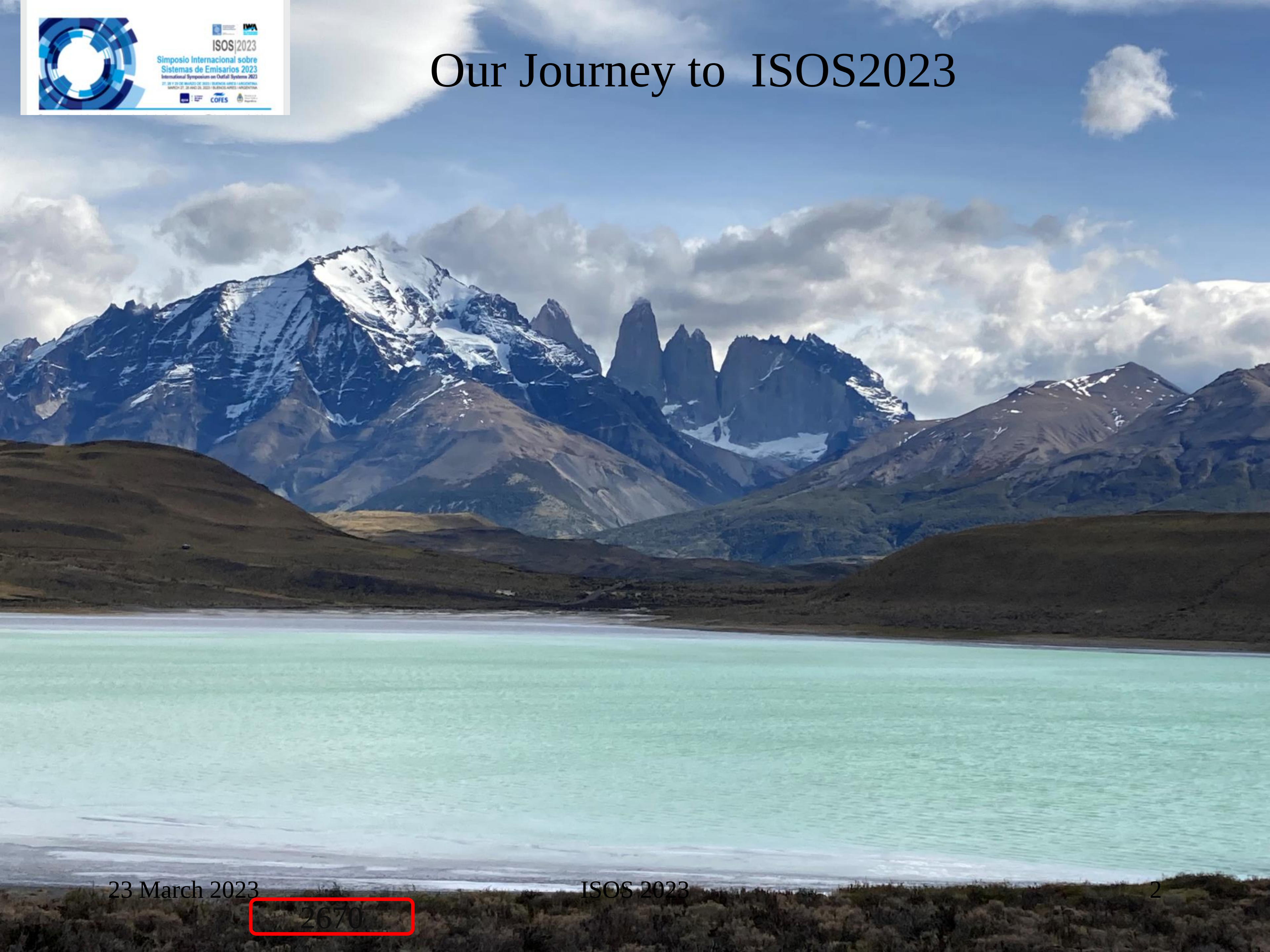
Modeling vertical, tiered, radial diffusers using the Visual Plumes UM3 Model

On Initiatives to Maintain and Advance the Visual Plumes Modeling Application

(Original and Alternative Title)

ISOS|2023
Simposio Internacional sobre Sistemas de Emisarios 2023
International Symposium on Outfall Systems 2023

Our Journey to ISOS2023



2670

Visual Plumes Guide

United States Environmental Protection Agency
National Exposure Research Laboratory
Research Triangle Park NC 27709
EPA/600/R-03/025
March 2003

Dilution Models for Effluent Discharges

4th Edition
(Visual Plumes)

by

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4 March 2003

Ecosystems Research Division, NERL, ORD
U.S. Environmental Protection Agency
960 College Station Road
Athens, Georgia 30605-2700

On Initiatives to Maintain and Advance the Visual Plumes Modeling Application

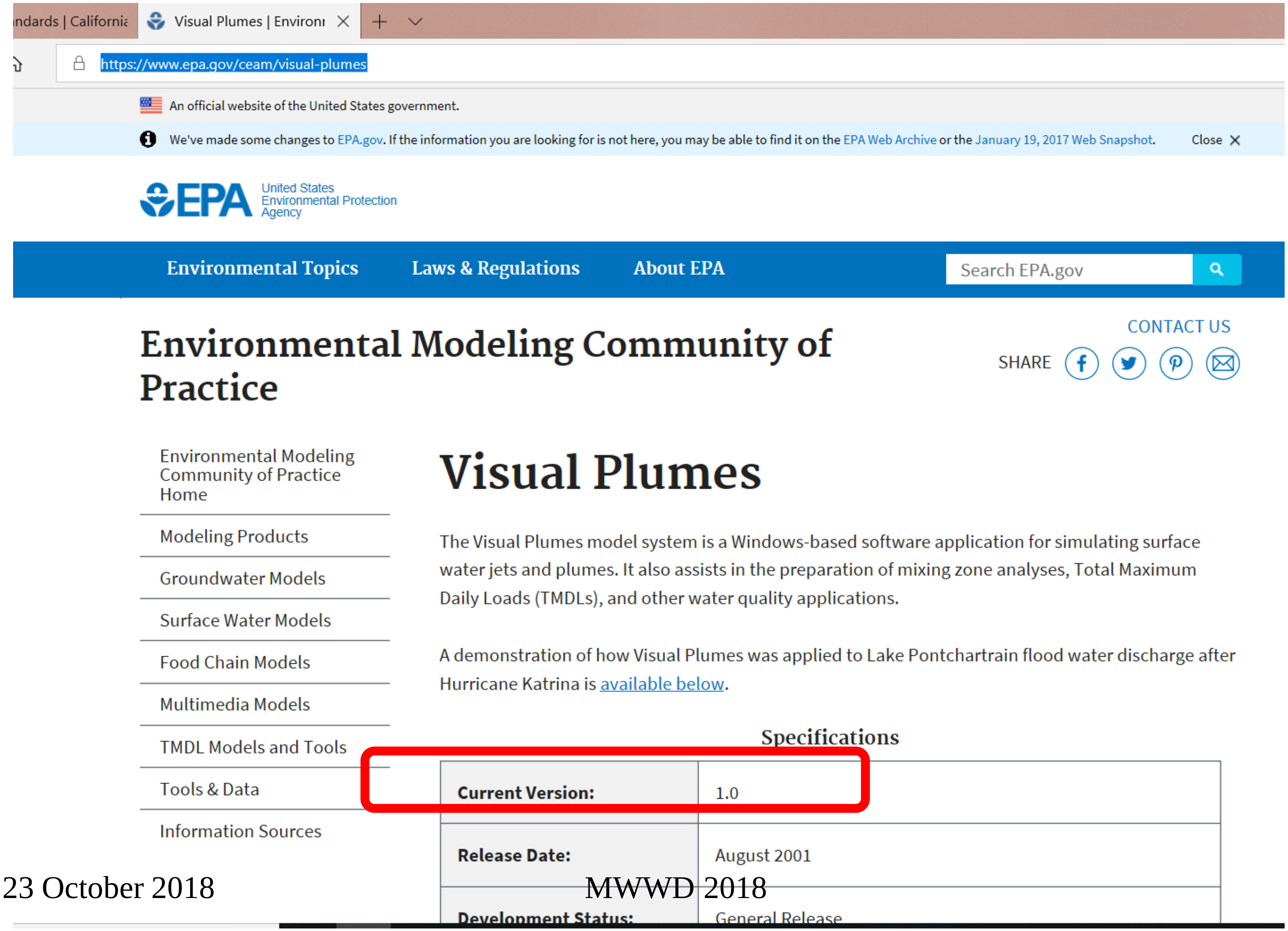
As you may know:

With the support of the **California Waterboards**
and in consultation with **Drs. Phil Roberts and Walter Frick**,
a group at the **San Francisco Bay Estuaries Institute**, (Richmond, California)
headed by **Dr. Anthony (Tony) Hale**
is working to **update and revise Visual Plumes** (VP).

You can find information on **Tony Hale, Gemma Shusterman, Lorenzo Flores**
and others at their website:
Environment Informatics Program | San Francisco Estuary Institute (sfei.org)

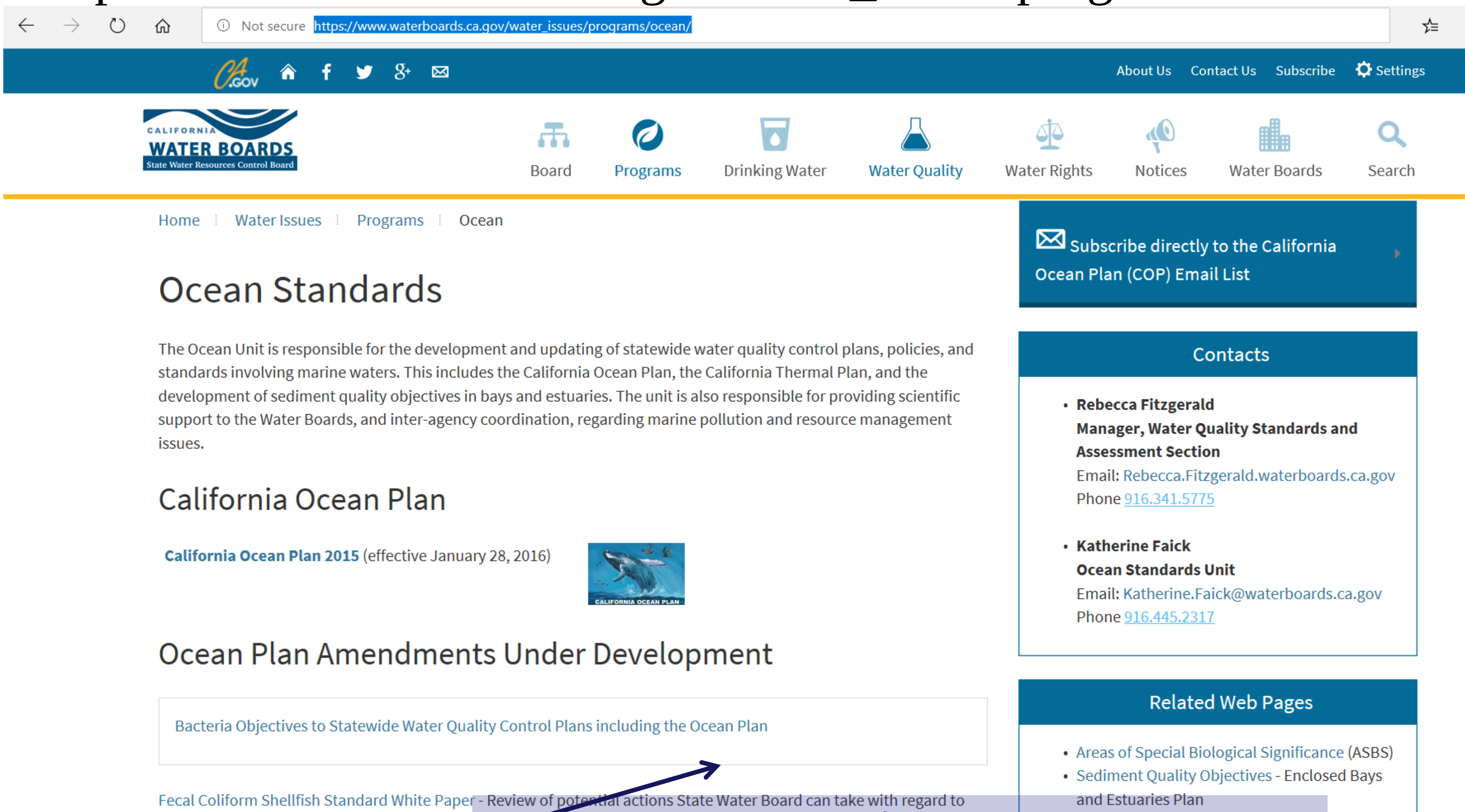
The USEPA website

Search: “EPA visual plumes” yields
https://www.epa.gov/ceam/visual-plumes



The California website

Search: “california water board visual plumes” yields https://www.waterboards.ca.gov/water_issues/programs/ocean/



Not secure https://www.waterboards.ca.gov/water_issues/programs/ocean/

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CALIFORNIA WATER BOARDS State Water Resources Control Board

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Home | Water Issues | Programs | Ocean

Ocean Standards

The Ocean Unit is responsible for the development and updating of statewide water quality control plans, policies, and standards involving marine waters. This includes the California Ocean Plan, the California Thermal Plan, and the development of sediment quality objectives in bays and estuaries. The unit is also responsible for providing scientific support to the Water Boards, and inter-agency coordination, regarding marine pollution and resource management issues.

California Ocean Plan

California Ocean Plan 2015 (effective January 28, 2016)

Ocean Plan Amendments Under Development

Bacteria Objectives to Statewide Water Quality Control Plans including the Ocean Plan

Fecal Coliform Shellfish Standard White Paper - Review of potential actions State Water Board can take with regard to

Subscribe directly to the California Ocean Plan (COP) Email List

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  Ocean Standards Unit
  Email: Katherine.Faick@waterboards.ca.gov
  Phone 916.445.2317

Related Web Pages

- Areas of Special Biological Significance (ASBS)
- Sediment Quality Objectives - Enclosed Bays and Estuaries Plan

Simulation stopped at 2nd trap level; for negatively buoyant plumes, corresponds to max fall

The California website (continued)

https://www.waterboards.ca.gov/water_issues/programs/ocean/

CALIFORNIA OCEAN PLAN

er Development

Plans including the Ocean Plan

potential actions State Water Board can take with regard to
for Shellfish harvesting in state recreational waters. This is
11-2013.

ently Adopted

Nice logo

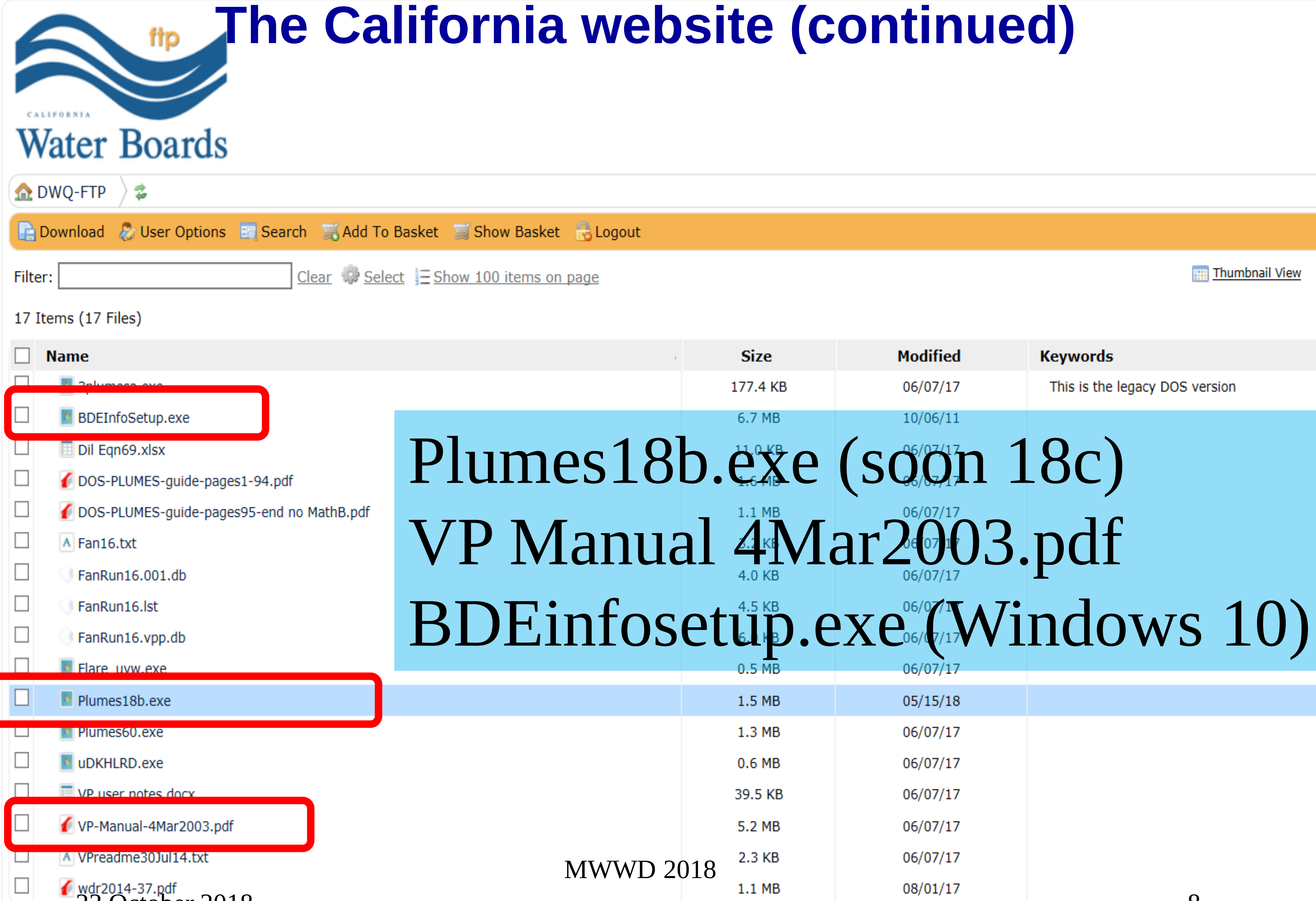
- **Katherine Faick**
  Ocean Standards Unit
  Email: Katherine.Faick@waterboards.ca.gov
  Phone 916.445.2317

Related Web Pages

- Areas of Special Biological Significance (ASBS)
- Sediment Quality Objectives - Enclosed Bays and Estuaries Plan
- Ocean Plan and Triennial Review Archives
- Visual Plumes Model (FTP site)

Other Related Links

The California website (continued)



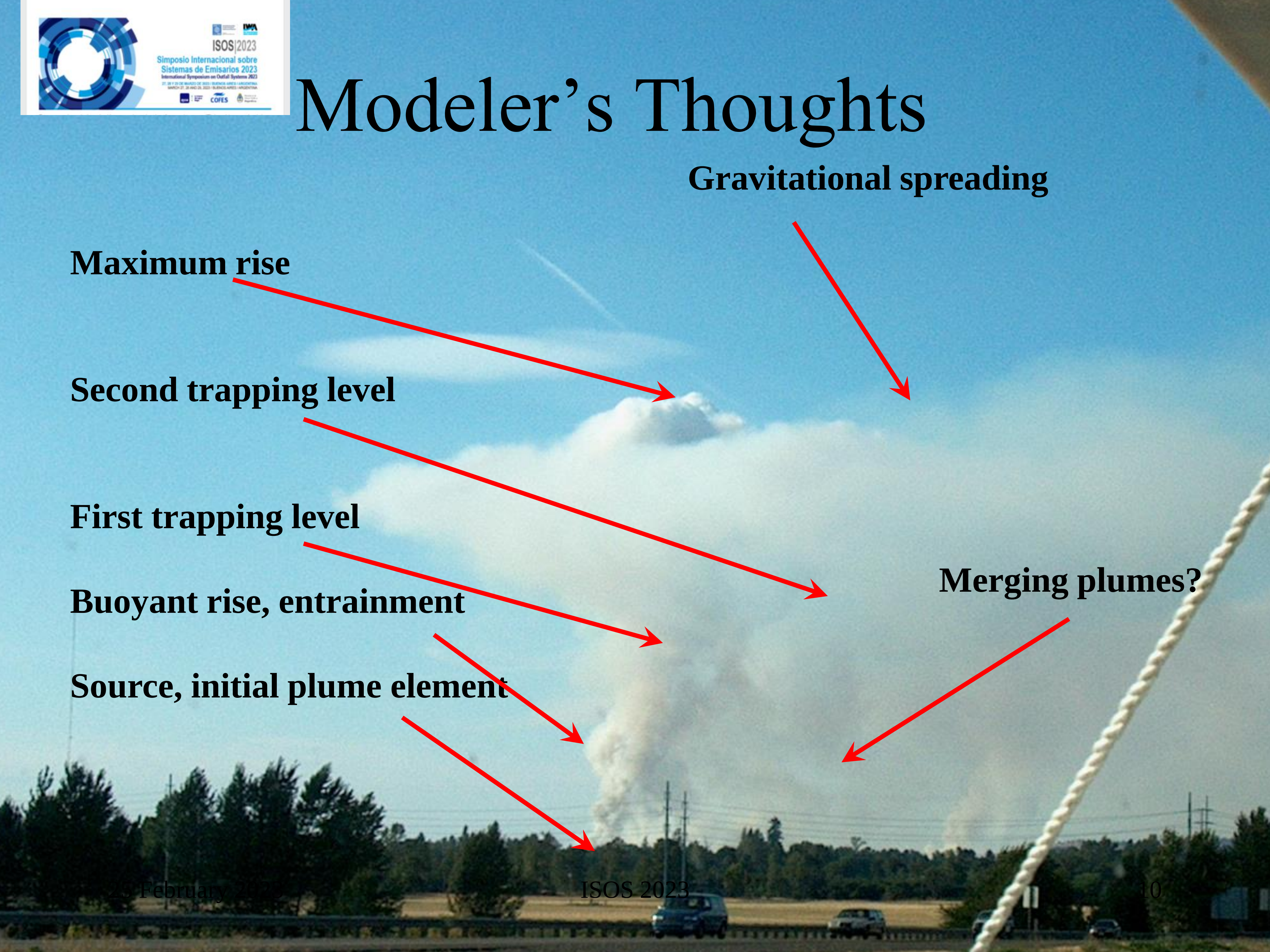
Plumes18b.exe (soon 18c)

VP Manual 4Mar2003.pdf

BDEinfosetup.exe (Windows 10)

Birdseye View of a Wastewater Source

Modeler's Thoughts



Lagrangian plume element

A material element

A Lagrangian plume element traced through time

$dt = t_{lead} - t_{trail} = 4\text{sec}$

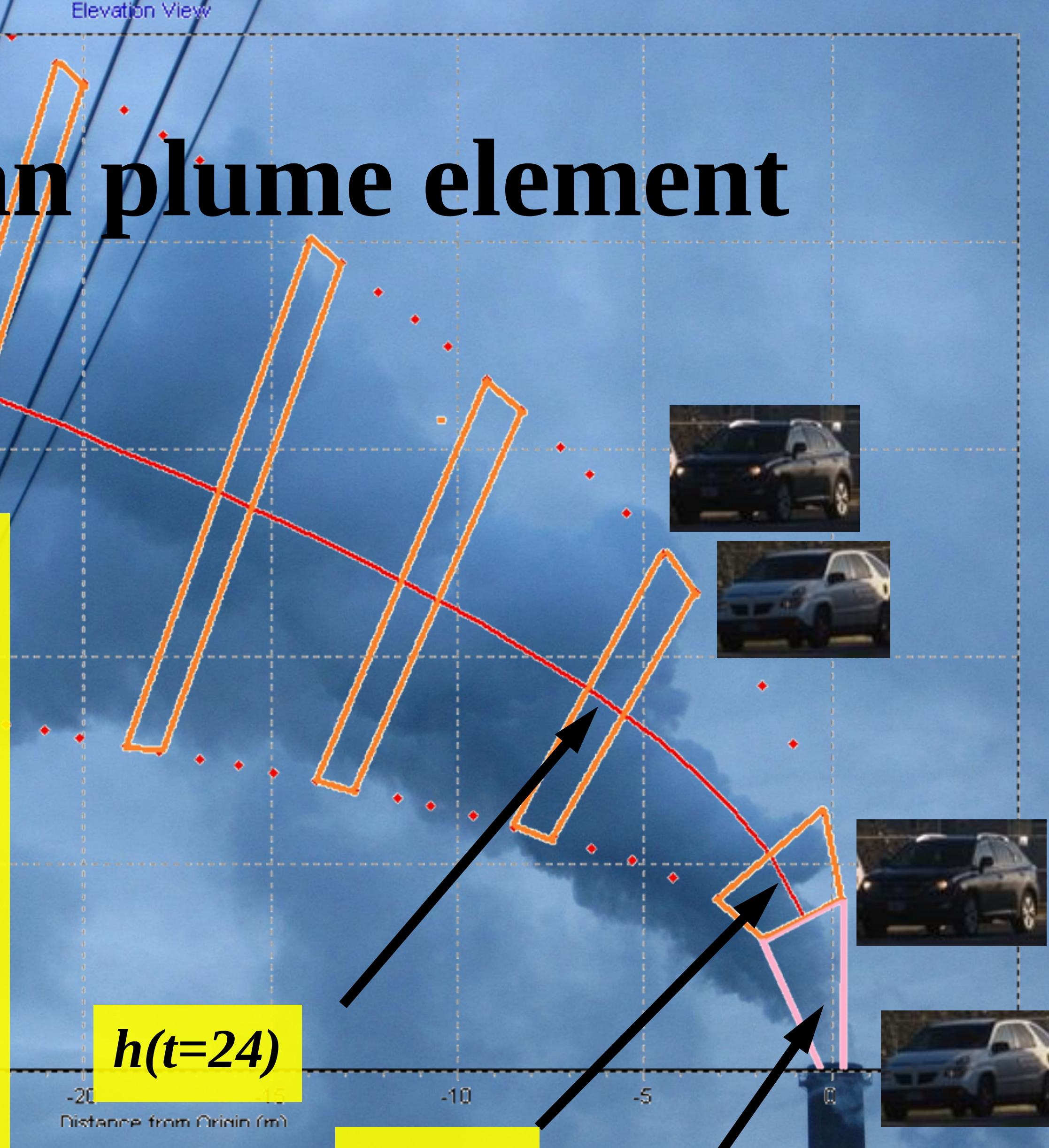
Element age (r to l):

0, 4, 24, 44, 64, and 94 sec

The element contains the same effluent it had at age 0

Length (*h*) is variable

Cross-section round



Notes

Initial Dilution

For ocean discharges, to be permitted to discharge effluent one must meet ocean criteria for achieving appropriate dilutions, the second trap level is a good candidate for defining initial dilution

Initial Dilution is the process which results in the rapid and irreversible turbulent mixing of wastewater with ocean water around the point of discharge.

For a submerged buoyant discharge, characteristic of most municipal and industrial wastes that are released from the submarine outfalls, the momentum of the discharge and its initial buoyancy act together to produce turbulent mixing. Initial dilution in this case is completed when the diluting wastewater ceases to rise in the water column and first begins to spread horizontally.

For shallow water submerged discharges, surface discharges, and nonbuoyant discharges, characteristic of cooling water wastes and some individual discharges, turbulent mixing results primarily from the momentum of discharge. Initial dilution, in these cases, is considered to be completed when the momentum induced velocity of the discharge ceases to produce significant mixing of the waste, or the diluting plume reaches a fixed distance from the discharge to be specified by the Regional Board, whichever results in the lower estimate for initial dilution.

How to Mitigate and Comply?
E.g. Build a Long Linear Diffuser Outfall

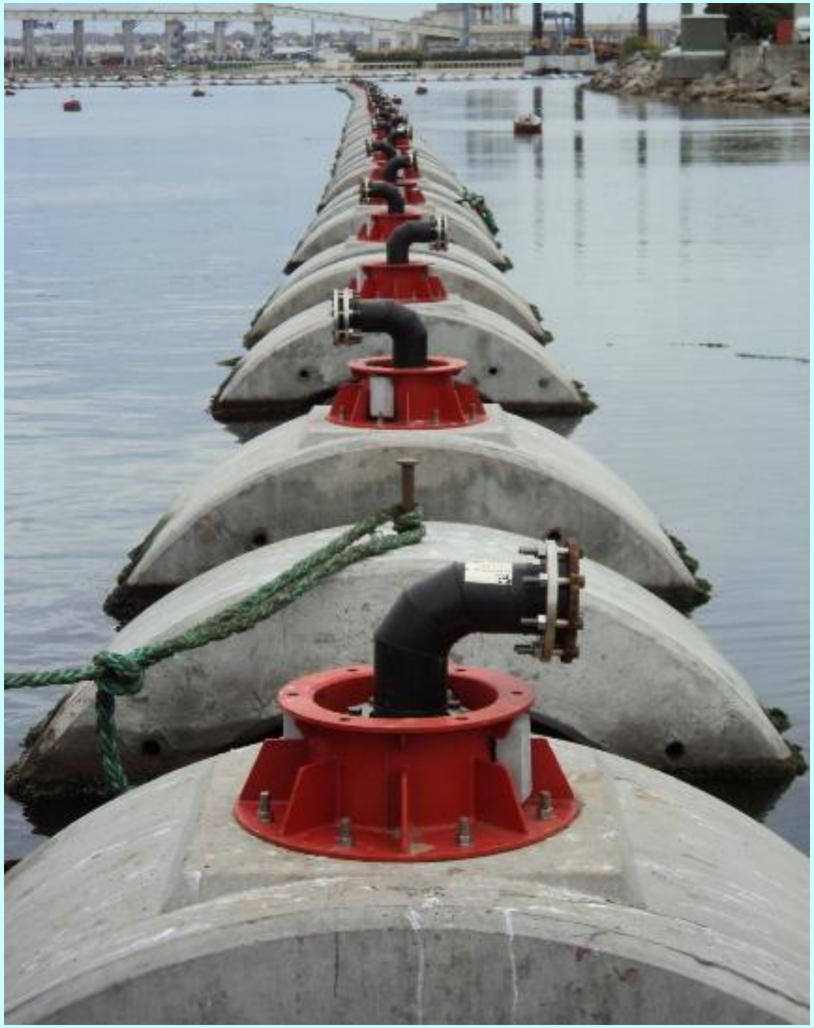
Design Comes First

Design Considerations:

For Example:

30 cm end port for prevent internal sedimentation
Prevent seawater intrusión
Port Froude Number > 1

Etc.



(Scagliola, Comino, et al, 2018)

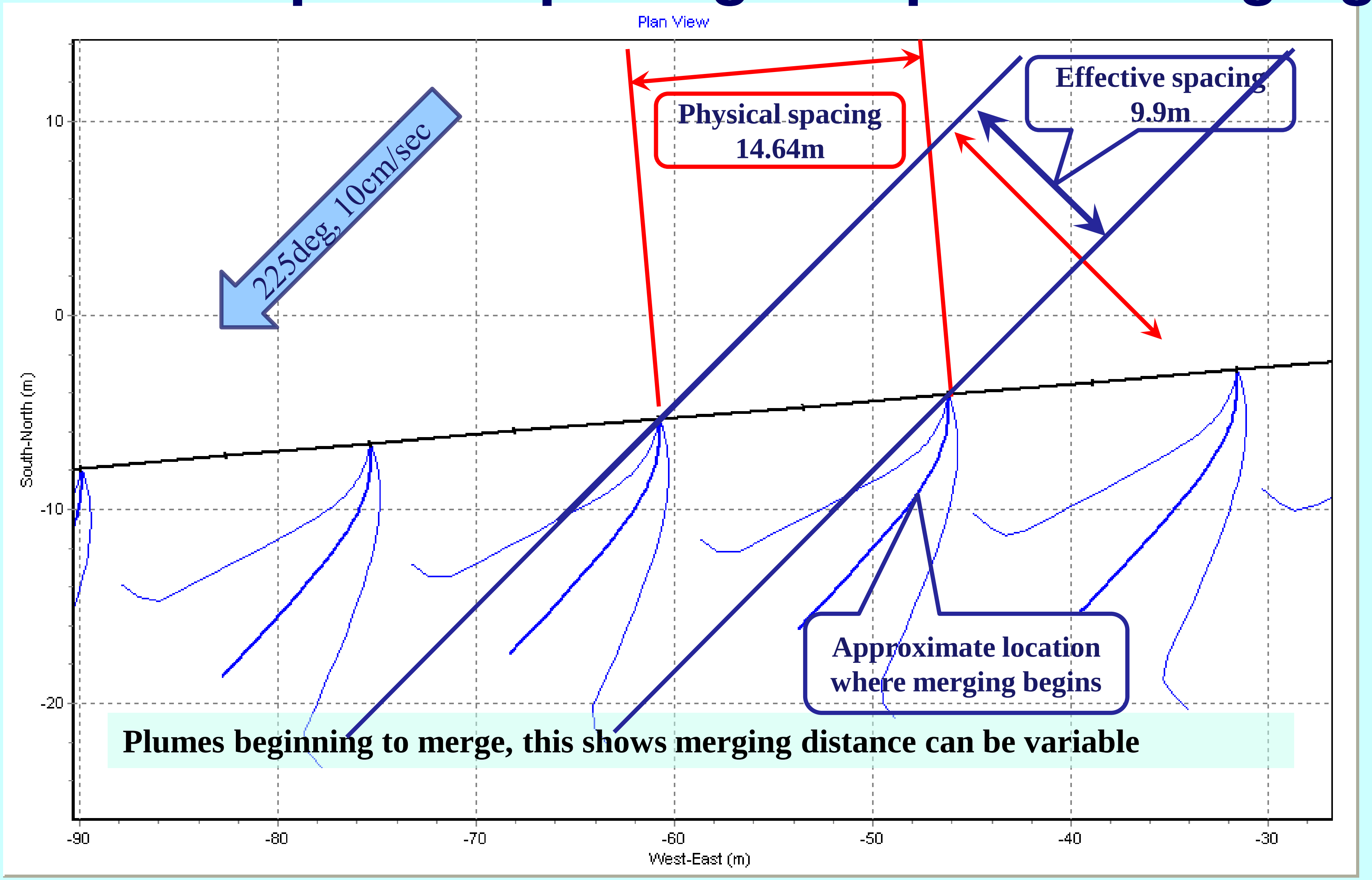
Mar del Plata Submarine outfall: awaiting deployment

Diffuser Design:

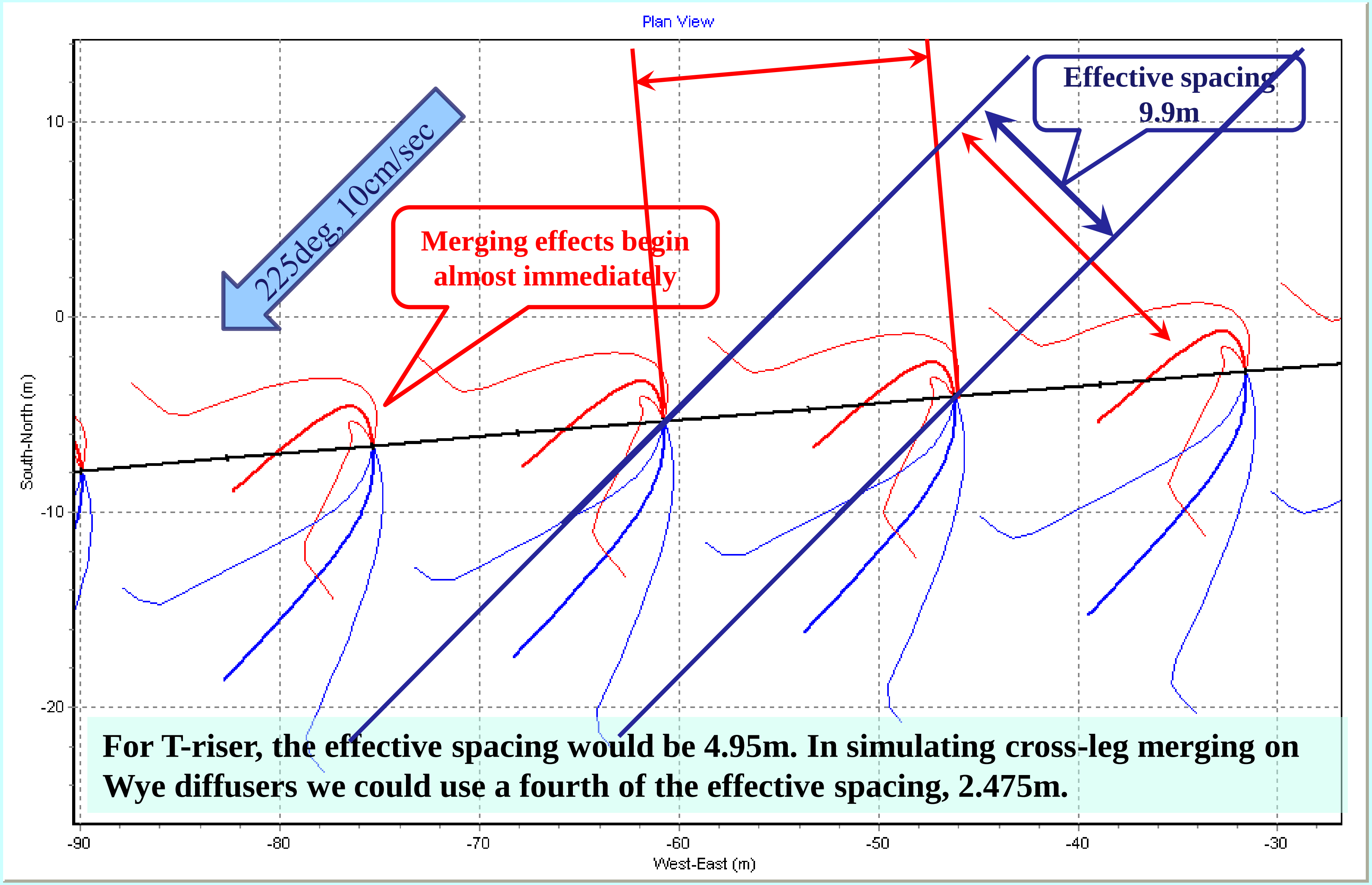
Visual Plumes, receiving wáter impacts

PlumeHyd or similar internal hydraulics

Critical: plume spacing and plume merging



Cross-diffuser merging



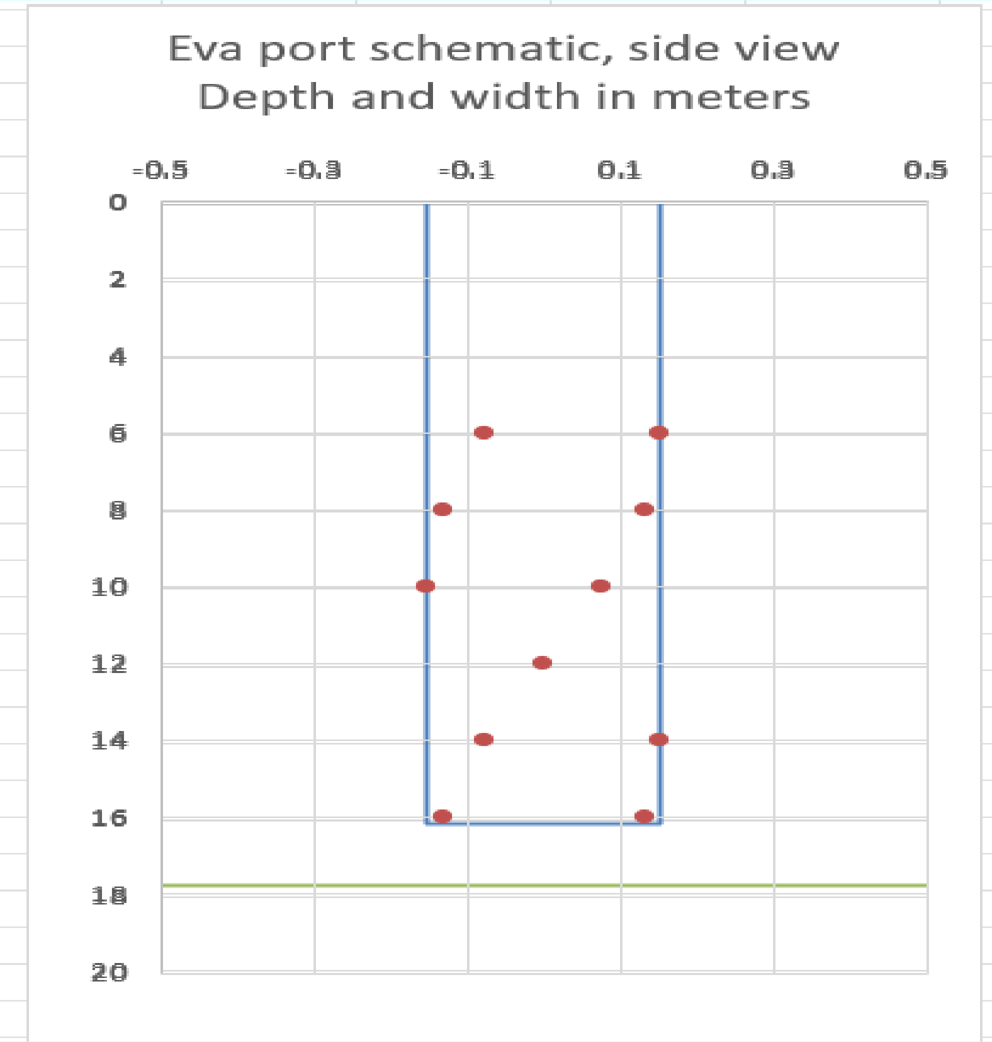
For T-riser, the effective spacing would be 4.95m. In simulating cross-leg merging on Wye diffusers we could use a fourth of the effective spacing, 2.475m.


Interlude

Small Source
(Not Buenos Aires)

Alternative
Vertical diffusers
Easier to maintain
More economical

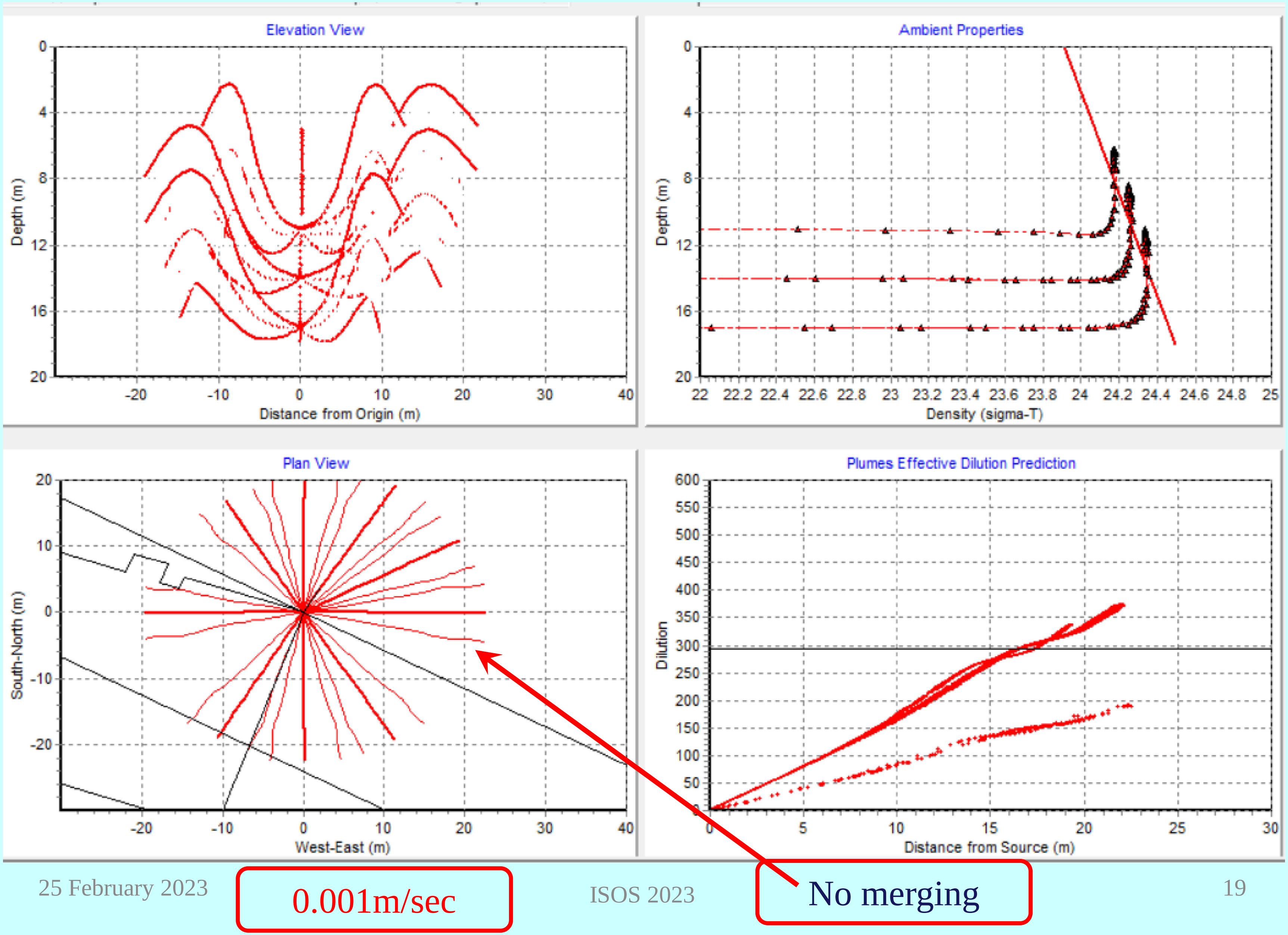
Alternative: Vertical Radial Outfall



Vertical pipe with ports arranged in spiral fashion to minimize the effects of plume merging

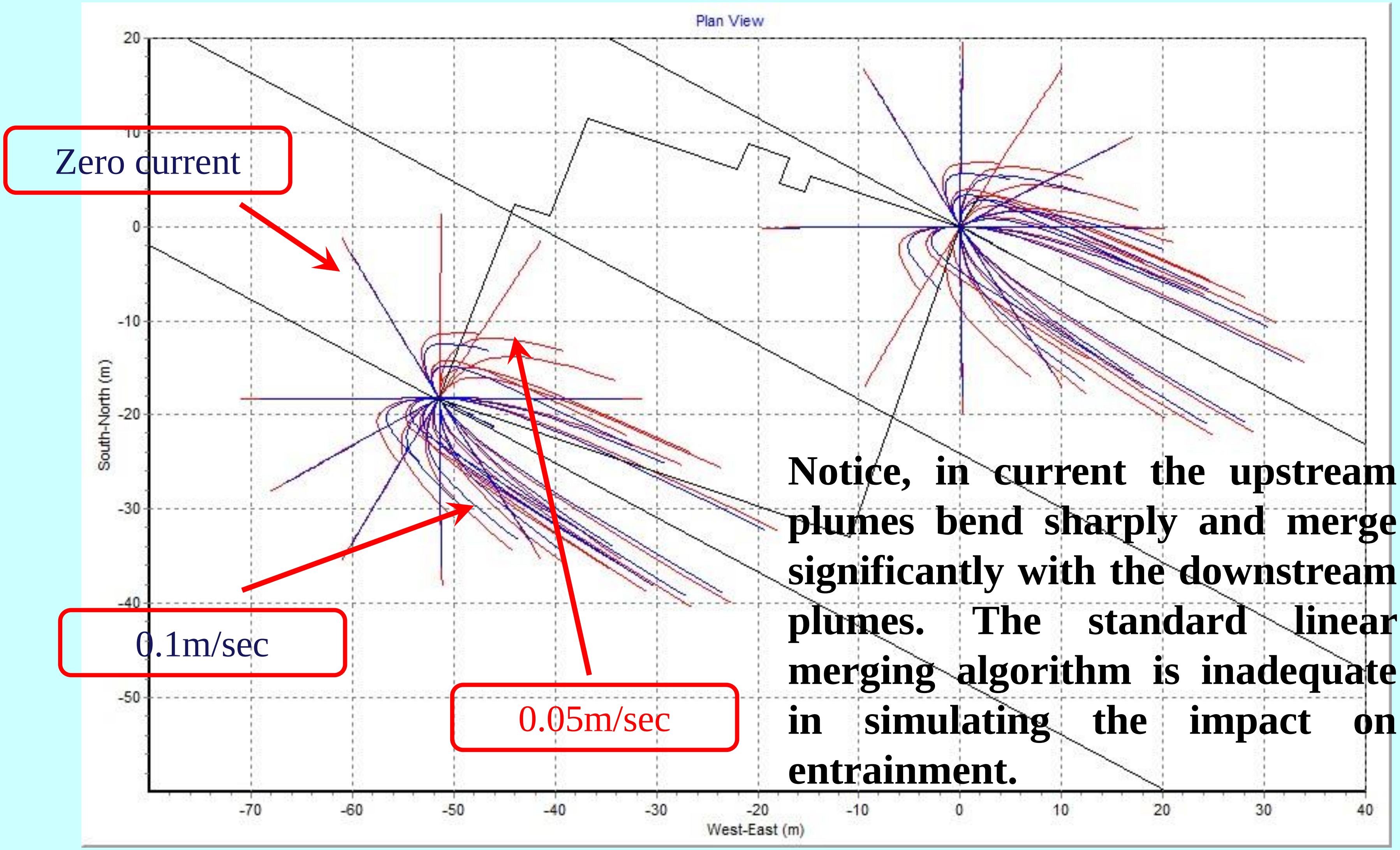
Rosette Elevation and Plan Views,…

Current direction 330 (-30) deg, almost zero



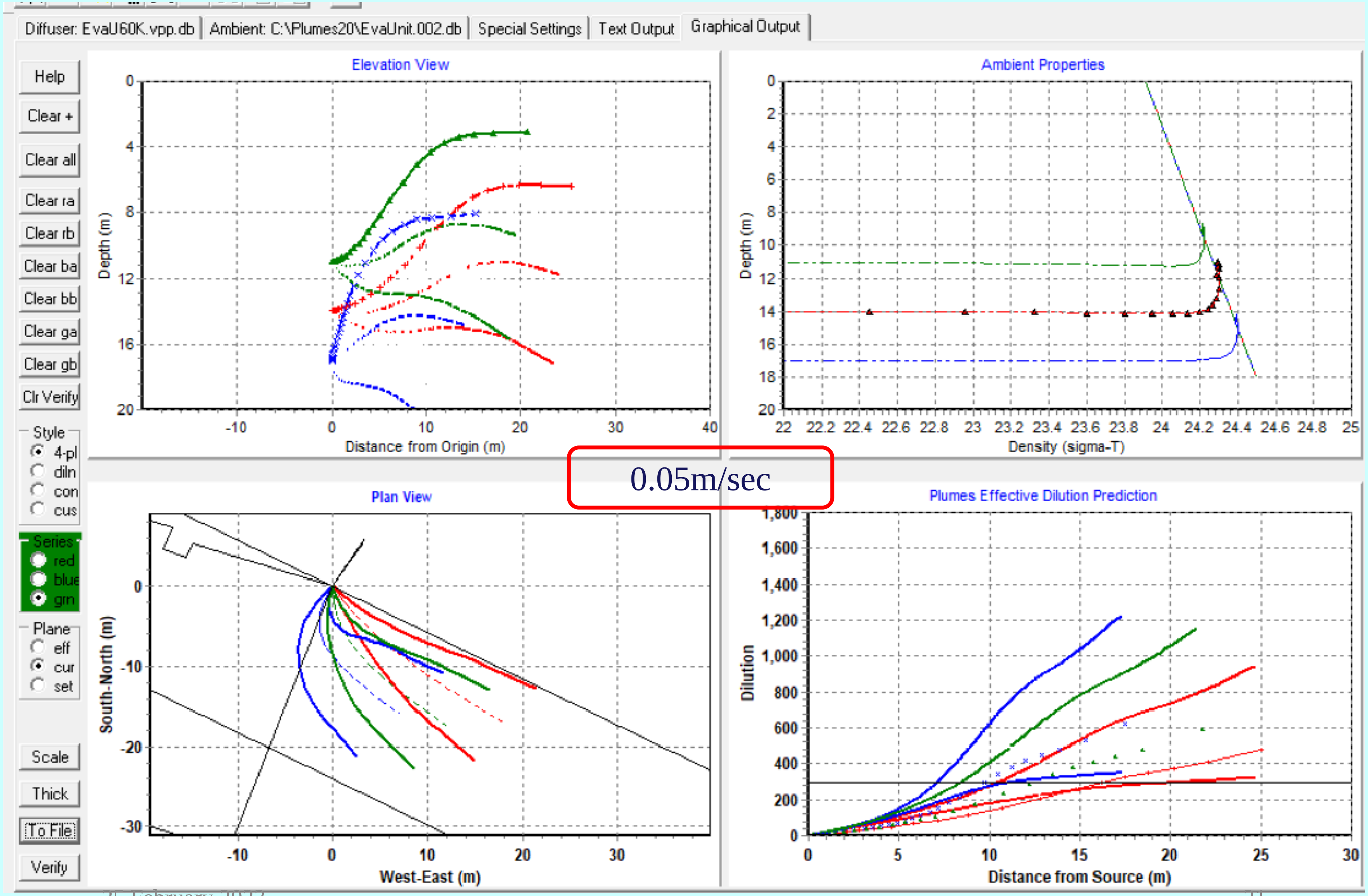
Plume Centerlines in Plan View

Three Current Scenarios



Notice, in current the upstream plumes bend sharply and merge significantly with the downstream plumes. The standard linear merging algorithm is inadequate in simulating the impact on entrainment.

Cluster Initial Dilution?



What to do?

Simulating Merging of Radial Plumes

Upstream Plume Concentration at Point of Merging

Ambient Inputs

	Measurement depth or height	Near-field current speed	Near-field current dir.	Ambient salinity(*)	Ambient temperature	Background concentration	Pollutant decay rate(*)	n/r	n/r	Far-field diffusion coeff
Depth or Height		depth	depth	depth	depth	depth	depth	depth	depth	depth
Extrapolation (sfc)		constant	constant	constant	constant	constant	constant	constant	constant	constant
Extrapolation (btm)		constant	constant	constant	constant	extrapolated	constant	constant	constant	constant
Measurement unit	m	m/s	deg	psu	C	ppm	s-1	m/s	deg	m0.67/s2
	0	0.001	330	31.9999	13.93	0.61	0			0.0003
	18			32.4	12.54					

txt2db

UM3

Ambient file list
Filename
rosette.001.db 1 1

Alternative: Simulate the upstream plumes to provide information on dilution (and concentration) achieved at the second trapping level. Input that as the background concentration for the appropriate downstream plumes. (This corresponds best to the second trapping level; little entrainment of dynamic properties.)

Box Model Validation Tool

From Phil Roberts, received 5 Jan 2022

(1986), which shows four candidate discharge sites. For only two of these was zero onshore transport predicted. The visitation frequencies are also very useful for assessing and showing impacts on areas of particular significance, such as shellfish areas.

3.3.4 Long-term flushing

Finally, we consider the long-term buildup of contaminants in the vicinity of the discharge, or coastal "flushing" which occurs on long time scales (Figure 3.2). In the previous section, we divided the plume into "young" and "old" puffs. The young puffs, whose travel times are of order a day or less, contribute most of the local bacterial impacts and can be analyzed by means of the statistical model presented above. The "old" puffs are subject to considerable decay and diffusion and generate a concentration that can be considered to be a "background" mean concentration field in the vicinity of the diffuser. The level of this concentration is governed primarily by flushing due to the mean drift, horizontal diffusion, and, for non-conservative substances, chemical and biological decay. One approach to predicting the physical dilution caused by these processes is to estimate it from a solution to the two-dimensional diffusion equation (Csanady 1983a; Koh 1988). We here consider a simpler method, however, which is particularly useful for comparing the relative orders of magnitude of the various processes. This is a mass-balance box model (Csanady, 1983b) as shown in Figure 3.31.

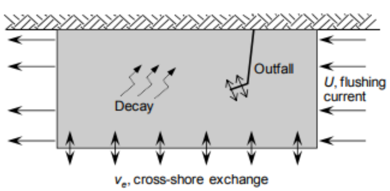


Figure 3.31 Box model for estimating long-term buildup of contaminants (after Csanady 1983b)

Tidal currents distribute the effluent over an area, or "box" whose dimensions are approximately equal to the tidal amplitude. These

dimensions are approximately $X = u_t T/2$ and $Y = v_t T/2$, in the alongshore and cross-shore directions, respectively, where u_t and v_t are the amplitudes of the tidal currents, and T is the tidal period. Csanady (1983b) calls this area the "extended source region." It would be comparable to the outer edge of the visitation frequency contours, for example Figure 3.30.

Long-term average current speeds are usually much slower than instantaneous values. They lead to an average dilution equal to UhY/Q_T, where Q_T is the total effluent flowrate, h the average depth of the plume over the extended area, and U the long-term average "flushing velocity."

This can be extended to include the other processes by applying a mass balance to the box. This yields a "long-term average dilution" S_p:

$$S_p = \frac{UhY}{Q_T} + \frac{v_e hX}{Q_T} + \frac{khXY}{Q_T} \qquad (3.47)$$

The first term on the right hand side is the dilution due to flushing by the mean current. The second is dilution due to cross-shore mixing. This is parameterized by v_e, a mass transfer "diffusion velocity," which can be assumed equal to the standard deviation of the cross-shore tidal fluctuations (probably an underestimate). The third term is "dilution" due to chemical or biological decay, where k is a first-order decay rate. It can be seen that the total effective dilution is the sum of these individual dilutions.

Consider a typical outfall problem. Suppose we have a discharge $Q_T = 5$ m³/s into a tidal current whose alongshore amplitude is $u_t = 0.25$ m/s, and cross-shore amplitude is $v_t = 0.08$ m/s, and cross-shore rms velocity is $v_e = 0.04$ m/s. Suppose the average current speed (the flushing velocity) is $U = 0.06$ m/s. For a semi-diurnal tide, the period T is about 12 hours. Suppose further that the average depth (thickness) of the wastefield is 15 m, and the bacterial decay rate (averaged over 24 hours) is $T_{90} = 10$ hours, corresponding to $k \approx 6\times10^{-5}$ s⁻¹.

Then the extended source area (size of the box in Figure 3.31) is:

$$X = u_T T/2 = 0.25\times12\times3600/2 \approx 5{,}400 \text{ m} \approx 5.4 \text{ km} \quad \text{and}$$
$$Y = v_T T/2 = 0.08\times12\times3600/2 \approx 1{,}700 \text{ m} \approx 1.7 \text{ km}$$

and the dilutions are (Eq. 3.47):

Due to the mean current: $\frac{UhY}{Q_T} = \frac{0.06\times15\times1700}{5} \approx 300$

Due to cross-shore exchange: $\frac{v_e hX}{Q_T} = \frac{0.04\times15\times5400}{5} \approx 650$

Due to decay: $\frac{khXY}{Q_T} = \frac{6\times10^{-5}\times15\times5400\times1700}{5} \approx 1650$

The total effective dilution, the sum of these dilutions, is about 2600.

These are obviously only approximate order of magnitude calculations, but they are very useful for estimating long-term impacts. They can be applied to other substances such as toxic materials to estimate their potential accumulation.

3.4 Conclusions

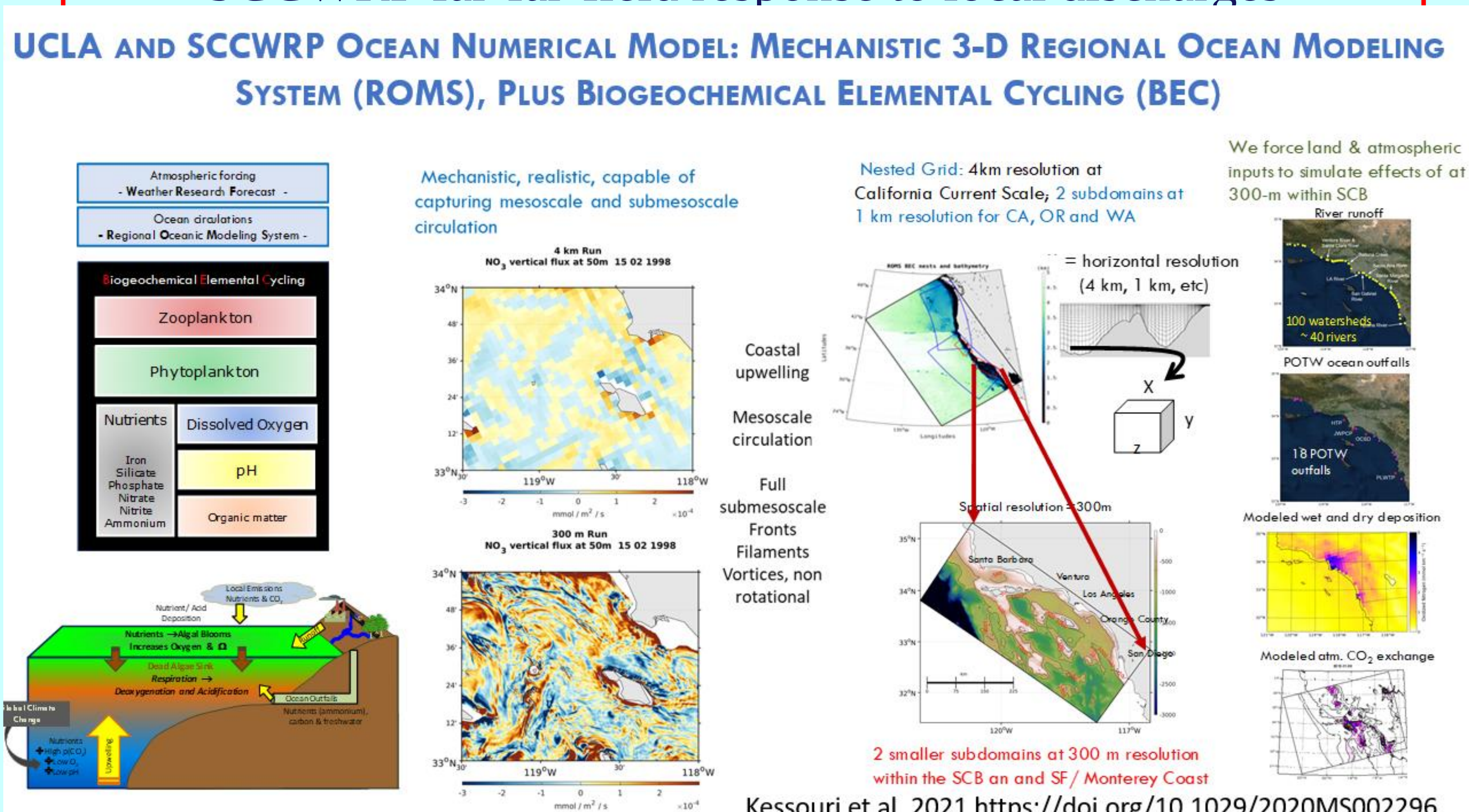
This chapter has focused on the main processes that determine the fate and transport of wastewater discharged from ocean outfalls, means to predict them, and their implications for outfall design. It will usually be possible to design an outfall that achieves initial dilutions of 100:1 and greater. The conclusions from the far field modeling examples are typical of many coastal discharges. An unsteady and spatially variable current field is a very dispersive environment. It results in rapid decrease in visitation frequency, mean contaminant concentration levels, and other measures of bacterial impact with distance from the diffuser. This will ensure that any measurable environmental impact is confined to a small area around the discharge, even with minimal treatment. This has been confirmed in many outfall field studies. Mean current circulation patterns and other mechanisms will usually prevent significant accumulation or "background levels" of contaminants around the discharge. The calculations presented in this chapter confirm the importance of diffusion and dispersion in coastal waters, and why they are usually more important than treatment in minimizing the environmental impact of a marine disposal system.

The box model approach may be used to help validate the results obtained from UM3. It helped to confirm the background concentration approach to simulating merging of radially discharged plumes at different levels.

The Future of Regulations?

Regional Model Results

SCCWRP far-far-field response to local discharges



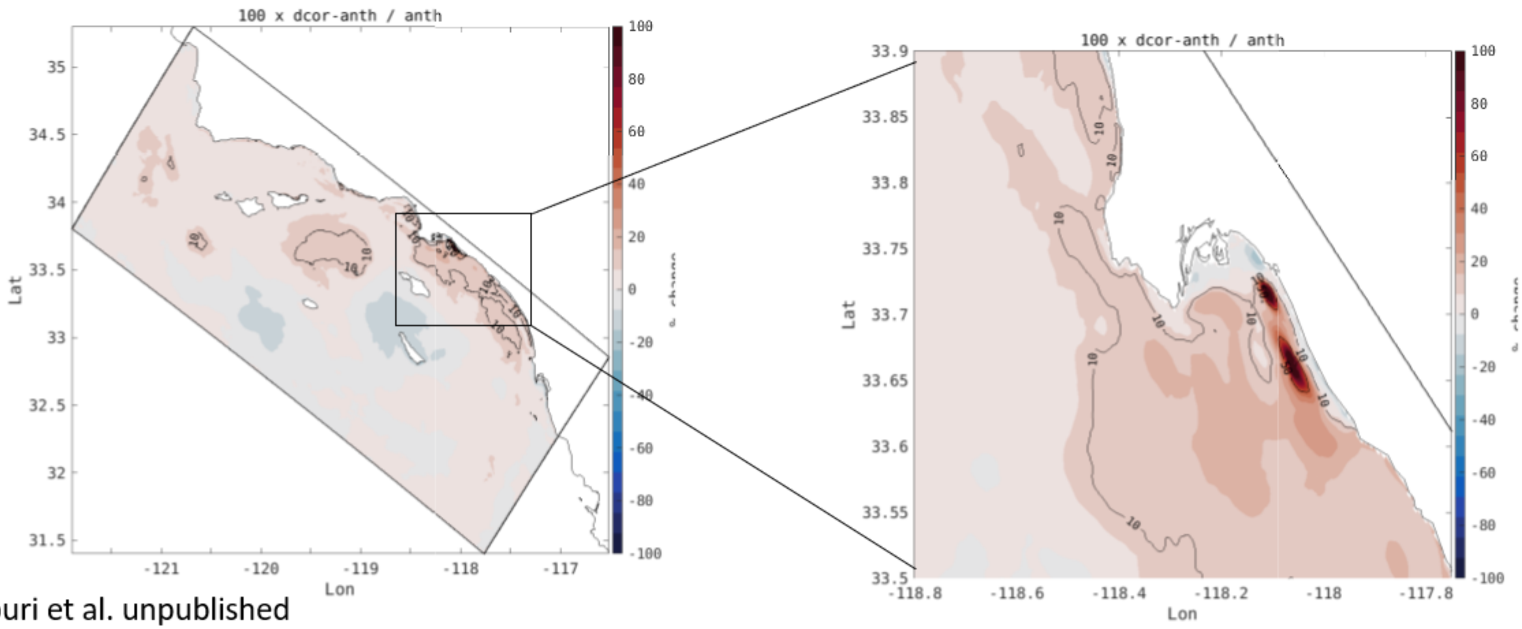
Courtesy of Dr. Martha Sutula of SCCWRP

Regional Model Results cont.

SCCWRP far-far-field response to local discharges

SIMULATED INCREASED ALGAL PRODUCTION RATE OF UP TO 50%, LOCALIZED AROUND PLATFORM OUTFALL, LOW BUT DETECTABLE OFFSHORE

Change assessment: integrated primary production rate in surface waters



Kessouri et al. unpublished

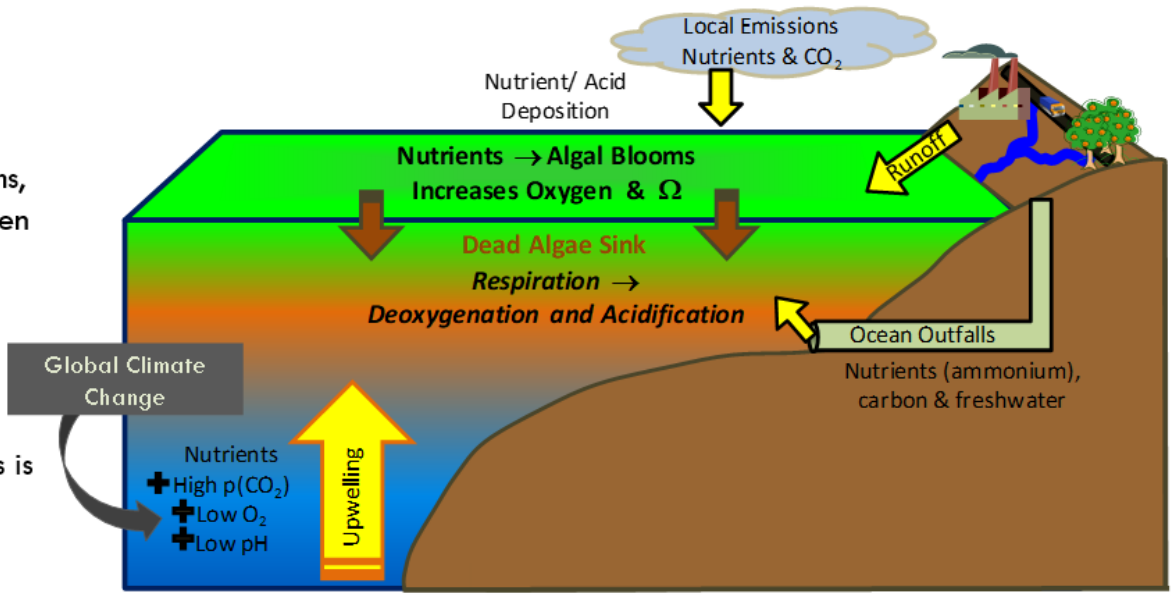
Coastal Processes

SCCWRP far-far-field response to local discharges

End of Pipe of Assessments of Nutrient Effects Do Not Address Potential for the Wider Scale Impacts

Nutrients fuel algal blooms, which can decrease oxygen and pH

Scales at which this occurs is well beyond nearfield mixing

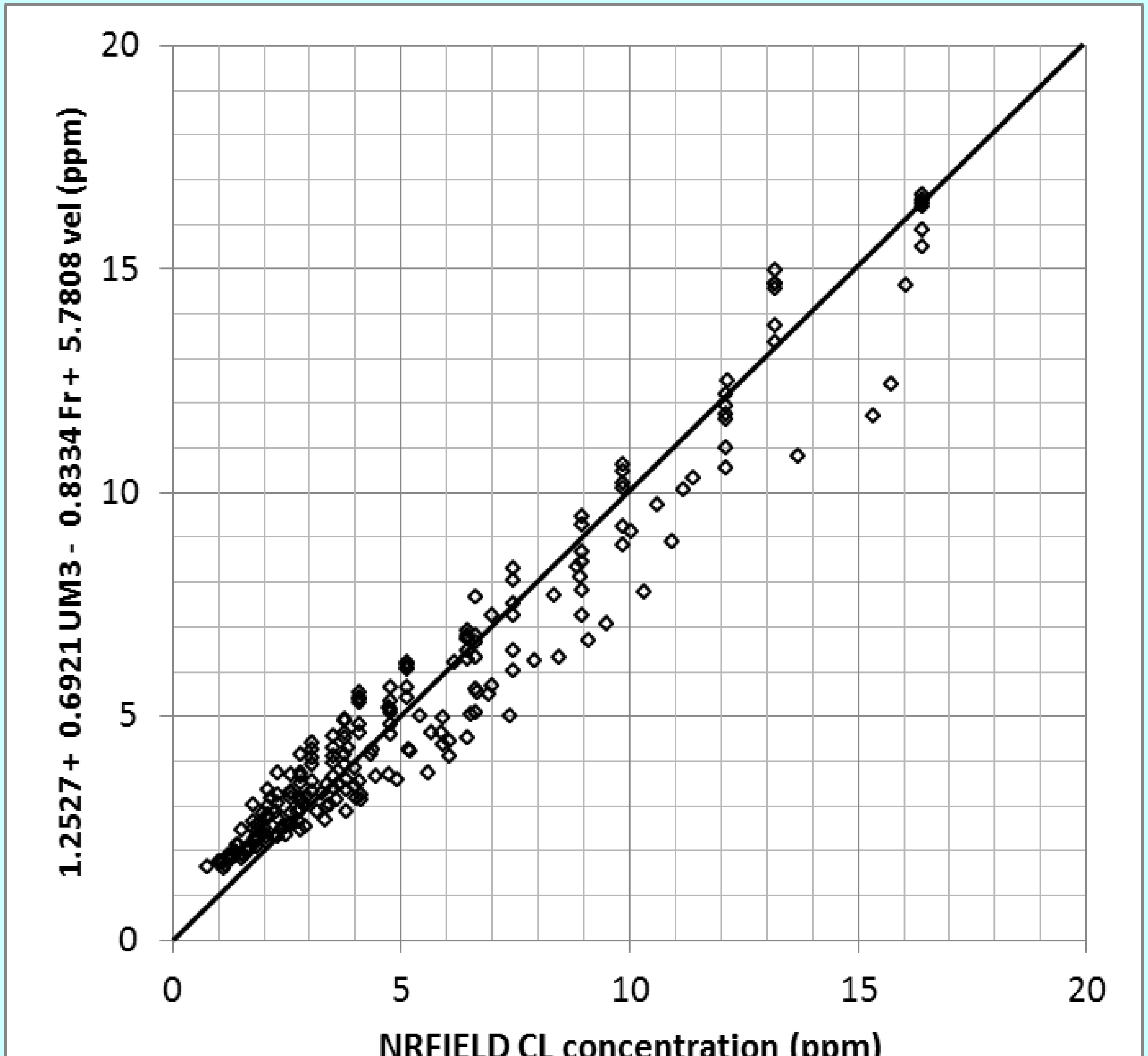


Kessouri et al. 2021 https://doi.org/10.1073/pnas.2018856118

Acknowledgements

I wish to thank my wife, Dr. Anne Sigleo, for her review comments; also Engineer Jay Rao for oversight, guidance, and support; Dr. Martha Sutula for providing content relating to SCCWRP ROMS-BEC modeling; Dr. Phil Roberts for collaboration in improving and providing content for Visual Plumes; staff of the California Waterboards and the San Francisco Bay Estuaries Institute for their continued efforts to support and update Visual Plumes modernization efforts; and all individuals who kindly help me in ways too numerous to recount here.

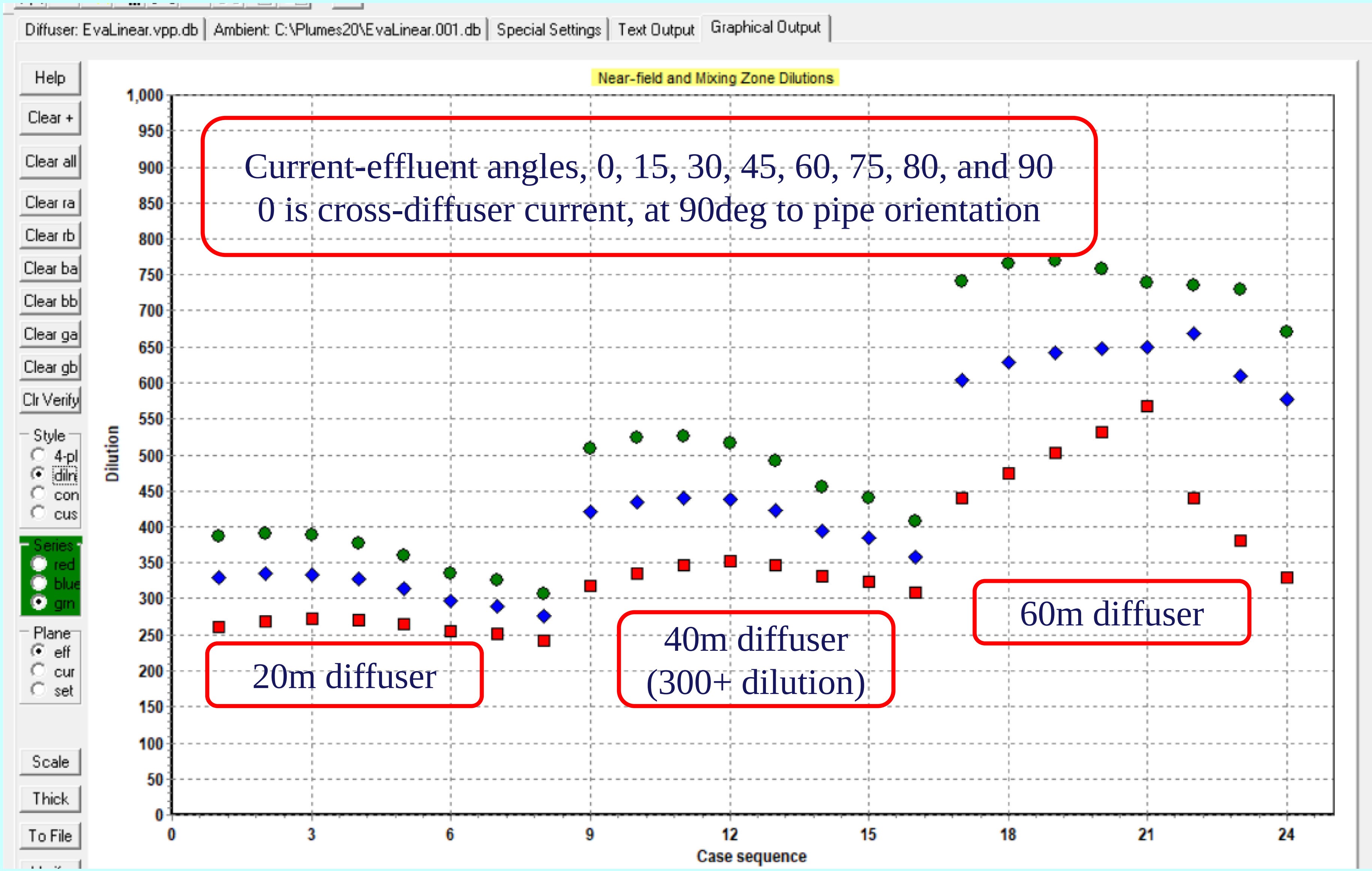
Virtual Beach Multi-linear Regression



Glaciares National Park

Thank you

Linear Bottom Diffuser, 1, 2, and 3m Spacing



Effective and Volume Output

Ambient Table:

Depth	Amb-cur	Amb-dir	Amb-sal	Amb-tem	Amb-pol	Decay	Far-spd	Far-dir	Disprsn	Density
m	m/s	deg	psu	C	kg/kg	s-1	m/s	deg	m0.67/s2	sigma-T
0.0	0.050	330.0	32.00	13.93	2.0000E-6	0.0	-	-	0.0003	23.91077
18.00	0.050	330.0	32.40	12.54	2.0000E-6	0.0	-	-	0.0003	24.49442

Diffuser table:

P-dia	VertAng	H-Angle	SourceX	SourceY	Ports	MZ-dis	Isoplth	P-depth	Ttl-flo	Eff-sal	Temp	Polutnt
(m)	(deg)	(deg)	(m)	(m)	()	(m)	(concent)	(m)	(bbl/d)	(psu)	(C)	(ppm)
0.03249	-4.0000	300.00	0.0	0.0	1.0000	1000.0	0.0	14.000	3333.0	20.030	51.667	1000.0

Simulation:

Froude No: 161.2; Strat No: 3.63E-5; Spcg No: 8.44E+9; k: 242.5; eff den (sigmaT) 1.600960; eff vel 12.13(m/s);

Step	Depth	Amb-cur	P-dia	Polutnt	net Dil	x-posn	y-posn	Iso dia
	(m)	(m/s)	(m)	(ppm)	()	(m)	(m)	(m)
0	14.00	0.050	0.0254	1000.0	1.000	0.0	0.0	0.0;

Potential for more dilution

Ambient species greater than plume isopleth value, physical boundary graphed

178	14.11	0.050	1.207	21.35	46.84	1.447	-2.259	1.2074; local maximum rise or fall;
200	14.08	0.050	1.786	14.53	68.81	2.171	-3.244	1.7863;
285	11.92	0.050	6.359	4.458	224.3	8.372	-9.686	6.3592; trap level;
344	10.97	0.050	9.104	3.485	287.0	13.02	-13.42	9.1045; local maximum rise or fall;
385	11.79	0.050	11.01	3.081	324.6	18.12	-17.22	11.012; trap level;

Horiz plane projections in effluent direction: radius(m): 2.2584; CL(m): 23.969 Lmz(m): 26.228

forced entrain 1 7.71E+9 2.208 11.01 0.985

Rate sec-1 0.0 dy-1 0.0 kt: 0.0 Amb Sal 32.2606

;

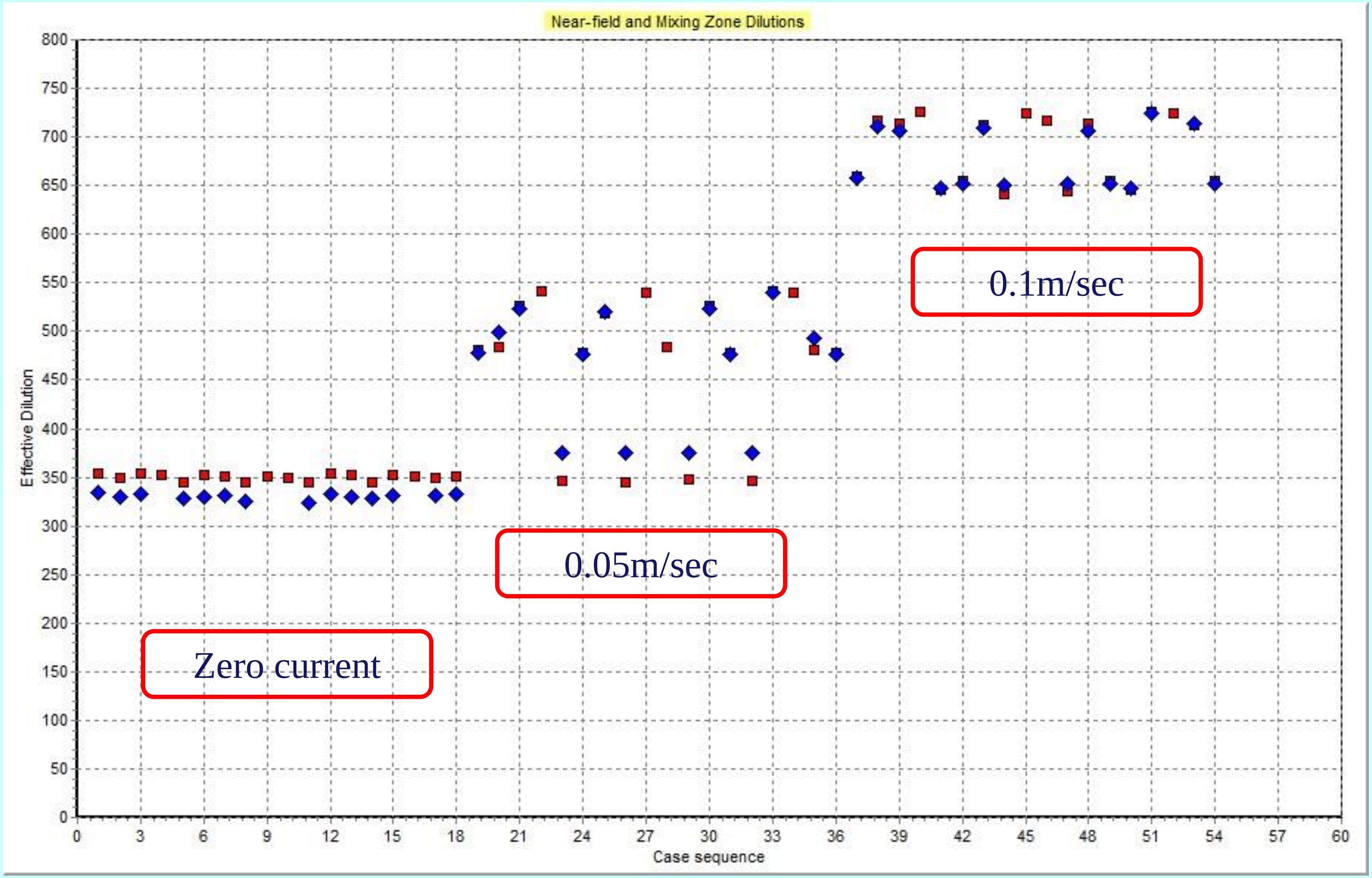
	Depth	Amb-cur	P-dia	Polutnt	Dilutn	x-posn	y-posn	Iso dia
490	14.84	0.050	13.74	2.846	1246.8	7.071	-16.03	13.743; trap level;

	Depth	Amb-cur	P-dia	Polutnt	net Dil	x-posn	y-posn	Iso dia
490	14.84	0.050	13.74	2.846	351.4	7.071	-16.03	13.743; trap level;

	Depth	Amb-cur	P-dia	Polutnt	Dilutn	x-posn	y-posn	Iso dia
419	9.348	0.050	12.76	2.893	1177.5	12.51	-17.79	12.761; trap level;

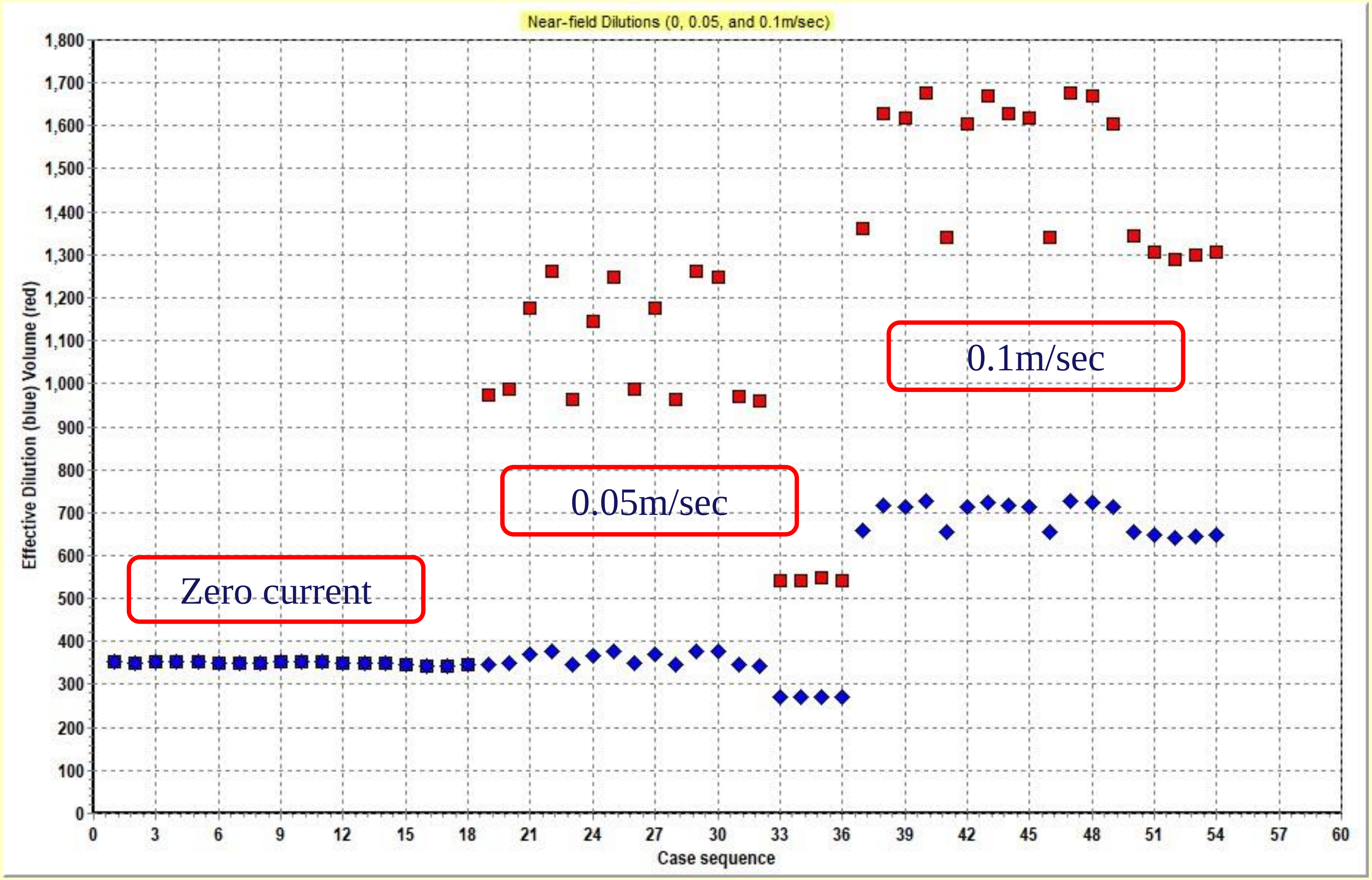
Effective Dilutions in Stratified Ambient

blue: 40K bbl/day, 14ports, red: 60K bbl/day, 18ports



Comparing Effective and Volume Dilutions

60K bbl/day, 18ports; red volume, blue effective measues



Effective Dilution

United States Environmental Protection Agency
Office of Research and Development Washington DC 20460
EPA/600/R-94/086 June 1994

EPA

Dilution Models for Effluent Discharges

Third Edition

$$\frac{c_e}{c_p} \;'\; \frac{v_e \;\%\; v_a}{v_e} \;'\; S_a \qquad \textbf{(5)}$$

Equation 5 demonstrates that for the special case of zero ambient concentration the volumetric dilution factor also describes the dilution of a pollutant. In most regulatory uses of the plume models, however, it is necessary to consider the actual, nonzero, ambient concentration of the suite of pollutants in the effluent. In the remainder of this report the term "effective dilution factor" (S_{aei}) is used to describe the dilution achieved for each pollutant in a plume. That is,

$$S_{ae_i} \;'\; \frac{c_{e_i}}{c_{p_i}} \qquad \textbf{(6)}$$

$S_{ae} = c_e / c_p$ for each pollutant individually

where the index, *i*, is used to demonstrate that in determining the final concentration of a pollutant in the diluted effluent the effective dilution must be determined for each pollutant individually.

Effective and Volume Output

Ambient Table:

Depth	Amb-cur	Amb-dir	Amb-sal	Amb-tem	Amb-pol	Decay	Far-spd	Far-dir	Disprsn	Density
m	m/s	deg	psu	C	kg/kg	s-1	m/s	deg	m0.67/s2	sigma-T
0.0	0.050	330.0	32.00	13.93	2.0000E-6	0.0	-	-	0.0003	23.91077
18.00	0.050	330.0	32.40	12.54	2.0000E-6	0.0	-	-	0.0003	24.49442

Diffuser table:

P-dia	VertAng	H-Angle	SourceX	SourceY	Ports	MZ-dis	Isoplth	P-depth	Ttl-flo	Eff-sal	Temp	Polutnt
(m)	(deg)	(deg)	(m)	(m)	()	(m)	(concent)	(m)	(bbl/d)	(psu)	(C)	(ppm)
0.03249	-4.0000	300.00	0.0	0.0	1.0000	1000.0	0.0	14.000	3333.0	20.030	51.667	1000.0

Simulation:

Froude No: 161.2; Strat No: 3.63E-5; Spcg No: 8.44E+9; k: 242.5; eff den (sigmaT) 1.600960; eff vel 12.13(m/s);

Step	Depth	Amb-cur	P-dia	Polutnt	net Dil	x-posn	y-posn	Iso dia	
	(m)	(m/s)	(m)	(ppm)	()	(m)	(m)	(m)	
0	14.00	0.050	0.0254	1000.0	1.000	0.0	0.0	0.0;	
Potential for more dilution									
Ambient species greater than plume isopleth value, physical boundary graphed									
178	14.11	0.050	1.207	21.35	46.84	1.447	-2.259	1.2074;	local maximum rise or fall;
200	14.08	0.050	1.786	14.53	68.81	2.171	-3.244	1.7863;	
285	11.92	0.050	6.359	4.458	224.3	8.372	-9.686	6.3592;	trap level;
344	10.97	0.050	9.104	3.485	287.0	13.02	-13.42	9.1045;	local maximum rise or fall;
385	11.79	0.050	11.01	3.081	324.6	18.12	-17.22	11.012;	trap level;

Horiz plane projections in effluent direction: radius(m): 2.2584; CL(m): 23.969 Lmz(m): 26.228

forced entrain 1 7.71E+9 2.208 11.01 0.985

Rate sec-1 0.0 dy-1 0.0 kt: 0.0 Amb Sal 32.2606

;

	Depth	Amb-cur	P-dia	Polutnt	Dilutn	x-posn	y-posn	Iso dia	
490	14.84	0.050	13.74	2.846	1246.8	7.071	-16.03	13.743;	trap level;

	Depth	Amb-cur	P-dia	Polutnt	net Dil	x-posn	y-posn	Iso dia	
490	14.84	0.050	13.74	2.846	351.4	7.071	-16.03	13.743;	trap level;

	Depth	Amb-cur	P-dia	Polutnt	Dilutn	x-posn	y-posn	Iso dia	
419	9.348	0.050	12.76	2.893	1177.5	12.51	-17.79	12.761;	trap level;

To a Future of Sustainability

Reducing loading as we amortize resource recovery