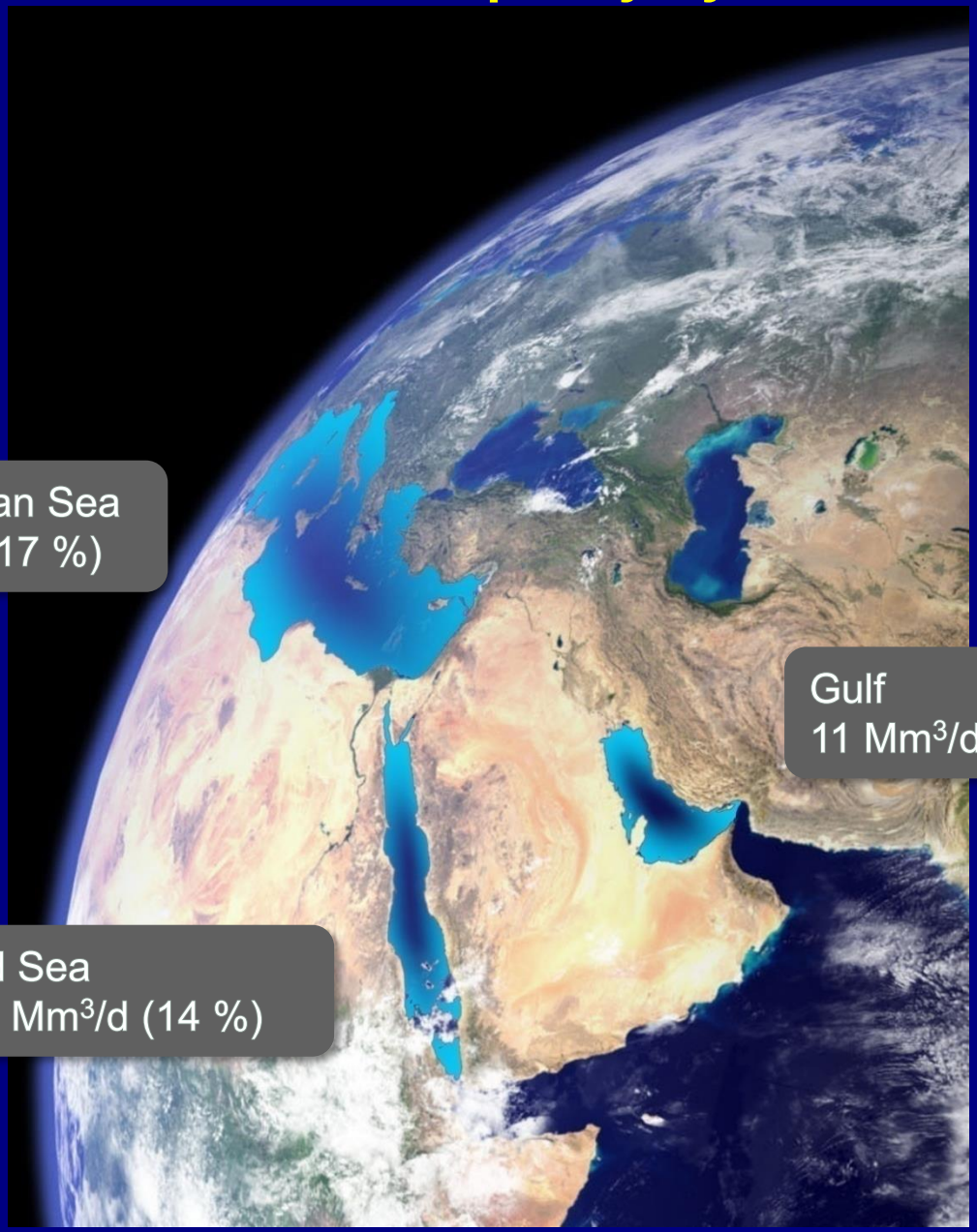
Desalinate Concentrate Disposal

Philip J. W. Roberts

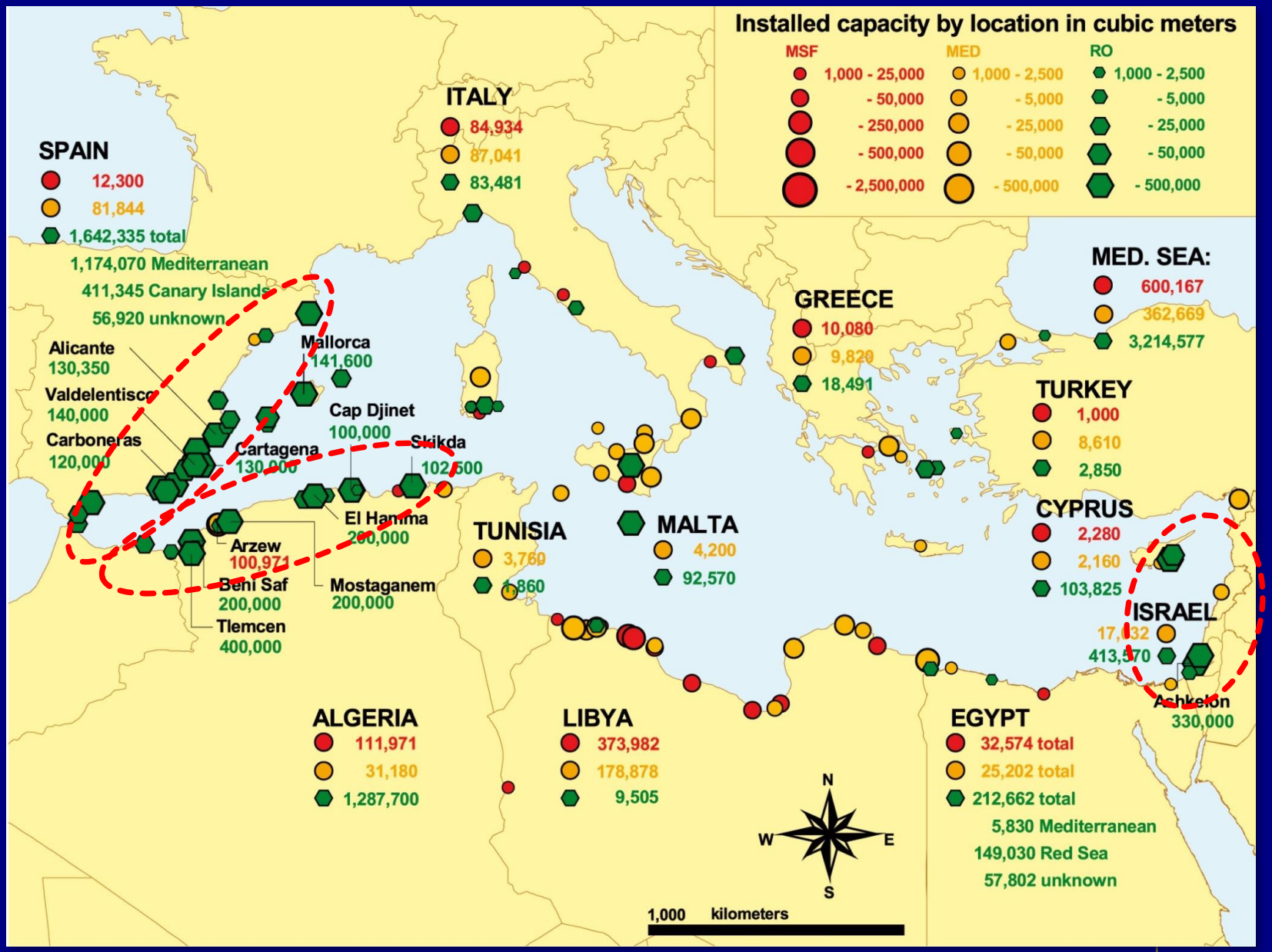
School of Civil and Environmental Engineering
Georgia Institute of Technology

Seawater Desalination – Capacity by Sea Area

76% of global capacity in three sea areas:

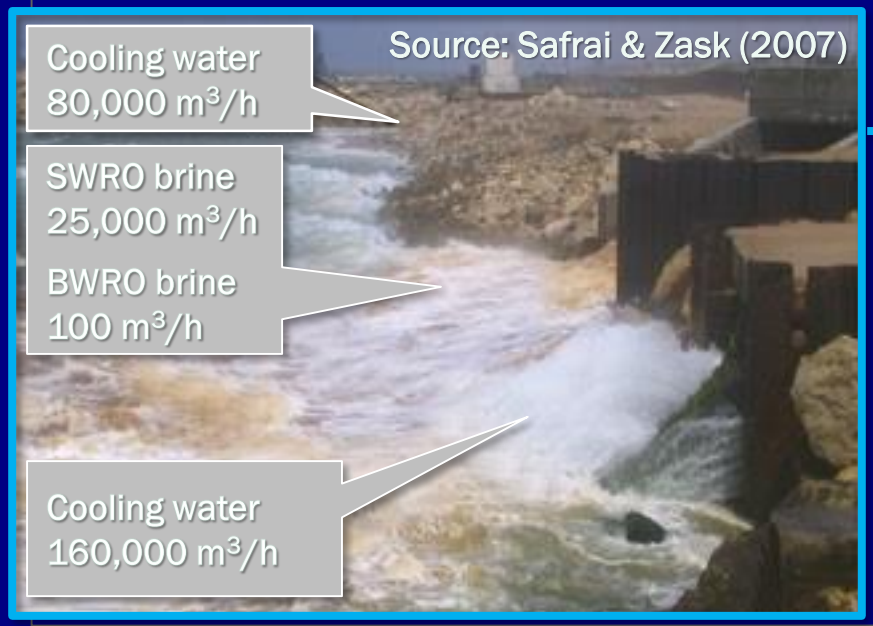


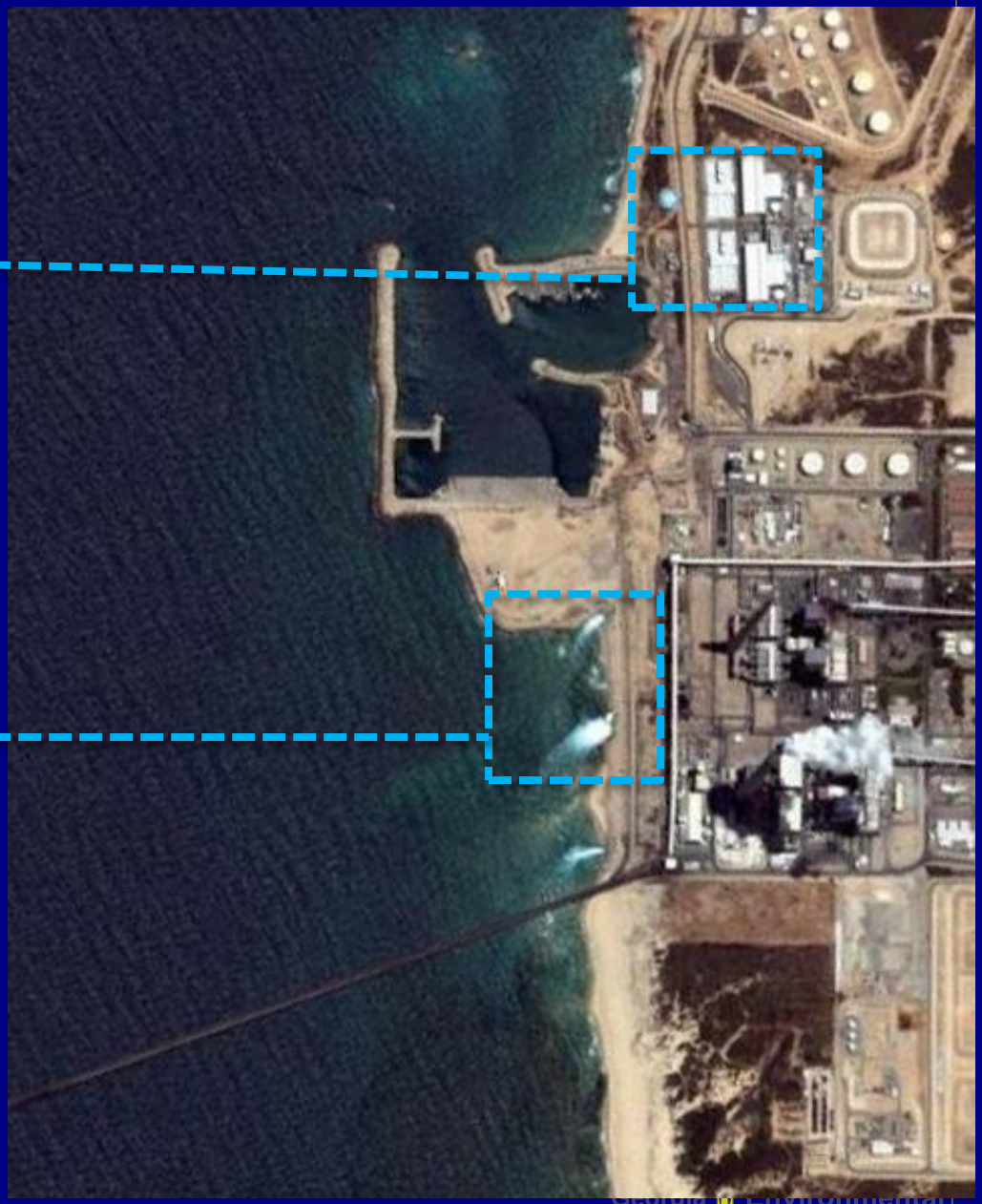
Mediterranean Sea



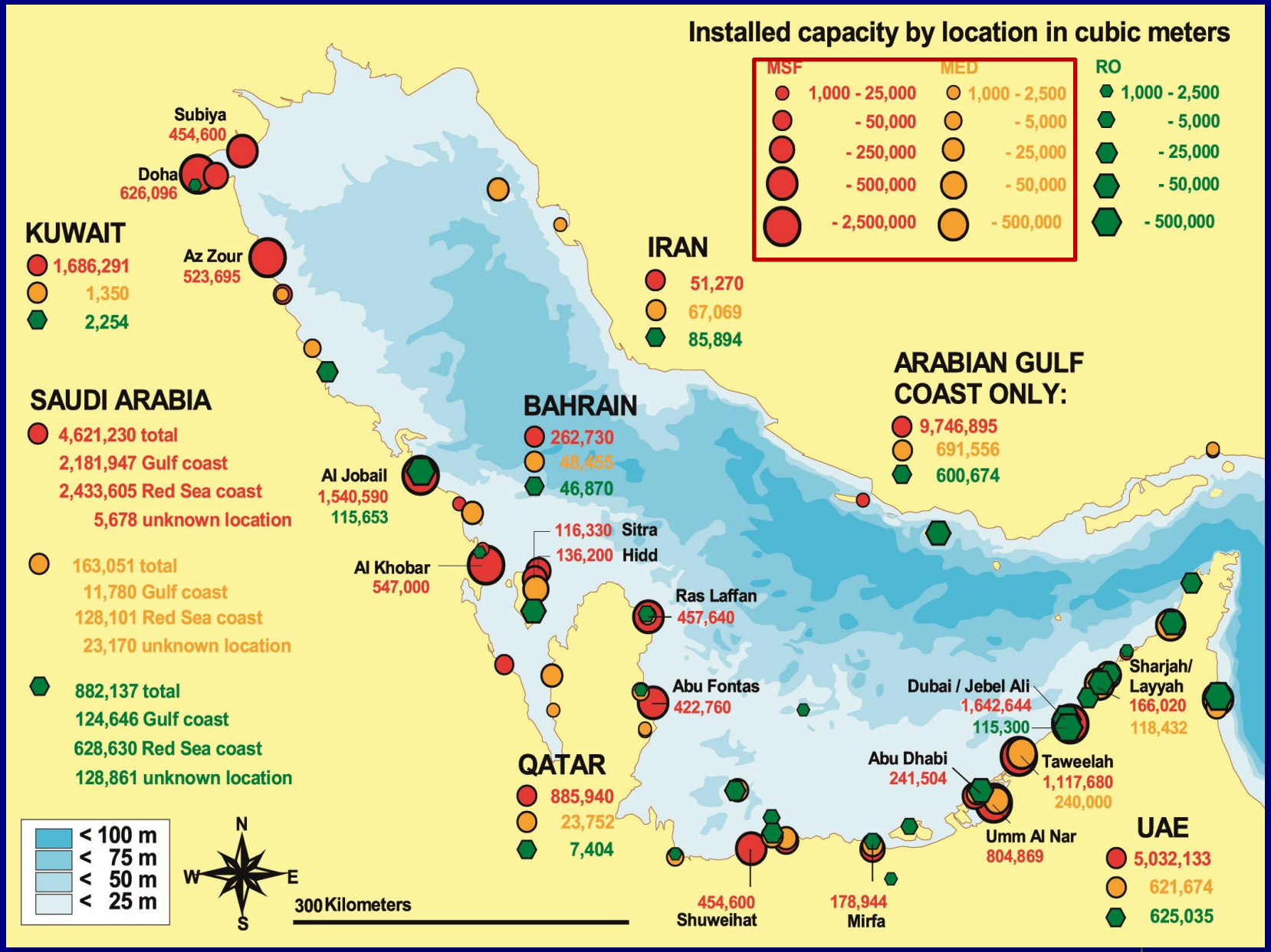
Lattemann and Höpner (2008), primary data from IDA (2006). Map includes all plants that are presumed online or in construction and all sites with a capacity > 1,000 m^3/day.

RO Plant Ashkelon (Israel)





Gulf of Arabia

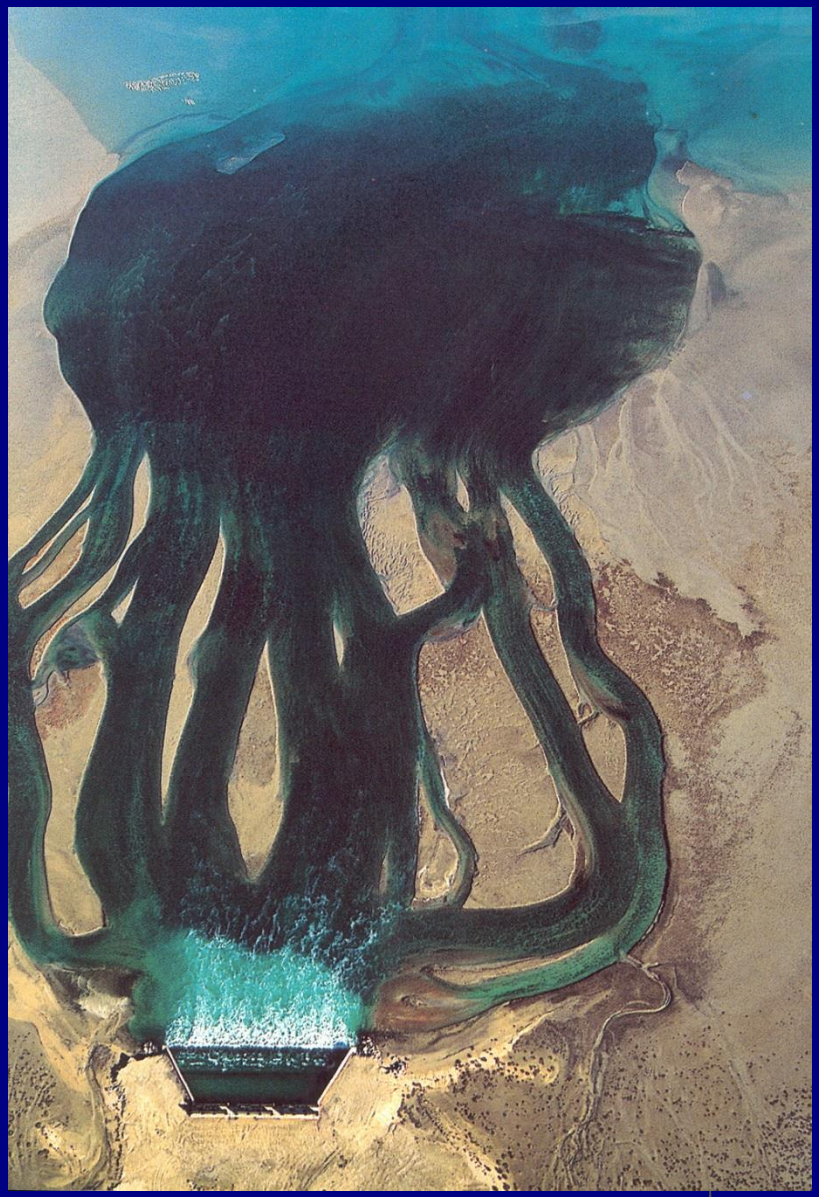


Lattemann and Höpner (2008), primary data from IDA (2006). Map includes all plants that are presumed online or in construction and all sites with a capacity > 1,000 m^3/day.

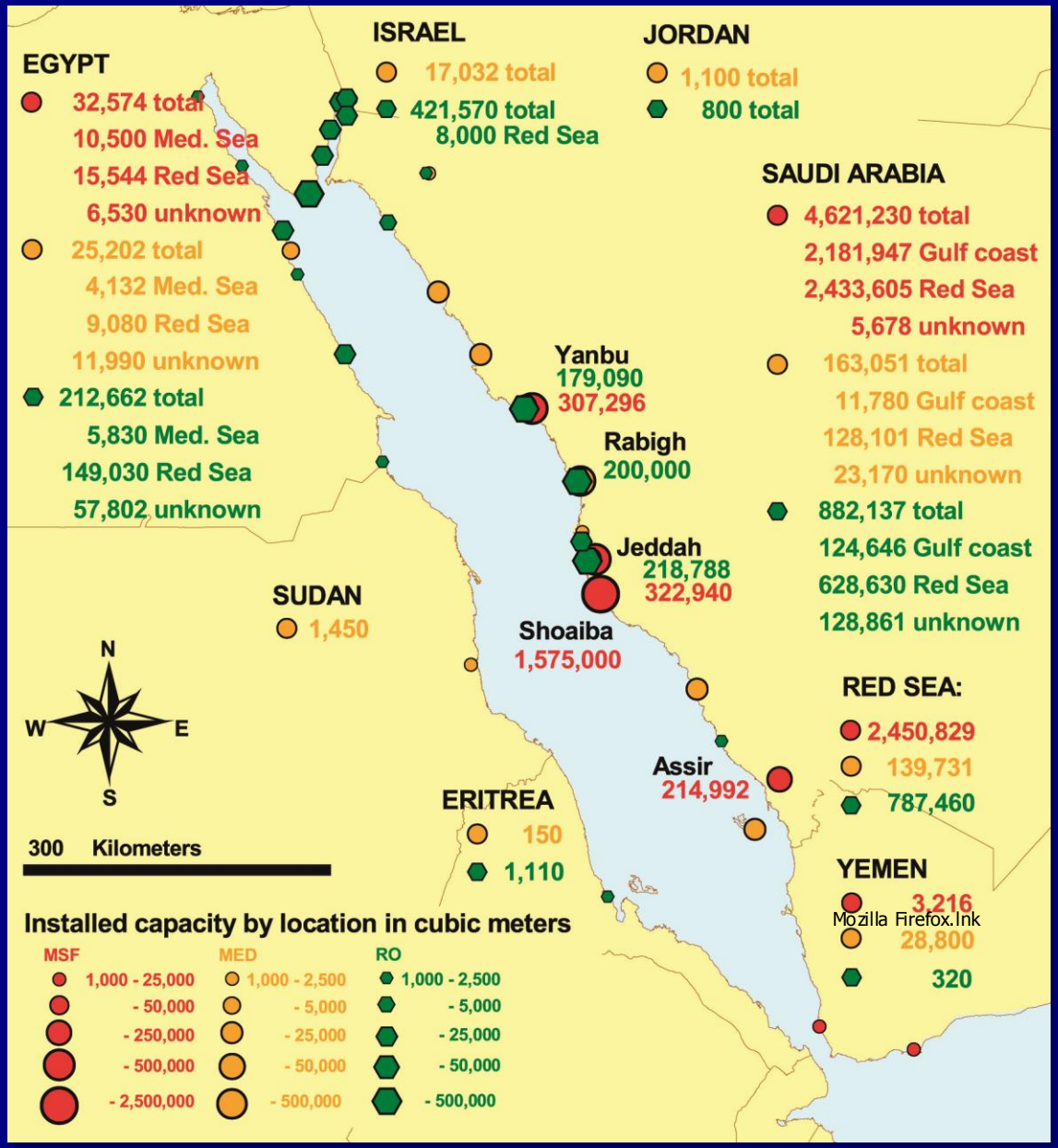
Discharge in Kuwait

Mixing devices

desalination plant discharge in Kuwait
http://www.icaen.uiowa.edu/fluidslab/gallery/images/flo20.jpg



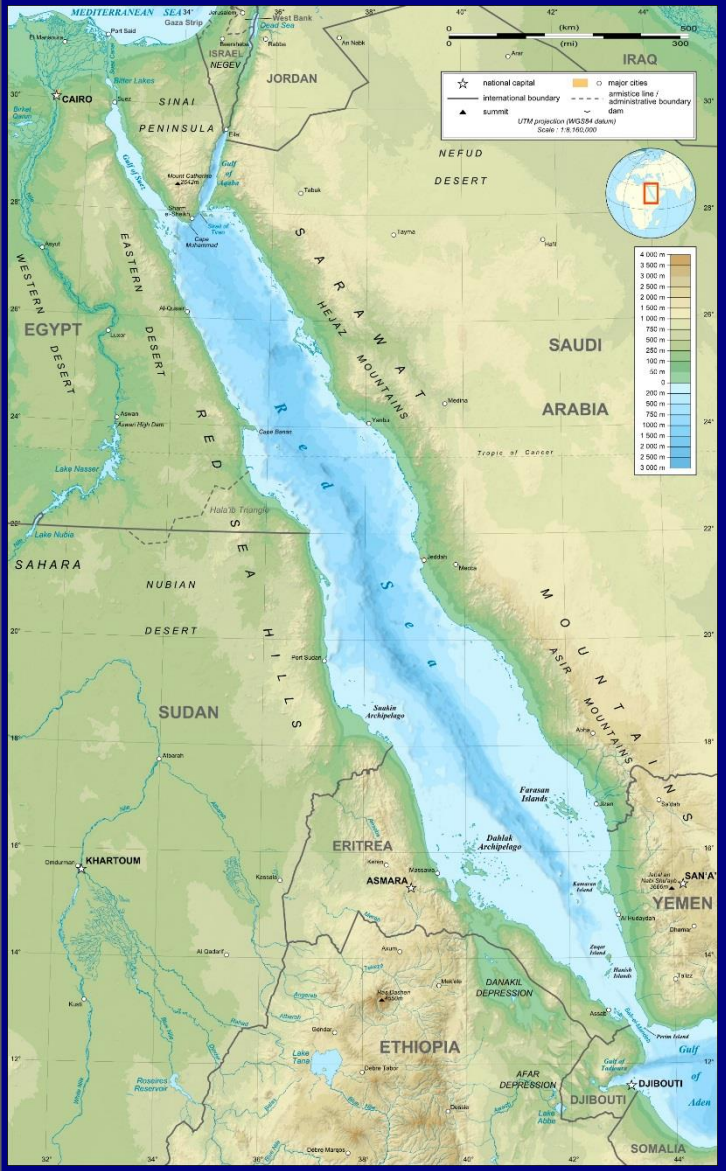
Red Sea



Lattemann and Höpner (2008), primary data from IDA (2006). Map includes all plants that are presumed online or in construction and all sites with a capacity > 1,000 m^3/day.

Are We Filling the Seas With Salt?

The Red Sea



Evaporates $\approx$ 2 m/yr!

Area $\approx$ 248,000 km^2

Flow $\approx 2 \times 248{,}000 \times 10^6$ / (365 days/yr $\times$ 86400 sec/day)

$\approx$ 16,000 m^3/s

Desal flow $\approx$ 100 m^3/s (2 billion gals/day)

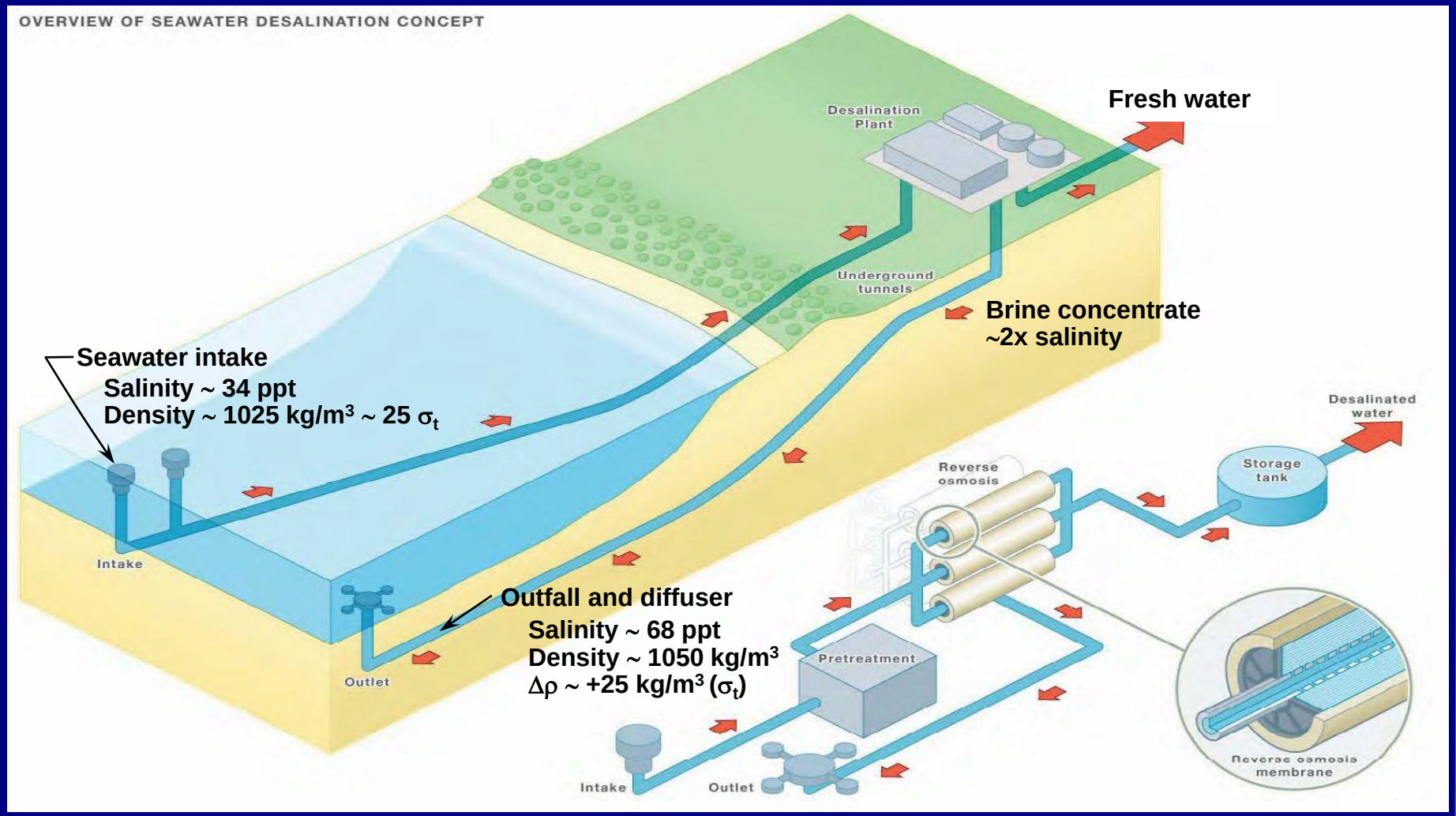
< 1%

Australia

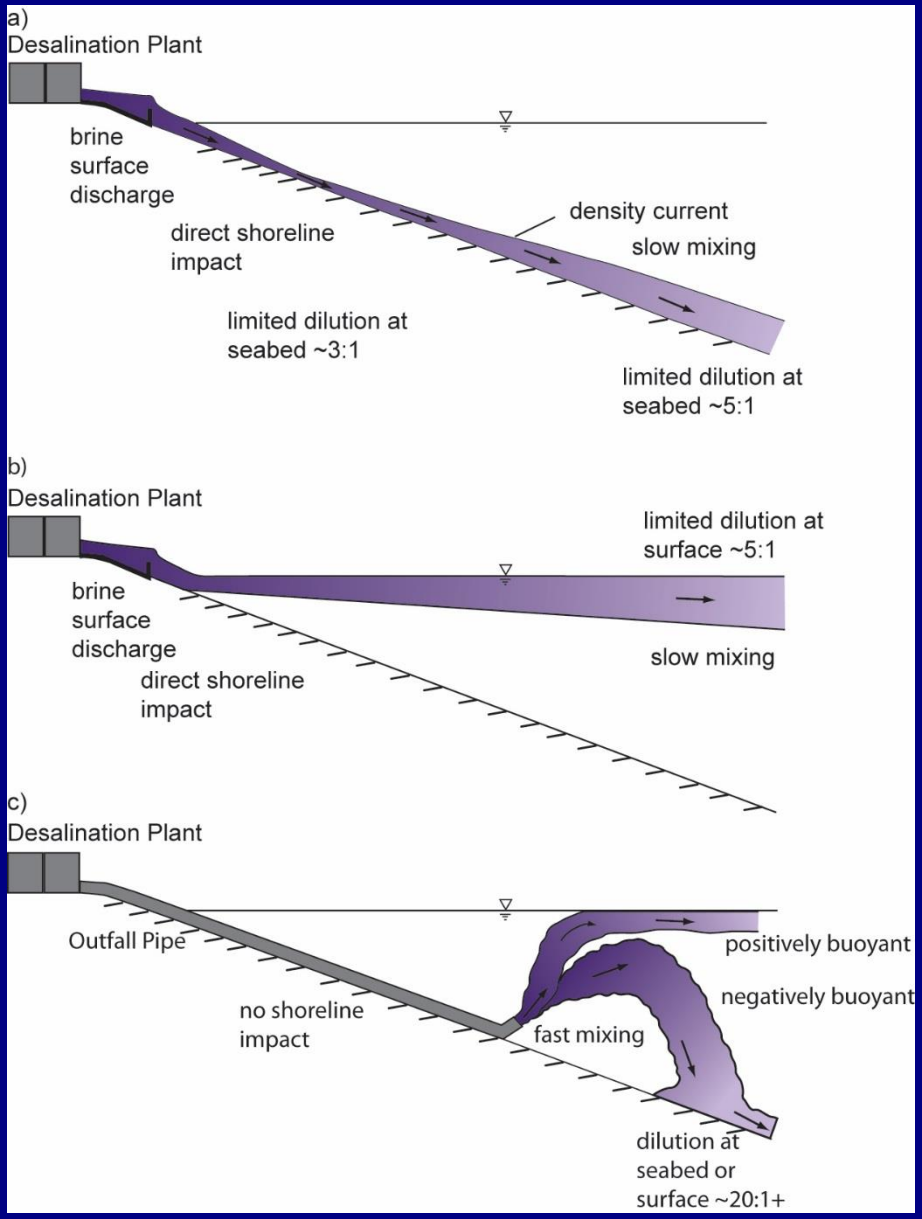
Largest projects:
400,000 m^3/d – 500,000 m^3/d

Source: IDA (2006), GWI (2007), www.DesalData.com

Typical RO Seawater Scheme



Discharge Modes



Flow augmentation

After Bleninger & Jirka (2009)

Carlsbad California Desalination Plant

Source: City of Carlsbad and Poseidon Resources 2005

California Ocean Plan

Appendix A Ocean Plan with the May 6, 2015 Final Desalination Amendment

Appendix A Ocean Plan with the Final Desalination Amendment and other nonsubstantive changes in blue strikeout or underline
Associated with the Final Staff Report Including the Final Substitute Environmental Documentation for the Desalination Amendment Adopted May 6, 2015

WATER QUALITY CONTROL PLAN

OCEAN WATERS OF CALIFORNIA

CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

201~~2~~5

Expert Panel:
Scientific Basis for Brine Discharge Guidelines

Philip Roberts, Georgia Tech, Chairman	Civil Engineering
Scott Jenkins, Scripps Institution of Oceanography	Physical Oceanography
Jeff Paduan, Naval Postgraduate School	
Daniel Schlenk, UC Riverside	Biochemistry/Toxicology
Judith Weis, Rutgers University	

Other SWRCB Desalination Activities:

- Expert panel review of Intakes: design and mitigation approaches
- Laboratory studies on brine toxicity (UC Davis)

Review of International Regulations

Region/Authority	Salinity Limit	Compliance Point	Source
US EPA	Increment ≤ 4 ppt		
Carlsbad, CA	Absolute ≤ 40 ppt	1,000 ft	San Diego Regional Water Quality Control Board 2006
Huntington Beach, CA	Absolute ≤ 40 ppt salinity (expressed as discharge dilution ratio of 7.5:1)	1,000 ft	Santa Ana Regional Water Quality Control Board 2012
Western Australia guidelines	Increment < 5%		
Oakajee Port, Western Australia	Increment ≤ 1 ppt		The Waters of Victoria State Environment Protection Policy
Perth, Australia/Western Australia EPA	Increment ≤ 1.2 ppt at 50 m and ≤ 0.8 ppt at 1,000m	50 m and 1,000 m	Wec, 2002
Sydney, Australia	Increment ≤ 1 ppt	50-75 m	ANZECC (2000); Sydney Water et al. (2005).
Gold Coast, Australia	Increment ≤ 2 ppt	120 m	GCD Alliance (2006).
Okinawa, Japan	Increment ≤ 1 ppt	Mixing zone boundary	Okinawa Bureau for Enterprises
Abu Dhabi	Increment ≤ 5%	Mixing zone boundary	Kastner (2008)
Oman	Increment ≤ 2 ppt	300 m	Sultanate of Oman (2005)

Literature

WATER RESEARCH 44 (2010) 5117–5128

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ScienceDirect

journal homepage: www.elsevier.com/locate/watres

WATER RESEARCH

Review

Impacts of desalination plant discharges on the marine environment: A critical review of published studies

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Toxicology
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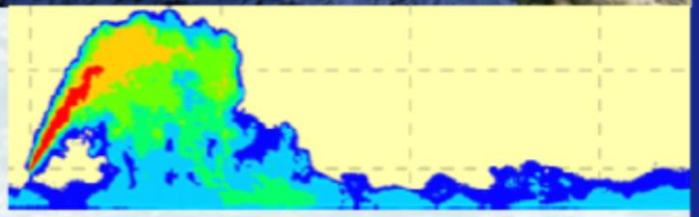
Impact

ABSTRACT

Desalination of seawater is an increasingly common means by which nations satisfy demand for water. Desalination has a long history in the Middle East and Mediterranean, but expanding capacities can be found in the United States, Europe and Australia. There is therefore increasing global interest in understanding the environmental impacts of desalination plants and their discharges on the marine environment. Here we review environmental, ecological and toxicological research in this arena including monitoring and assessment of water quality and ecological attributes in receiving environments. The greatest environmental and ecological impacts have occurred around older multi-stage flash (MSF) plants discharging to water bodies with little flushing. These discharge scenarios can lead to substantial increases in salinity and temperature, and the accumulation of metals, hydrocarbons and toxic anti-fouling compounds in receiving waters. Experiments in the field and laboratory clearly demonstrate the potential for acute and chronic toxicity, and small-scale alterations to community structure following exposures to environmentally realistic concentrations of desalination brines. A clear consensus across many of the reviewed articles is that discharge site selection is the primary factor that determines the extent of ecological impacts of desalination plants. Ecological monitoring studies have found variable effects ranging from no significant impacts to benthic communities, through to widespread alterations to community structure in seagrass, coral reef and soft-sediment ecosystems when discharges are released to poorly flushed environments. In most other cases environmental effects appear to be limited to within 10 s of meters of outfalls. It must be noted that a large proportion of the published work is descriptive and provides little quantitative data that we could assess independently. Many of the monitoring studies lacked sufficient detail with respect to study design and statistical analyses, making conclusive interpretation of results difficult. It is clear that greater clarity and improved methodologies are required in the assessment of the ecological impacts of desalination plants. It is imperative to employ Before–After, Control-Impact monitoring designs with adequate replication, and multiple independent reference locations to assess potential impacts adequately.

Management of Brine Discharges to Coastal Waters
Recommendations of a Science Advisory Panel

Prepared for:
The State Water Resources Control Board



Scott Jenkins
Jeffrey Paduan
Philip Roberts
Daniel Schlenk
Judith Weis

Southern California Coastal Water Research Project

Technical Report 694 - March 2012

Executive Summary

EXECUTIVE SUMMARY

A panel of five experts in diverse fields related to brine disposal in the ocean was convened to advise the State Water Resources Control Board on best practices for brine disposal in support of the development of an amendment to the Ocean Plan. The brine concentrates can result from desalination of brackish groundwater, recycling domestic wastewater, and especially desalination of seawater. The potential of seawater desalination to provide potable water in the state is growing rapidly, with many plants currently proposed or in the planning stage. The state presently has no regulations on brine discharges and each plant is considered on a case-by-case basis.

The panel reviewed extensive material, including peer-reviewed journal articles, articles in the gray literature, NPDES permits that have been issued, various regulations from around the world, and results of monitoring studies, and heard presentations about experience with operating discharges.

From these reviews it is apparent that concentrate can be disposed of with minimal environmental effects if properly executed. Desirable methods of discharge include co-disposal with heated cooling water from power plants or domestic wastewater, or from a multiport diffuser if "pure" brine is released. Discharges with rapid initial dilution into areas of good flushing result in impacts that extend only a few tens of meters from the discharge. Conversely, poorly implemented disposal schemes with low initial dilution in poorly flushed areas can cause widespread alterations of community structure in seagrass, coral reef, and soft-sediment systems.

Extensive literature on the toxic effects of concentrates were reviewed. The effects (or lack thereof) of desalination concentrate vary widely, depending on the organism, site, the biotic community at the site, the nature of the concentrate, and to what degree it is dispersed. It appears that benthic infaunal communities and sea grasses are the most sensitive; some communities seem to be tolerant of effects of up to 10 psu increases, while others are affected by increases of only 2-3 psu. None of the studies reviewed indicated any impacts of elevated salinity levels less than 2-3 psu. It should be noted, however, that very few peer-reviewed studies have evaluated sublethal effects of desalination discharges either in the laboratory or in the field. It should also be noted that few studies have evaluated "worst-case" embayment scenarios and chronic impacts on demersal vertebrates, particularly those which have significant life history behaviors (i.e., reproduction, migration) driven by salinity variations. For example, embayments with limited flushing may have thresholds lower in anadromous fish such as salmonids or estuarine demersal flatfish, which undergo saltwater acclimation and significant endocrine alterations. Additional and long-term studies are needed on sublethal endpoints such as reproduction and on different types of concentrates and mixtures with antiscalants and other chemicals associated with RO.

We also reviewed regulations and standards that have been applied around the world. These range from salinity increments within 1 ppt, 5%, or absolute levels such as 40 ppt. These limits typically apply at the boundary of a mixing zone whose dimensions are of order 50 to 300 m around the discharge.

Because discharges can be designed to result in rapid initial dilution around the discharge, we recommend that they be regulated by a mixing zone approach wherein the water quality regulations are met at the mixing zone boundary. The mixing zone should encompass the near field processes, defined as those influenced hydrodynamically by the discharge itself. These processes typically occur within a few tens of meters from the discharge, therefore we conservatively recommend that the mixing zone extend 100 m from the discharge structure in all directions and over the whole water column.

Based on the studies of effects of brine discharges we recommend an incremental salinity limit at the mixing zone boundary of no more than 5% of that occurring naturally in the waters around the discharge. Expressing the limit as a percentage increase allows for natural variability in the background waters. For most California open coastal waters this increment will be about 1.7 ppt; for a typical seawater desalination plant where the brine is concentrated by a factor of roughly two times, this corresponds to a dilution of about 20:1, which should be readily achievable. The dilution is the combination of in-pipe dilution in the case of co-discharges, and near field mixing. In addition to the salinity requirement, the discharge should meet toxicity and other requirements in the Ocean Plan at the edge of the mixing zone.

Co-discharges with power plant cooling water or domestic effluent can be positively buoyant, i.e. less dense than the receiving water. In that case, the regulatory framework of the Ocean Plan should be sufficient for protection of beneficial uses. Near field models should be re-run, however, to account for the increase in effluent density and flow rates on plume behavior.

The preferred methods of discharge are from a multiport diffuser for "raw" effluents, or co-disposal with power plant cooling water or domestic wastewater that results in significant in-pipe dilution. These discharges can be either a shoreline surface discharge (if positively buoyant) or through an existing multiport diffuser. Shoreline discharge of raw effluent is discouraged due to slow near field mixing and potentially high exposures of benthic organisms to elevated salinity.

In computing near field dilutions of negatively buoyant discharges from diffusers, conservative assumptions should be applied: that ocean currents do not increase dilution, and the seabed is flat and horizontal. To account for possible reductions in dilution in areas of poor flushing, estimates of overall flushing of the discharge site should be made to ensure that the dilution requirement at the edge of the mixing zone is still met.

No specific mathematical models are endorsed, but it is recommended that calculations be made using either tested semi-empirical equations available in the literature or by integral mathematical models based on entrainment assumptions. Mathematical models should be validated, and attention should be made to special conditions that occur with typical negatively buoyant discharges such as reduction in dilution due to Coanda effects and jet merging in the case of multiport diffusers.

Because of uncertainties in plume modeling and predicting the biological effects of the discharges, a field monitoring program should be used. Monitoring should include pre-discharge conditions and continue after discharge has begun to evaluate changes in the ecosystem. We recommend that the receiving water monitoring programs be based on Before-After Control-Impact (BACI) monitoring that includes multiple reference locations, samples at various distances from the discharge, and repeated sampling over time. The effluent should also be monitored for specified physical and chemical parameters.

Main Environmental Recommendations

- Concentrate can be disposed of with minimal environmental effects if properly executed;
- Regulate by a mixing zone approach wherein the water quality regulations are met at the mixing zone boundary;
- Mixing zone should encompass the near field processes: influenced hydrodynamically by the discharge itself;
- 100 m from the discharge structure in all directions and over the whole water column;
- Incremental salinity limit at the mixing zone boundary of less than 5% (about 1.7 ppt, dilution of about 20:1);
- Dilution can be any combination of in-pipe dilution and near field mixing;
- Should also meet toxicity and other requirements in the Ocean Plan at the edge of the mixing zone;
- For positively buoyant discharges, the regulatory framework of the Ocean Plan should be sufficient (e.g. OCSD).

Main Recommendations of Expert Panel on Discharges

- Preferred methods of discharge:
  - Diffuser that results in significant near field mixing;
  - Co-disposal if significant in-pipe dilution with:
    - power plant cooling water

      - Discharge can be shoreline surface discharge (if positively buoyant) or through an existing multiport diffuser
    - domestic wastewater
- Shoreline discharge of raw effluent is discouraged.

Suggested Reading!

WATER IN THE WEST | STANFORD WOODS INSTITUTE FOR THE ENVIRONMENT | THE BILL LANE CENTER FOR THE AMERICAN WEST | The Nature Conservancy | CENTER FOR OCEAN SOLUTIONS | Monterey Bay Aquarium

Uncommon Dialogue: Marine and Coastal Impacts of Desalination in California
January 14-15, 2016

SUGGESTED READING

For any participants who, in advance of the workshop, would like more background on desalination and regulation of desalination facilities in California, we encourage you to review a series of reports prepared by the Pacific Institute and available at the bottom of the following page: http://pacinst.org/publication/costs-and-financing-of-seawater-desalination-in-california/.

In addition, the materials related to 2015 Water Resources Control Board desalination amendments to California's Ocean Plan can be found here: http://www.waterboards.ca.gov/water_issues/programs/ocean/desalination/. This includes the policy, a lengthy supporting report, and a fact sheet.

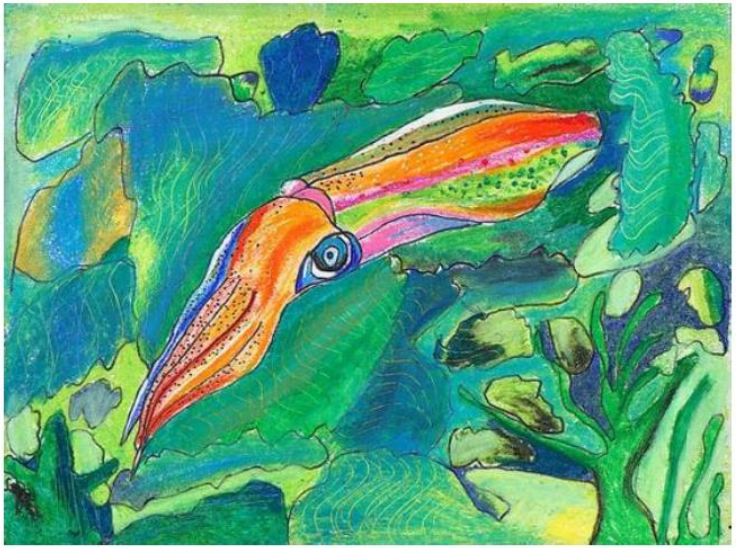
Amendment Discussions

Final Staff Report Including the Final Substitute Environmental Documentation
Adopted May 6, 2015

Amendment to the Water Quality Control Plan
For Ocean Waters of California

Addressing

DESALINATION FACILITY INTAKES, BRINE DISCHARGES, AND THE INCORPORATION OF OTHER NON-SUBSTANTIVE CHANGES

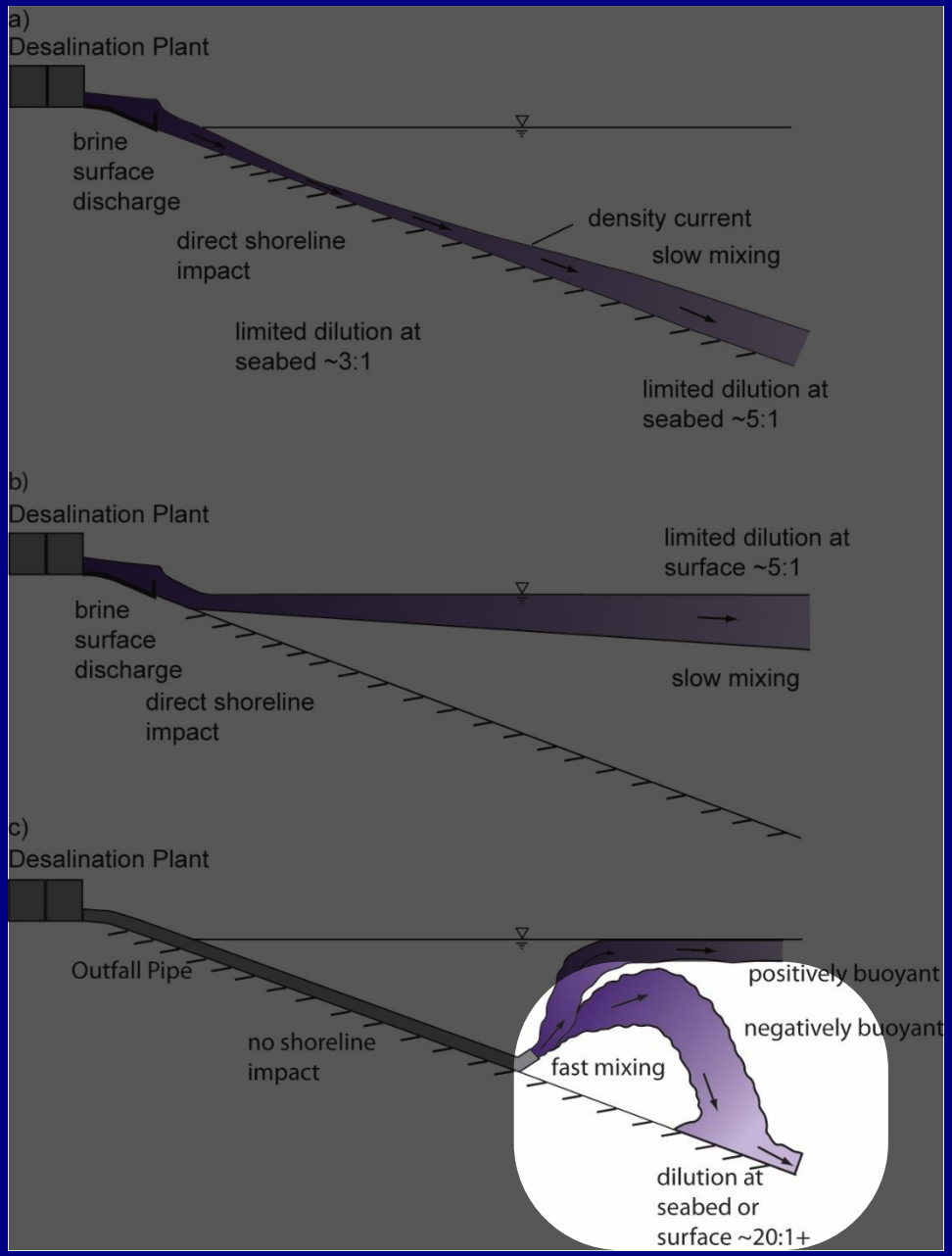


May 6, 2015

Options and recommendations for:

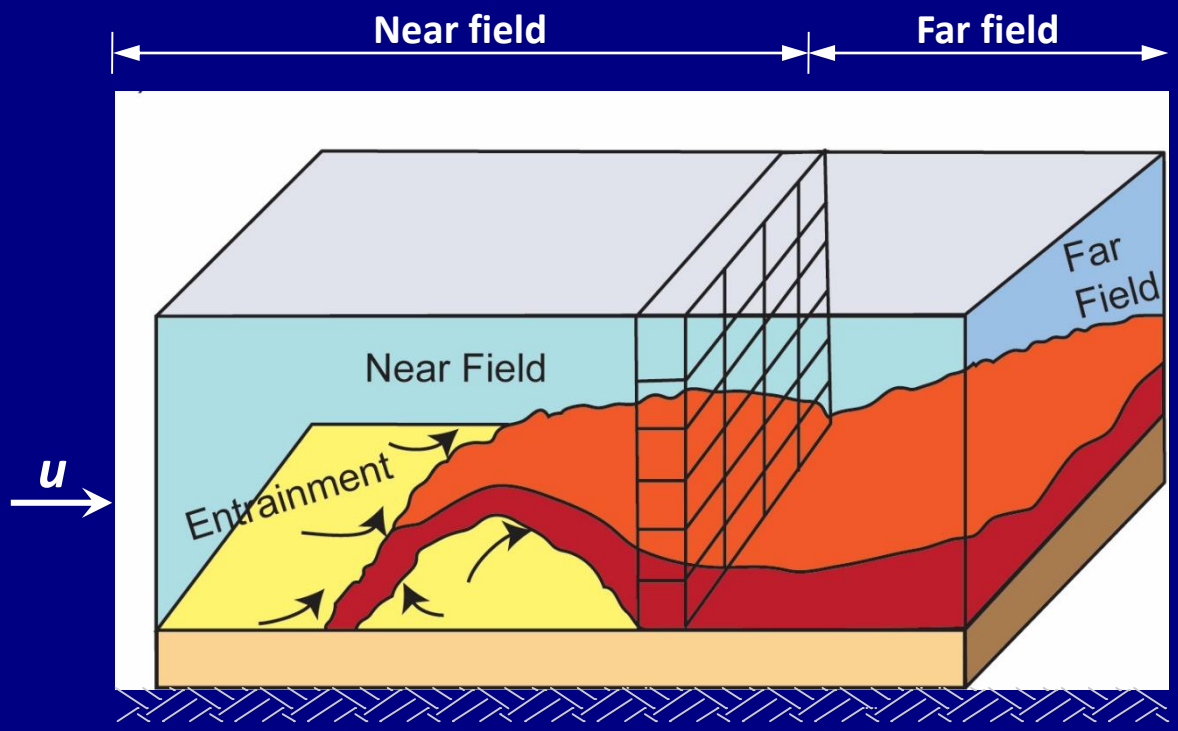
- Disposal methods
- Regulation

Discharge Modes



After Bleninger & Jirka (2009)

Definitions



Near field: Self-induced turbulence

Far field: Ambient turbulence

Mixing zones: Regulatory

Clean Water Act 301(h) ZID

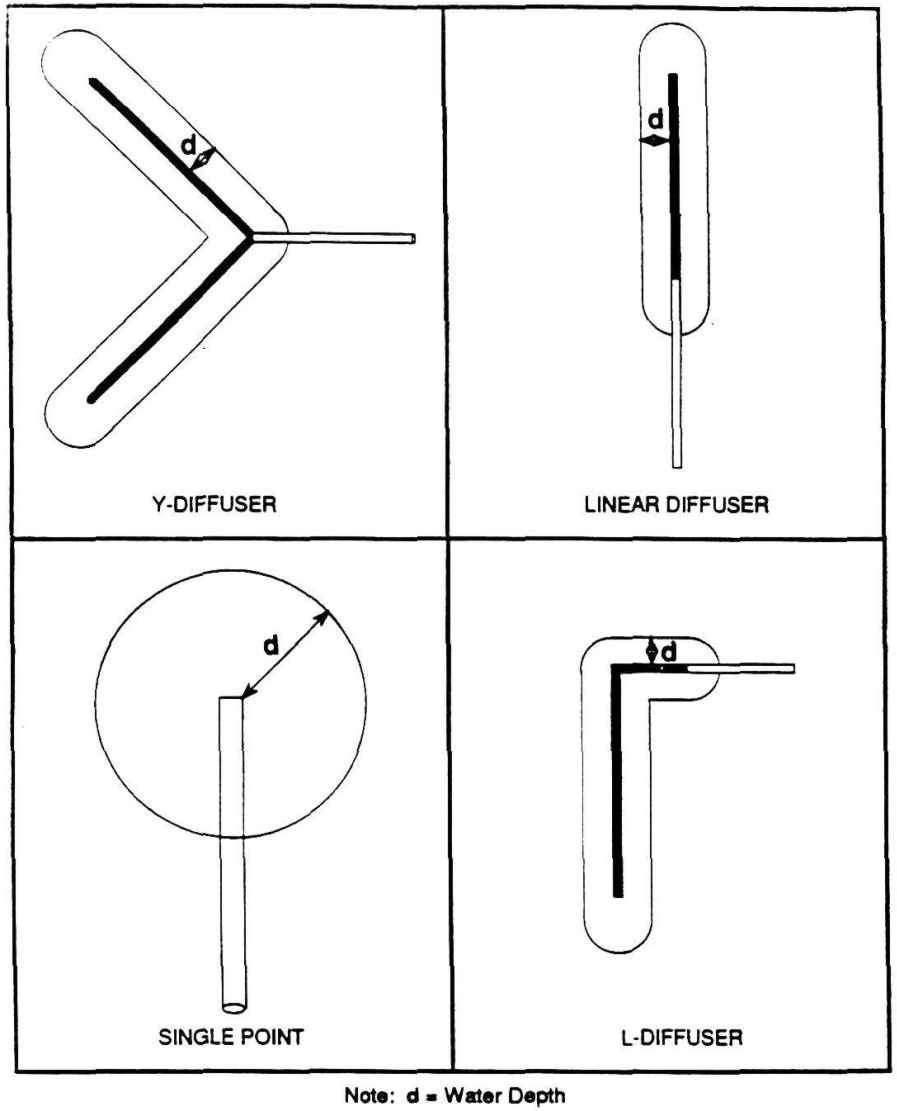
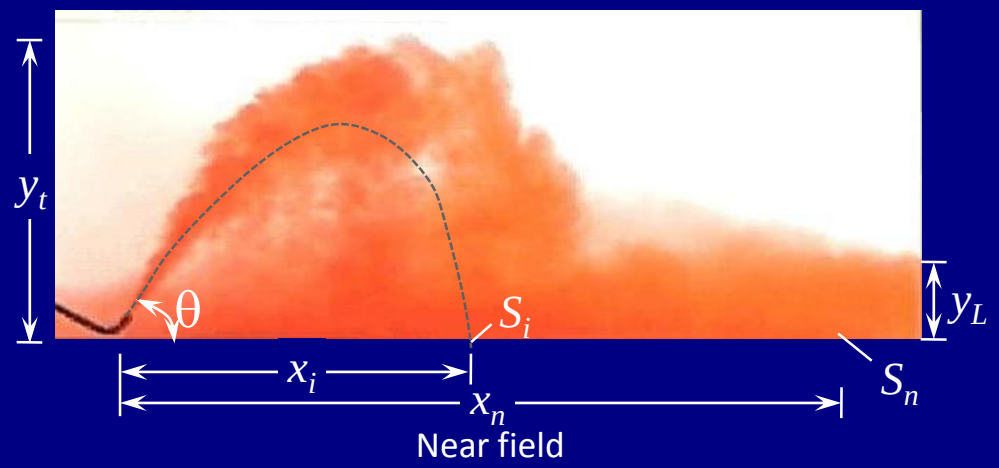


Figure 2. Diffuser types and corresponding ZID configurations.

10 percentile current

Single Inclined Dense Jet

Discharge as high velocity jet to achieve high dilution and reduce salinity to safe levels



Kinematic fluxes:

Volume: $Q = (\pi/4) d^2 u$

Momentum: $M = uQ$

Buoyancy: $B = g_o' Q$

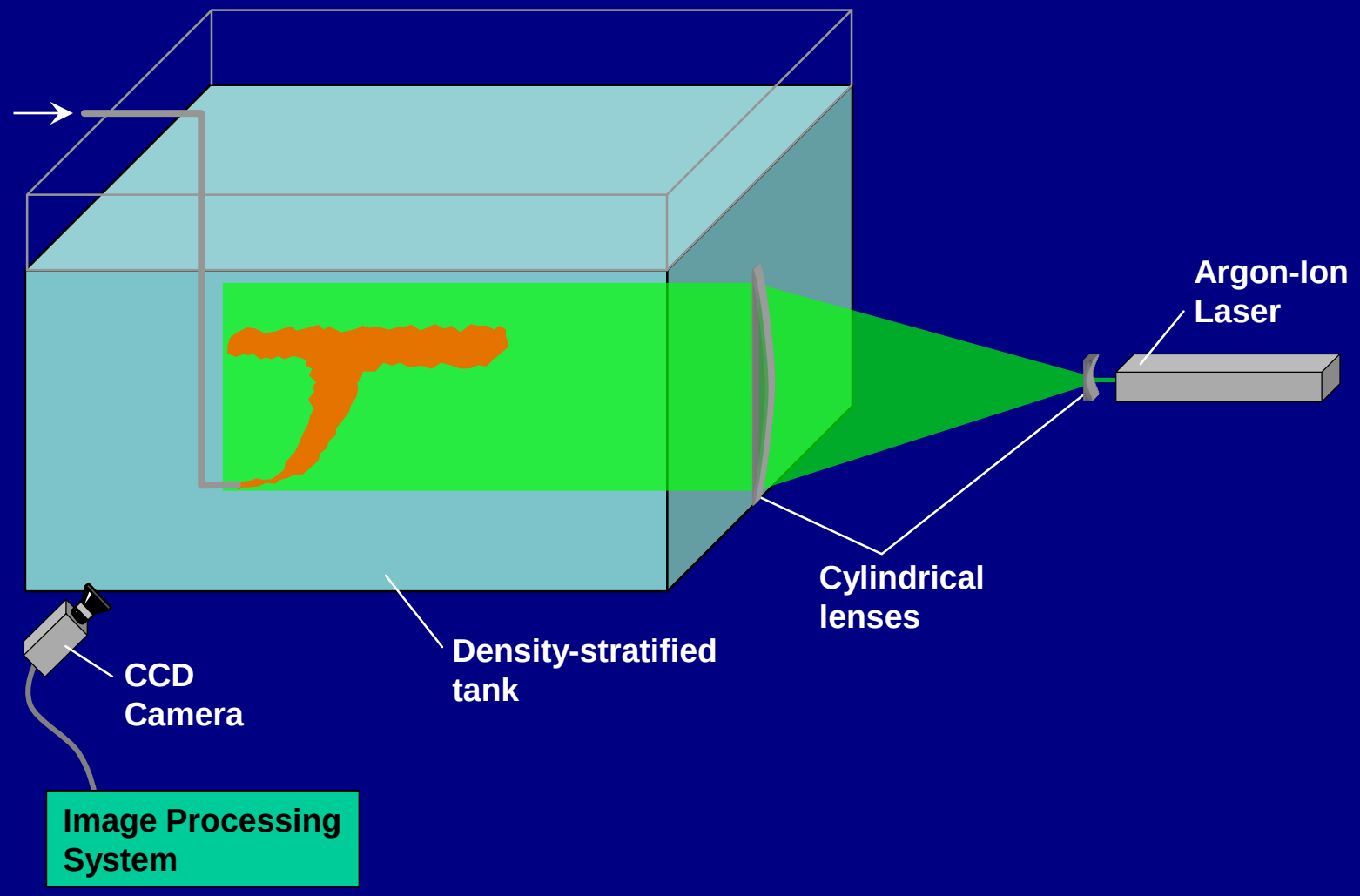
where: $g_o' = g \dfrac{\Delta\rho}{\rho_a}$

Length scale: $l_M = \dfrac{M^{3/4}}{B^{1/2}} \sim d\mathsf{F}$

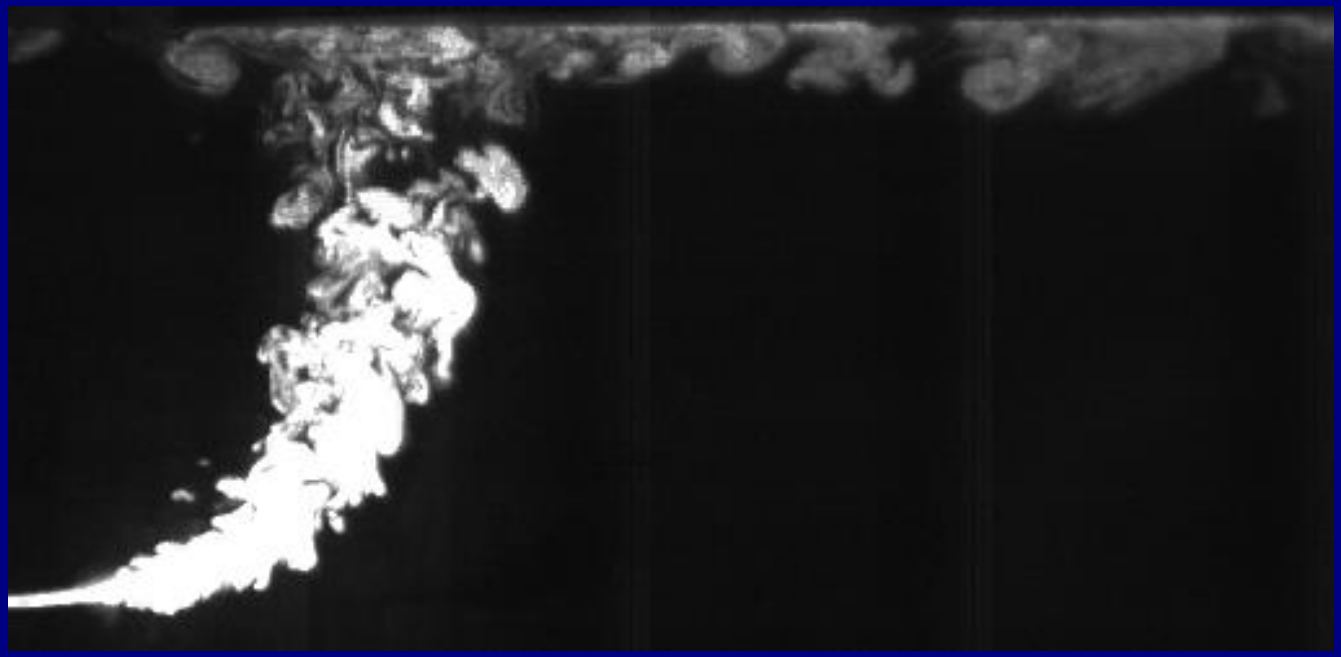
$\mathsf{F} = \dfrac{u}{\sqrt{g_o' d}}$ Densimetric Froude number

Dimensional analysis: $y_t = f(M, B) \Rightarrow \ldots \dfrac{y_t}{d\mathsf{F}}, \dfrac{y_L}{d\mathsf{F}}, \dfrac{S_n}{\mathsf{F}} = \text{Constants}$

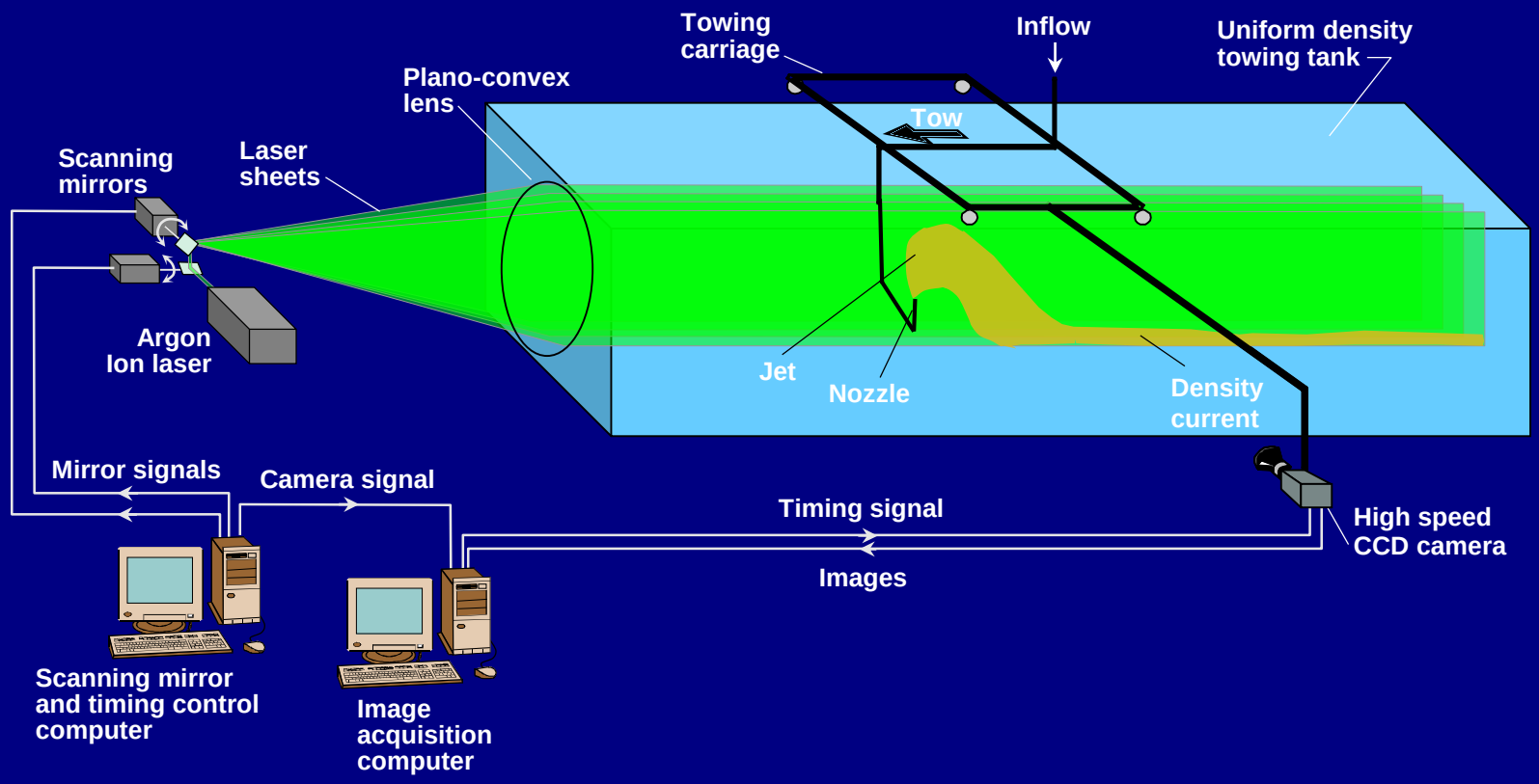
Laser-Induced Fluorescence (LIF)



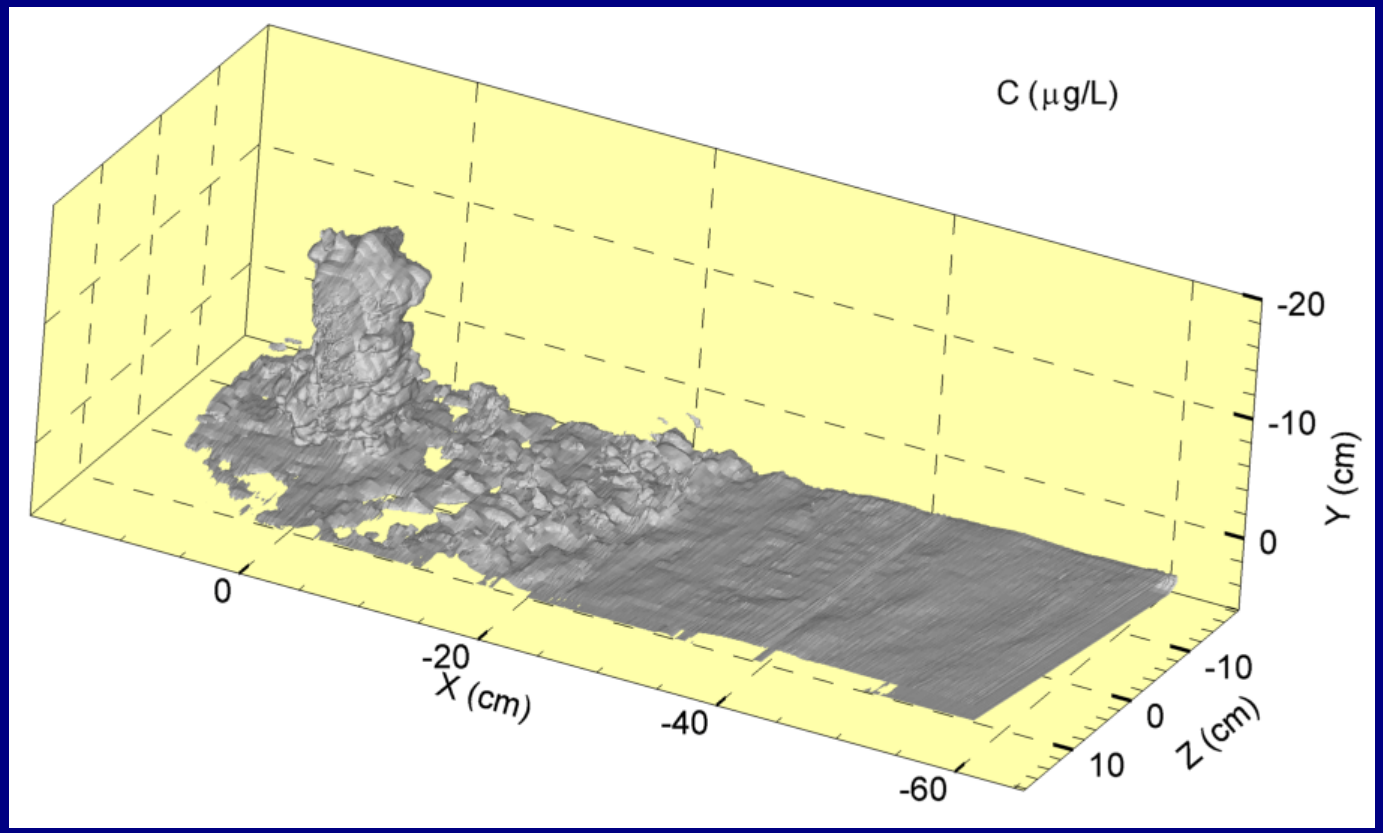
LIF Images of Horizontal Buoyant Jet



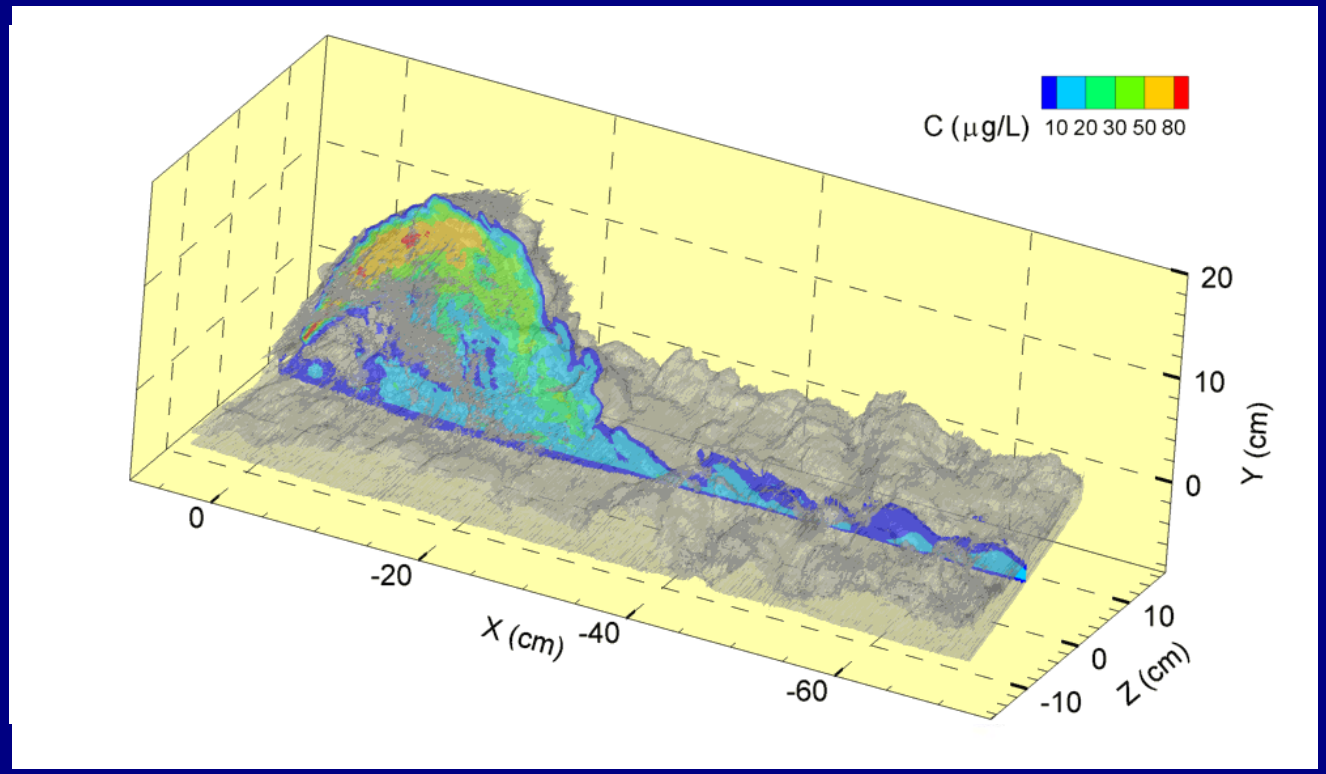
3D Laser-Induced Fluorescence Experiments

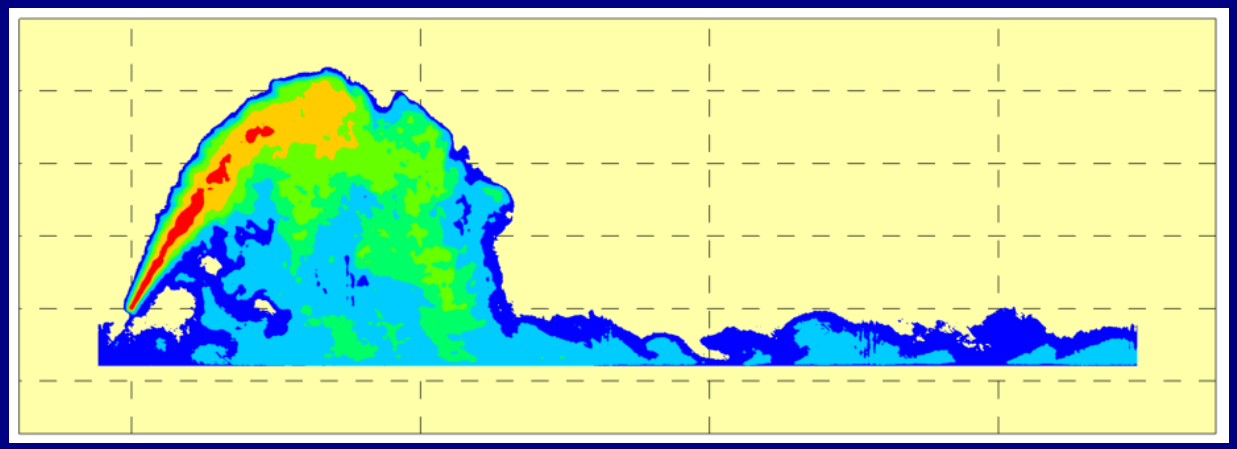


Vertical Dense Jet

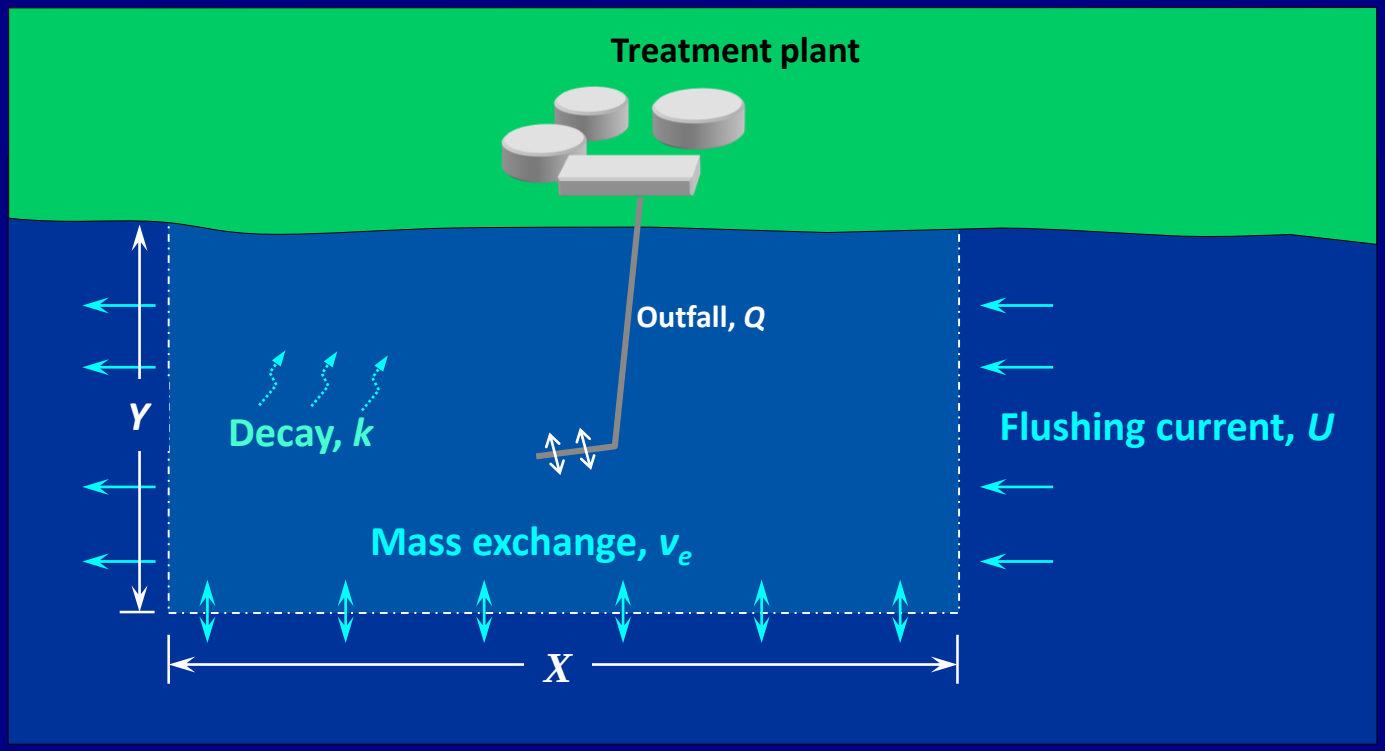


60° Inclined Jet





Long-Term Flushing: Box Model



Long-term dilution:

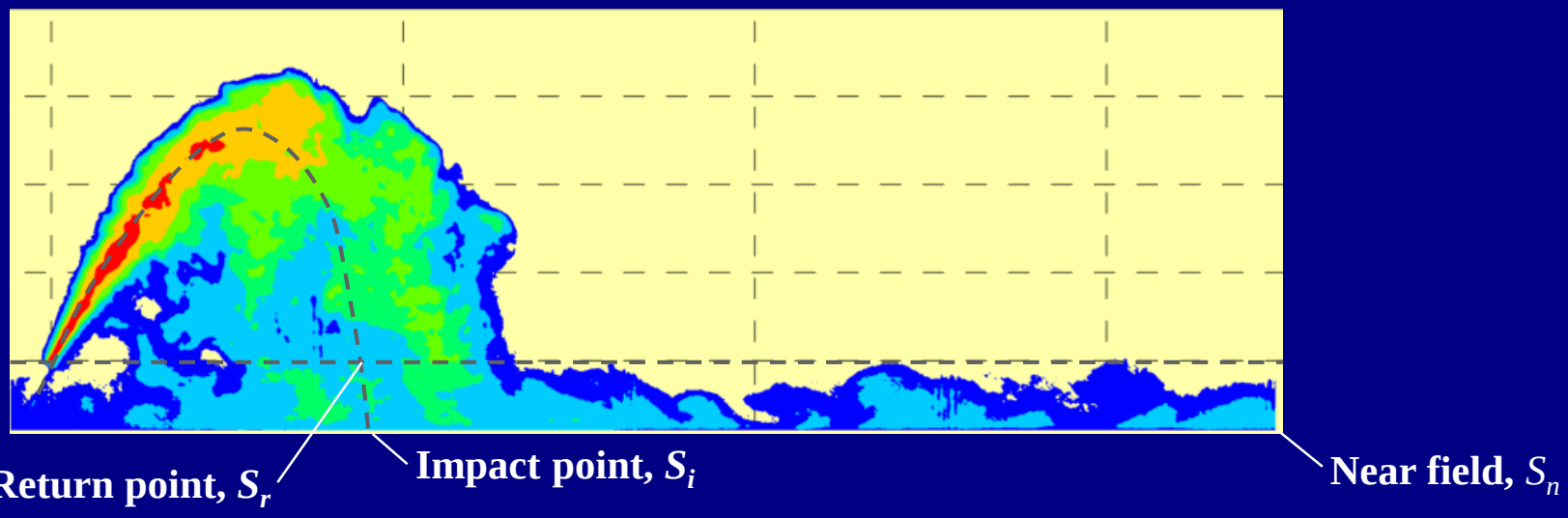
$$S_p = \underbrace{\frac{khXY}{Q}}_{\text{Decay}} + \underbrace{\frac{v_e hX}{Q}}_{\text{Cross-shore exchange}} + \underbrace{\frac{UhY}{Q}}_{\text{Flushing}}$$

For example,

$U \sim 5$ cm/s
$Y \sim 1$ km
$h \sim 5$ m
$Q \sim 2$ m^3/s

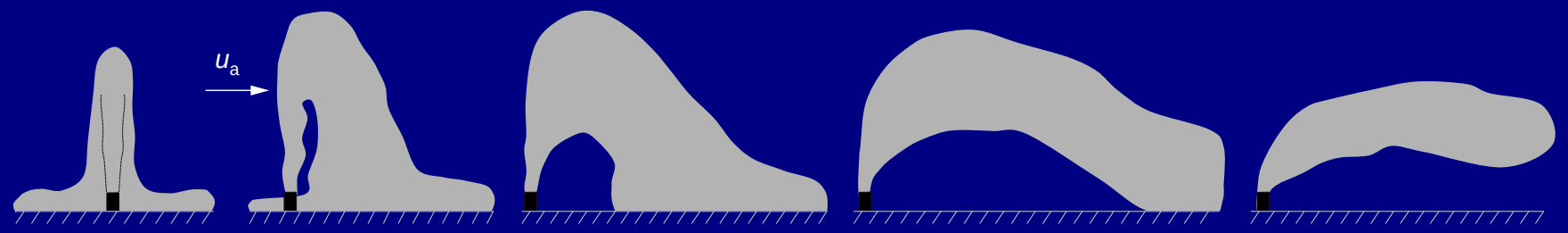
$$S_p \sim \frac{0.05 \text{ x } 5 \text{ x } 1000}{2} \sim 125$$

What Does 2 ppt Increment Mean?



Effect of Currents on Dense Jets

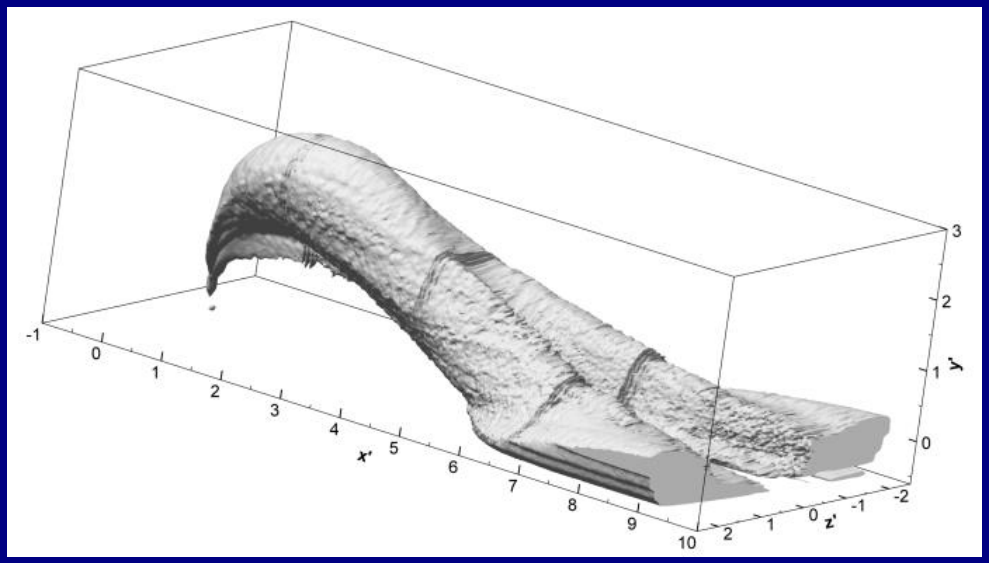
Flow characteristics for various $u_r F$



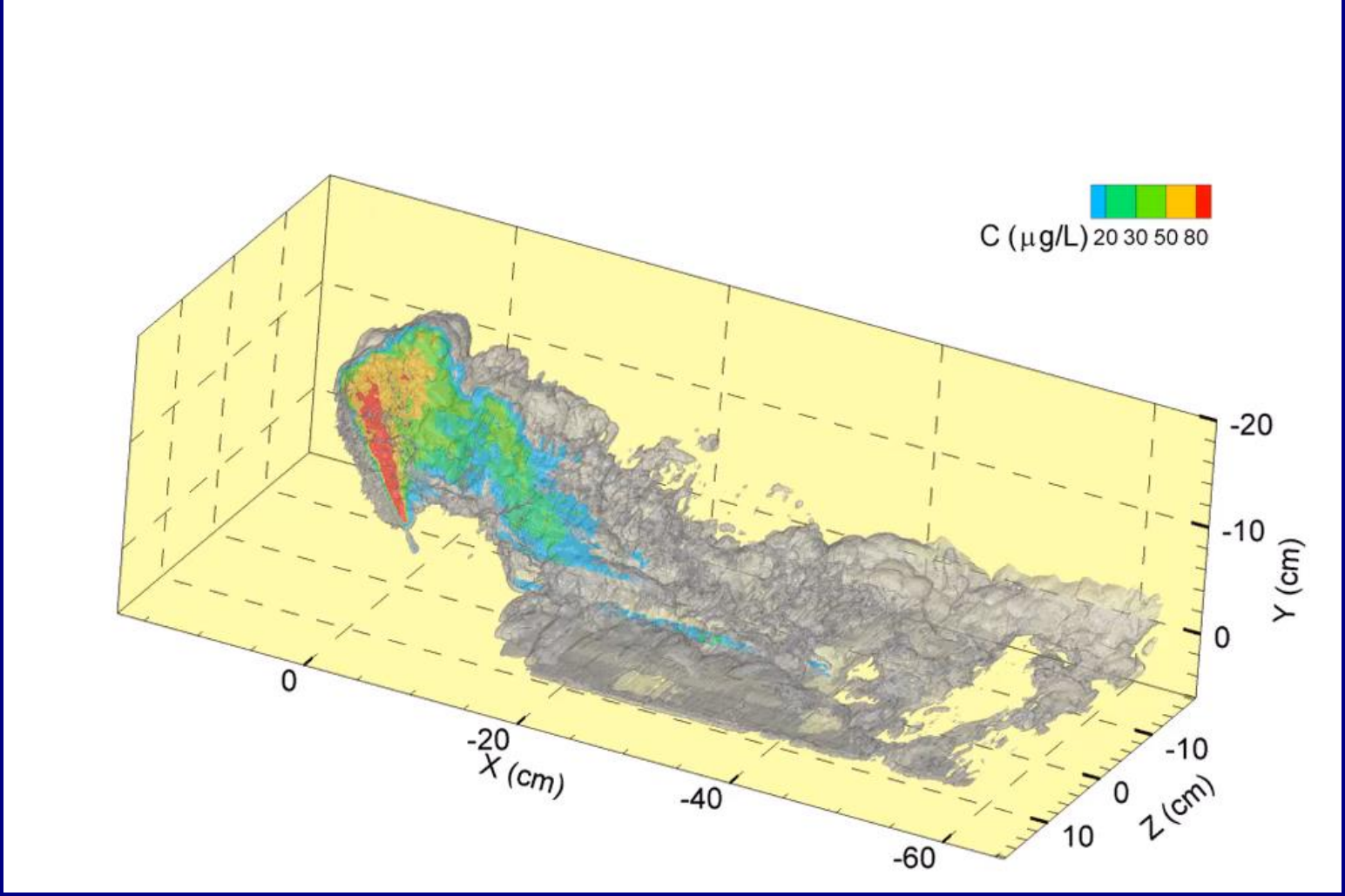
$u_r F = 0$ Falls back	$u_r F \approx 0.2$ Slight deflection, upstream wedge	$u_r F \approx 0.5$ No upstream wedge, maximum rise height	$u_r F \approx 1$ Significantly bent	$u_r F \approx 2$ Almost horizontal
Perth:	3 cm/s	9 cm/s	17 cm/s	34 cm/s

Results

Fast current: u_rF = 0.9



Dense Jet in Counter Current



Turbulence and Shear Effects on Organisms

Perth Diffuser

Turbulence and Shear Effects?

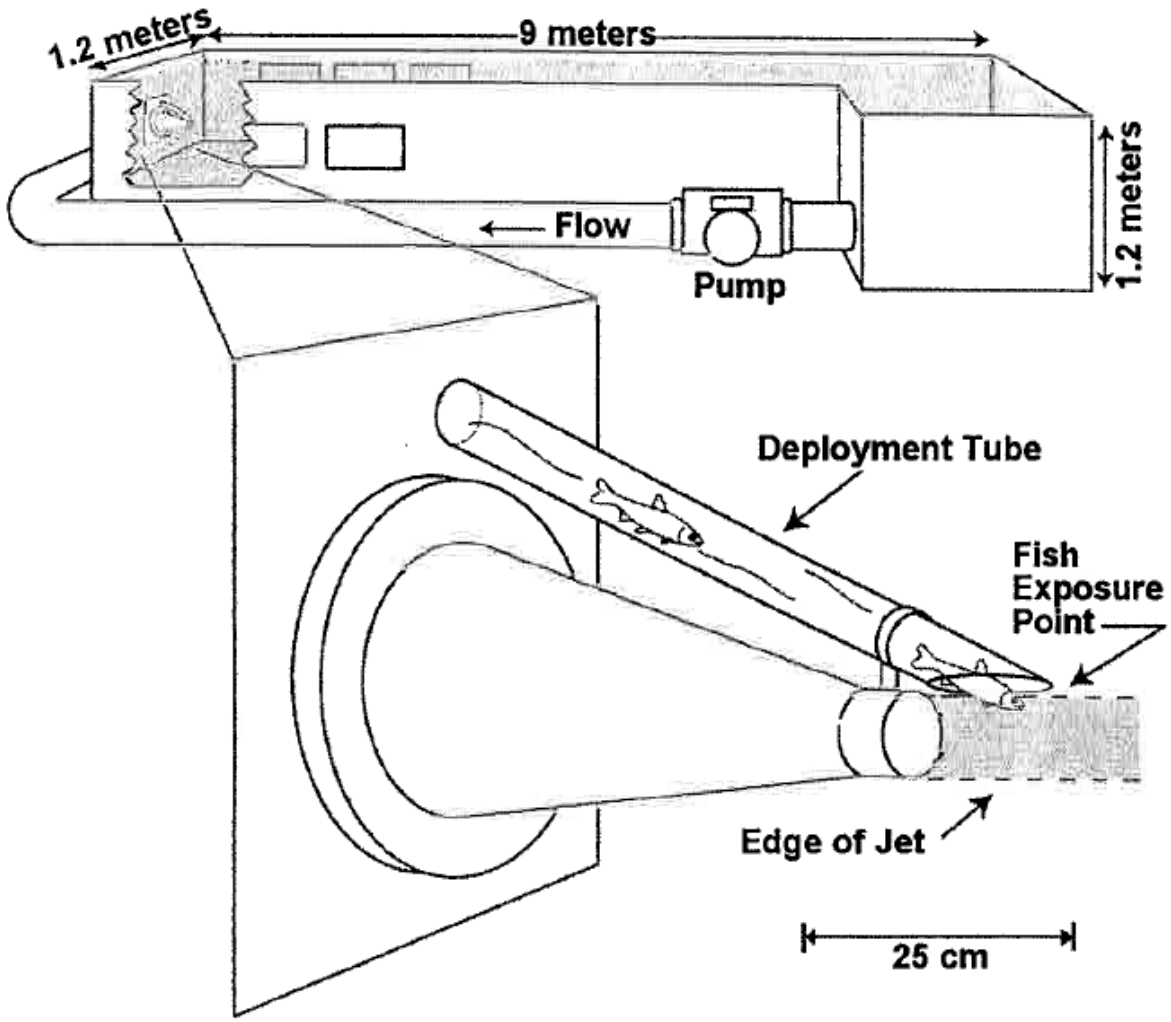
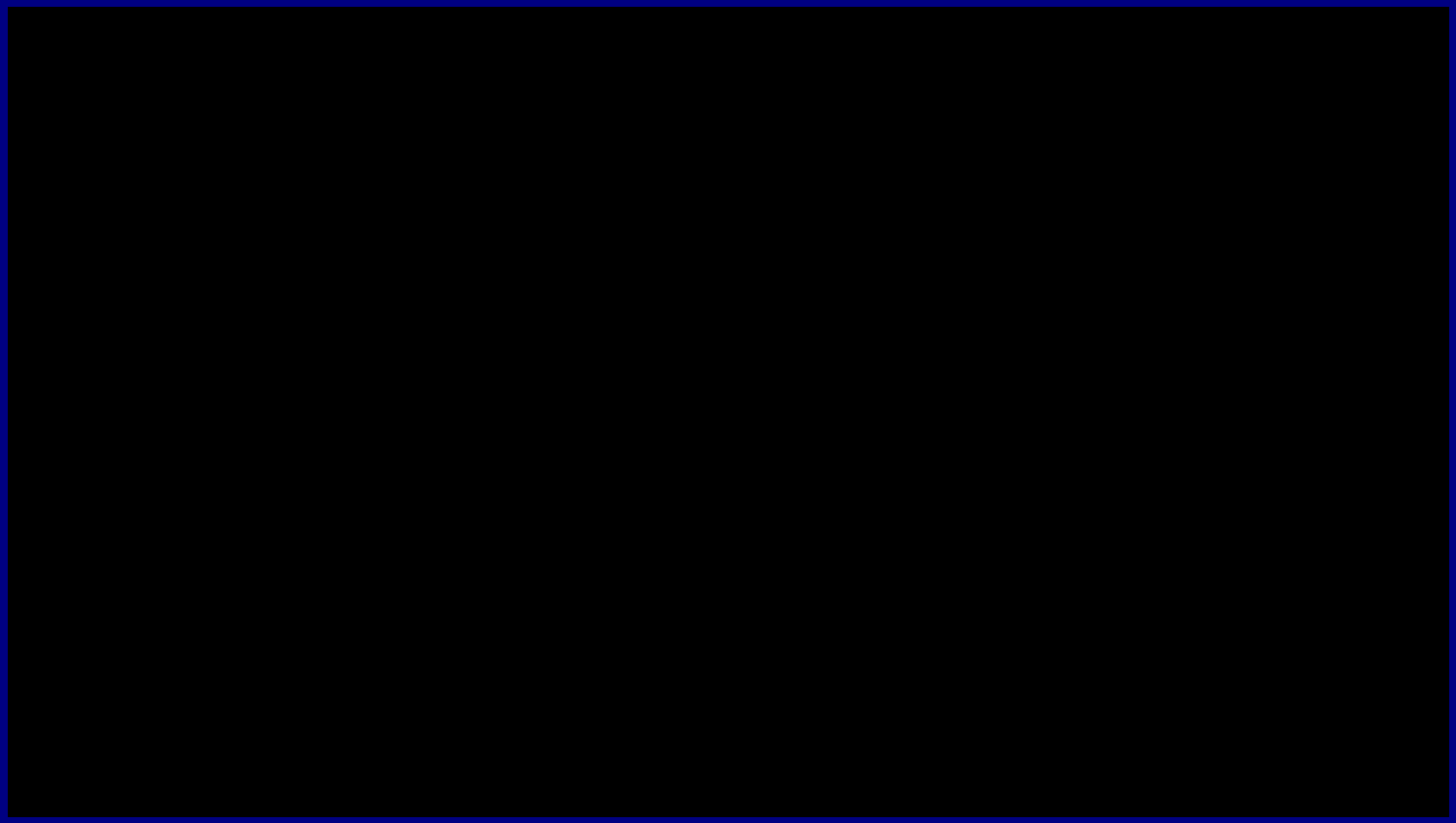


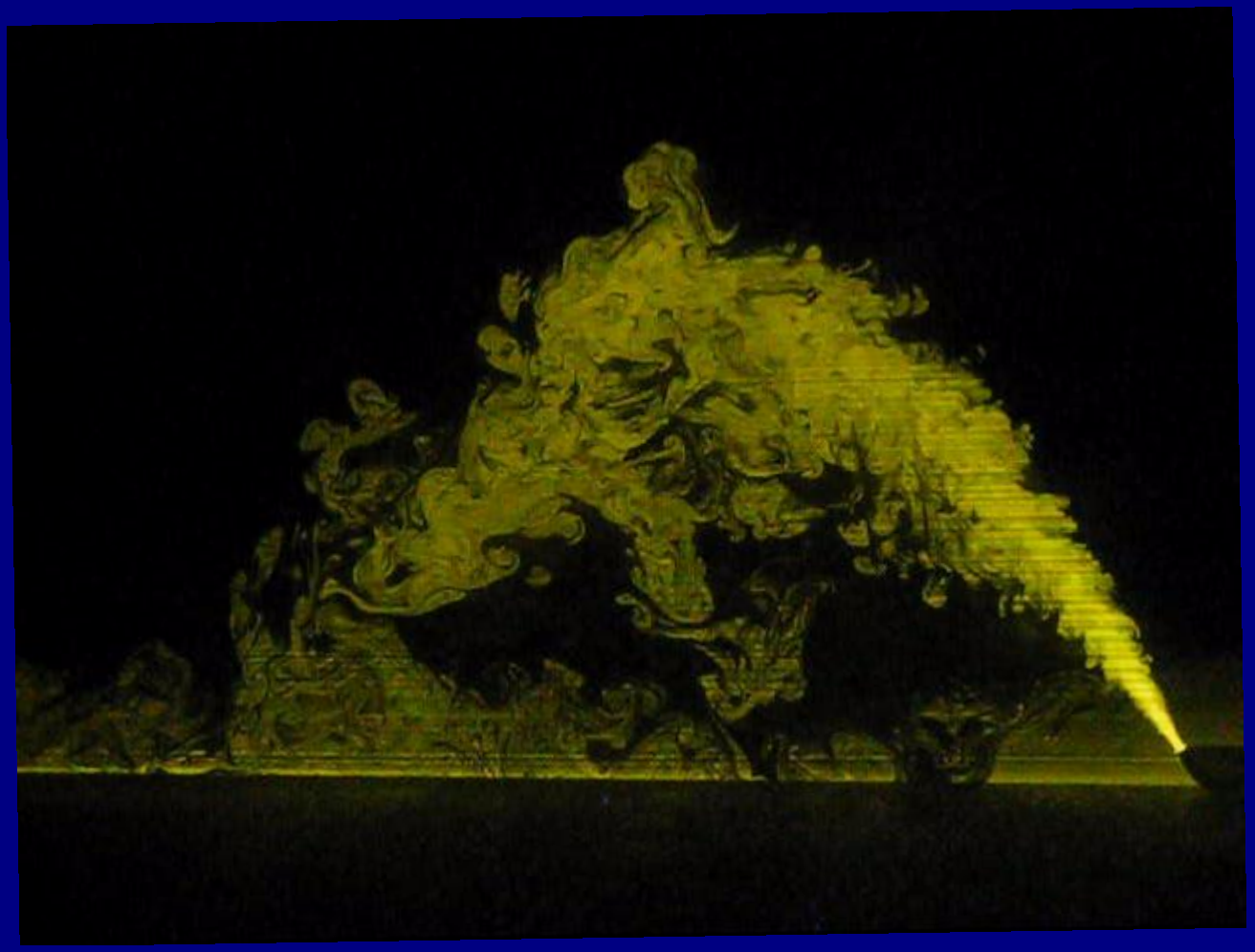
FIGURE 1.—Plan view of the shear test facility, including a closeup of how test fish entered the shear environment via a deployment tube.

Neitzel et al. 2004

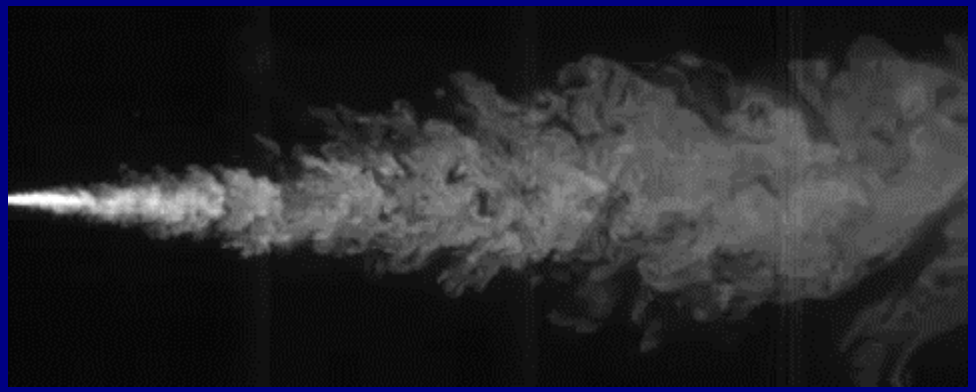
Perth Desalination Plant



LIF Video



Jet Diffusion



Velocity, *u*
Diameter, *d*

Rehmann, C. R., et al. (2003). "Effect of turbulence on the mortality of zebra mussel veligers." Canadian Journal Zoology 81: 1063-1069.

Kolmogorov scale on centerline:

$$\frac{\eta_c}{x} = 0.24\,\mathrm{Re}^{-3/4} \qquad \mathrm{Re} = \frac{ud}{\nu}$$

Diffuser Jet Effects on Living Organisms?

For the Perth brine diffuser, we have: u = 4.1 m/s, d = 0.13 m, so assuming $\nu = 10^{-6}$ m^2/s, Re = 5.3×10^5

Conclusions:

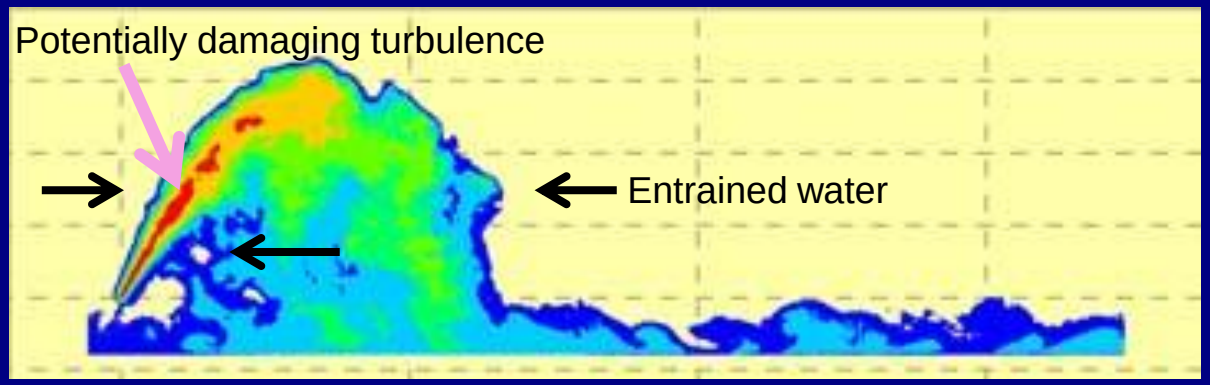
Kolmogorov scales ~ 0.01 to 0.1 mm

Mean shear rates range from about 21 sec^{-1} near the nozzle to 0.2 sec^{-1} at the terminal rise height

Exposure times ~ 10 - 50 sec

Only 23-38% of entrained water is exposed to potentially damaging turbulence

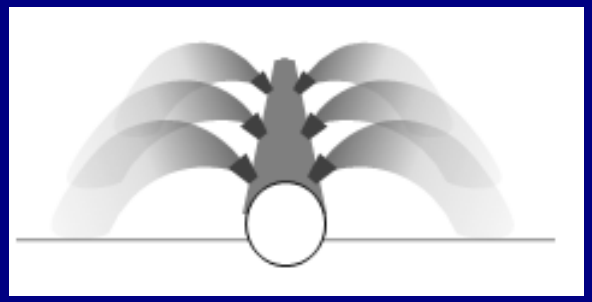
Significant??



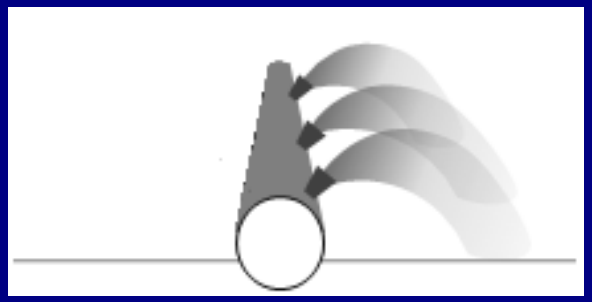
CONCLUSION: ENTRAINMENT IMPACTS FROM DIFFUSERS ARE LIKELY TO BE LOW,
and likely lower than impacts from yet to be demonstrated in-plant dilution where impacts can occur from passing through pipes and pumps, during in-plant mixing with brine water, and from possible discharge into unfavorable environments.
Need field measurements.

Multiport Diffusers

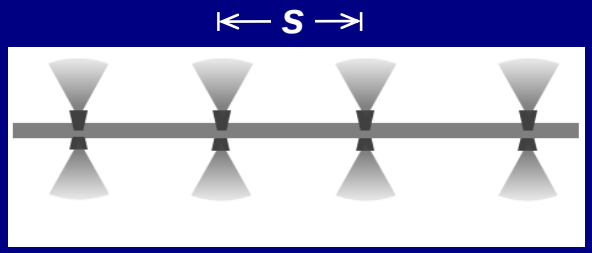
Conventional



Two-sided



One-sided



RECLAMATION
Managing Water in the West

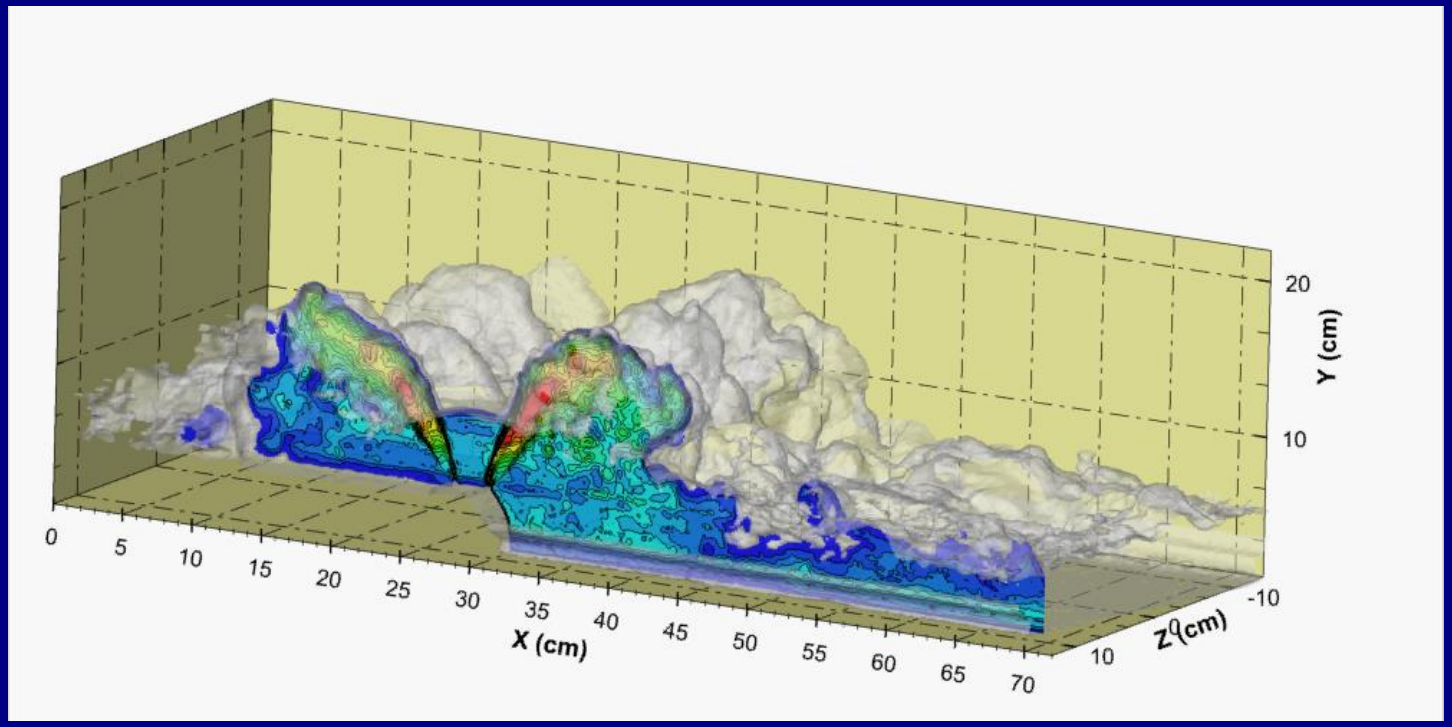
USBR

Optimum design?

Effects of currents?

Multiport Diffuser

Unsteady Animation

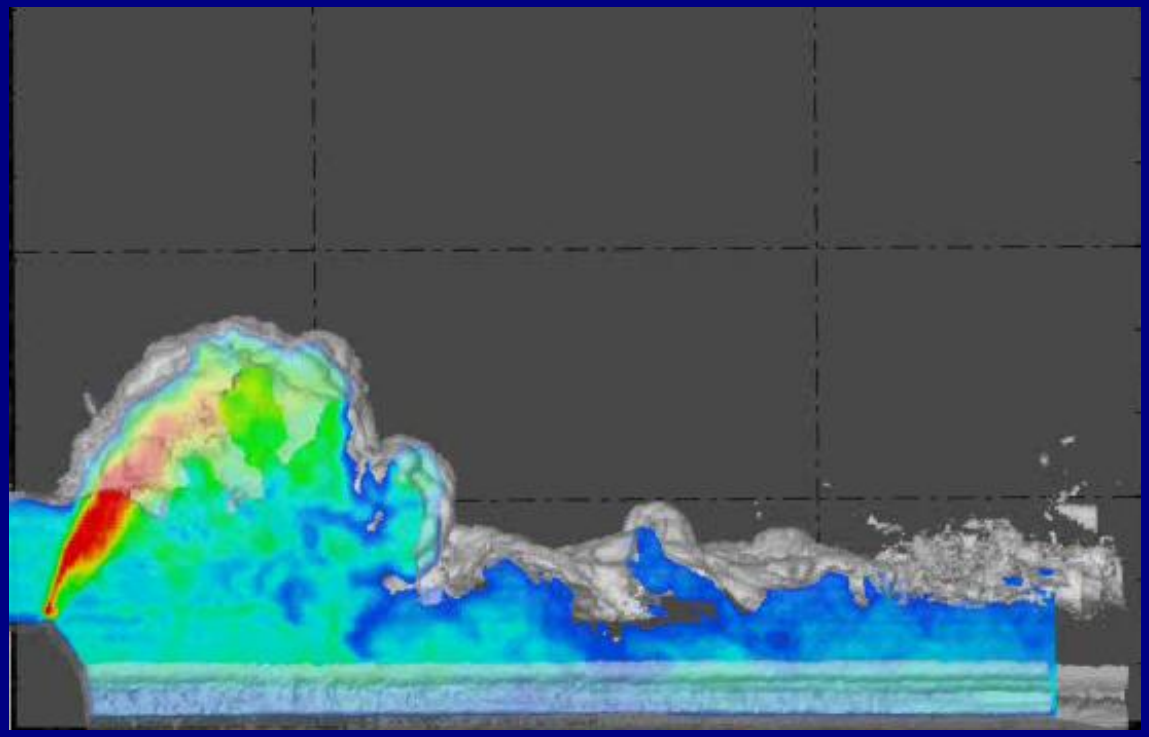


$F = 29$

$\frac{s}{dF} = 0.93$

Multiport Diffuser

Unsteady Animation - Side View



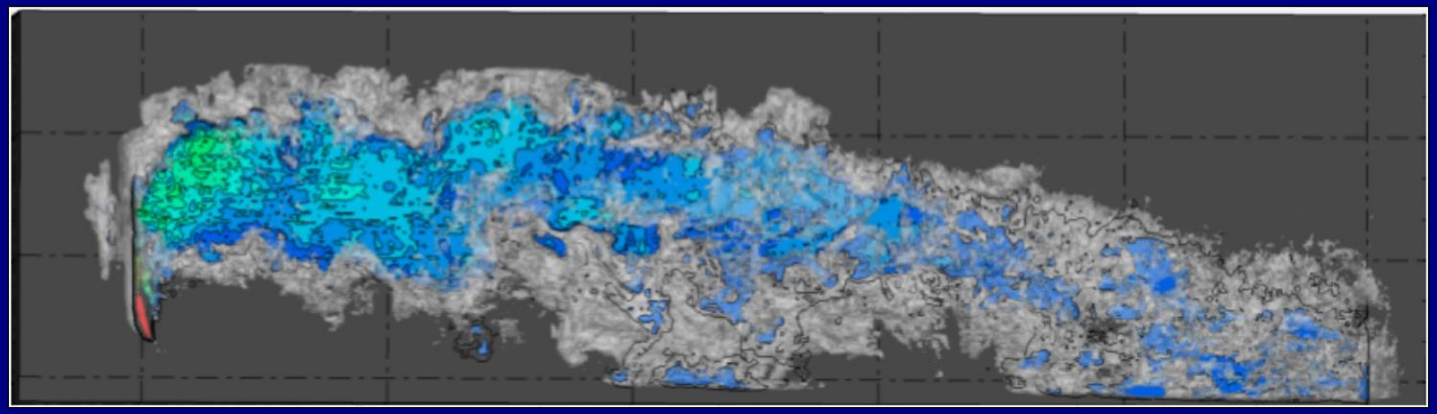
$F = 29$

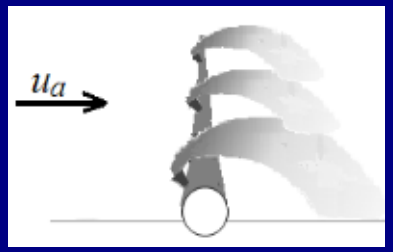
$\frac{s}{dF} = 0.93$

Abessi, O., and Roberts, P. J. W. (2014). "Multiport Diffusers for Dense Discharges." *J. Hydraul. Eng., ASCE,* Published online April 1, 2014

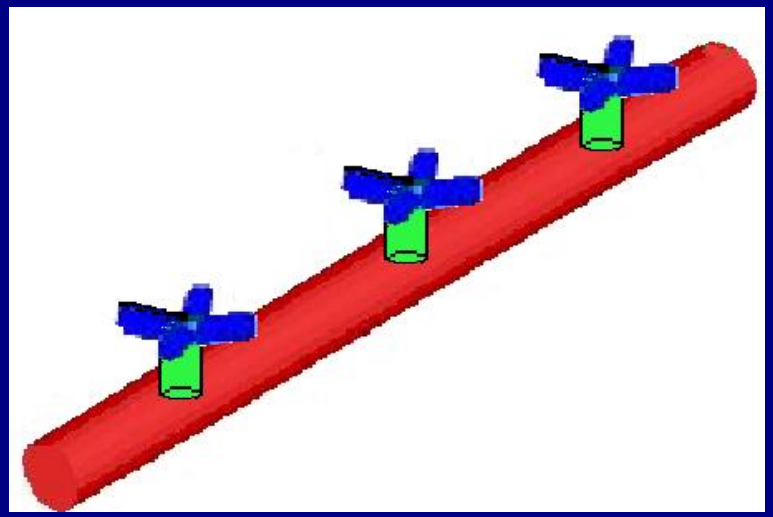
One-Sided Multiport Diffuser

Counter flow current





Rosette Diffusers

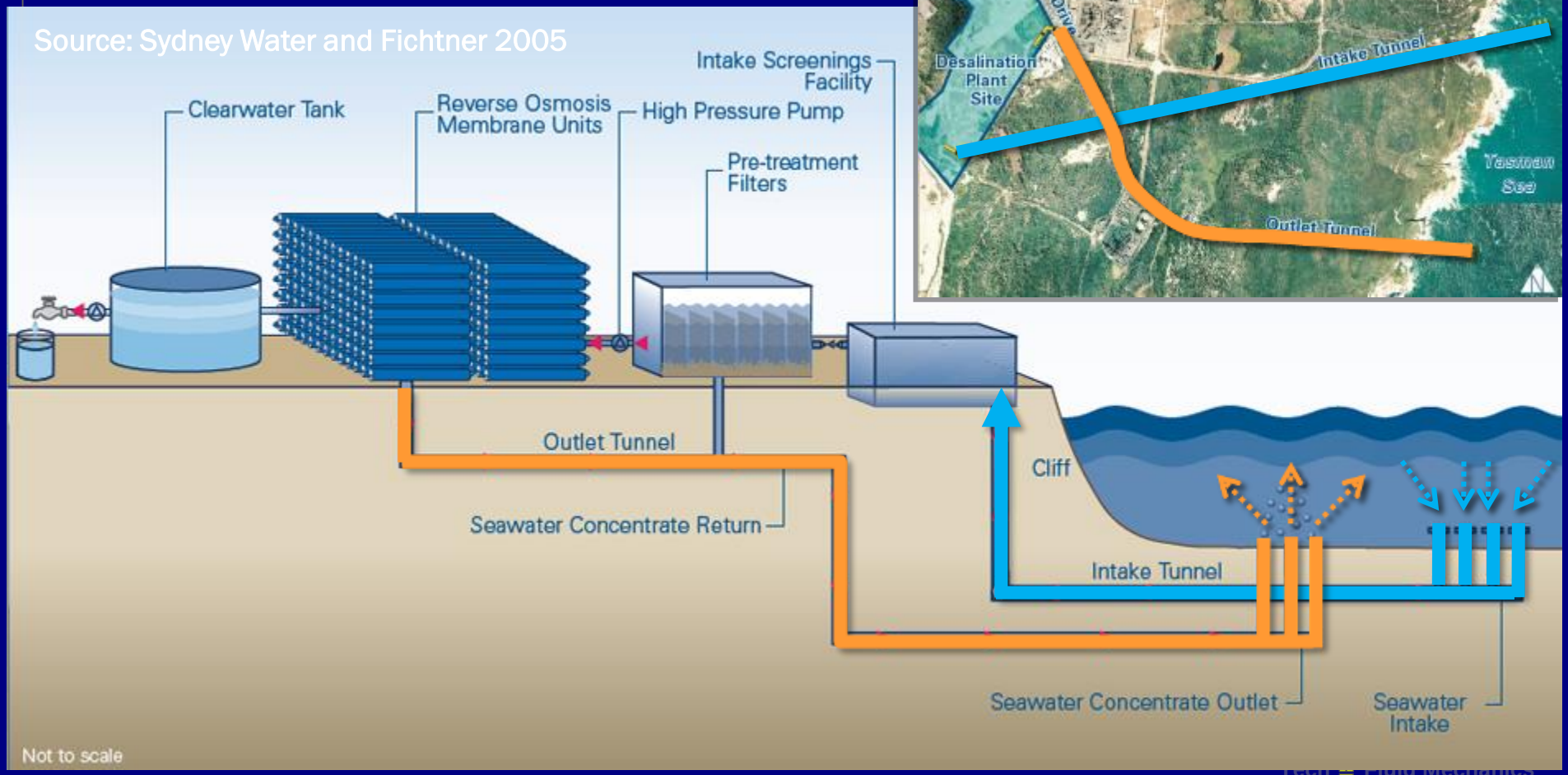


e.g. Sydney, Australia

Sydney SWRO Plant

(125,000-500,000 m^3/d)

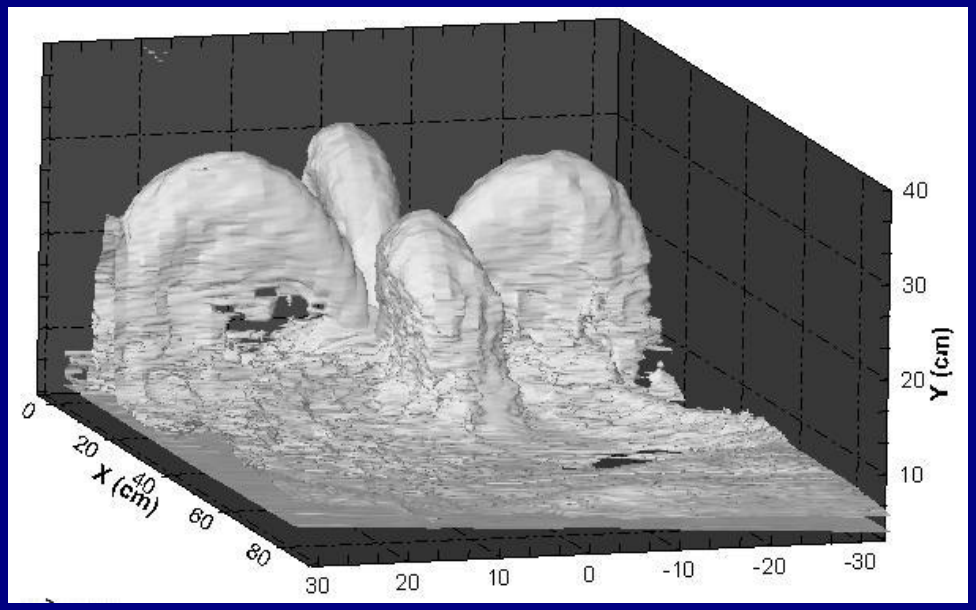
- submerged intake
- intake tunnel
- diffuser
- discharge tunnel



Aldbrough, England

Single Rosette

No Current

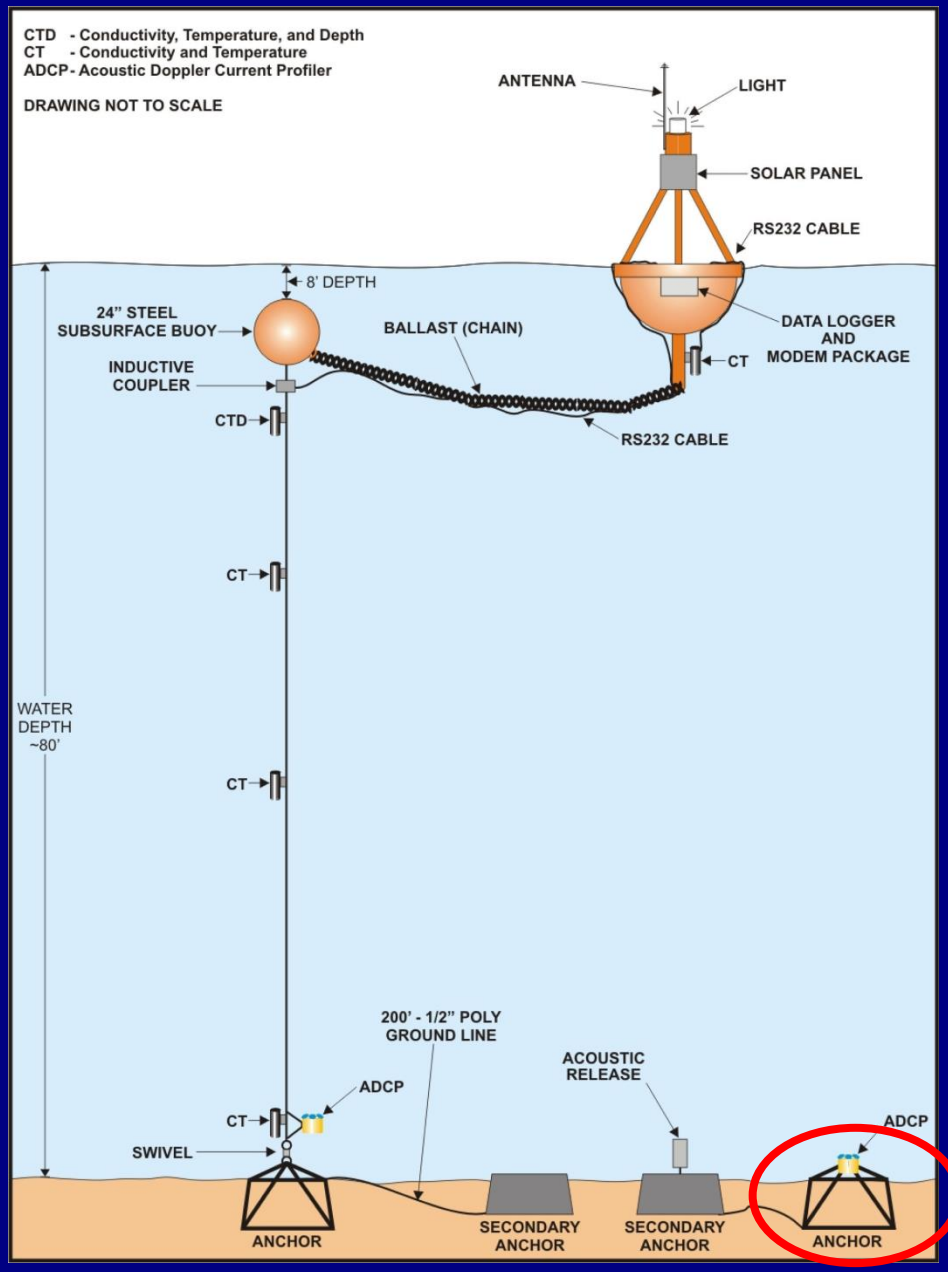


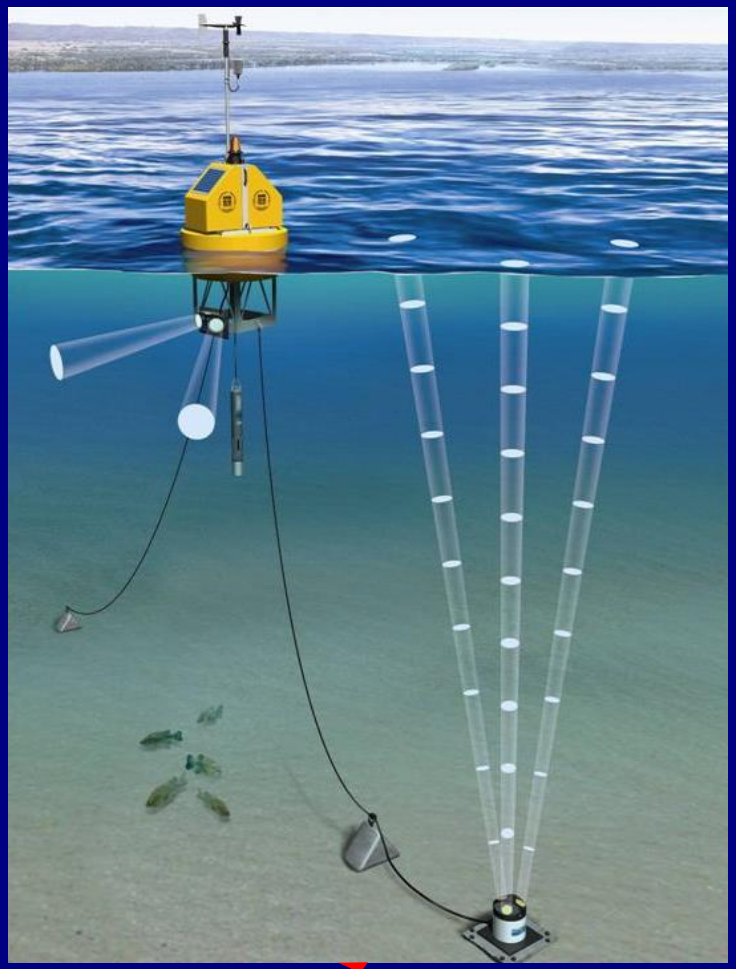
$$F = 33$$

$$\frac{s}{dF} = 9.9$$

San Francisco NPDES Field Studies

Field Studies





Ocean Plan Revisions

ii. In order to reduce entrainment, all surface water intakes must be screened with a 1.0 mm (0.04 in) or smaller slot size screen when the desalination facility* is withdrawing seawater.*

iii. An owner or operator may use an alternative method of preventing entrainment so long as the alternative method results in intake and mortality of eggs, larvae, and juvenile organisms that is less than or equivalent to a 1.0 mm (0.04 in) slot size screen. The owner or operator must demonstrate the effectiveness of the alternative method to the regional water board. The owner or operator must conduct a study to demonstrate the effectiveness of the alternative method, and use an Empirical Transport Model* (ETM)/ Area of Production Forgone* (APF) approach* to estimate entrainment. The study period shall be at least 12 consecutive months. Sampling for environmental studies shall be designed to account for variation in oceanographic or hydrologic conditions and larval abundance and diversity such that abundance estimates are reasonably accurate. Samples must be collected using a mesh size no larger than 335 microns and individuals collected shall be identified to the lowest taxonomical level practicable. The ETM/APF analysis* shall evaluate entrainment for a broad range of species, species morphologies, and sizes under the environmental and operational conditions that are representative of the entrained species and the conditions at the full-scale desalination facility.* At their discretion, the regional water boards may permit the use of existing entrainment data to meet this requirement.

iv. In order to minimize impingement, through-screen velocity at the surface water intake shall not exceed 0.15 meters per second (0.5 feet per second).

(2) Considerations for Brine* Discharge Technology:

(a) The preferred technology for minimizing intake and mortality of all forms of marine life* resulting from brine* discharge is to commingle brine* with wastewater (e.g., agricultural, municipal, industrial, power plant cooling water, etc.) that would otherwise be discharged to the ocean. The wastewater must provide adequate dilution to ensure salinity* of the commingled discharge meets the receiving water limitation for salinity* in chapter III.M.3. Nothing in this section shall preclude future recycling of the wastewater.

(b) Multiport diffusers* are the next best method for disposing of brine* when the brine* cannot be diluted by wastewater and when there are no live organisms in the discharge. Multiport diffusers* shall be engineered to maximize dilution, minimize the size of the brine mixing zone,* minimize the suspension of benthic sediments, and minimize mortality of all forms of marine life.*

(c) Brine* discharge technologies other than wastewater dilution and multiport diffusers,* may be used if an owner or operator can demonstrate to the regional water board that the technology provides a comparable level of intake and mortality of all forms of marine life* as wastewater dilution if wastewater is available, or multiport diffusers* if wastewater is unavailable. The owner or operator must evaluate all of the individual and cumulative effects of the proposed alternative discharge method on the intake and mortality of all forms of marine life,* including (where applicable): intake-related entrainment, osmotic stress, turbulence that occurs during water conveyance and mixing, and shearing stress at the point of discharge. When determining the intake and mortality associated with a brine* discharge technology or combination of technologies, the regional water board shall require the owner or operator to use empirical studies or modeling to:

i. Estimate intake entrainment impacts using an ETM/APF approach.*

ii. Estimate degradation of all forms of marine life* from elevated salinity* within the brine mixing zone,* including osmotic stresses, the size of impacted area, and the duration that all forms of marine life* are exposed to the toxic conditions. Considerations shall be given to the most sensitive species, and community structure and function.

iii. Estimate the intake and mortality of all forms of marine life* that occurs as a result of water conveyance, in-plant turbulence or mixing, and waste* discharge.

iv. Within 18 months of beginning operation, submit to the regional water board an empirical study that evaluates intake and mortality of all forms of marine life* associated

* See Appendix I for definition of terms.

201~~2~~5 Ocean Plan

* See Appendix I for definition of terms.

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Ocean Plan Revisions

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* See Appendix I for definition of terms.

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(d) Flow augmentation* as an alternative brine* discharge technology is prohibited with the following exceptions:

i. At facilities that use subsurface intakes* to supply augmented flow water for dilution. Facilities that use subsurface intakes* to supply augmented flow water for dilution are exempt from the requirements of chapter III.M.2.d.(2)(c) if the facility meets the receiving water limitation for salinity* in chapter III.M.3.

ii. At a facility that has received a conditional Water Code section 13142.5(b) determination and is over 80 percent constructed by [the effective date of this plan]. If the owner or operator of the facility proposes to use flow augmentation* as an alternative brine* discharge technology, the facility must: use low turbulence intakes (e.g., screw centrifugal pumps or axial flow pumps) and

* See Appendix I for definition of terms.

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Ocean Plan Revisions

3. Receiving Water Limitation for Salinity*

a. Chapter III.M.3 is applicable to all desalination facilities discharging brine* into ocean waters,* including facilities that commingle brine* and wastewater.

b. The receiving water limitation for salinity* shall be established as described below:

(1) Discharges shall not exceed a daily maximum of 2.0 parts per thousand (ppt) above natural background salinity* measured no further than 100 meters (328 ft) horizontally from each discharge point. There is no vertical limit to this zone.

(2) In determining an effluent limit necessary to meet this receiving water limitation, permit writers shall use the formula in chapter III.C.4 that has been modified for brine* discharges as follows:

Equation 1: Ce= Co + Dm(2.0 ppt)
Ce= (2.0 ppt + Cs) + Dm(2.0 ppt)

Where:

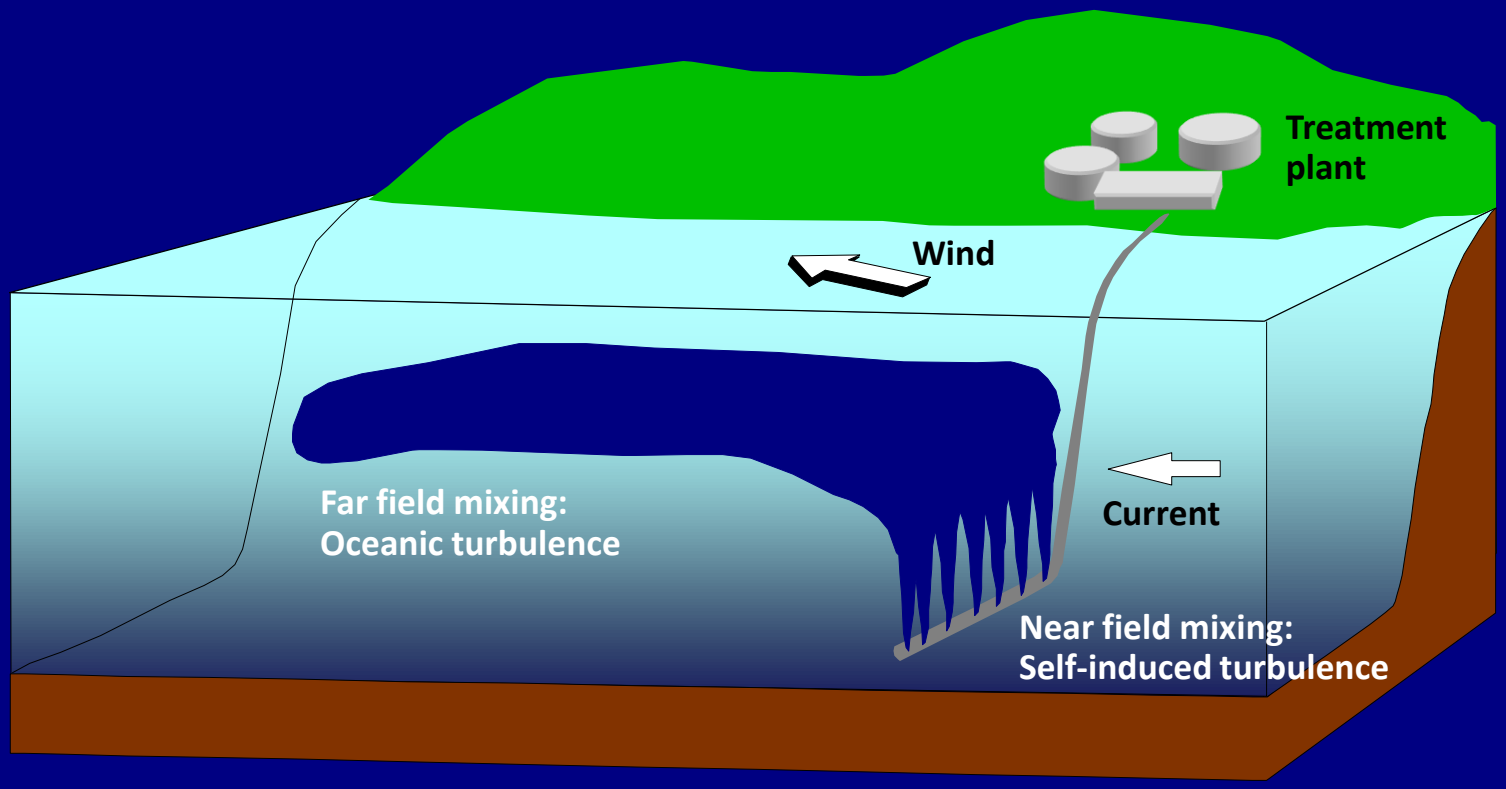
Ce= the effluent concentration limit, ppt
Co= the salinity* concentration to be met at the completion of initial* dilution= 2.0 ppt + Cs
Cs= the natural background salinity,* ppt
Dm= minimum probable initial dilution* expressed as parts seawater* per part brine* discharge

(a) The fixed distance referenced in the initial dilution* definition shall be no more than 100 meters (328 feet).

(b) In addition, the owner or operator shall develop a dilution factor (Dm) based on the distance of 100 meters (328 feet) or initial dilution,* whichever is smaller. The dilution factor (Dm) shall be developed within the brine mixing zone* using applicable water quality models that have been approved by the regional water boards in consultation with State Water Board staff.

* See Appendix I for definition of terms.

Coastal Outfall Dispersion Processes



Shear effect mortality estimates must be included

Alternative mixing zone of 200 m may be considered if plant 80% completed

Final Comments

- Design and siting are important!
- Wouldn't normally expect widespread effects
- Mostly near field effects
- Use caution with entrainment models
- Often simple empirical formulae ok
- Physical modeling may be needed
- Emerging issue: Turbulence and/or shear mortality of fish and organisms