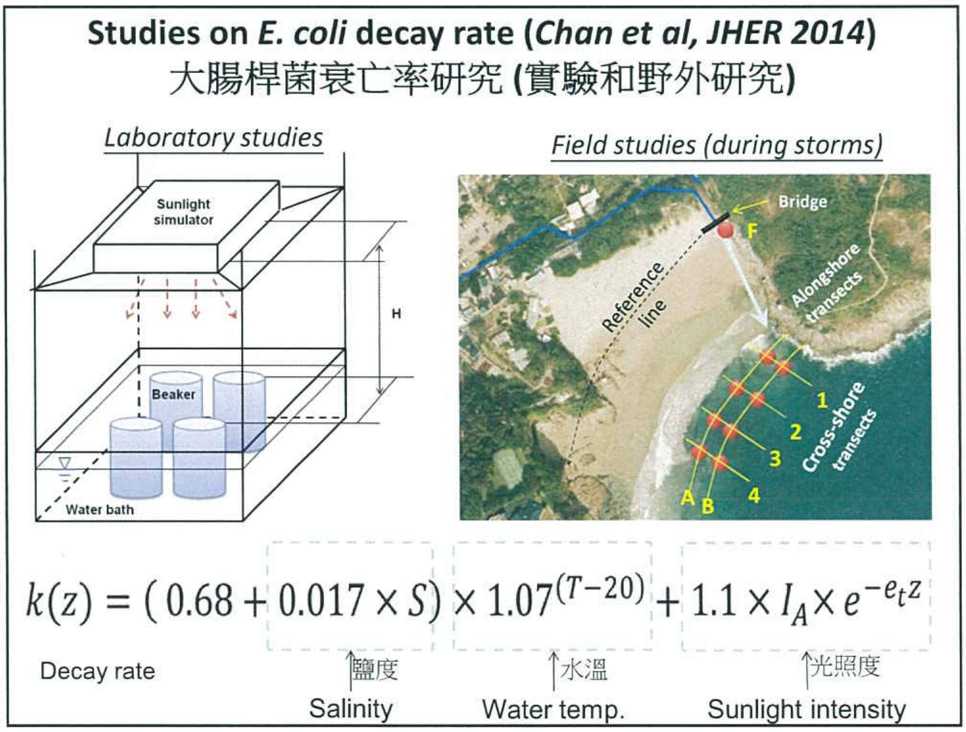
Data assimilation

Past data

Beach water quality forecast



Environmental factors affecting beach water quality
影響水質的環境因素



Studies on *E. coli* decay rate (*Chan et al, JHER 2014*)
大腸桿菌衰亡率研究 (實驗和野外研究)

Laboratory studies

Field studies (during storms)

$$k(z) = (0.68 + 0.017 \times S) \times 1.07^{(T-20)} + 1.1 \times I_A \times e^{-e_t z}$$

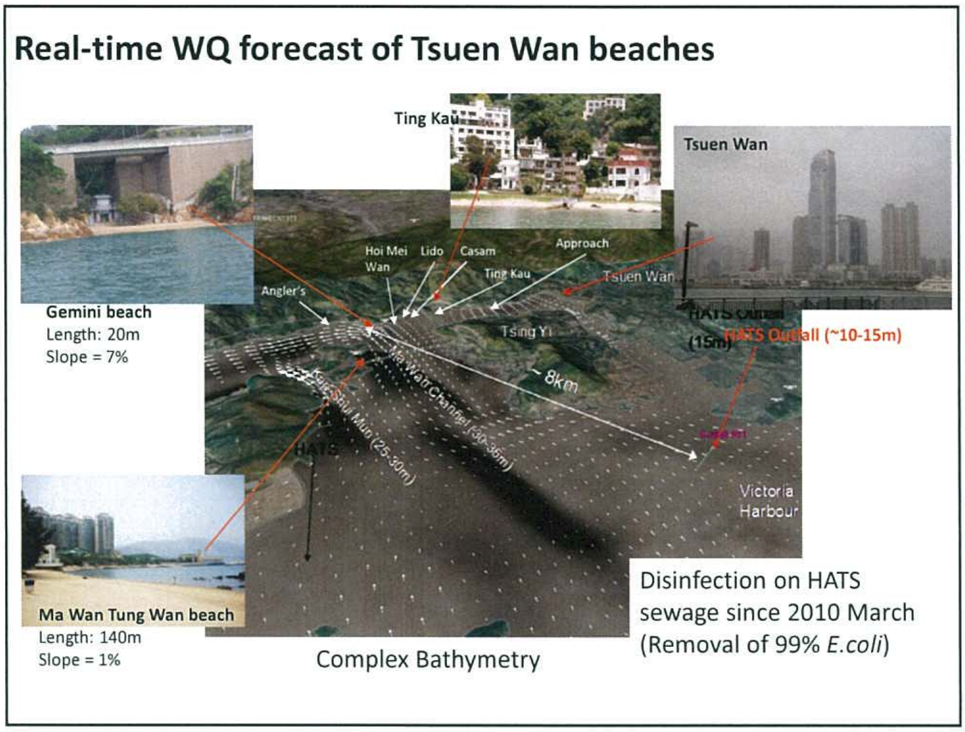
Decay rate

鹽度 Salinity

水溫 Water temp.

光照度 Sunlight intensity

Real-time WQ forecast of Tsuen Wan beaches



Gemini beach
Length: 20m
Slope = 7%

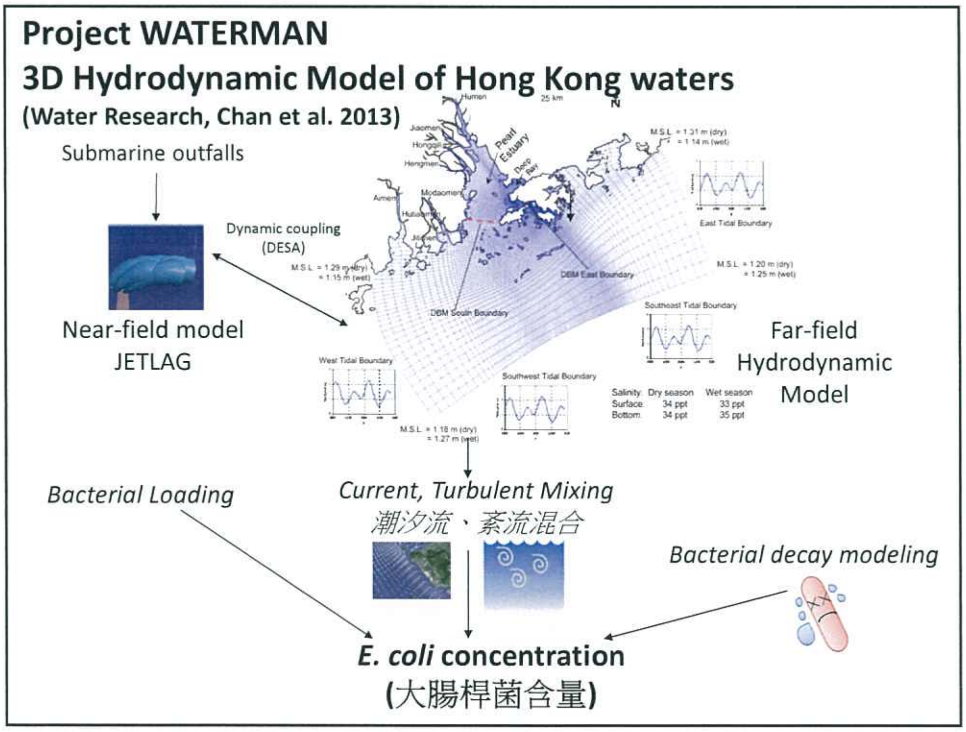
Ma Wan Tung Wan beach
Length: 140m
Slope = 1%

Complex Bathymetry

Disinfection on HATS sewage since 2010 March (Removal of 99% *E.coli*)

Project WATERMAN
3D Hydrodynamic Model of Hong Kong waters

(Water Research, Chan et al. 2013)



Submarine outfalls

Near-field model JETLAG

Dynamic coupling (DESA)

Far-field Hydrodynamic Model

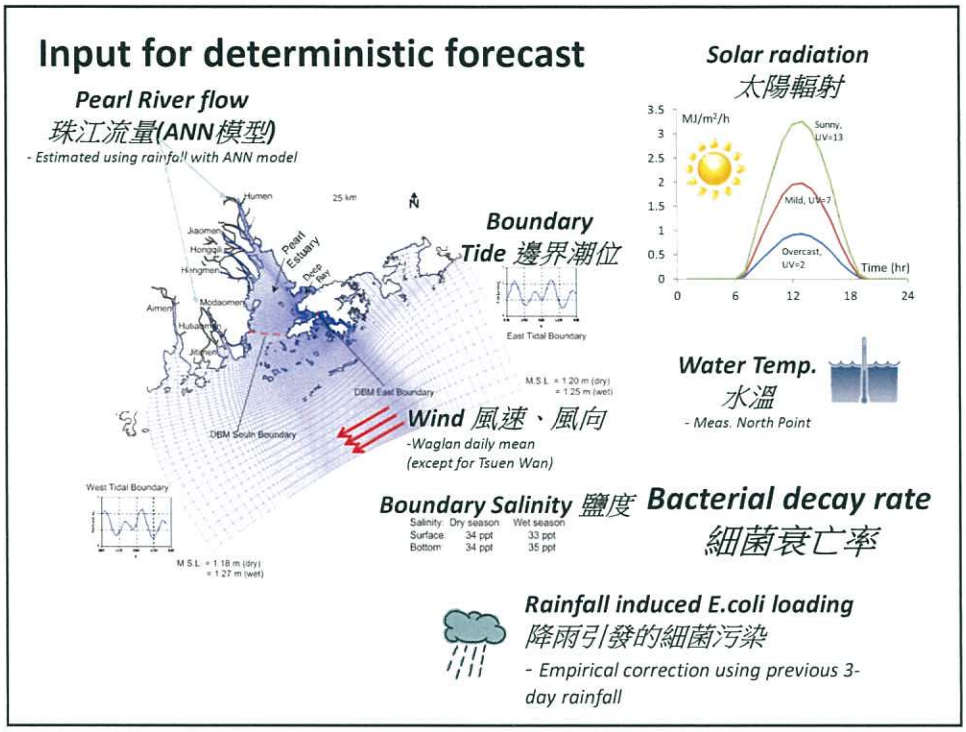
Salinity	Dry season	Wet season
Surface	34 ppt	33 ppt
Bottom	34 ppt	35 ppt

Bacterial Loading

Current, Turbulent Mixing
潮汐流、紊流混合

Bacterial decay modeling

***E. coli* concentration**
(大腸桿菌含量)



Input for deterministic forecast

Pearl River flow
珠江流量(ANN模型)
- Estimated using rainfall with ANN model

Boundary Tide 邊界潮位

Wind 風速、風向
-Waglan daily mean
(except for Tsuen Wan)

Boundary Salinity 鹽度

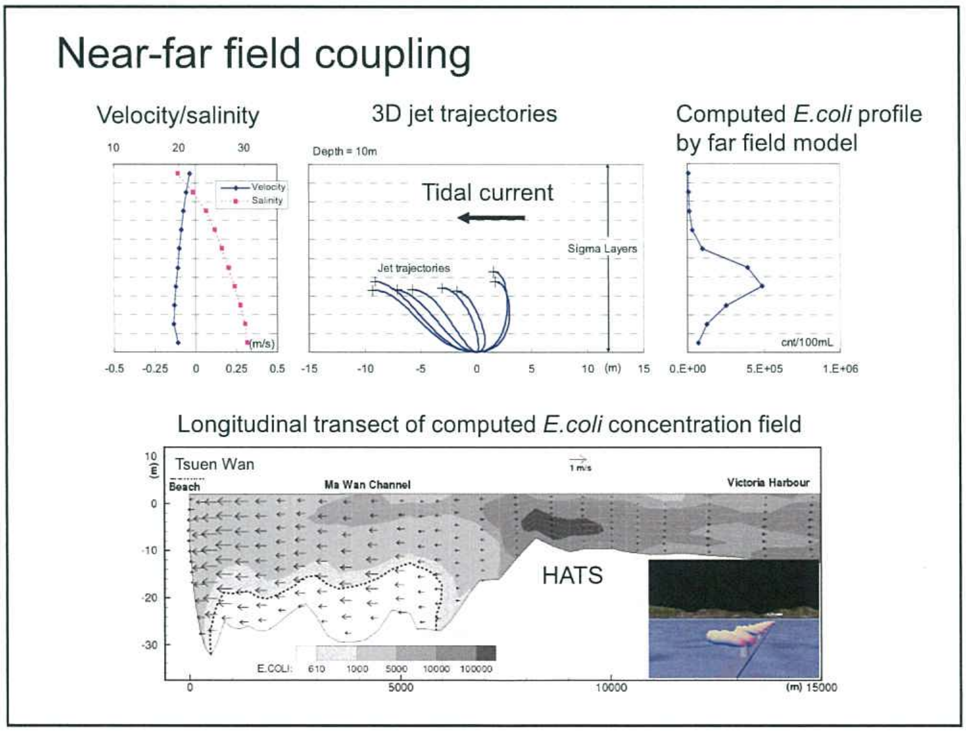
Salinity:	Dry season	Wet season
Surface:	34 ppt	33 ppt
Bottom:	34 ppt	35 ppt

Solar radiation
太陽輻射

Water Temp.
水溫
- Meas. North Point

Bacterial decay rate
細菌衰亡率

Rainfall induced E.coli loading
降雨引發的細菌污染
- Empirical correction using previous 3-day rainfall



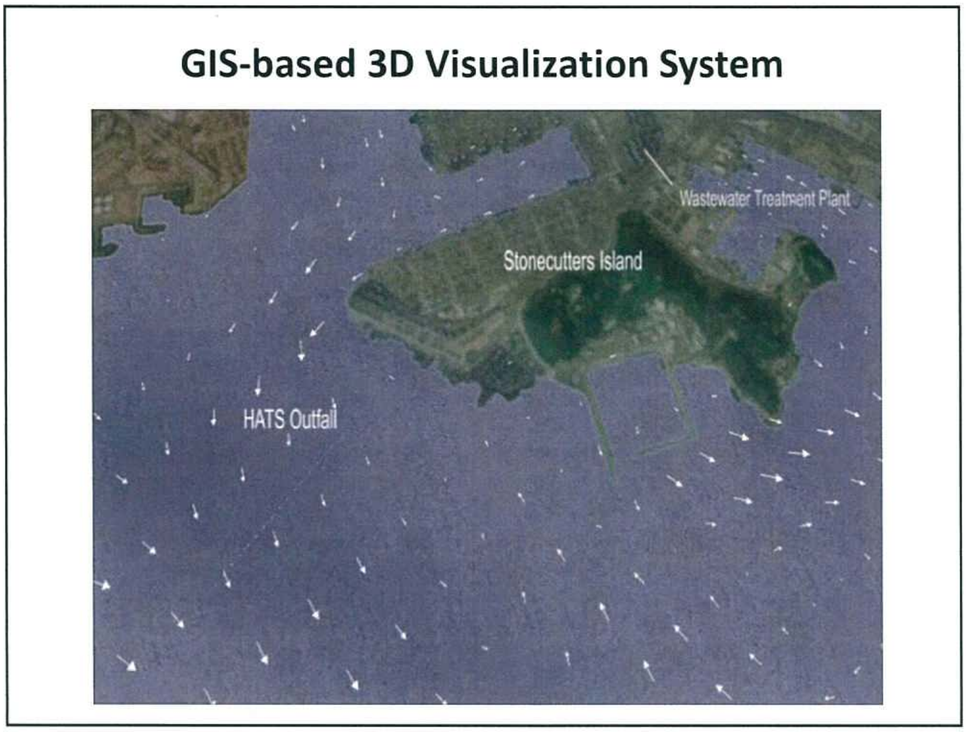
Near-far field coupling

Velocity/salinity

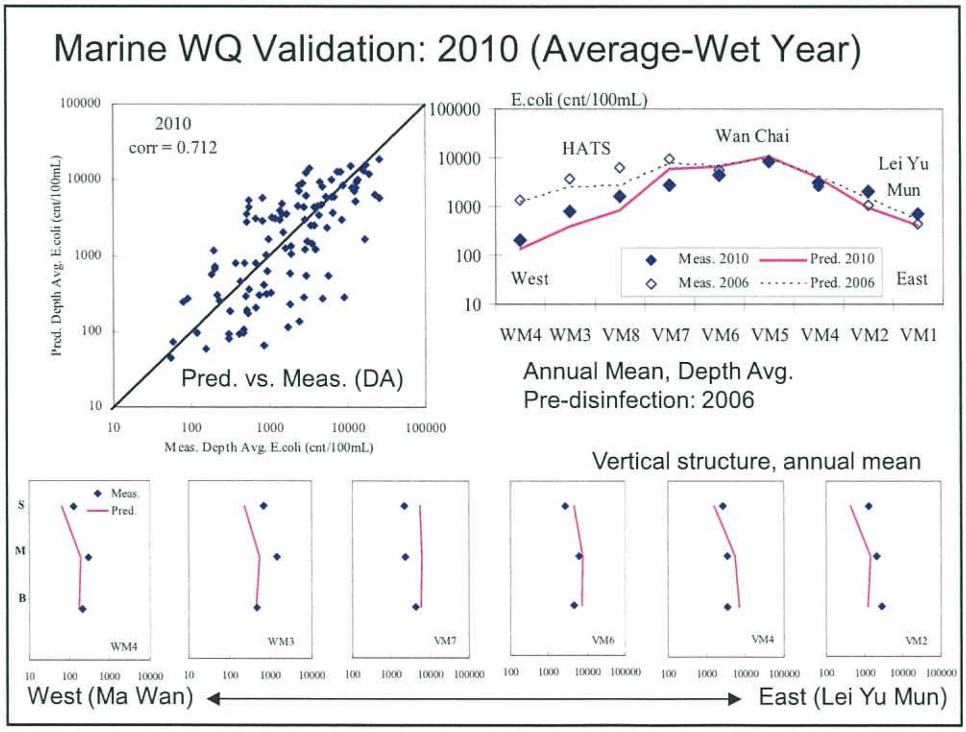
3D jet trajectories

Computed *E.coli* profile by far field model

Longitudinal transect of computed *E.coli* concentration field



GIS-based 3D Visualization System



Marine WQ Validation: 2010 (Average-Wet Year)

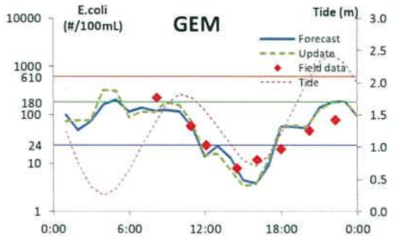
Annual Mean, Depth Avg.
Pre-disinfection: 2006

Vertical structure, annual mean

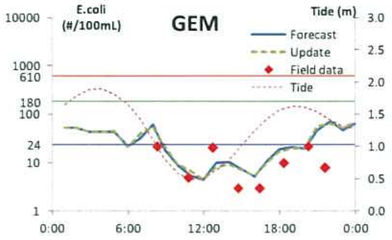
West (Ma Wan) ← → East (Lei Yu Mun)

Diurnal Variation: Beach WQ better for diurnal tides

Gemini

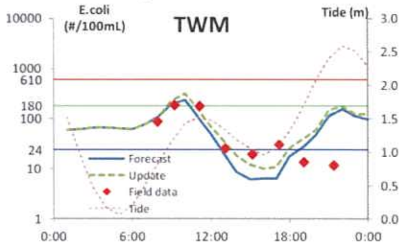


27-Oct-2011, sunny day, semi-diurnal

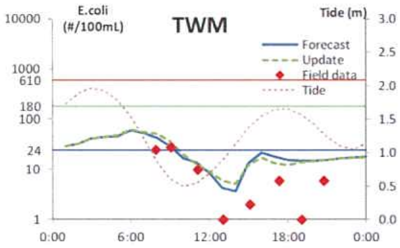


4-Nov-2011, sunny day, diurnal

Ma Wan Tung Wan



26-Nov-2011, overcast day, semi-diurnal



19-Nov-2011, overcast day, diurnal

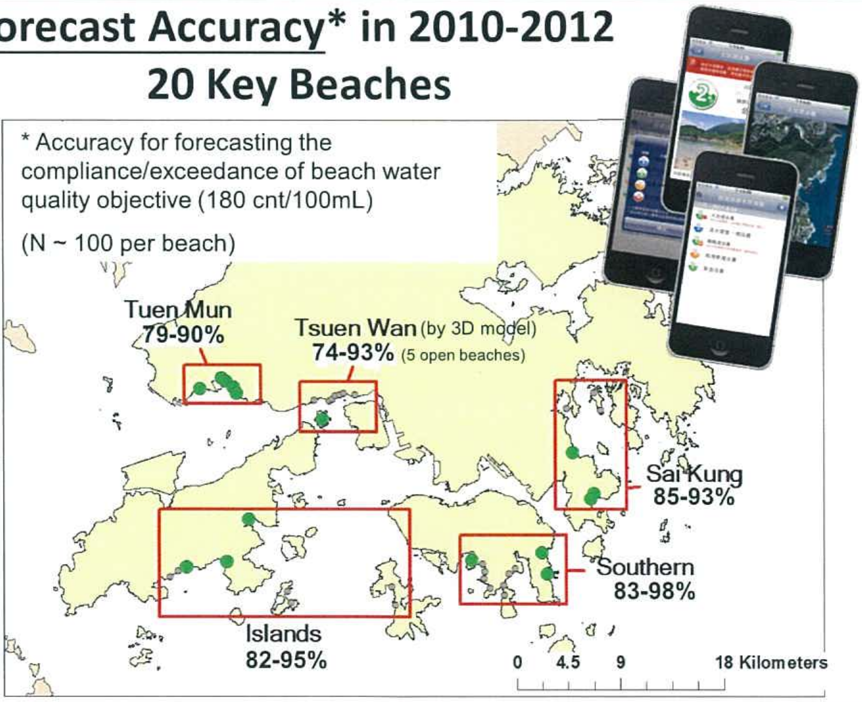
Diurnal Beach *E.coli* Variation

- Beach WQ depends on tidal variation and solar radiation
- Beach WQ better under strong solar radiation; lower bacterial counts during low tide
- During diurnal tides beach WQ is relatively better than during semi-diurnal tides
- Longer travel time (from HATS to TW beaches) during diurnal tide, allows for more bacterial decay by solar radiation (Chan et al, 2013).

Application of WATERMAN system in coastal water quality management

- Definition of mixing zones
- Daily beach water quality prediction
- Setting of effluent discharge standards
- Emergency response/disaster mitigation
- Optimal disinfection dosage control

Forecast Accuracy* in 2010-2012
20 Key Beaches


* Accuracy for forecasting the compliance/exceedance of beach water quality objective (180 cnt/100mL)

(N ~ 100 per beach)

WATERMAN Beach Water Quality Forecast System: setting of effluent *E.coli* standard

Stage I, ADF (Q = 1.4 x 10^6 m^3/d)
Monthly G-mean *E.coli* < 2 x 10^5 counts/100mL

Stage 2A (Q = 1.8 x 10^6 m^3/d)
Monthly G-mean *E.coli* < 2 x 10^4 counts/100mL

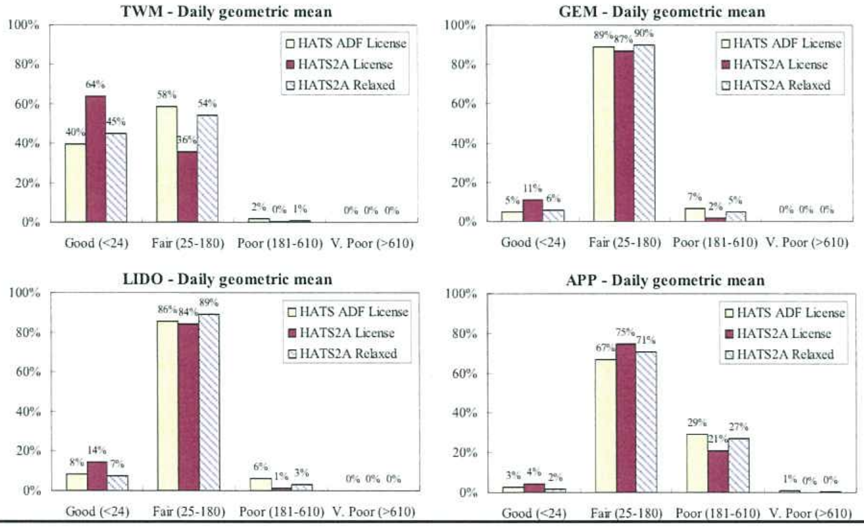
Previous studies based on typical average wet/dry season conditions - without beach water quality field data validation

The assimilative capacity should be assessed by accounting for entire range of discharge & ambient conditions – only thus can standards be set that are not excessively severe

Predicted daily beach grading distribution – bathing season

- Stage 1 ADF $C_0 = 2 \times 10^5$ count/100mL, current license standard
- Stage 2A $C_0 = 2 \times 10^4$ count/100mL, current license standard
- Stage 2A $C_0 = 2 \times 10^5$ count/100mL, relaxed standard

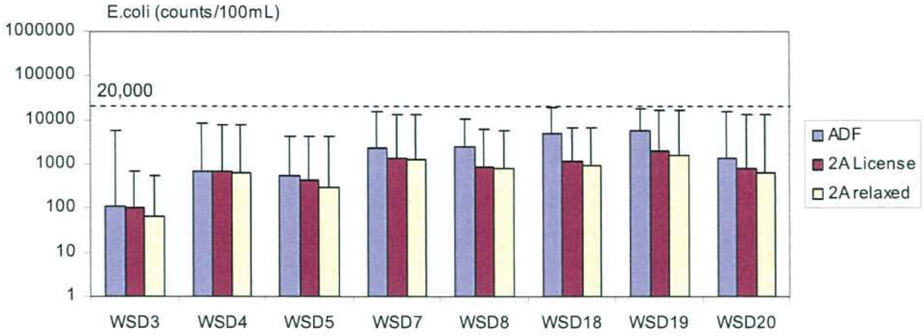
N = 245



Flushing/Sea Water Intakes

- Criteria: *E.coli* < 20,000 count/100mL at any time

Predicted *E.coli* (depth-average, hourly data, N = 2880)



Column: Geometric mean *E.coli* conc.
Error bar: Max *E.coli* conc.

Ma Wan fish culture zone

- Criteria: *E.coli* < 610 count/100mL for annual geometric mean

Predicted depth-average *E.coli* (hourly data, N = 5880)

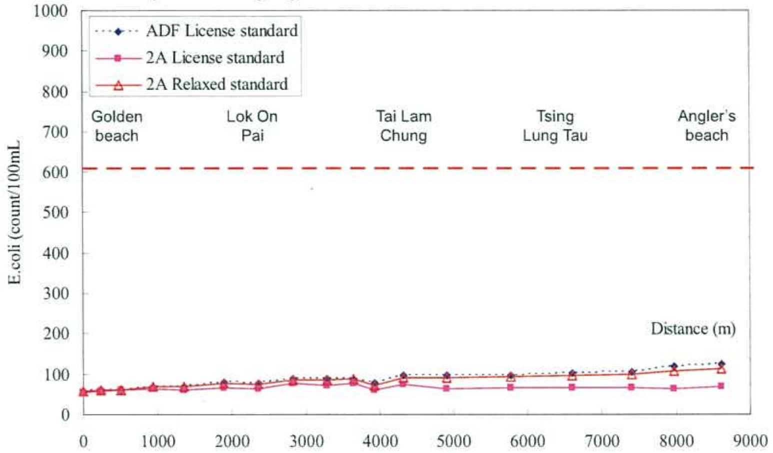
Scenario	E.coli standard (count/100mL)	Geometric mean (count/100mL)	% > 610
ADF Current license	200,000	53	0%
HATS-2A 2014 License standard	20,000	32	0%
HATS-2A 2014 Relaxed license	200,000	45	0%

- The geometric mean of E.coli level in Ma Wan FCZ are well below 610 count/100mL
- There would be some improvement in the bacterial level after Stage 2A (license and relaxed conditions).

Secondary contact zones

- Criteria: Annual mean *E.coli* < 610 count/100mL

Predicted depth-average geometric mean *E.coli*



Recommendation on effluent *E.coli* standard

- Under HATS-2A (Q = 1.8 x 10^6 m^3/d), HATS effluent *E.coli* standard in bathing season can be relaxed from the current license level of 2 × 10^4 count/100mL to 2 × 10^5 count/100mL. This will help reduce chlorine consumption, save energy and operational cost whilst protecting the environment
- A less restrictive effluent *E.coli* standard (e.g. 8x10^5 count/100mL) can be adopted for diurnal tides without violating the WQO.
- More understanding on the disinfection system is required for optimizing disinfection dosage :
  - Hydraulics and mixing of the ADF
  - Relation between chlorine dosing and effluent *E.coli* concentration

Application of WATERMAN System in Emergency Response Incidents

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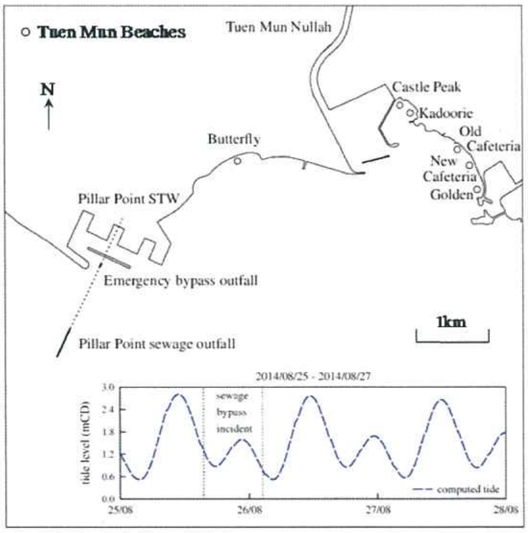
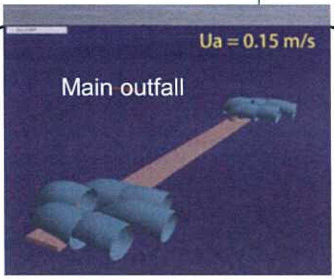
Emergency Sewage Overflow, Pillar Point Sewage Treatment Works, 25-26 August 2014

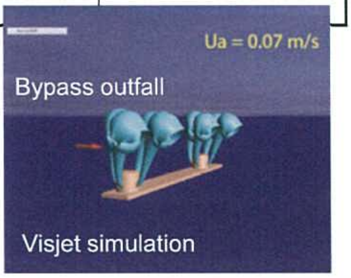
- Malfunction of the fine screens at the Pillar Point Sewage Treatment Works (PPSTW) on August 25, 2014,
- a total 95,000 m^3 of raw sewage was discharged through an emergency bypass outfall for 11 hr.
- All 14 beaches in Tuen Mun and Tsuen Wan were closed immediately on August 25.



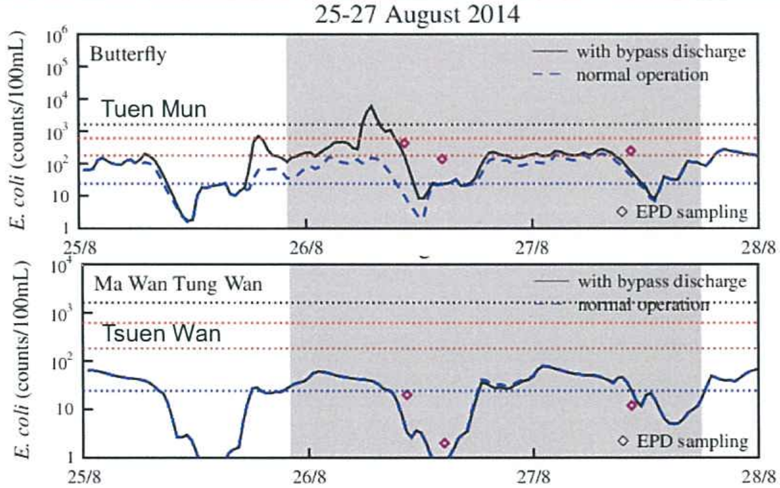
Pillar Point outfall parameters

Outfall	Main	Bypass
Diffuser length (m)	425	50
Depth (m)	15	10
No. of riser (ports per riser)	9 (6)	3 (4)
Jet diameter (m)	0.26	1.05
Jet velocity (m/s)	0.701	0.193
Densimetric Froude number Fr	3.14	0.43
Typical current u_a (m/s)	0.15-1.10	0.07-0.40
Near field dilution	50-115	15-40





Visjet simulation



25-27 August 2014

- *Impact of bypass discharge results in elevated beach E.coli levels on Tuen Mun beaches but no impact on Tsuen Wan beaches*
- *The effect of pollution is dissipated in about 8-10 hours*

Optimization of Disinfection Performance & Fluid Mechanics of Chlorine Mixing

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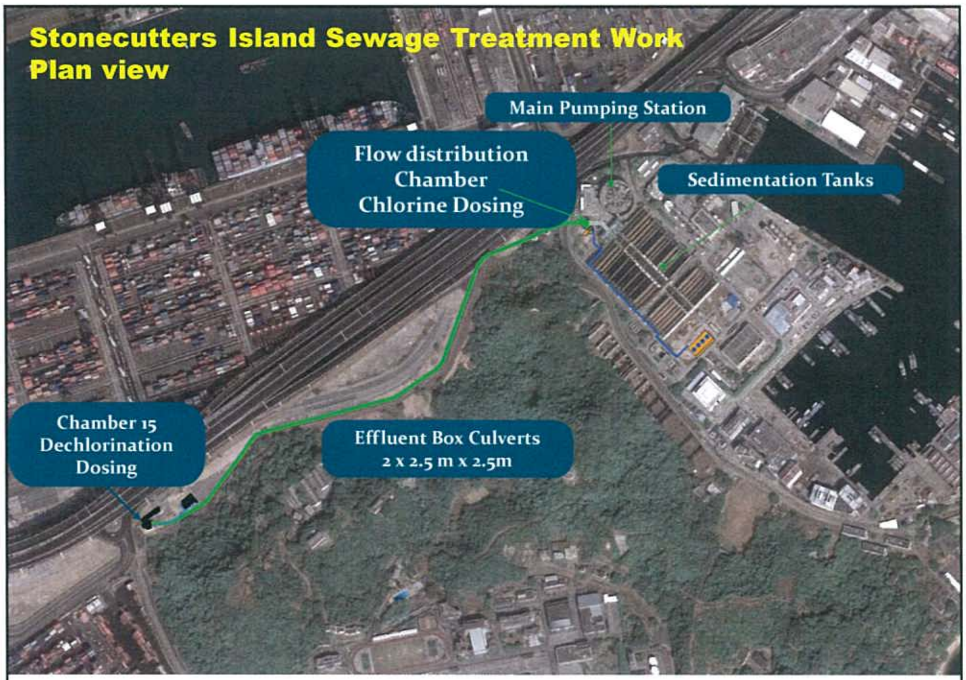
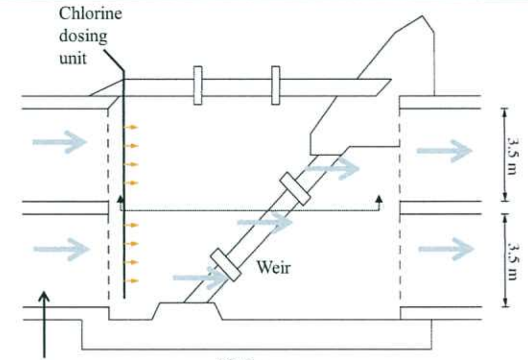
Stonecutters Island Sewage Treatment Work Plan view



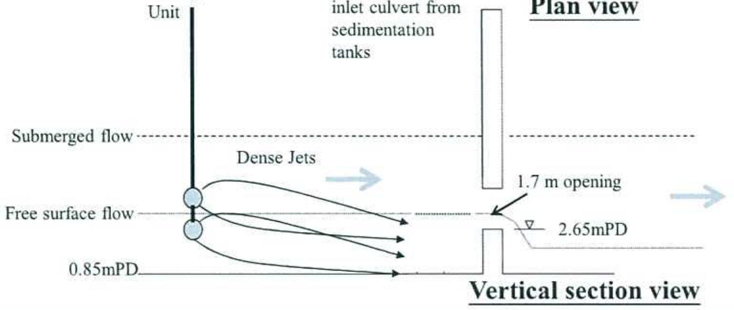
Flow Distribution Chamber (Chlorine dosing unit)

- *Chlorine conc = 100,000 ppm*
- *Target well-mixed chlorine concentration = 10-20 ppm*
- *Required dilution ~ 10,000*

Q ~ 10 – 20 m3/s



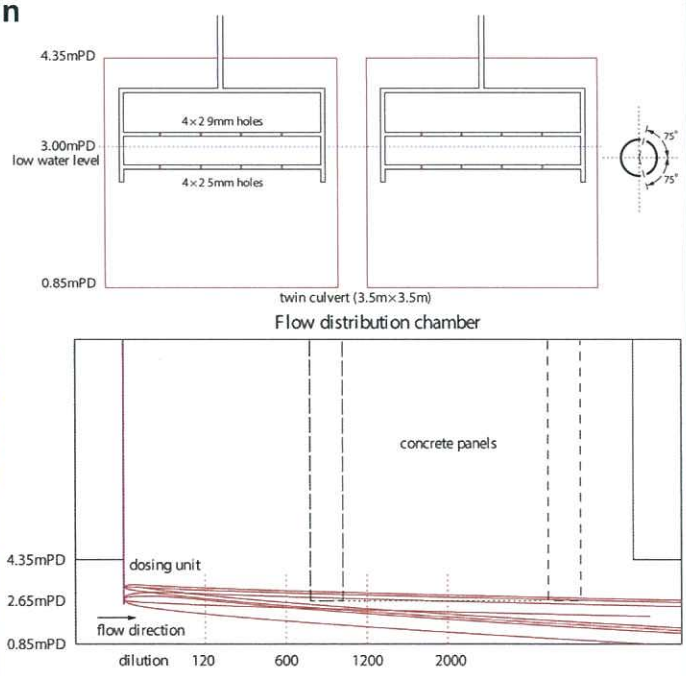
Plan view

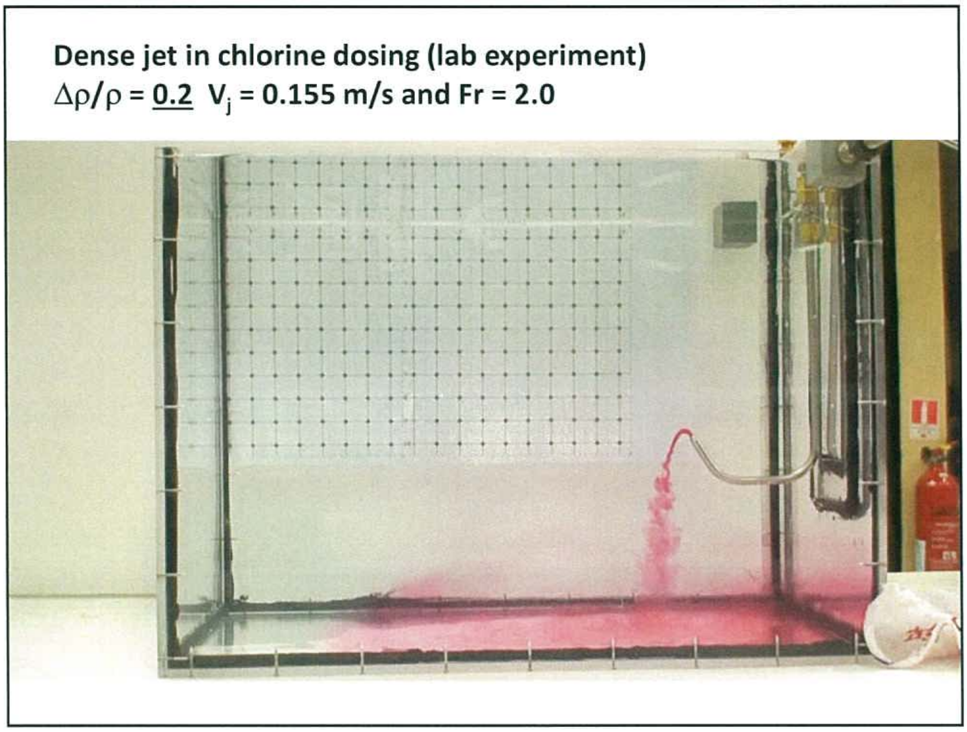


Vertical section view

Chlorine dosing in flow distribution chamber

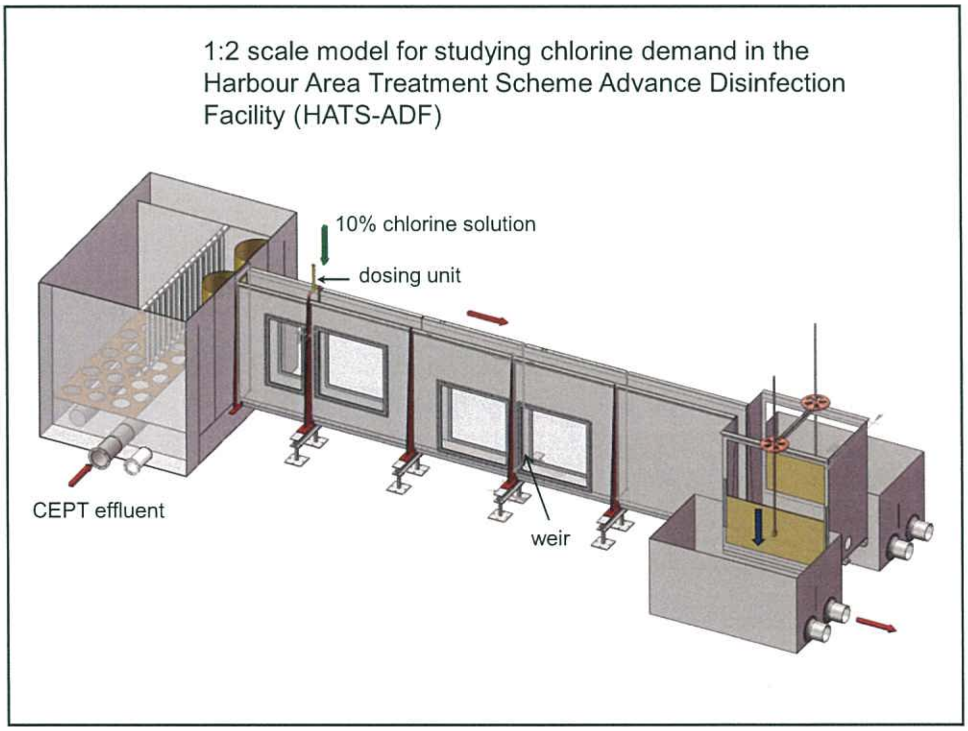
Chlorine dosing unit **(2 rows of jets)**





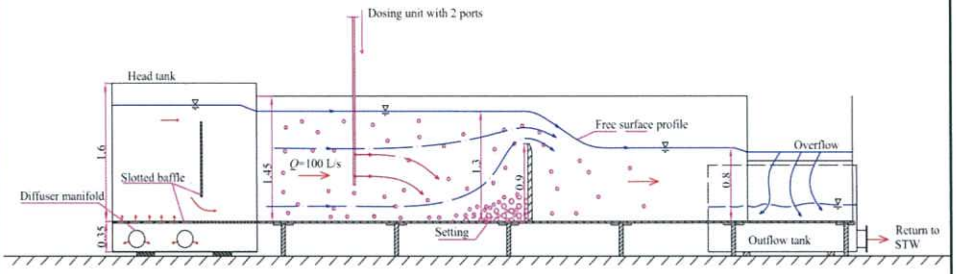
Dense jet in chlorine dosing (lab experiment)

$\Delta\rho/\rho$ = <u>0.2</u> V_j = 0.155 m/s and Fr = 2.0



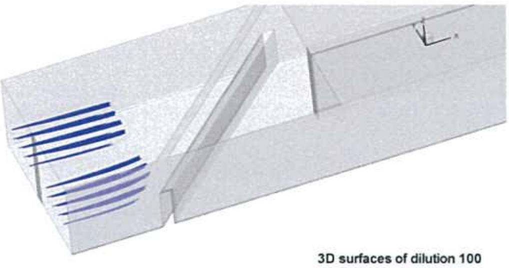
1:2 scale model for studying chlorine demand in the Harbour Area Treatment Scheme Advance Disinfection Facility (HATS-ADF)

- Onsite field monitoring on a 1:2 Froude scale model of a slice of the sewage treatment plant flow;
- The jet mixing of the chlorine with the sewage flow will be simulated;
- The exertion of chlorine demand through the interactions of chlorine with effluent impurities including both soluble and settled particles can be studied; and
- To determine of total residual chloride (TRC) fluctuations at various locations along the test flume to understand the effects of the dosing unit and the weir upon the mixing of the chlorine;



centerline section view

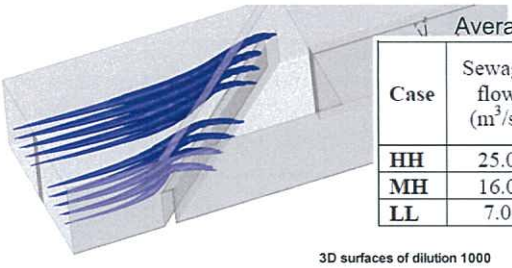
CFD prediction of dosing jets



3D surfaces of dilution 100

Computed 3D surface of dilution 100 and 1000 contour for the present dosing unit design

Velocity (medium flow/high dosage):
Upper jet = 2.0 m/s
Lower jet = 2.0 m/s
Ambient = 0.65 m/s



3D surfaces of dilution 1000

Average chlorine conc. (C/C_a) at x = 60m

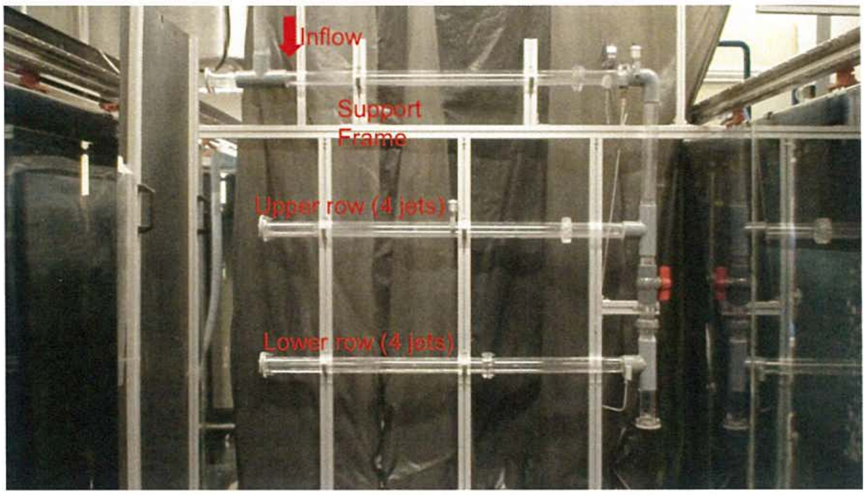
Case	Sewage flow (m^3/s)	Chemical flow (L/s)	Chemical	
			Left culvert C/C_a	Right culvert C/C_a
HH	25.0	4.17	1.19	0.90
MH	16.0	2.67	1.21	0.89
LL	7.0	0.58	1.10	0.95

Uneven distribution of chlorine

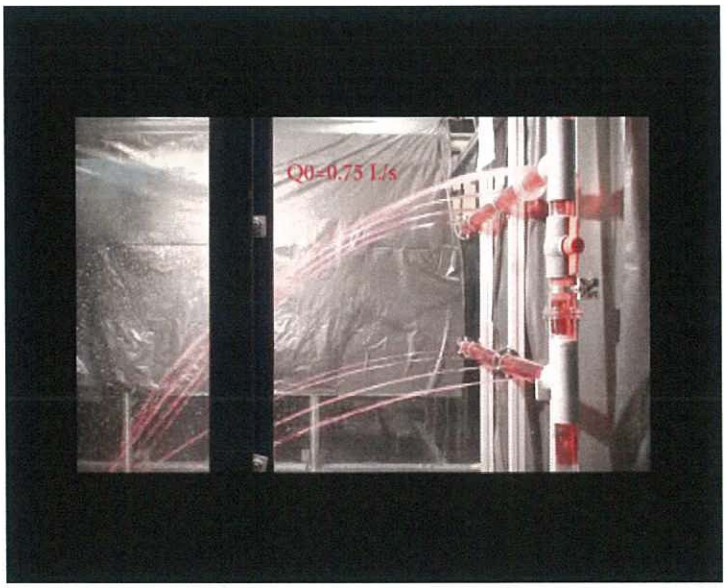
C_a = well mixed conc. = 20mg/L

Full-scale Experiments of Internal Hydraulics of Dosing Jets

Water jets into air ($\Delta\rho/\rho = 1.0$) - Limiting case of dense jet



Side view of water jets into air experiments



Conclusions

1. Real time water quality forecast systems can be used for environmental engineering and control and management – in particular setting of a sensible sewage effluent discharge standard and the planning of emergency response in pollution accidents/disasters
2. The environmental impact on nearby beaches and sensitive receivers can be managed by optimizing operation strategy and disinfection dosage.
3. Optimal disinfection dosage control depends on the mixing of chlorine with the saline sewage flow - localized high chlorine concentration may lead to more chlorine demand and less *E. coli* kill.

Thank you!