Chapter 1

Introduction to Environmental Hydraulics

Contents

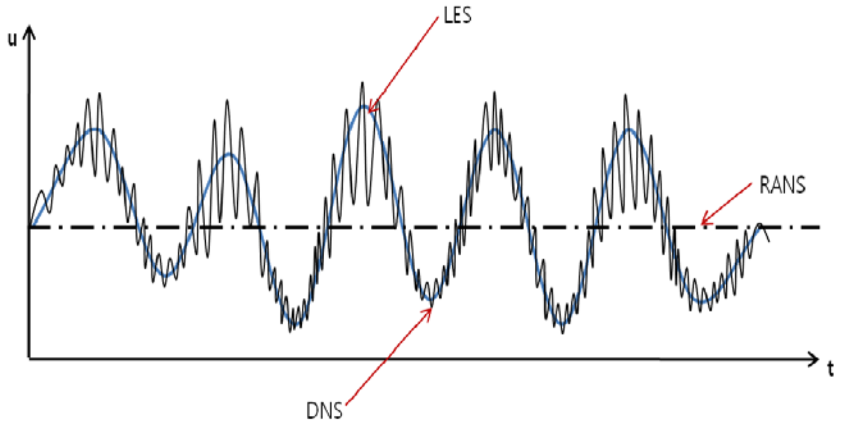
Objectives

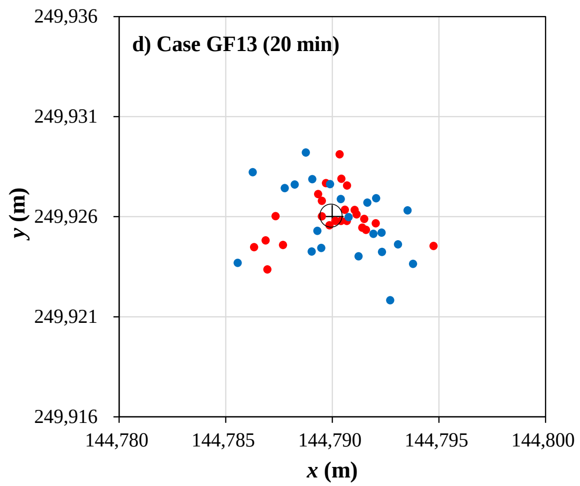
- Study fundamental concept of environmental management in water systems
- Introduce basic theories of Environmental Hydraulics
- Introduce methodology for mixing analysis and modeling

1.1 Environmental Management

1.1.1 Water Quality Management

- To study water quality [*C(x, y, z, t)*] in surface waters, we need to study
- water quantity [Q, U, H, W, S_0]
- hydrodynamics of transport and mixing [$\bar{u}, u', \varepsilon, D_{L,T}, K$]
- chemistry and biology of natural water systems [k, α]





1.1 Environmental Management

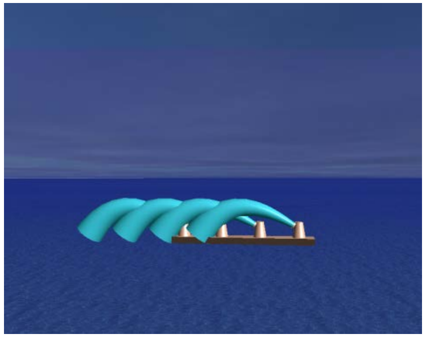
- **Environmental Fluid Mechanics**

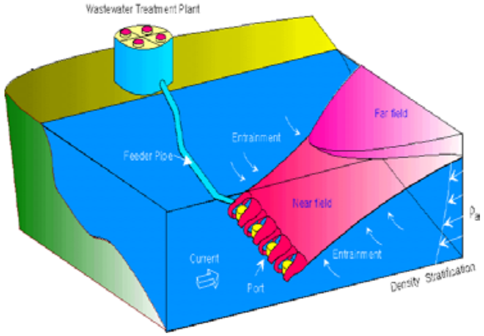
- Study of fluid motions in the lower atmosphere, in the ground, and in rivers, lakes, and seas that relate to problems connected to human activities within the environment

- **Environmental Hydraulics**

- study of water motions in the ground, and in rivers, lakes, and seas that relate to problems connected to human activities within the environment.

1) Diffusion and Dispersion
2) Turbulent Jets and Plumes
3) Stratified Flows





1.1 Environmental Management

- **Environmental Control System**

- Optimization of

1) control of pollutants at the source

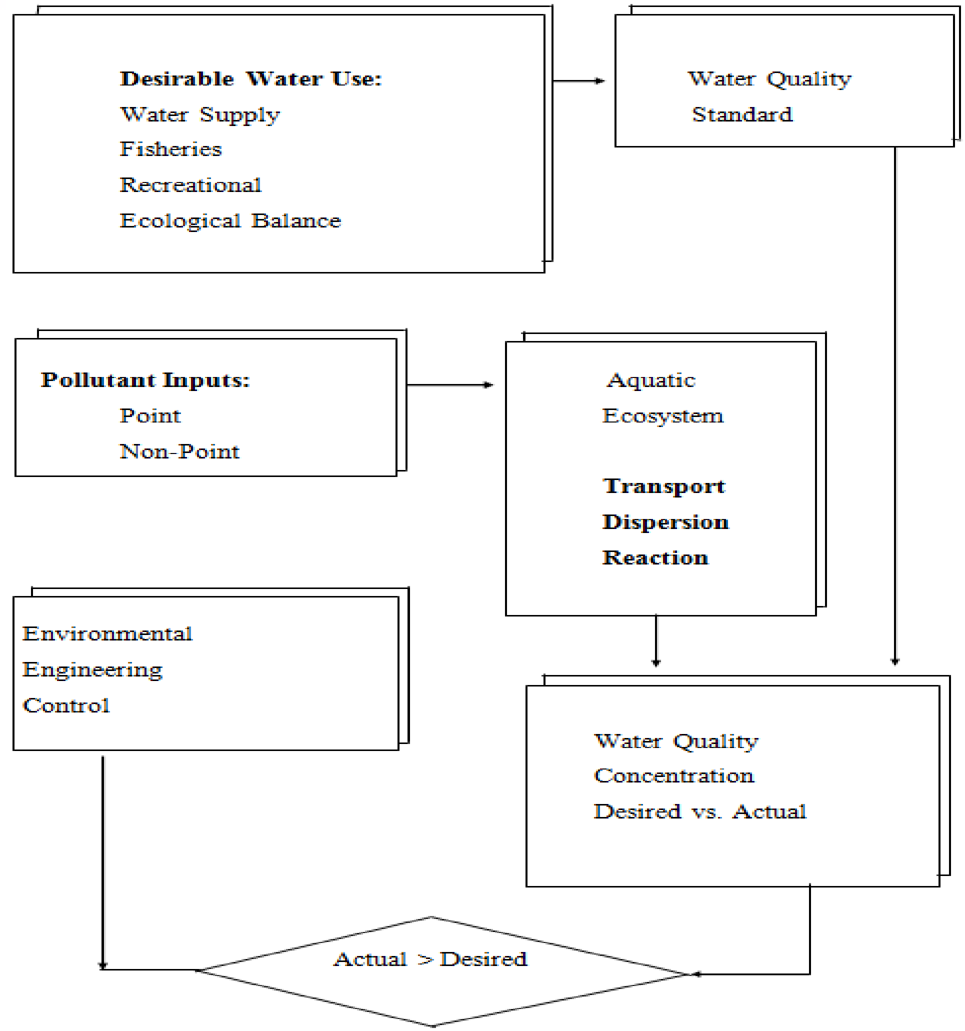
(pre-treatment, clean technology)

2) wastewater treatment

(primary, secondary treatment)

3) disposal in the environment

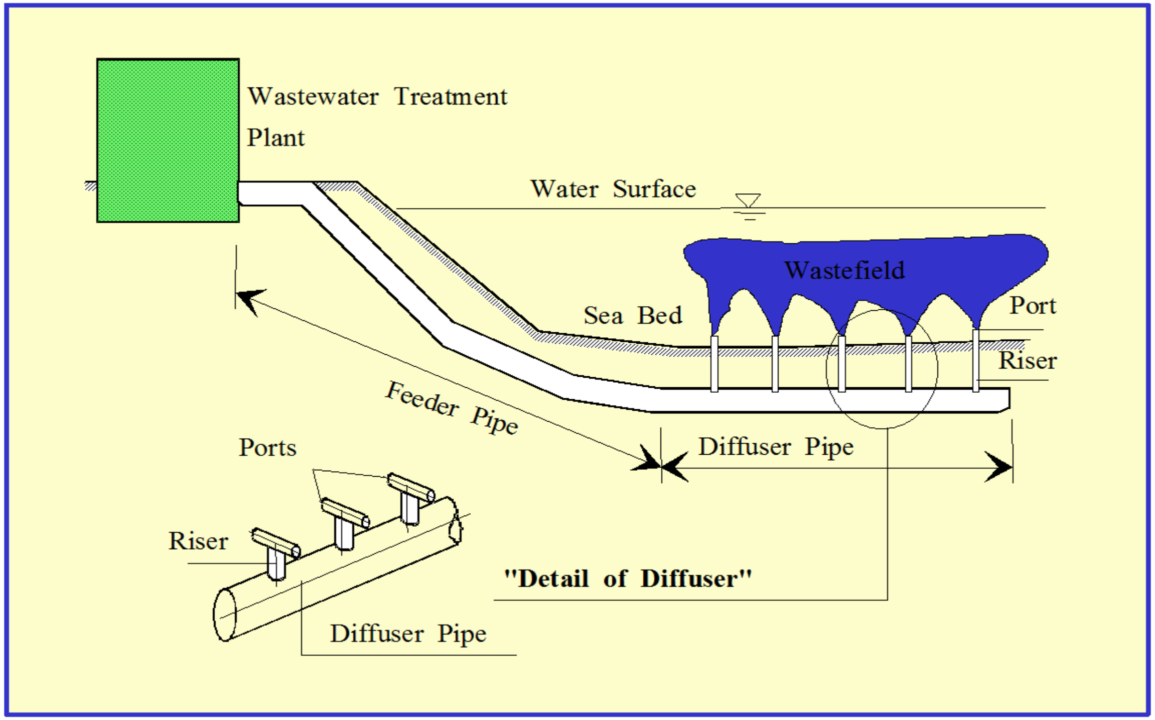
(post-treatment, wastewater outfalls)



1.1 Environmental Management

- **Role of hydraulic engineer in environmental management**

1) Design of hydraulic structure (outfalls, diffusers) **-> jets and plumes**



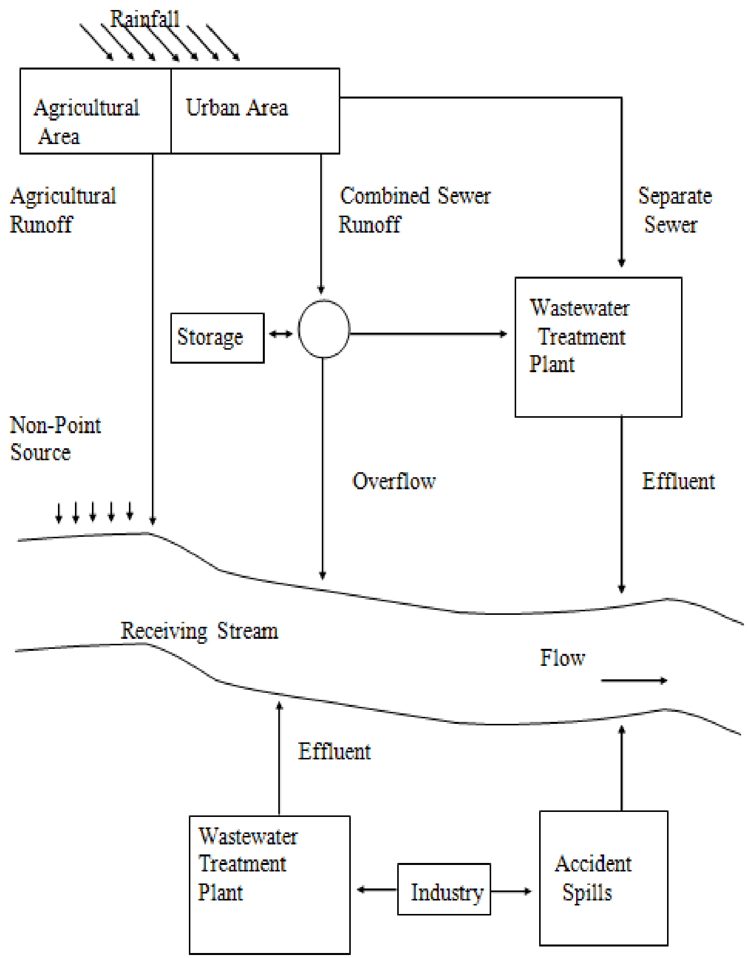
Multiport diffuser for wastewater treatment plant

1.1 Environmental Management

2) Analyze water quality processes

⇒ Fate of pollutants depends on transport (diffusion and dispersion)+ transformation + accumulation

⇒ Processes that takes places between the point where a pollutant is discharged into the water environment and some other sites (downstream site in rivers) where the ambient water quality is observed.



River water quality process

1.1 Environmental Management

[Re] Classification of pollutants

Point / Non-point	Conservative / Reactive	Miscible / Immiscible
Instantaneous / Continuous	Dissolved / Suspended	Organic / Inorganic

1.1 Environmental Management

1.1.2 Types of Pollutants

1.1.2.1 Classification of Pollutants

(1) Classification by mass conservation

- Conservative pollutants
- Non-conservative pollutants ~ decaying pollutants

[Re] Conservation of mass

- Flux of substance source must balance the fluxes for subsequent transport and diffusion with <u>adjustments for chemical and biological conversions and sinks, such as deposition on the river bed or sea floor.</u>

[Re] flux of solute mass

- mass of a solute crossing a unit area per unit time in a given direction
- For steady state, total influx = total efflux

1.1 Environmental Management

(2) Classification by pollutant source

- Point source
- discharges from a structure which is specially designed for the outflow of waste water
- effluents from industrial and municipal sewerage system, release of heated water from power plant
- accidental spill: accidental spill of chemicals or oil from a ship
- Nonpoint source
- Widely distributed points where pollutants are introduced into the hydrologic cycle

  [Ex] runoff of salts, soil erosion, acid rainfall, street drainage

(3) Classification by input period

Continuous input - municipal sewerage system, heated water from power plant

Instantaneous input - accidental spills

1.1 Environmental Management

Effluent discharge from Tancheon STP

1.1 Environmental Management

(4) Classification by density changes

- **Dynamically active substance:**
- cause significant density changes to affect the flow dynamics
- massive heated water discharge
- need to recalculate flow fields at each time step → coupled model
- **Dynamically passive substance:**
- does not cause density changes
- wastewater discharge
- flow fields are separately calculated and used as given input to mixing analysis

  → scalar transport model

[Cf] conservative substance: conserve mass

non-conservative substance: reactive, BOD

1.1 Environmental Management

- **Typical pollutants** (from the least dangerous to the most hazardous)

(1) Natural inorganic salts and sediments

- not toxic unless in excessive doses

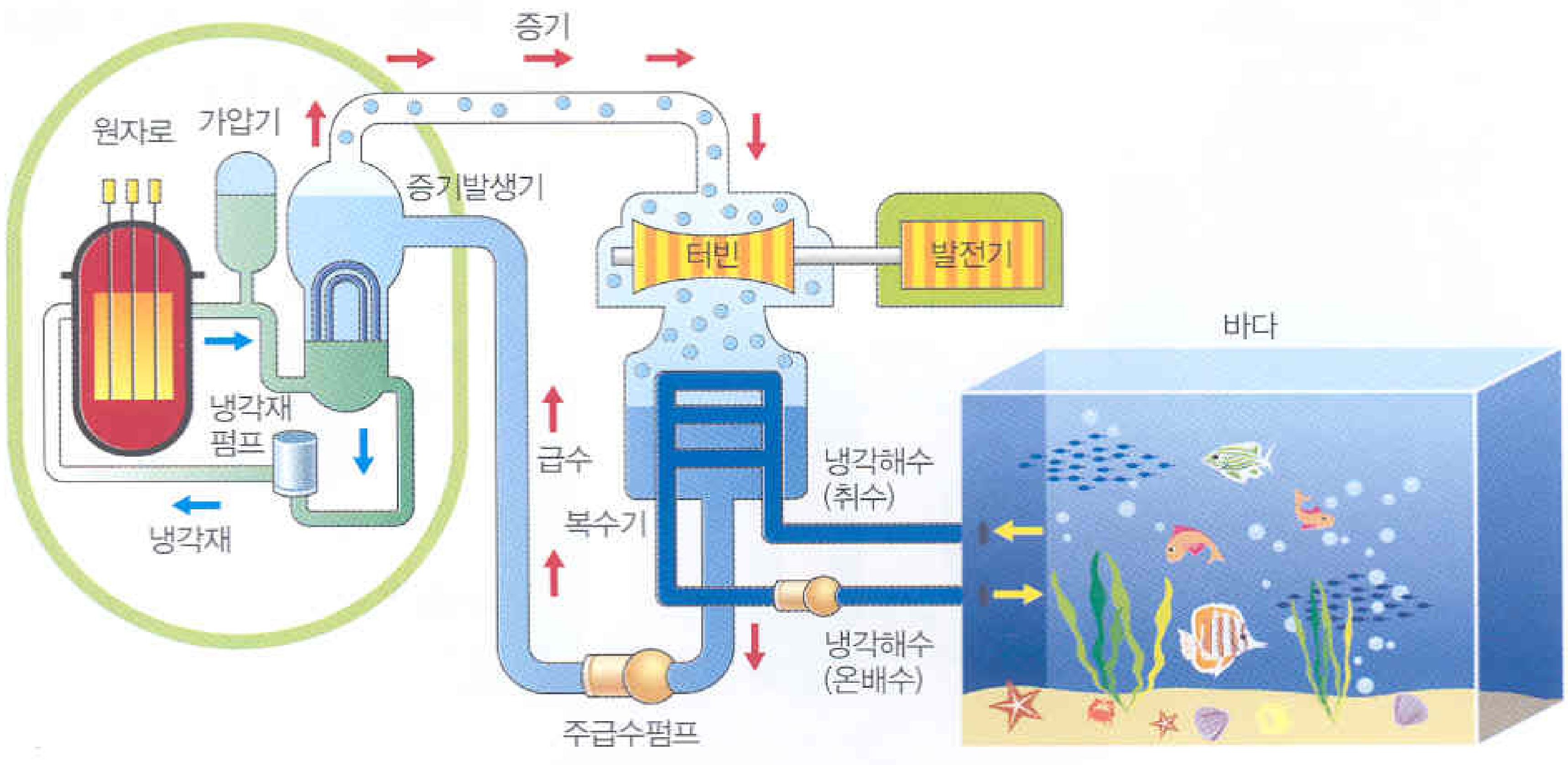
(2) Waste heat or heated water discharges

- cooling water for electric generating plants
- decrease water's assimilative capacity for oxygen

Yangz River

Nakdong River

1.1 Environmental Management



Cooling system for nuclear power plant

1.1 Environmental Management

[Remark 1.1] Type of discharges

- Positive buoyant discharge (양부력 제트)

  - Heated water discharge (온배수)
  - Wastewater discharge (하폐수)

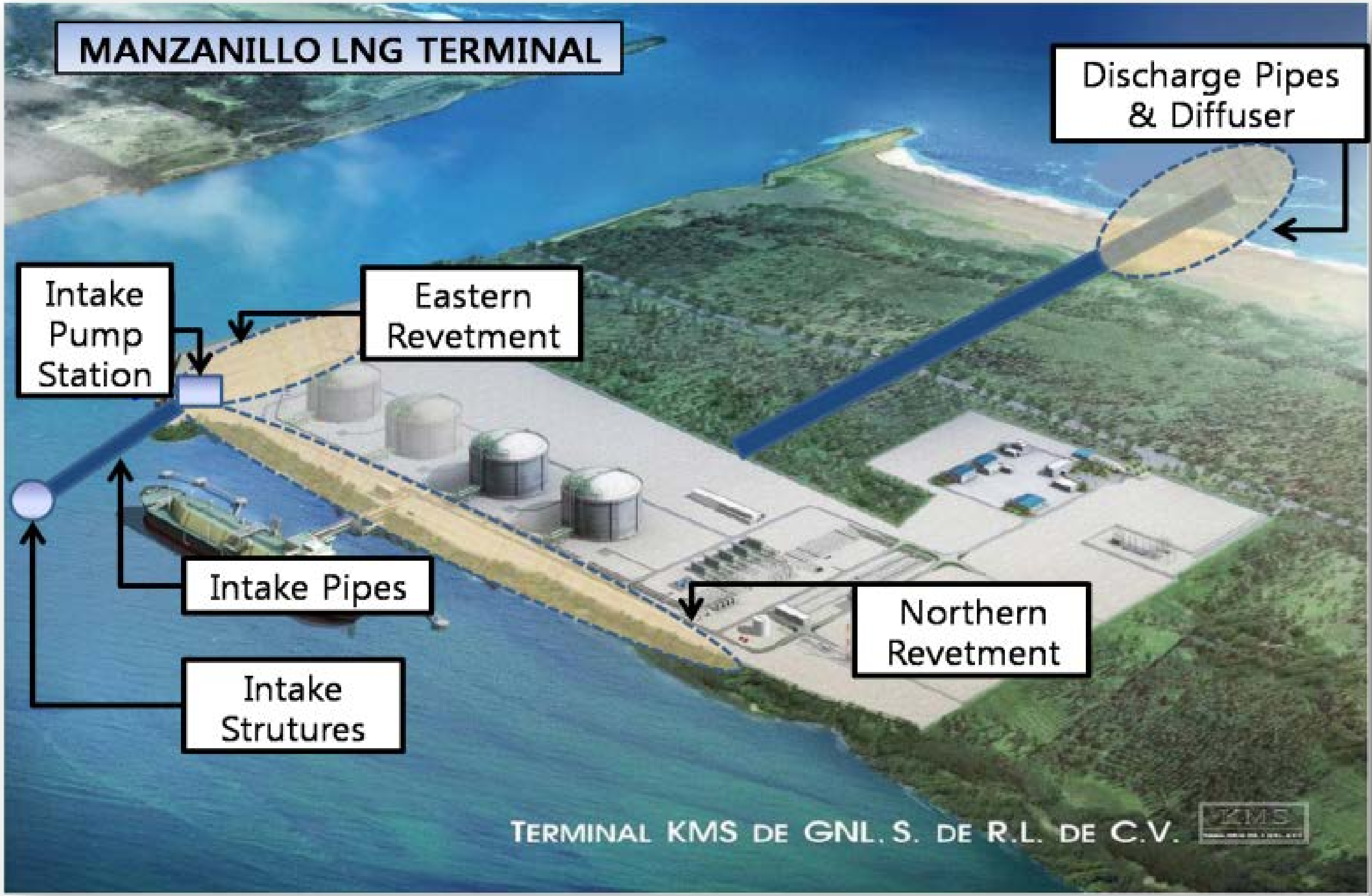
- Negative buoyant discharge (음부력 제트)

  - Cooled water discharge (냉배수)
  - Brine discharge (염수)

1.1 Environmental Management

Wastewater outfall of Sokcho STP (KORDI)

1.1 Environmental Management



Cooled water outfall of LNG terminal

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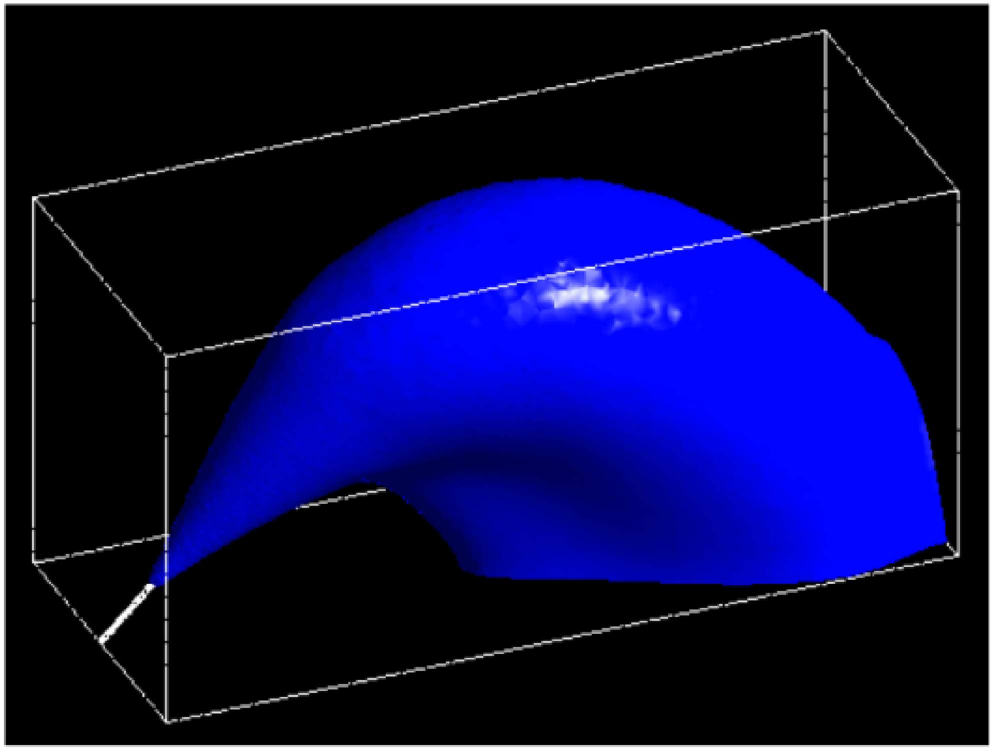

Figure 1. Steady State Turbulence (SST) model predictions of desalination plume behaviour. The plume was released of 45° and the image shows an isosurface that is representative of the outer edge of the flow.

Brine discharge from desalination plant

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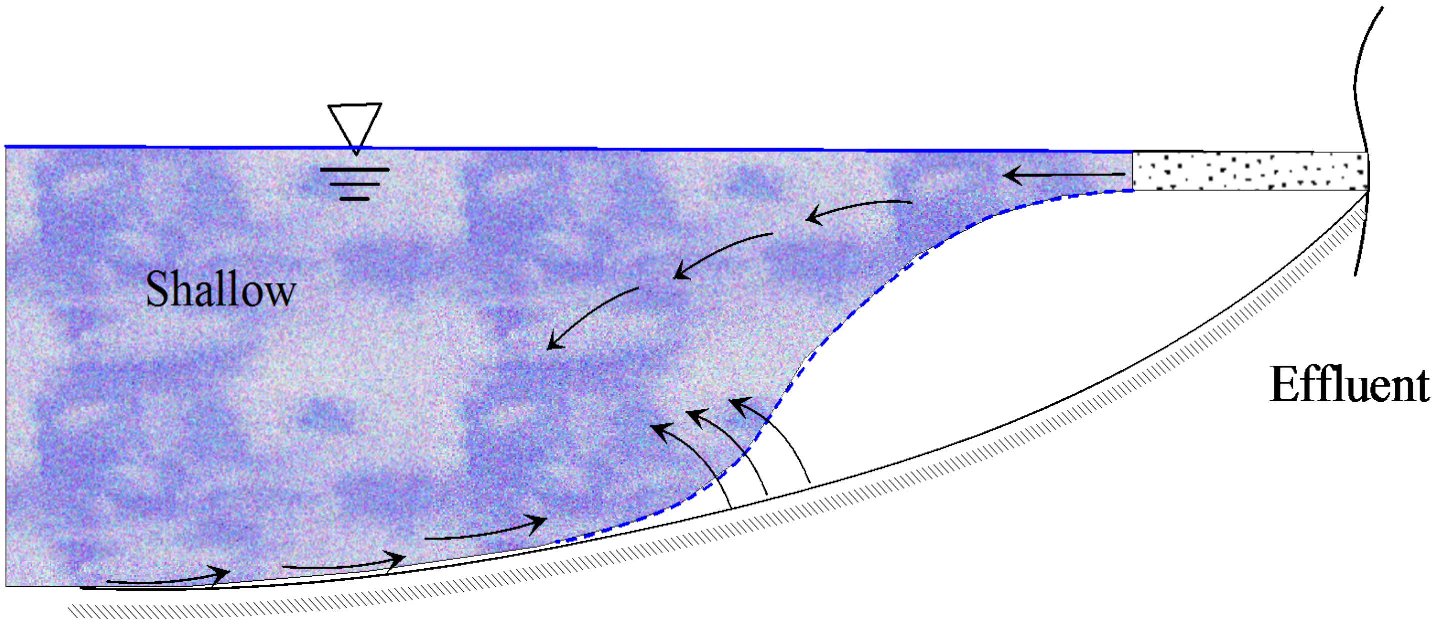
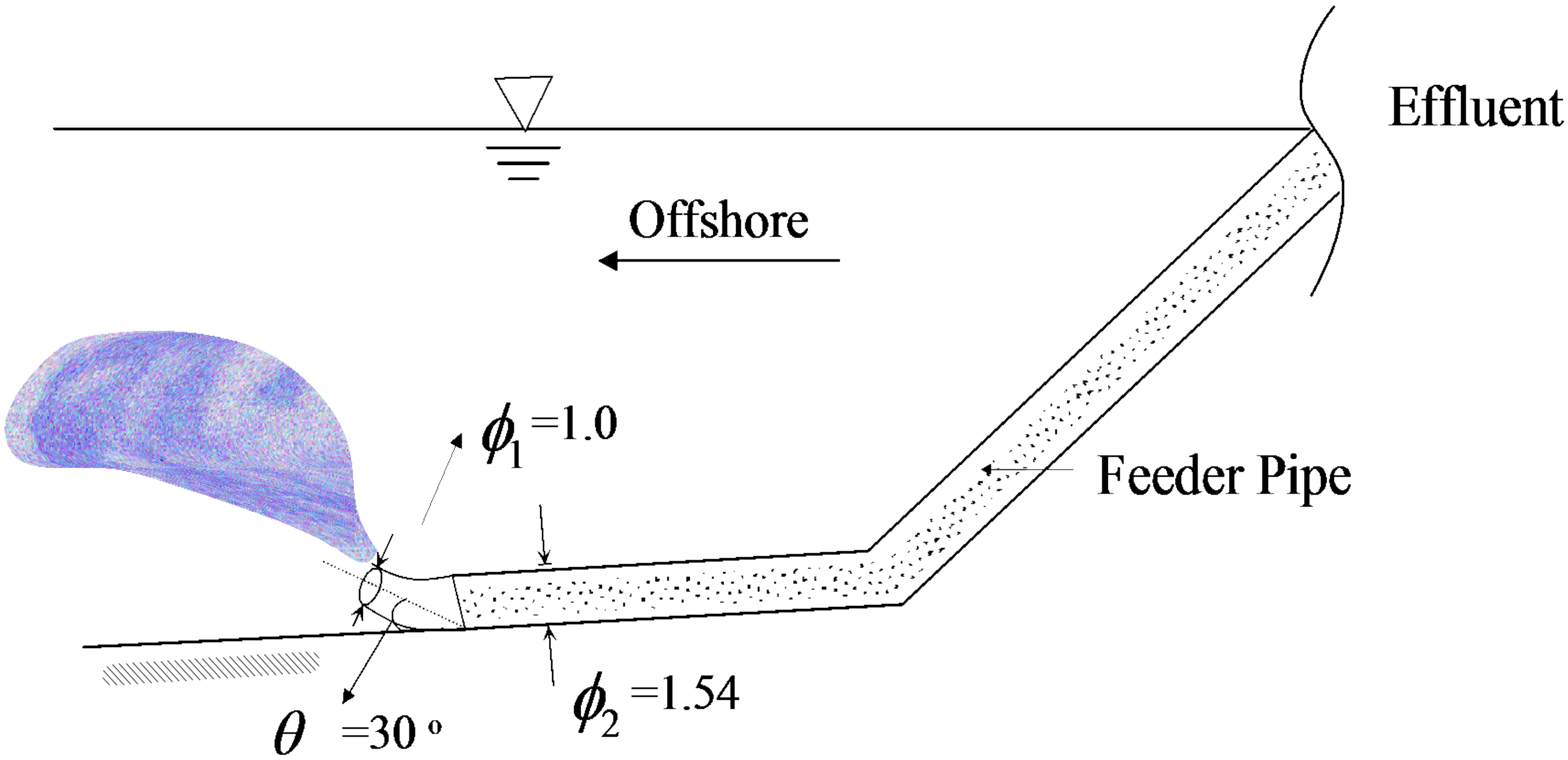
[Remark 1.2] Type of outfalls

1) Surface discharge

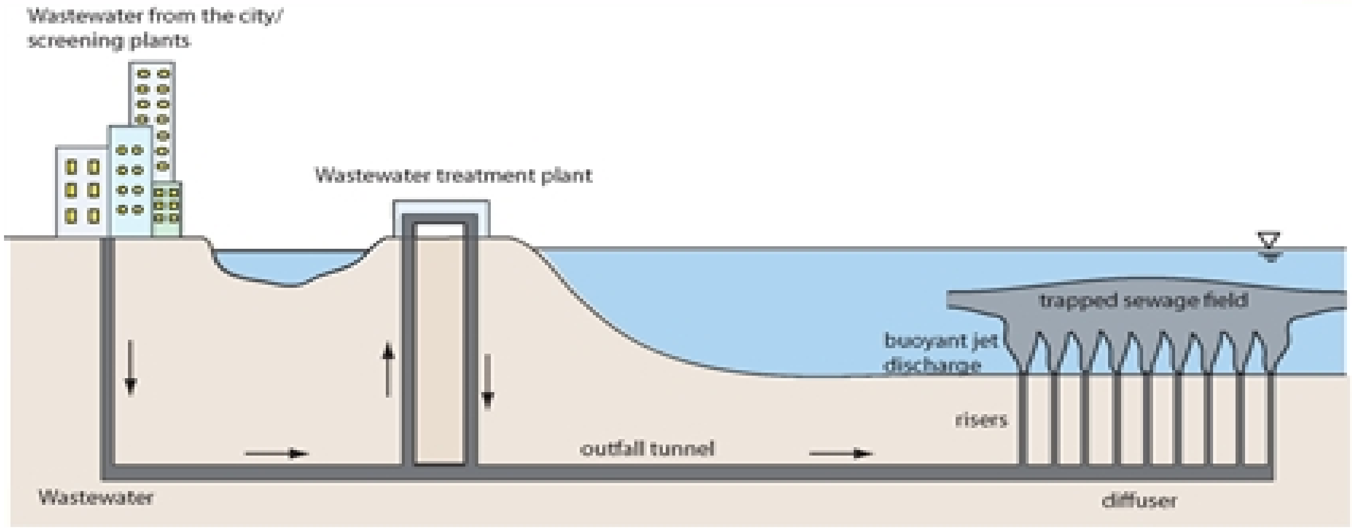


1.1 Environmental Management

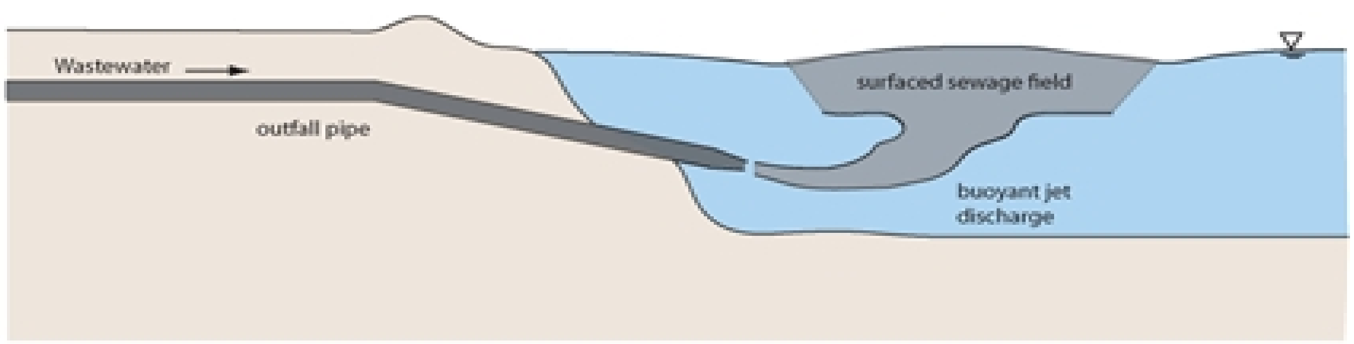
2) Single port diffuser



1.1 Environmental Management



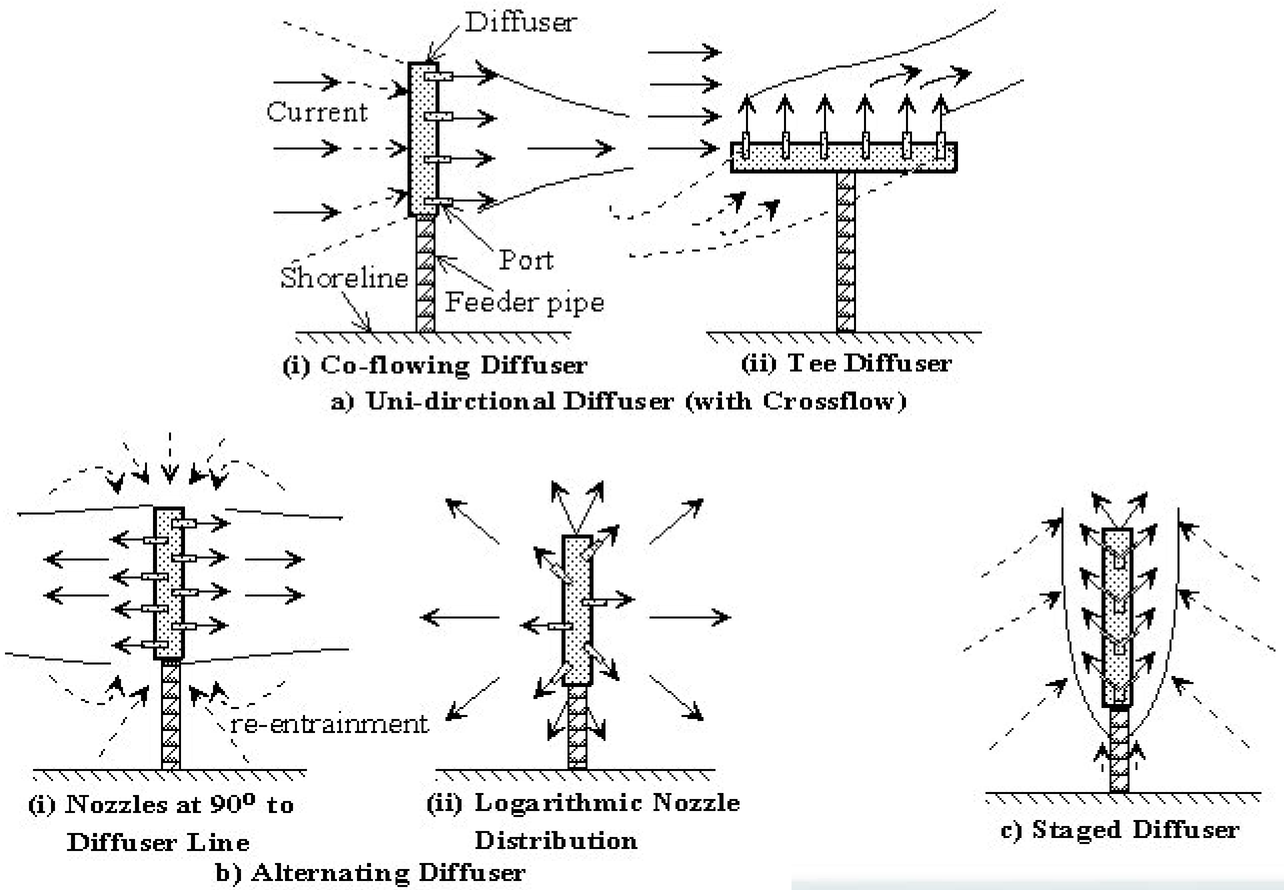
Tunnelled marine outfall



Single port outfall

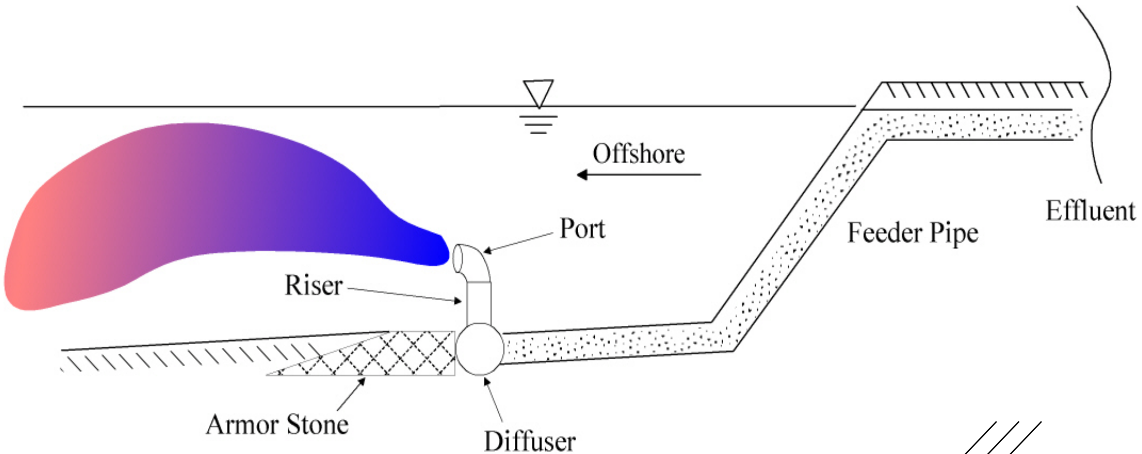
1.1 Environmental Management

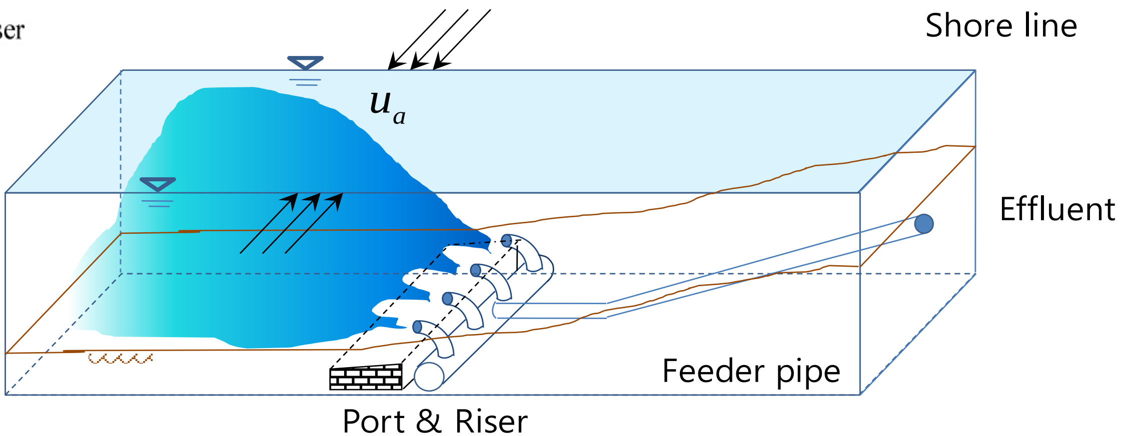
3) Multiport diffuser



1.1 Environmental Management

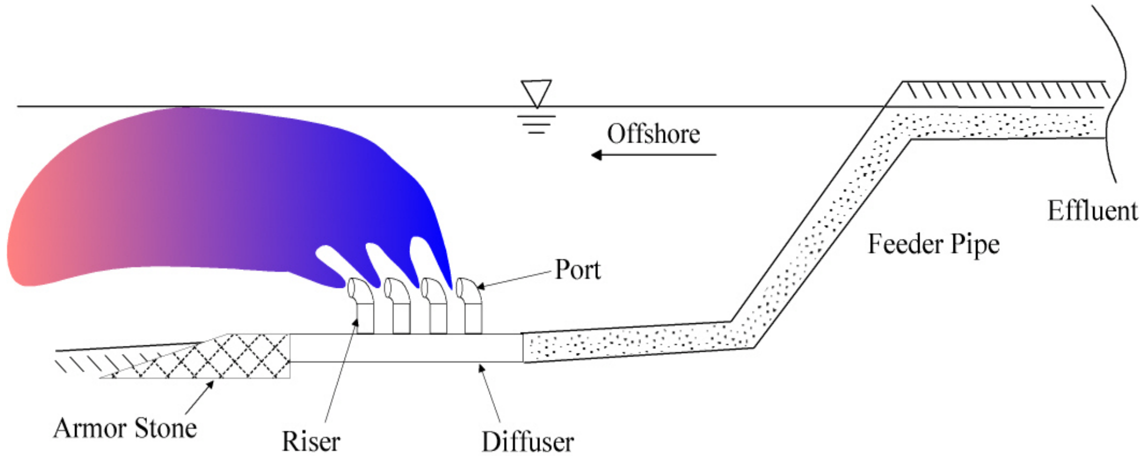
Tee diffuser

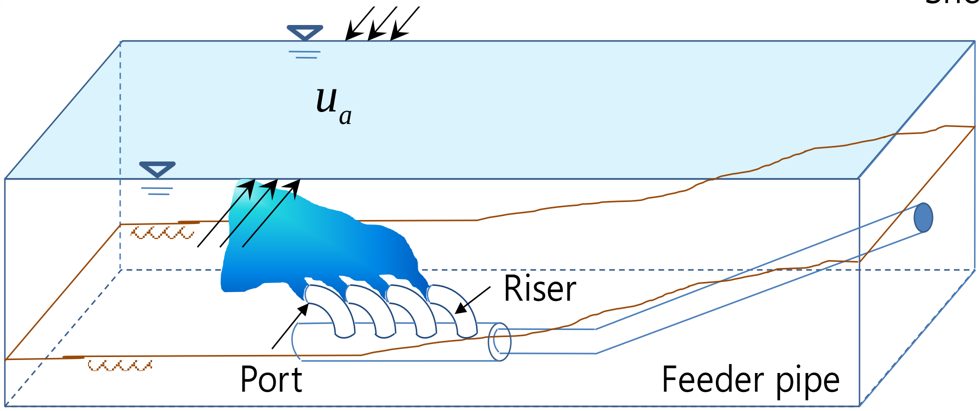




1.1 Environmental Management

Staged diffuser





1.1 Environmental Management

(3) Organic wastes

- domestic sewage → biochemical oxygen demand (BOD)
- carbon, nitrogen, phosphorous: nutrients → eutrophication

• BOD

- amount of dissolved oxygen for bacteria to oxidize the organic wastes in the water

• COD

- amount of dissolved oxygen to oxidize the organic wastes using chemicals

COD > BOD

bacteria

$$\text{Organic waste} + O_2 \rightarrow CO_2 + H_2O$$

[Re] "Dilution is the solution to pollution."

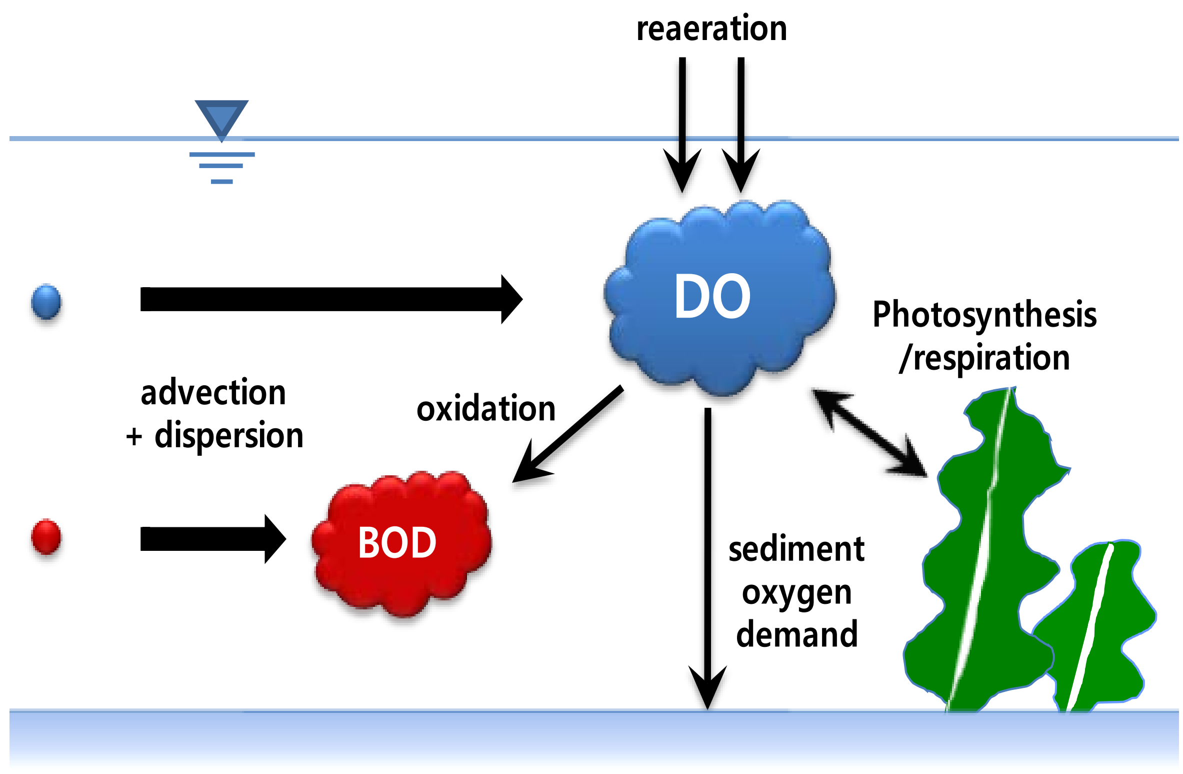
- suitable only for heat and natural organic materials

1.1 Environmental Management

- Drinking water quality

Class	BOD
1	< 1ppm
2	< 3ppm
3	< 6ppm
4	< 8ppm

- ppm = parts per million = mg/ℓ
1ppm = 1g of BOD/1,000,000g of water



BOD-DO coupled system

1.1 Environmental Management

(4) Trace metals

- industrial wastewater-electro-planting, battery manufacturing, mining, smelting, refining
- lead, mercury, cadmium, selenium
- toxic in high concentration (accumulation)

(5) Synthetic organic chemicals

- slow to degrade in environment
- bioaccumulate in the aquatic food chain
- industrial chemicals: phenol, benzenes, PCB(Poly-Chlorinated Biphenyls),
- agricultural chemicals: pesticides, herbicides, DDT

* biological process (multiplying the concentration by a factor of 10^5 in successive food chain steps)

⇔ physical process of mixing (= high dilution reduces the concentration)

1.1 Environmental Management

(6) Radioactive materials

- resulting from production of nuclear energy, nuclear weapons, and production of radioactive materials for industrial use
- plutonium - 239/240, strontium-90, cesium-137
- long-term storage of radio-active wastes w/o leakage

[Cf] radioisotopes for tracer materials: I-131 (half-life - 8.3 days)

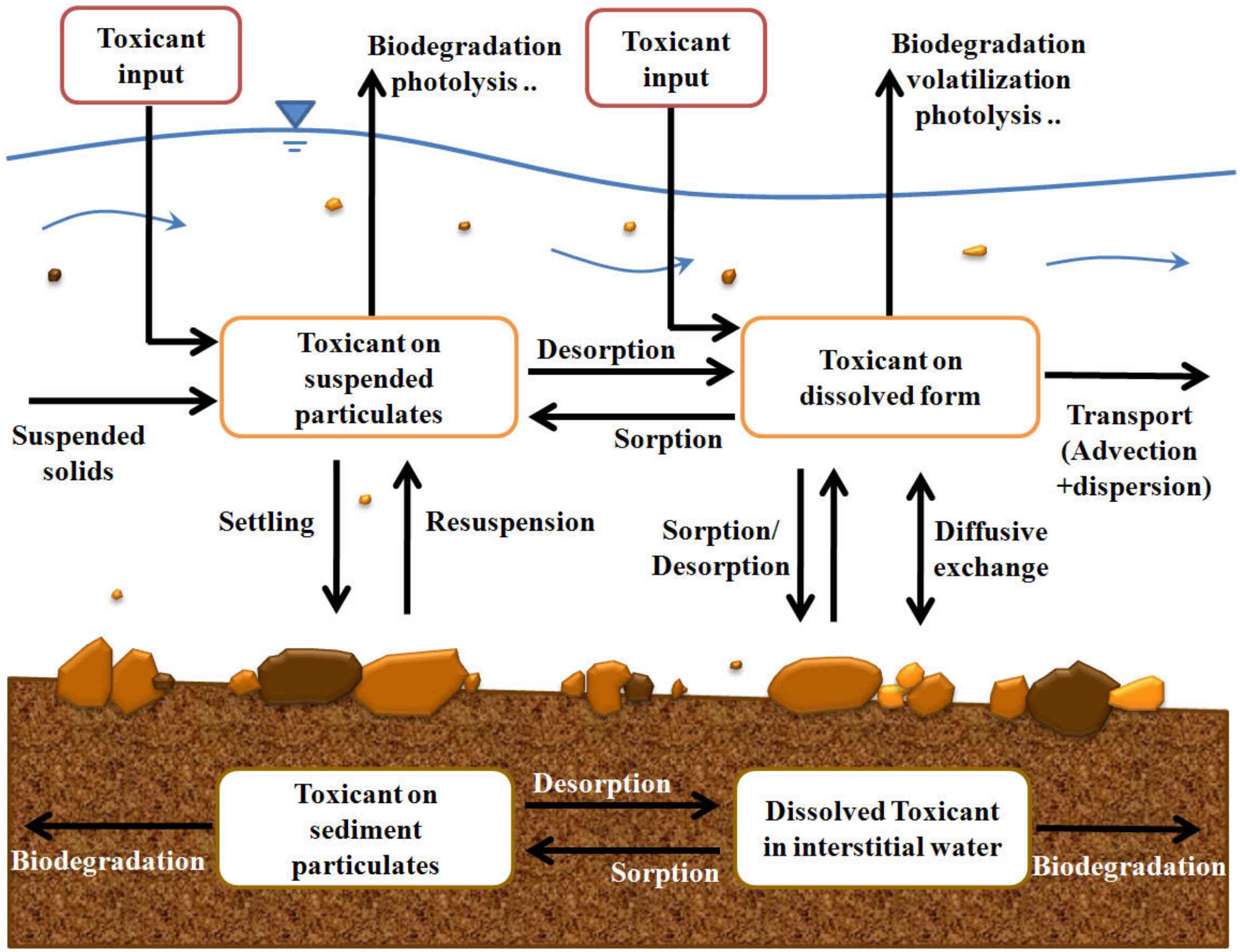
(7) Chemical and biological warfare agents

- exceedingly toxic; cannot be dispersed in the environment

[Re] Toxic substances: trace metals, synthetic chemicals, radioactive materials

- results in acute effects of mortality and long-term chronic effect
- tendency to sorb to particulates in the water body
- tendency to be toxic at relatively low concentrations of g/l or ng/l
- tendency to be concentrated by aquatic organisms and transferred up the food chain

1.1 Environmental Management



Transport of toxic materials

1.1 Environmental Management

1.1.3 Impacts of Hydraulic Works

- **Adverse effects of traditional hydraulic works on water quality**

- man-made reservoirs → summertime thermal stratification → oxygen depletion in the lower layer
- diversion water for consumptive uses → reduce river flow (inflow) and its ability to provide natural flushing
- canals → transport huge amount of dissolved salts, sediment, nutrients and parasites
- agricultural drainage system → accelerate the leaching of nutrients and salts from land to natural hydrologic systems
- breakwater for harbors → interfere with natural near-shore circulation which could otherwise carry away pollutants
- estuarine modification or barriers → radically change the circulation patterns decreasing flushing of pollutants

1.1 Environmental Management

Panama Canal

Breakwater for harbors

1.1 Environmental Management

Saemangeum sea dike

Saemangeum barrier

1.2 Environmental Hydraulics

1.2.1 Hydrologic Transport Processes

• **Hydrologic transport processes**

- physical processes of flow of natural water bodies which cause pollutants or natural substances to be transported and mixed, or exchanged with other media

⇔ man-made unit process (chemical plant)

(1) Advection: transport by an imposed current system of receiving (ambient) water bodies

(2) Convection: vertical transport induced by hydrostatic instability (buoyancy)

[Ex] - flow over a heated plate

- flow below a chilled water surface in a lake (winter time)

1.2 Environmental Hydraulics

(3) Molecular diffusion

- scattering of particles by random molecular motion
- Brownian motion
- described by Fick's law
- molecular diffusivity

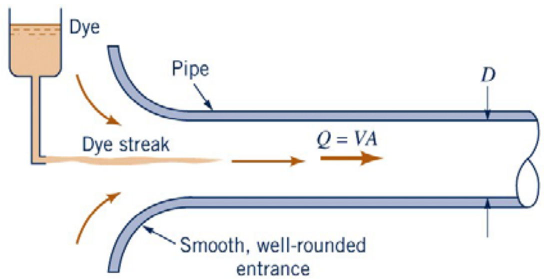
[Re] diffusion (physics): the process in which there is movement of a substance from an area of high concentration of that substance to an area of lower concentration

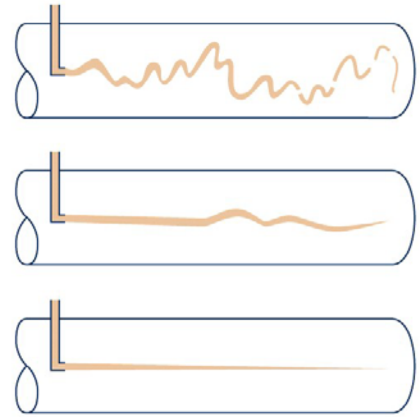
(4) Turbulent diffusion

- random scattering of particles by turbulent motion
- analogous to molecular diffusion
- molecular diffusion $\ll$ turbulent diffusion

[Ex] mixing in coffee cup: in rest vs. stirring

1.2 Environmental Hydraulics





Molecular and turbulent diffusions

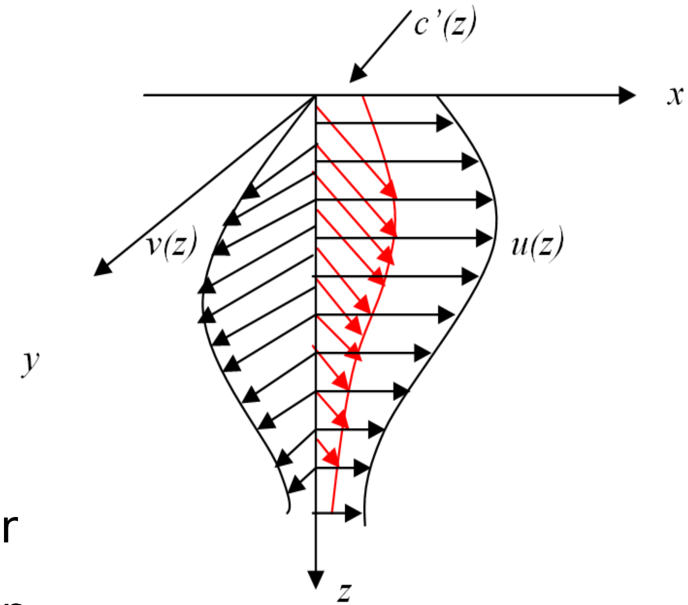
1.2 Environmental Hydraulics

(5) Shear (shear flow)

- advection of fluid at different velocities (direction and magnitude) at different positions

[Ex] - velocity distribution over stream bed

- complex flow in estuary or coastal areas



(6) Dispersion

- scattering of particles or cloud of contaminants

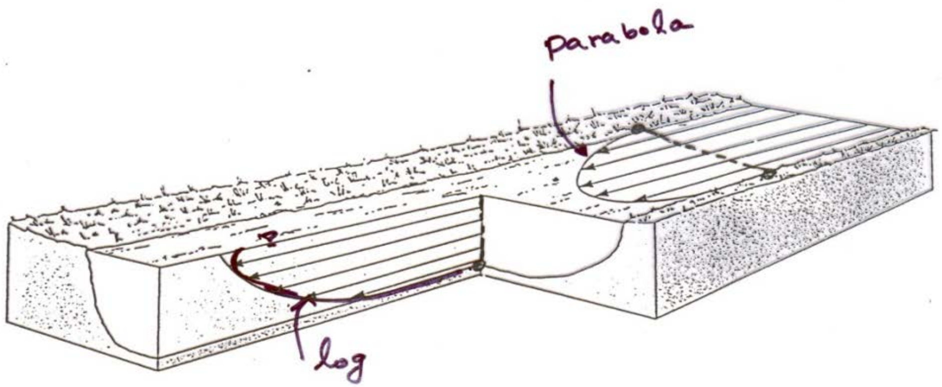
by the combined effects of shear and diffusion

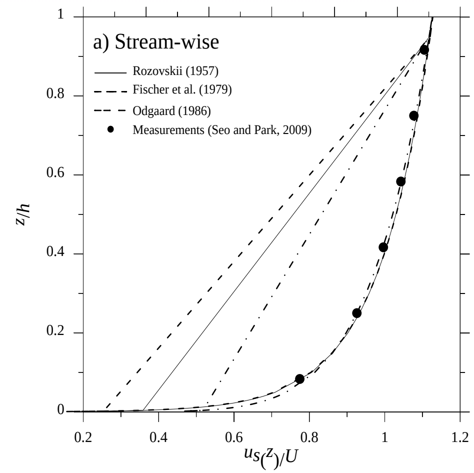
- shear advection + vertical and/or transverse diffusior

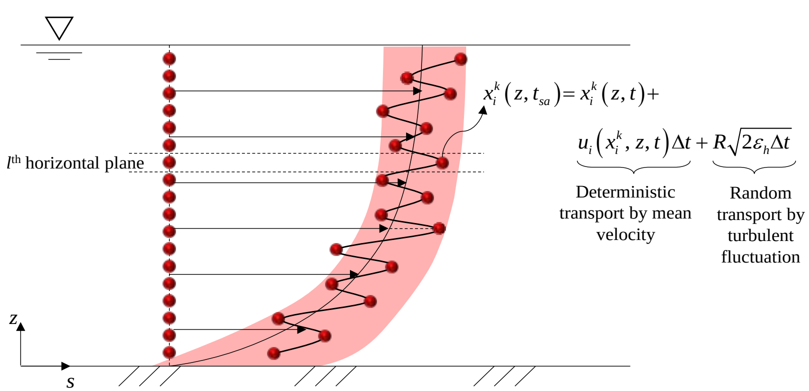
- molecular diffusion ≪ turbulent diffusion < dispersion

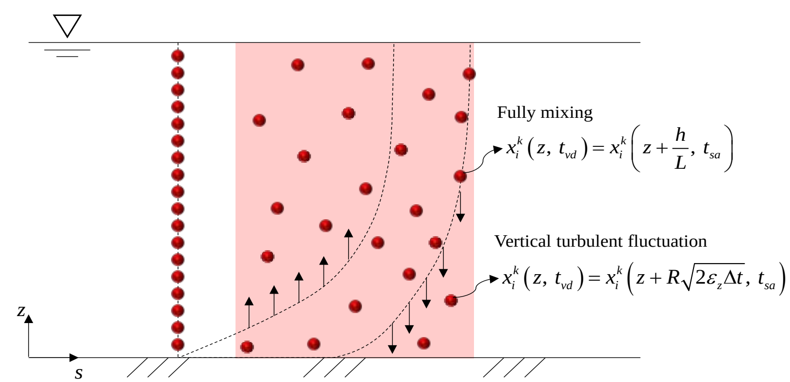
[Re] In optics, dispersion is the phenomenon in which the phase velocity of a wave depends on its frequency, or alternatively when the group velocity depends on the frequency.

1.2 Environmental Hydraulics



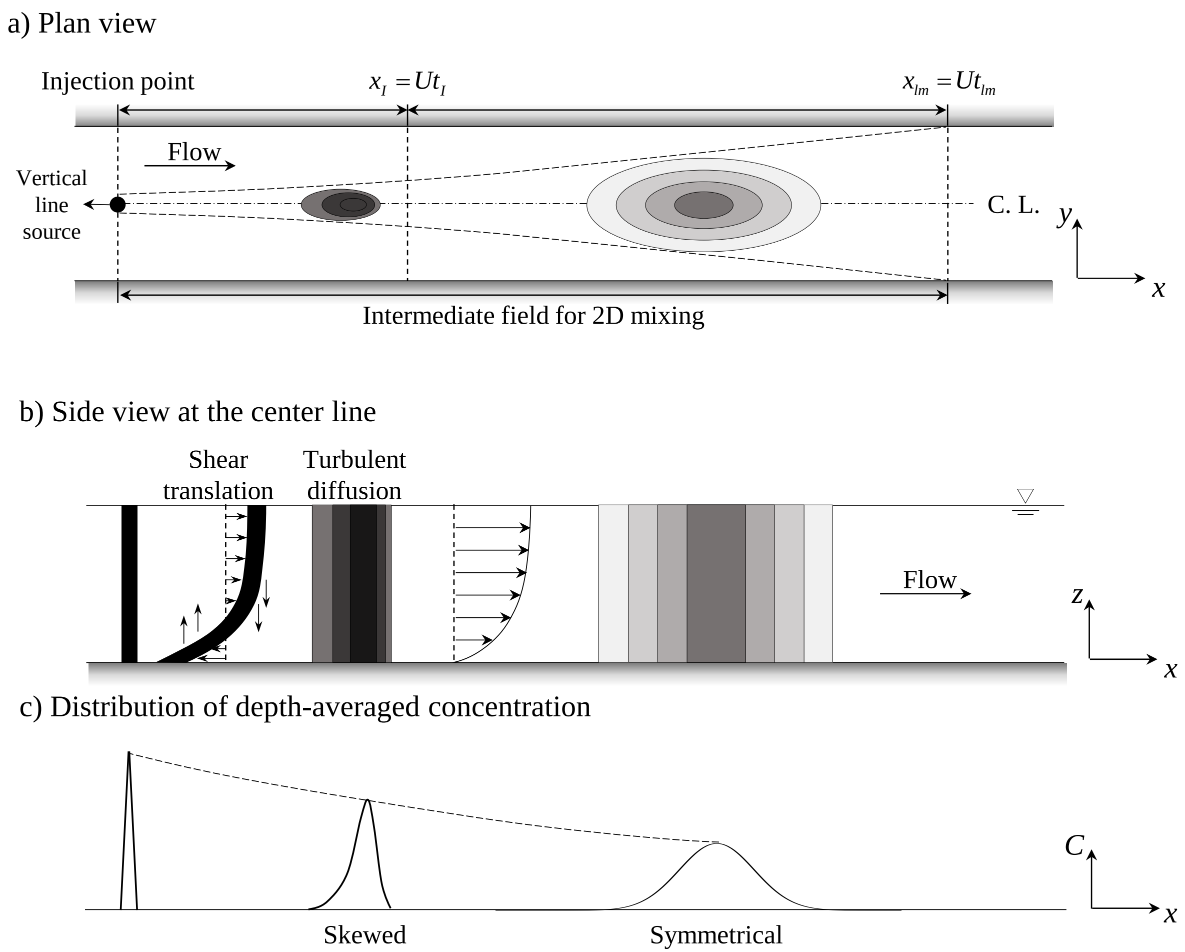






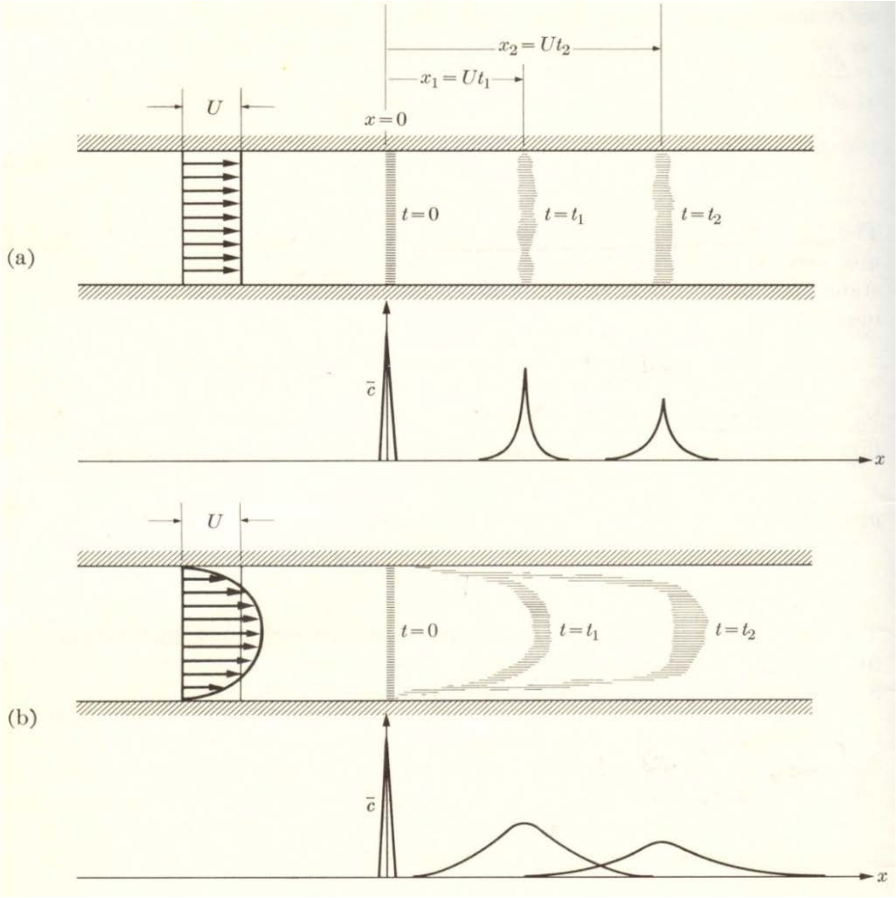
Shear flow dispersion

1.2 Environmental Hydraulics



2D dispersion of pollutants in open channels

1.2 Environmental Hydraulics



(a) Turbulent diffusion in uniform velocity flow;
(b) Turbulent dispersion due to non-uniform velocity distribution

1.2 Environmental Hydraulics

(7) Mixing

- diffusion or dispersion
- turbulent diffusion in buoyant jets and plumes
- any process which causes one parcel of water to be mixed with or diluted by another

(8) Evaporation

- transport of water vapor from a water or soil surface to the atmosphere

(9) Radiation

- flux of radiant energy at a water surface

(10) Particle settling

- sinking (or rising) of particles having densities different from the ambient fluid

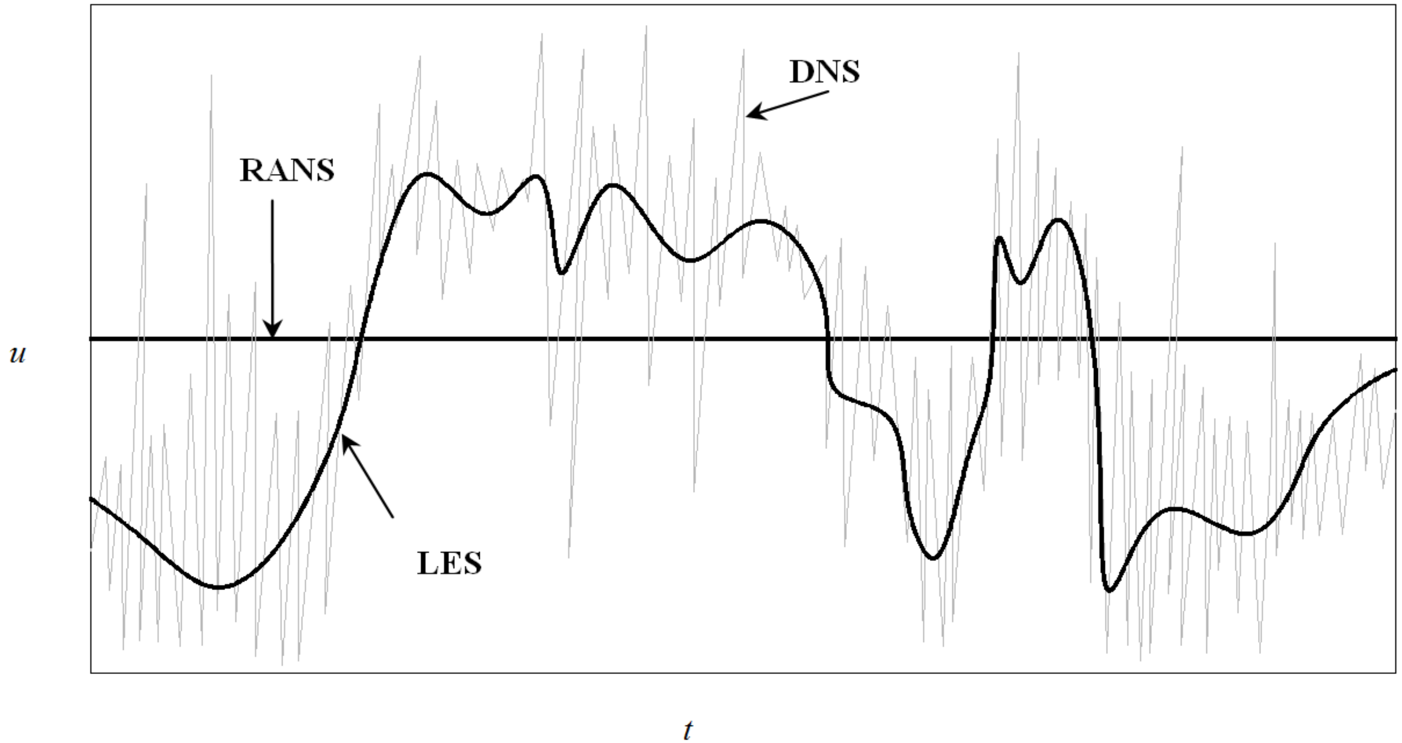
[Ex] sand grains, dead plankton → downward transport of nutrients in lakes and ocean

(11) Particle entrainment

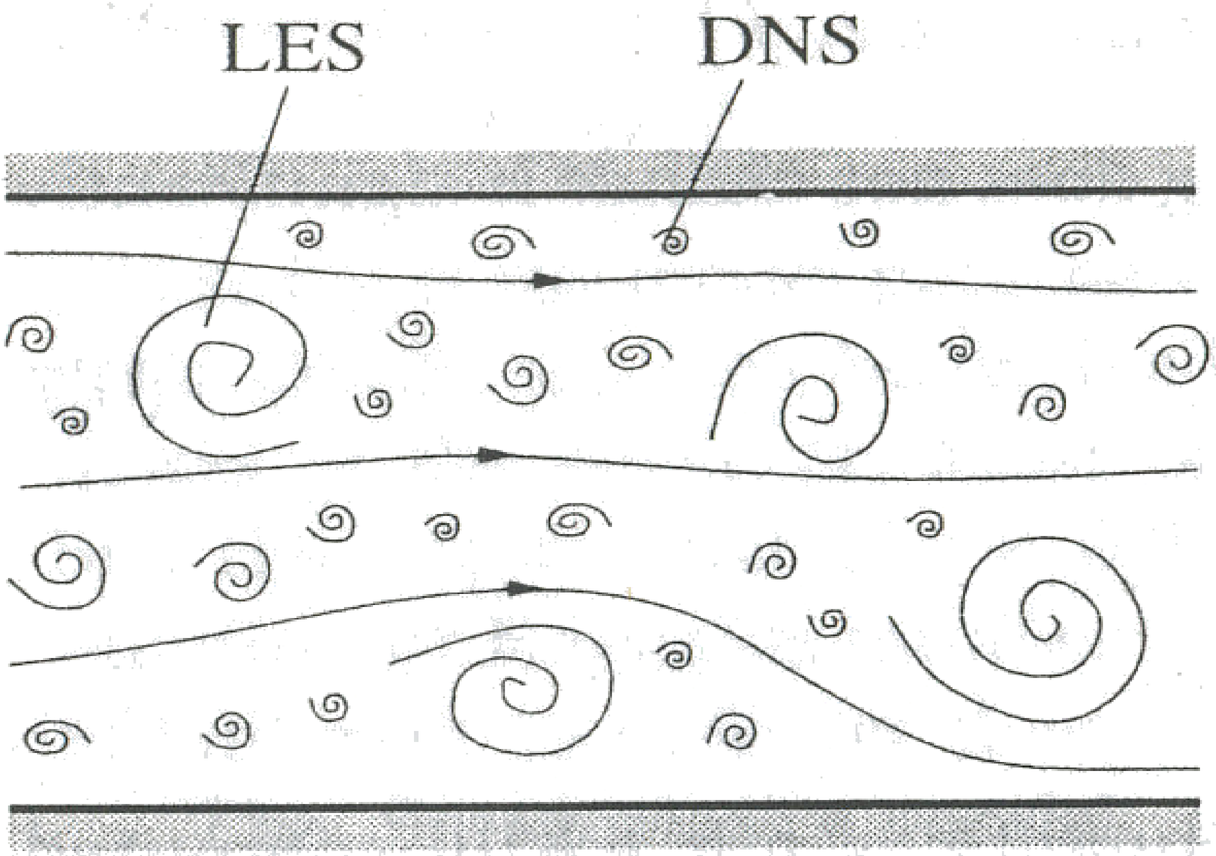
- picking up of particles (sand, organic detritus) from the bed by turbulent flow past the bed

1.2 Environmental Hydraulics

- Flow analysis - mean velocity is important
- Pollutant analysis - fluctuation and irregularities in hydrologic systems are equally important



1.2 Environmental Hydraulics



LES versus DNS

1.2 Environmental Hydraulics

1.2.2 Buoyant Jets and Plumes

• **submerged (momentum) jet**

- increase the dilution of effluent discharge with the surrounding waters

• **submerged buoyant jet**

- when discharge fluid is lighter or heavier than surrounding waters

- heated water discharge (momentum jet) vs. wastewater discharge (buoyant jet)

• **plume**

- initial momentum is not important

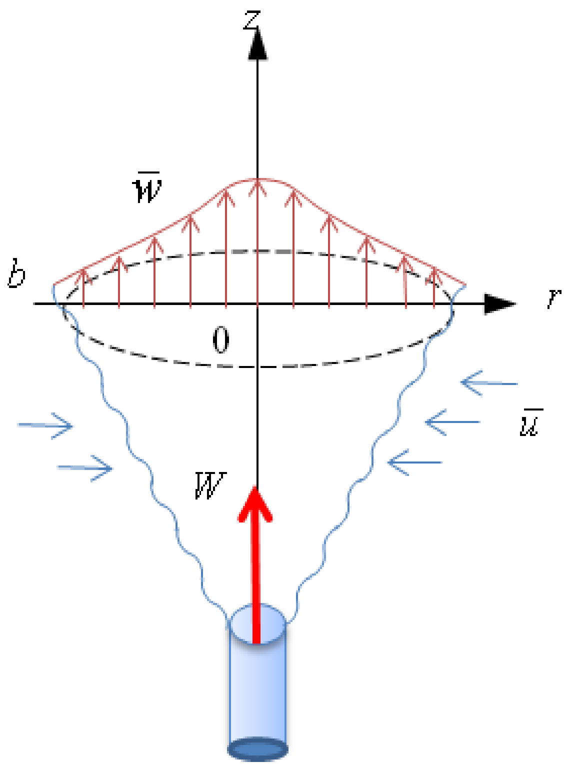
• **Analysis of buoyant jets and plumes → Design of Ocean Outfalls**

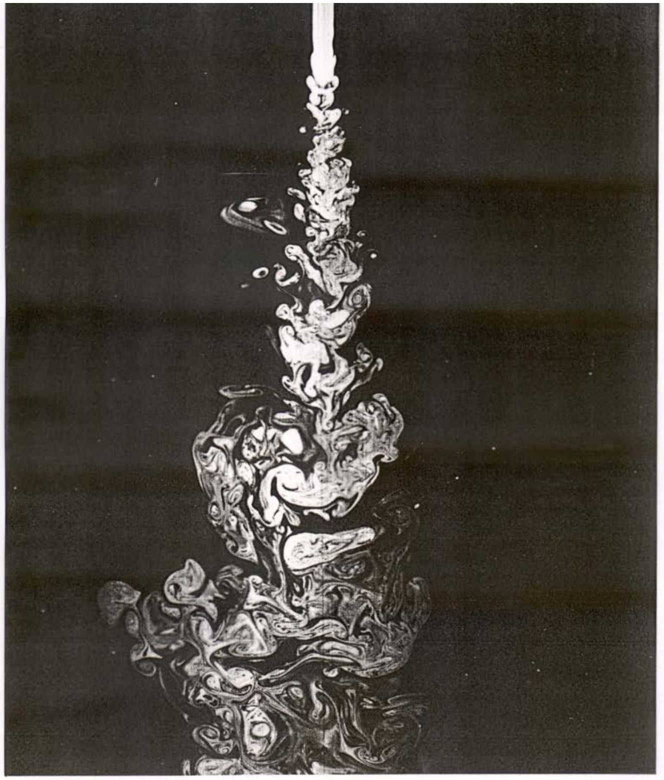
a) jet parameters: initial momentum flux, mass flux, buoyancy flux

b) ambient conditions: ambient density stratification, ambient velocity

c) geometric factors: jet shape, angle, orientation

1.2 Environmental Hydraulics

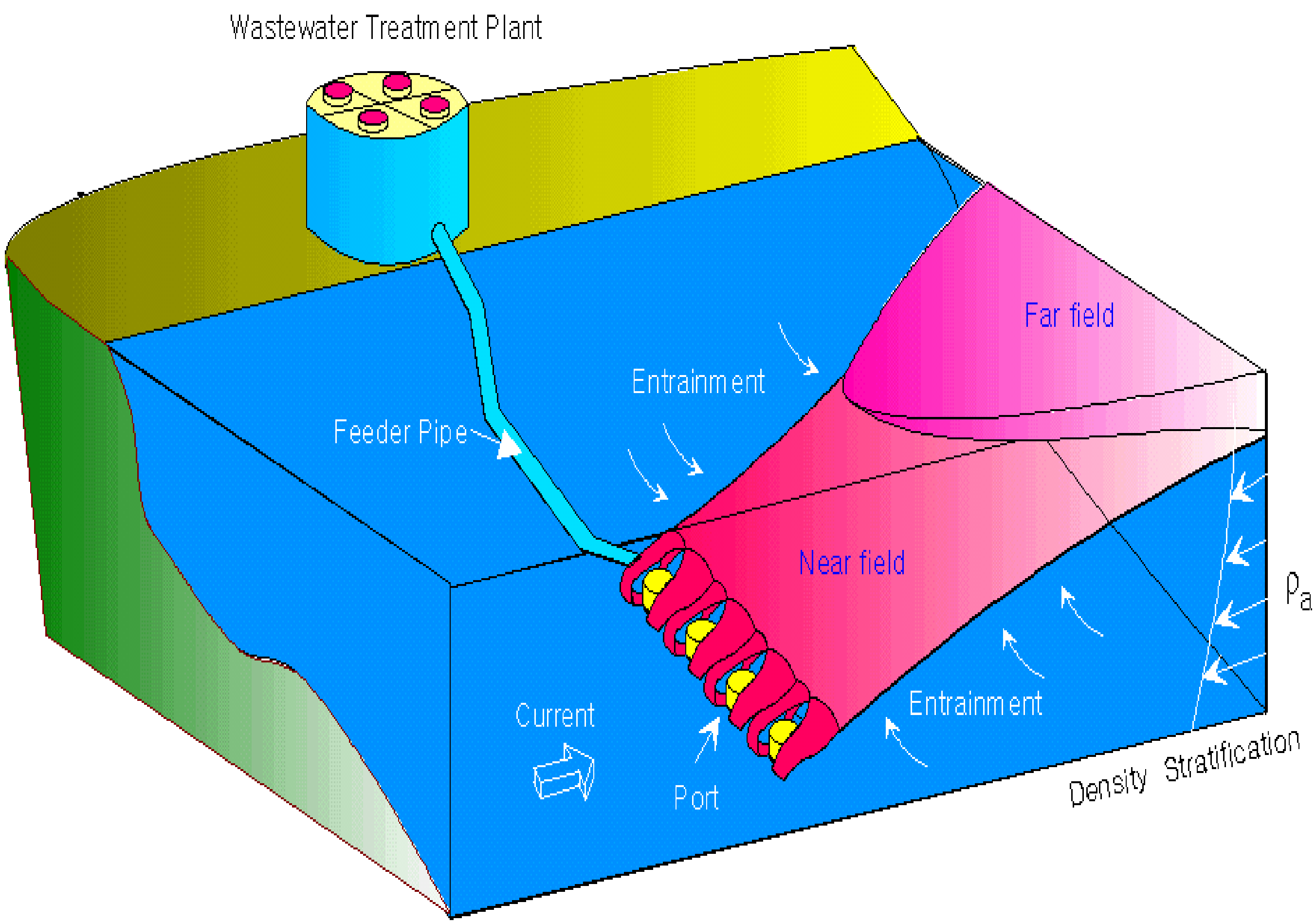




166. Turbulent water jet. Laser-induced fluorescence shows the concentration of jet fluid in the plane of symmetry of an axisymmetric jet of water directed downward into water. The Reynolds number is approximately 2300. The spatial resolution is adequate to resolve the Kolmogorov scale in the downstream half of the photograph. *Dimotakis, Lye & Papantoniou 1981*

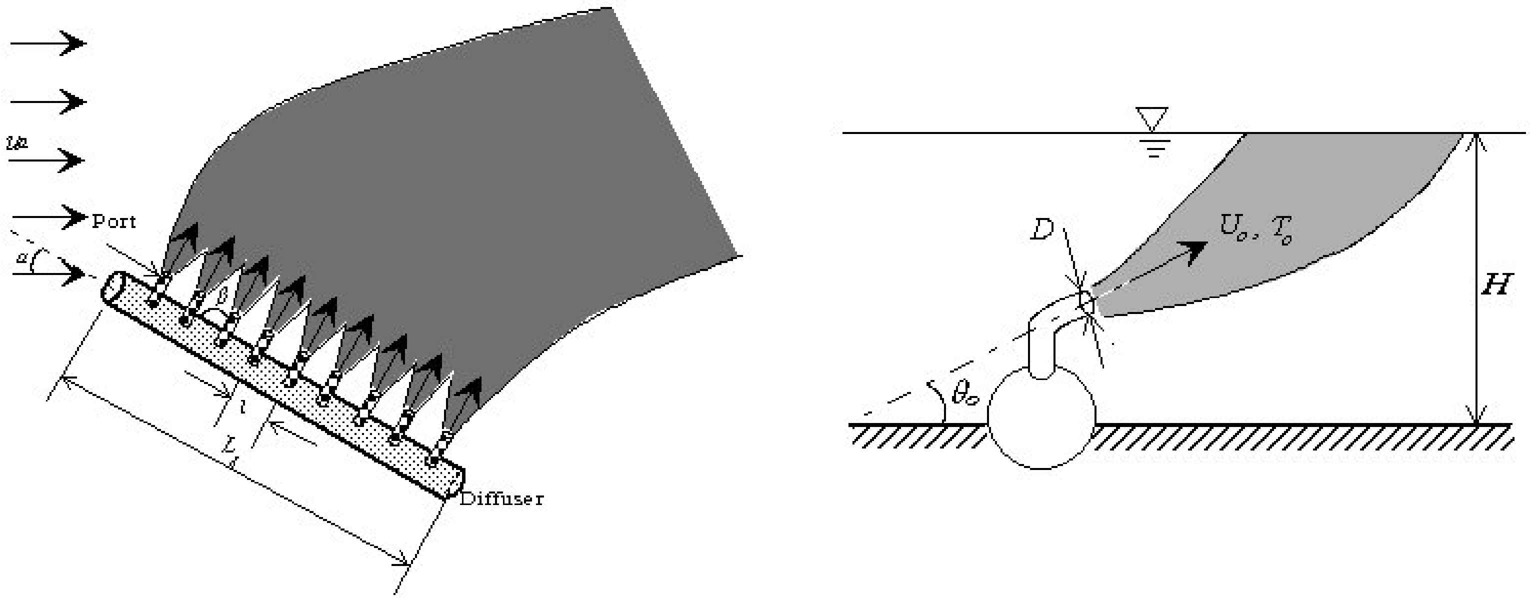
Turbulent jet

1.2 Environmental Hydraulics



Analysis of buoyant jets and plumes

1.2 Environmental Hydraulics



a) Plan View b) Side View

Configuration of Multiport Diffuser

1.2 Environmental Hydraulics

1.2.3 Stratified Flows

- weight density of water plays an important role in mixing in water body

weight density = weight per unit volume = ρg = weight/vol.

where ρ = mass density = *M/vol.*

g = gravitational acceleration

- Variation of ρ is less than 3% in estuary and ocean

⇒ unimportant for fluid acceleration (fluid dynamics)

⇒ however, weight (buoyancy) difference (= $g\Delta\gamma$) is important for buoyancy of discharges of stability of density-stratified flows (mixing mechanics)

- buoyancy per unit mass

$$g\frac{\Delta\rho}{\rho} = g' = \text{modified gravitational acceleration}$$

1.2 Environmental Hydraulics

- $\sigma_t = \sigma - units$ for water density

$$\rho = 1 + \frac{\sigma_t}{1000}(g/cm^3) = 1000 + \sigma_t (kg/m^3)$$

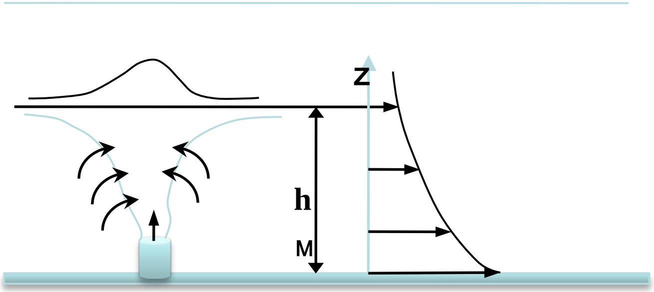
$$\sigma_t = \sigma - units$$
$$= f_n(temperature, salinity) \rightarrow See\ App.1$$

- Density stratification

→ lake, reservoirs - due to temperature variation

→ estuary - salinity profiles

- internal structure causes effect on both mean flow fields and turbulent mixing and dispersion



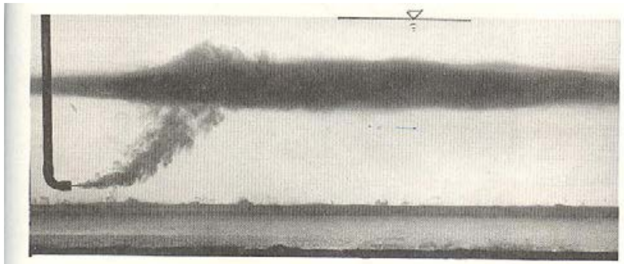


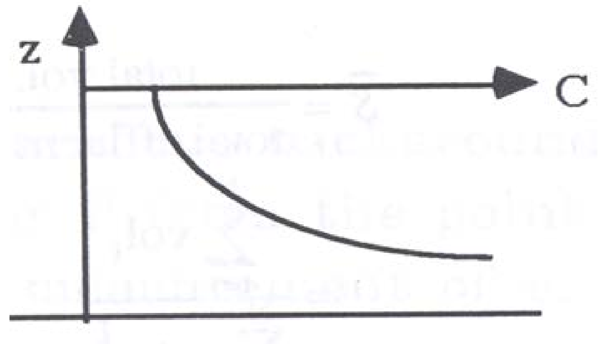
Figure 9.32 Horizontal turbulent buoyant jet in a density-stratified environment. $R_0 = 0.036$, $N = 0.56$. [From Fan (1967).]

1.2 Environmental Hydraulics

- density profile $\rho_a(z)$

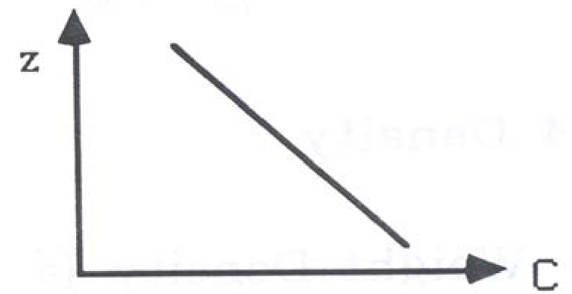
  z = vertical coordinates

$$\frac{d\rho_a}{dz} < 0$$



- linear density stratification

$$-g\frac{d\rho_a}{dz} = const.$$



1.2.4 Sedimentation and Erosion

- particle setting and entrainment, stream morphology
- erosion, transport and deposition → 『Sediment Transport』

1.3 Mixing Analysis

1.3.1 Strategies

- **Strategy:**

1) Identify problems

2) For large complicated problems, break a problem (of mixing) into sub-models (component parts)

3) Use two or more approaches (mixed approaches/hybrid modeling)

- interweaving of all of the approaches

- better than single approach

[Re] Approaches:

- computer modeling

- physical modeling - hydraulic model

- field experimentation

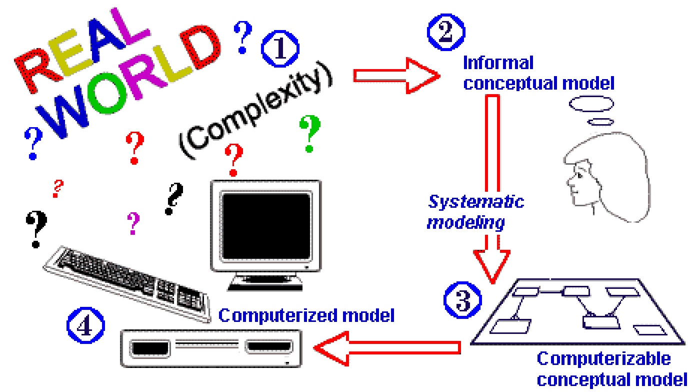
1.3 Mixing Analysis

1.3.2 Approaches

- Problem-solving tools

• **River model:**

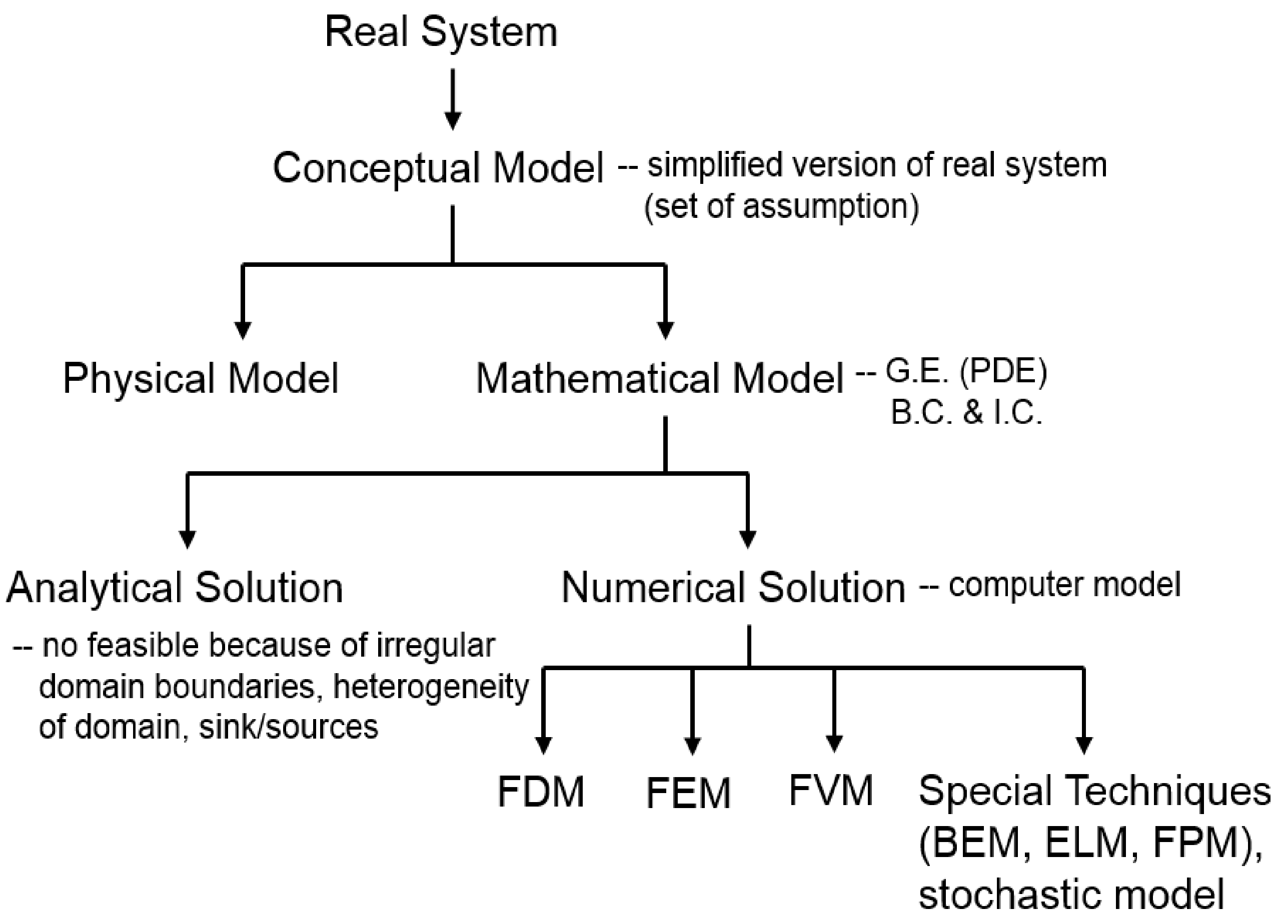
- describe the real system of river dynamics using physical or mathematical approach
- understanding and prediction of river dynamics
- accuracy depending on simplification level



• **Computer model**:

- numerical solution of mathematical equations
- cannot be better that the validity of the underlying approximations
- can include meteorological factors (wind, surface cooling)
- can avoid scaling errors

1.3 Mixing Analysis



Computer modeling

1.3 Mixing Analysis

- **Uncertainty**

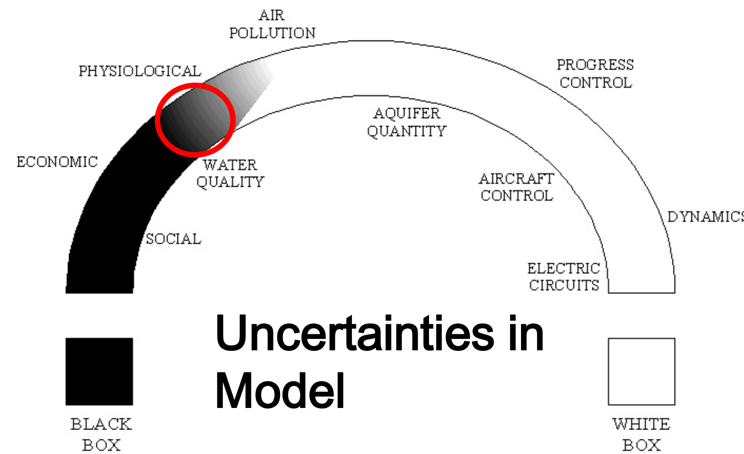
  Most models are intermediate forms between physical-based models and empirical models.

- **Parameter**

  Model parameters are usually varying.

  → Diurnal and seasonal changes

  → Consider the statistical variability



Uncertainties in Model

- **Calibration**

  Comparison of model output with observations to tune the model parameters

  → The calibrated models can be called empirical models

- **Validation**

  Comparison of output from the calibrated models with observations to evaluate validity of the calibrated models.

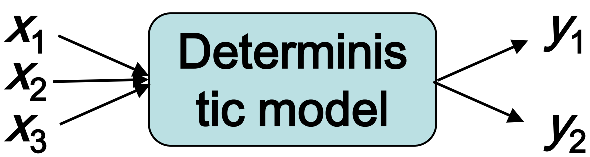
1.3 Mixing Analysis

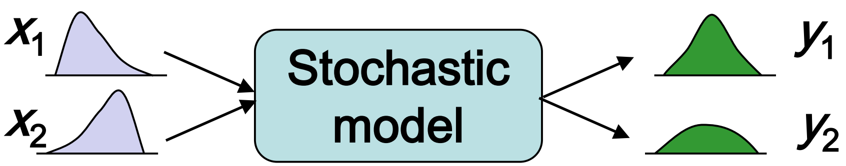
Dimensions of model

- 3-D: DNS, RANS (time-averaged model)
- 2-D: depth-averaged or horizontally averaged models
- 1-D: cross-sectional averaged model

Input & output data

- Deterministic model : Model output fully determined by parameters and input data
- Stochastic model : Parameters and input data leading to randomized output





Analysis method

- Physics-based model : Represents the physical process in the real world
- Data-based model : Estimates the phenomenon based on the acquired data

1.3 Mixing Analysis

• **Physical model:**

- reproduce complex 3-D flows (density-stratified flows)

- large scale phenomena (large scale vortices, internal waves and hydraulic jumps, multilayer shear flows, gravitational spreading) are represented

- scaling errors → viscous effects are too strong in reduced laboratory models

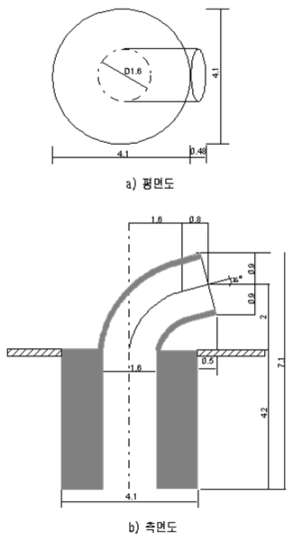
[Re] scaling based on Froude laws

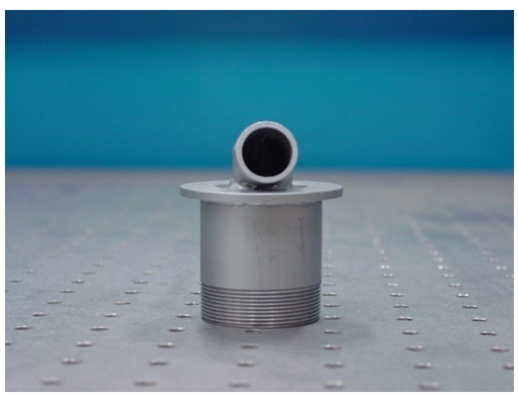
- Reynolds numbers are much reduced from the prototype

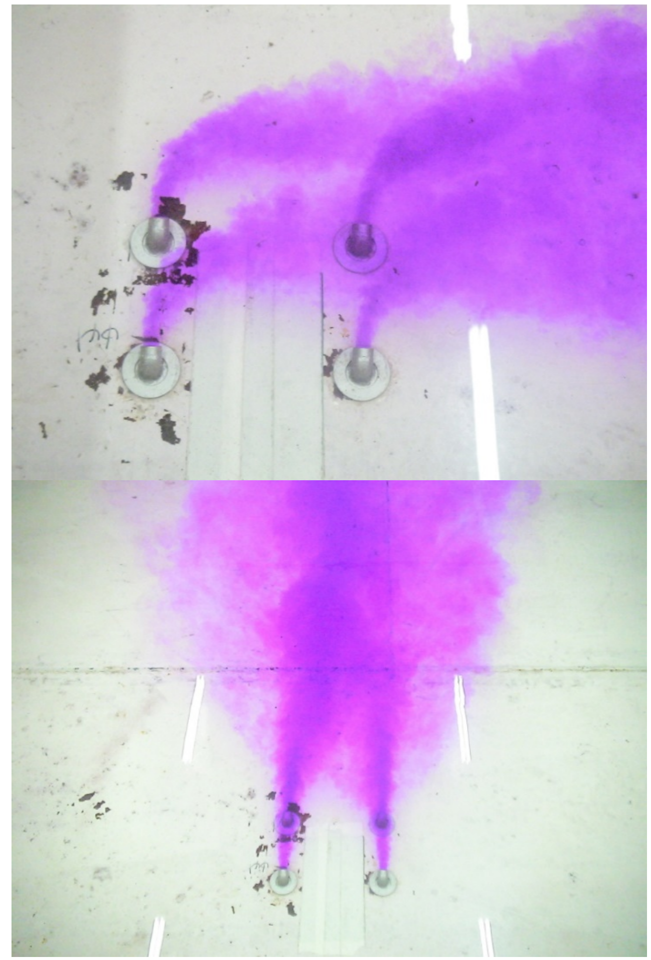
- alter turbulence and resistance characteristics

- distorted models are used for big estuary (river) model

1.3 Mixing Analysis







Physical models of heated water discharge

1.3 Mixing Analysis

• **Field Studies**

- can be used to verify or adjust numerical models

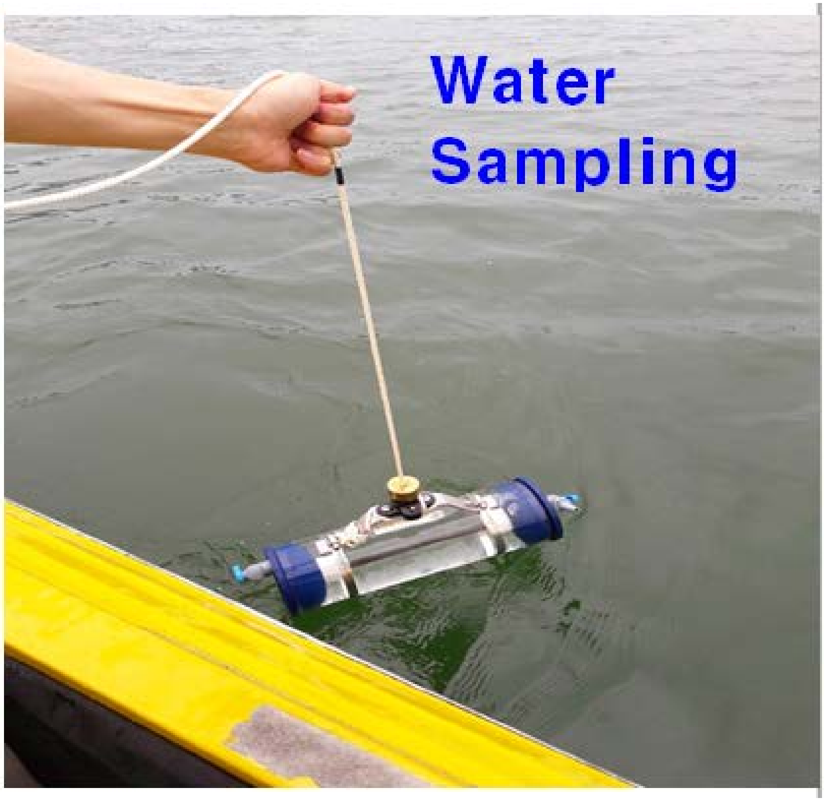
a. Eulerian-type measurements

- fixed-location recording meter → time series data at a fixed point

b. Lagrangian experiments

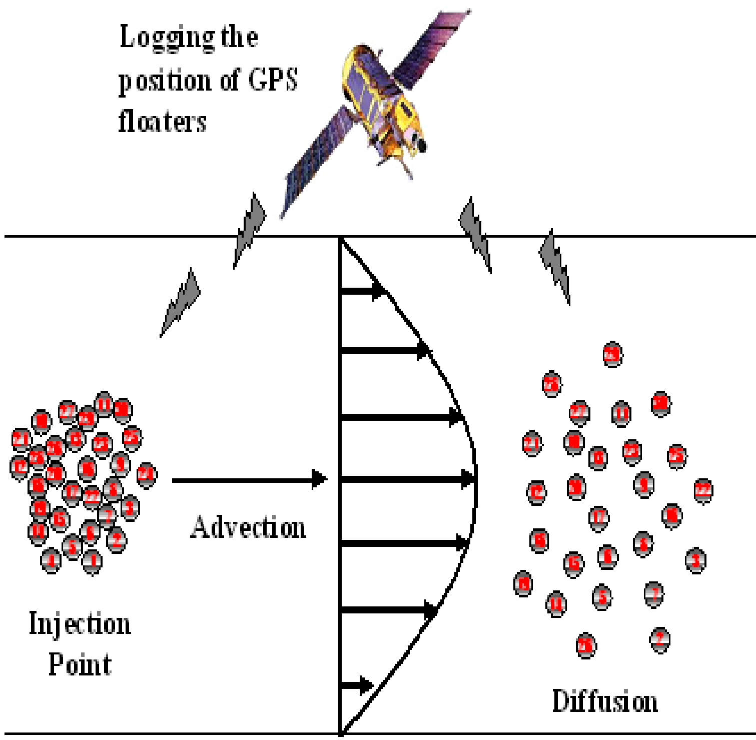
- follow drogues to track flow trajectories and dispersion → time series data for a given parcel of water

1.3 Mixing Analysis



Eulerian measurements

1.3 Mixing Analysis



Lagrangian measurements

1.3 Mixing Analysis

1.3.3 Interdisciplinary Modeling

- Fate of pollutants is governed by combination of physical, chemical and biological processes

- At different scales of length and time, different processes will be important

    - hydrodynamic mixing in the jets - min

    - dispersion, biochemical reaction - hours, days

    - biological or ecological effects - weeks, months

(1) Problem identification

a) For acute toxic effects

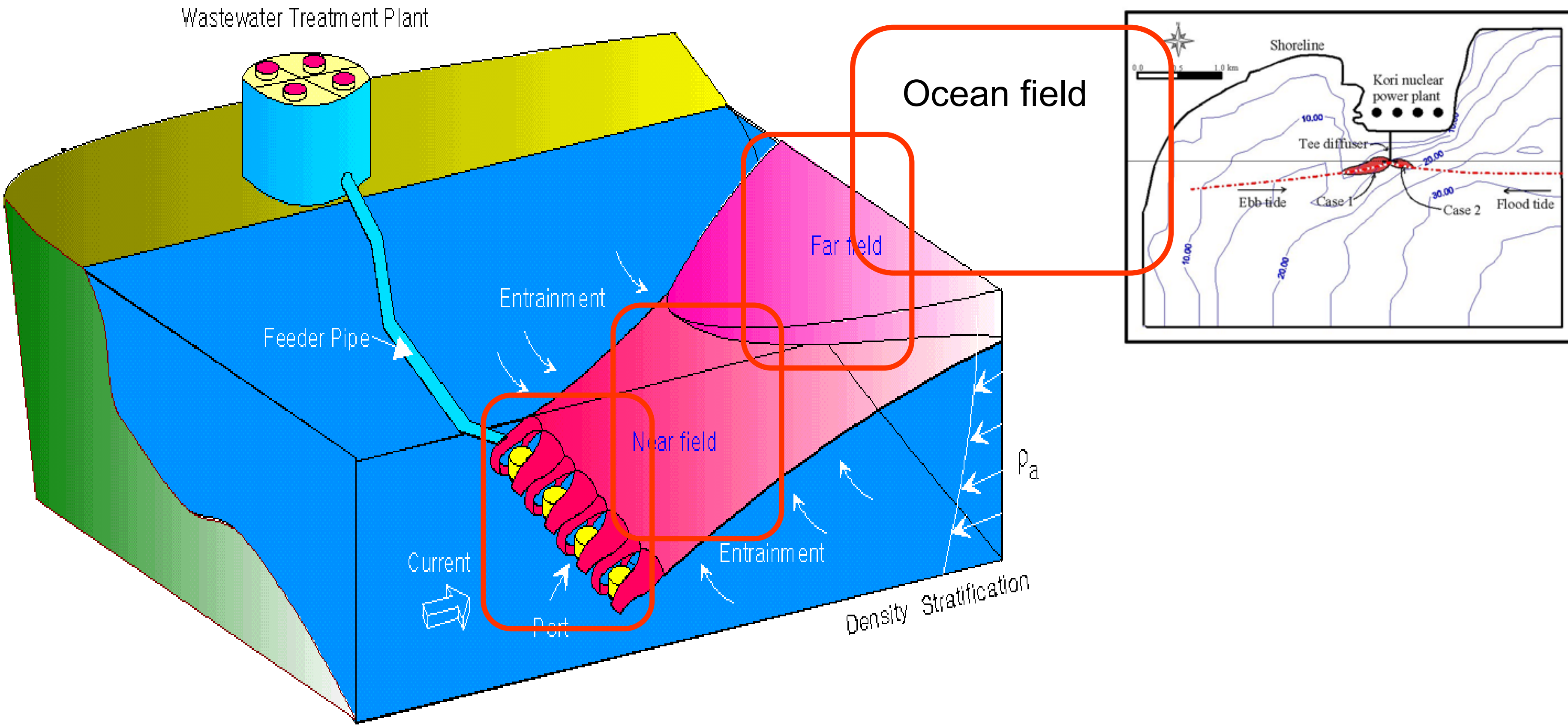
→ predict maximum instantaneous point concentration of a pollutant

b) For long-term ecological effects

→ predict changes in monthly averages over broad areas

At different scales of length and time, different processes will be important.

1.2 Environmental Hydraulics



Scales for mixing of sewage effluent discharged ocean diffusers

1.3 Mixing Analysis

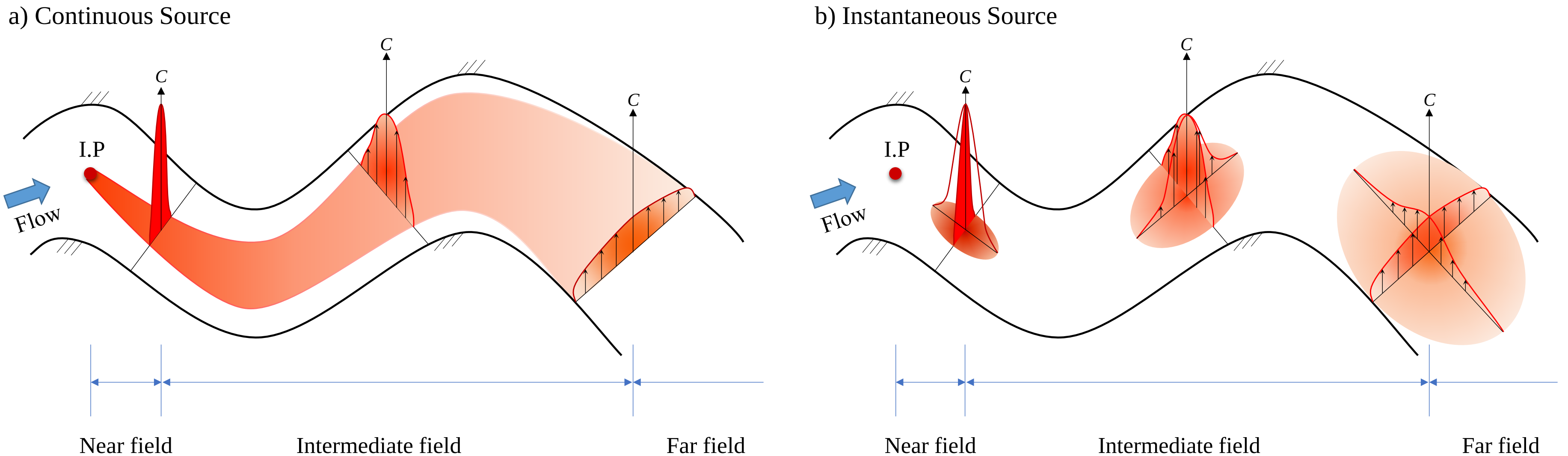
Time and length scales of mixing processes

Mixing phase	Mixing phenomenon	length scale (m)	time scale (sec)
Near-field	initial jet mixing	$< 10^2$	$< 10^3$
Intermediate-field	establishment of sewage field	$10 \sim 10^3$	$10^2 \sim 10^3$
Far-field	natural lateral diffusion / dispersion	$10^2 \sim 10^4$	$10^3 \sim 10^5$
	advection by currents	$10^3 \sim 10^5$	$10^3 \sim 10^6$
Ocean-field	large scale flushing (by tidal motion)	$10^4 \sim 10^6$	$10^6 \sim 10^8$

1.3 Mixing Analysis

[Remark 1.3] Mixing Process of Pollutants in Rivers

- Stage I: Three-dimensional mixing (vertical + lateral + longitudinal mixing)
- Stage II: Two-dimensional mixing (lateral + longitudinal mixing)
- Stage III: One-dimensional mixing (longitudinal mixing)



1.3 Mixing Analysis

(2) Definition of sub-models

a) Omnibus model

- cover all steps

b) Component models

- break problems into components for different length and time scales

- simplifying (idealized) representations can be made

- concentrate on the dominant processes and important features of the environment

[Ex] Thermal discharge problem

• Near-field mixing: active mixing

- initial jet and plume mixing occurs; momentum and buoyancy of the jet are important →

Hydraulic (physical) modeling is preferred.

- use jet-integral models: CORMIX, VISJET

1.3 Mixing Analysis

• Far-field mixing:

- heat loss, natural lateral dispersion and advection by currents are dominant (passive mixing)

→ Computer model is preferred.

-use non-hydrostatic 3D hydrodynamic models: OpenFoam

or hydrostatic 3D hydrodynamic models: EFDC, POM

• Coupling of near-field and far-field models

- Results from near-field model are used as input of far-field model

- dynamically interface between two models

1.3 Mixing Analysis

Coupling of near-field and far-field models

Method	Near-field analysis	Far-field analysis	Remarks
1	3D Non-hydrostatic model (fine grid)	3D Non-hydrostatic model (coarse grid)	Theoretically correct; Impossible due to huge computational time
2	3D Non-hydrostatic model (fine grid)	3D Hydrostatic model (coarse grid)	Ideal option; Still needs large computation time
3	Jet integral model (Corjet, Visjet)	3D Hydrostatic model (coarse grid)	Practical option; Semi-dynamic coupling

1.3 Mixing Analysis

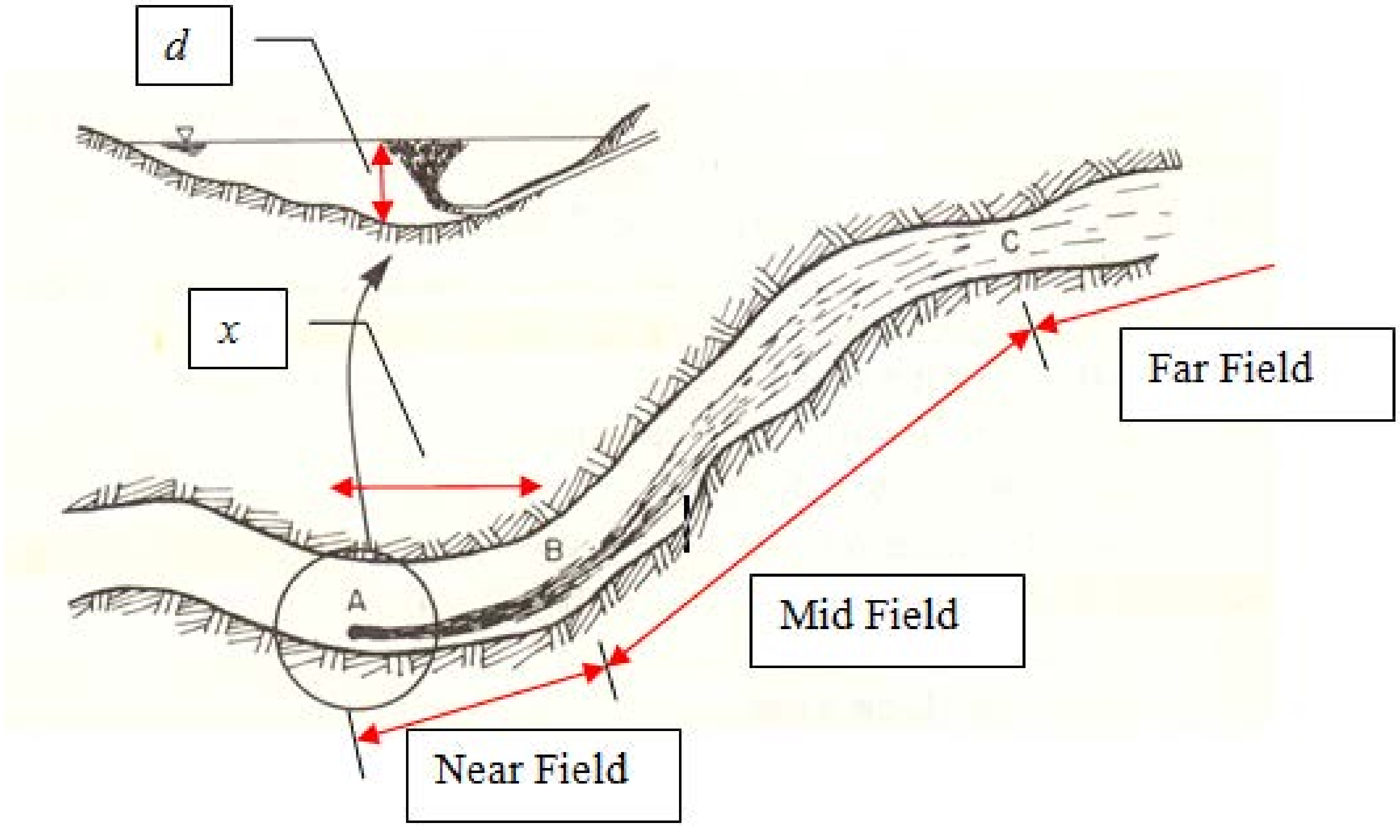
1.3.4 Order of magnitude analysis

- quick approximate solution (quick-and-dirty)
- scaling
- powers of ten
- show the correct dependence on the most important parameters
- based on dimensional analysis

[Ex] Complete vertical mixing

→ Find longitudinal distance required for complete vertical mixing of surface discharge pollutants

1.3 Mixing Analysis



Stages of pollutant mixing in rivers

1.3 Mixing Analysis

[Solution]

Mixing time; $T = \alpha \frac{d^2}{\varepsilon_v}$ (time scale)

where d = depth; ε_v = vertical eddy diffusivity (m^2/s)

set $\varepsilon_v = 0.07 u^* d$

u^* = shear velocity = $\bar{u}\sqrt{\frac{f}{8}}$

where f = Darcy-Weisbach friction factor

then $T = \alpha \frac{d^2}{0.07 d \bar{u}} \sqrt{\frac{8}{f}}$ assume $\sqrt{\frac{8}{f}} \approx 15$; $\alpha \approx 0.35$

$\therefore T \approx 75 \frac{d}{\bar{u}}$

substitute $x = \bar{u} T$ $\therefore \frac{x}{d} \approx 75 \approx 10^2$

x = longitudinal distance required for complete vertical mixing

1.4 Basic Definitions and Concepts

1.4.1 Concentration

• Concentration: units of mass of tracer or contaminant per unit volume

$$C = \lim_{\Delta V \to 0} \frac{\Delta M}{\Delta V}$$

where ΔM = tracer mass in elemental volume ΔV

• Time average of *C* $C = C(x, y, z, t)$

Smooth out turbulent fluctuations by averaging over time

$$\bar{C}(x, y, z, t_0) = \frac{1}{T} \int_{t_0}^{t_0 + T} C(x, y, z, t) dt$$

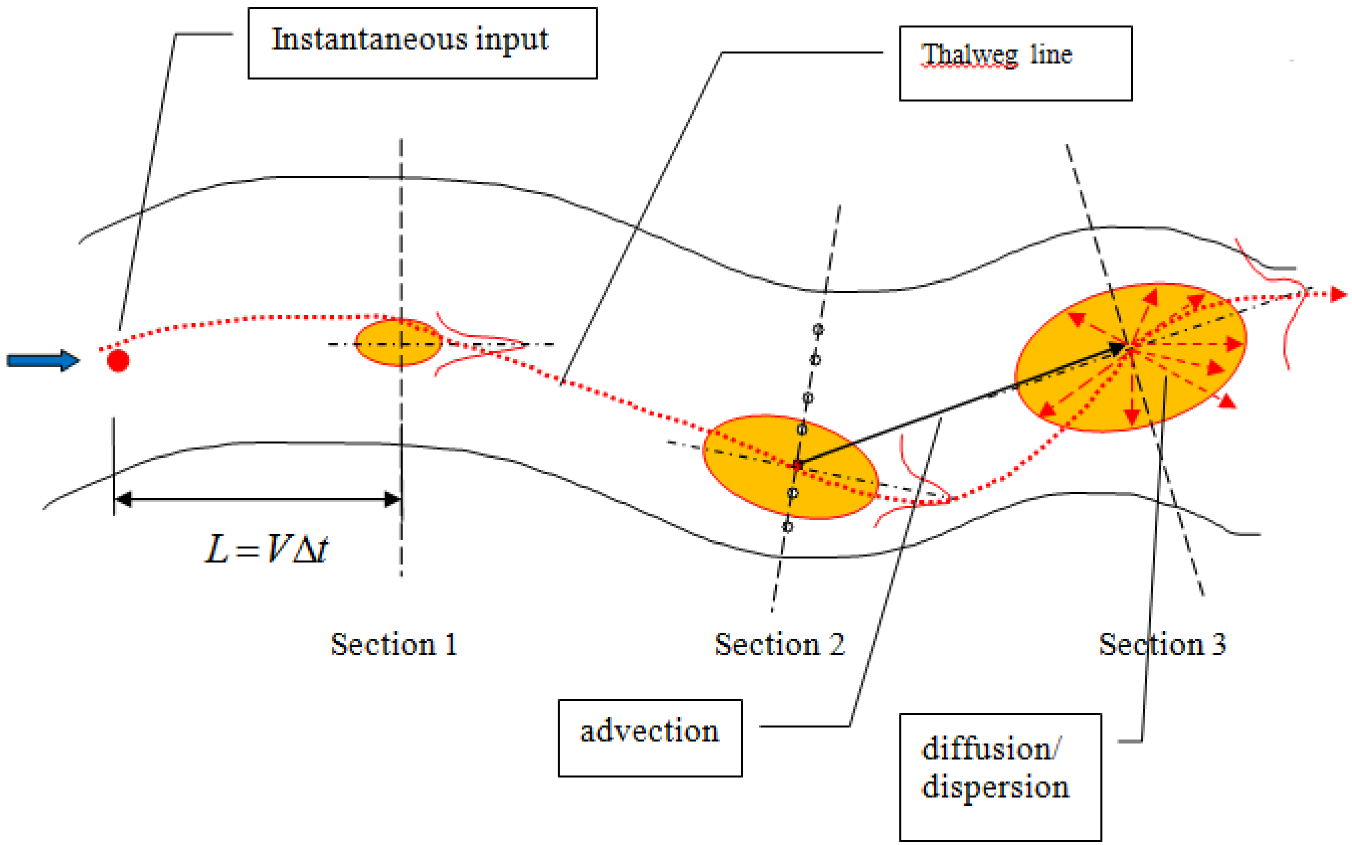
where *T* = averaging time interval: - sec, min for turbulence fluctuation

- hour, day for unsteady flow

$$\bar{C} = fn(x, y, z, t_0, T)$$

→ slowly varying function; reflects only change of flow rate and ambient water conditions

1.4 Basic Definitions and Concepts



Advection and diffusion

1.4 Basic Definitions and Concepts

- Spatial average of C

$$\bar{C}_V(x_0, y_0, z_0, t) = \frac{1}{V}\iiint_{\Delta V} C(x,y,z,t)dV$$

- wipes out turbulent fluctuations occurring on scales smaller than $V^{\frac{1}{3}}$

- Flux average of $C = \bar{C}_f$

Flux of contaminant mass through AA = $\bar{C}_f$ • (flux of water through AA)

$$\int_A C\ u\ dA = \bar{C}_f \int_A u\ dA = \bar{C}_f\ Q$$

$$\therefore\ \bar{C}_f(t) = \frac{1}{Q}\int_A C\,u\,dA$$

$$M = CVol = CQt = CuAt$$

$$mass\ flux = M/t = CuA = CQ$$

- Total mass *M*

$$M = \int_0^T \bar{C}_f(t)\ Qdt = \int_0^T \int_A C\ u\ dAdt$$

1.4 Basic Definitions and Concepts

1.4.2 Dilution

- Dilution: rate at which tracer is diluted, *S*

$$S = \frac{total\ volume\ of\ sample (= vol.\ of\ mixture)}{volume\ of\ effluent\ contained\ in\ the\ sample}$$

S =1 → undiluted effluent

p = volume fraction of effluent in a sample

= 1/*S* = relative concentration

After effluent is fully mixed across the section,

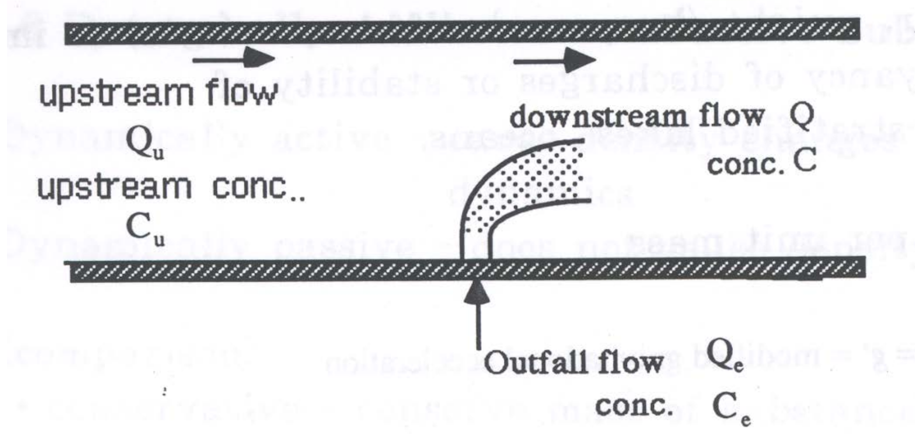
mass rate of substance upstream + mass rate added by outfall = mass rate of substance downstream from outfall

$$Q_u C_u + Q_e C_e = QC$$

$W \Rightarrow Q_e C_e$ = impact waste load [M/T]

1.4 Basic Definitions and Concepts

- Assume that the mixture of effluent is mixed completely with ambient water of background concentration C_a



terms	effluent	ambient water	mixture
vol.	vol_e	vol_a	$vol_e + vol_a$
conc. of contaminant	C_e	C_a	$\frac{vol_e C_e + vol_a C_a}{vol_e + vol_a}$ (<u>harmonic mean</u>)

1.4 Basic Definitions and Concepts

$$C = \frac{vol_e C_e + vol_a C_a}{vol_e + vol_a} = \frac{(vol_e + vol_a) C_a + vol_e (C_e - C_a)}{vol_e + vol_a}$$

$$= C_a + \frac{vol_e}{vol_e + vol_a}(C_e - C_a)$$

$$= C_a + P(C_e - C_a) \quad = C_a + \frac{1}{S}(C_e - C_a)$$

→ increment of concentration above background is reduced by the dilution factor S or p from the point of discharge to the point of measurement of effluent

$$\therefore \; p = \frac{C - C_a}{C_e - C_a} \qquad S = \frac{C_e - C_a}{C - C_a}$$

- dilution of a composite sample

$$\overline{S} = \frac{total \quad vol.}{total \;\; effluent \;\; vol.} = \frac{1}{P} = \frac{\sum_{i=1}^{N} vol_i}{\sum_{i=1}^{N} vol_i \frac{1}{S_i}}$$

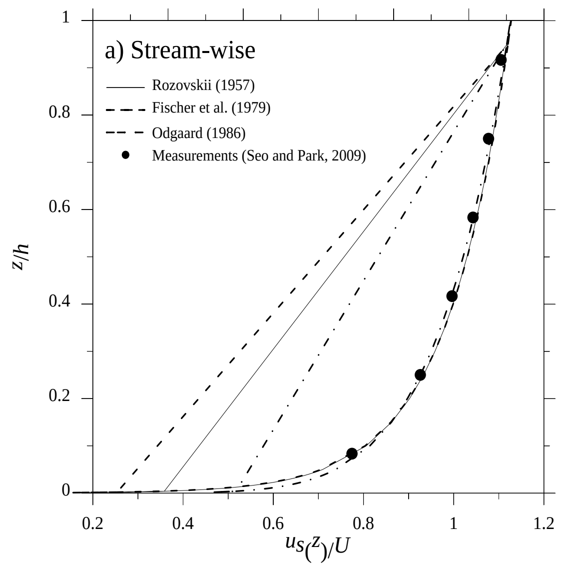
1.4 Basic Definitions and Concepts

1.4.3 Turbulent Shear Flow

- Turbulent shear flow in a long pipe or channel

- The resisting force (shear stresses at the wall) are counterbalanced driving force (pressure gradient and gravity)

- $u = u(y, z)$



- Vertical velocity distribution

- approximated by a logarithmic function

a) Pipe: $$u = \bar{u} + \frac{3}{2}\frac{u^*}{\kappa} + \frac{2.30}{\kappa}u^* \log_{10}\frac{z}{R} \qquad (1.27)$$

b) Wide channel: $$u = \bar{u} + \frac{u^*}{\kappa} + \frac{2.30}{\kappa}u^* \log_{10}\frac{z}{d} \qquad (1.28)$$

1.4 Basic Definitions and Concepts

where z = distance from the wall; R = pipe radius

d = channel depth; κ = Von Karman constant ≈ 0.4

• Mean velocity in the cross section is related to mean wall shear stress

$$\tau_o = \frac{1}{8} f \rho \bar{u}^2$$

where τ_o = mean wall shear stress

f = Darcy-Weisbach friction factor

f - estimated from Moody diagram for circular pipes

- use Moody diagram $R_h = D/4$ with for open channels

$$\bar{u} = \frac{1}{A}\int_A u(y,z)dA$$

$$\sqrt{\frac{\tau_o}{\rho}} = \sqrt{\frac{f}{8}}\bar{u}$$

1.4 Basic Definitions and Concepts

define shear (friction) velocity

$$u^* = \sqrt{\frac{\tau_o}{\rho}} = \sqrt{\frac{\gamma R_h S}{\rho}} = \sqrt{g R_h S}$$

$$\frac{\bar{u}}{u^*} = \sqrt{\frac{8}{f}}$$

1.4 Basic Definitions and Concepts

[Re] Darcy-Weisbach equation

$$h_L = f\frac{L}{D}\frac{u^2}{2g}$$

$$h_L = \frac{\tau_0 L}{\gamma R_h}$$

$$\therefore \tau_o \frac{L}{\gamma \frac{D}{4}} = f\frac{L}{D}\frac{u^2}{2g}$$

$$\therefore \tau_o = \frac{1}{8} f \rho u^2$$

[Re]

$$\tau_o = \gamma R_h \frac{h_L}{l} = \gamma R_h S_f = \gamma R_h S_0$$

S_0 = channel slope for uniform flow

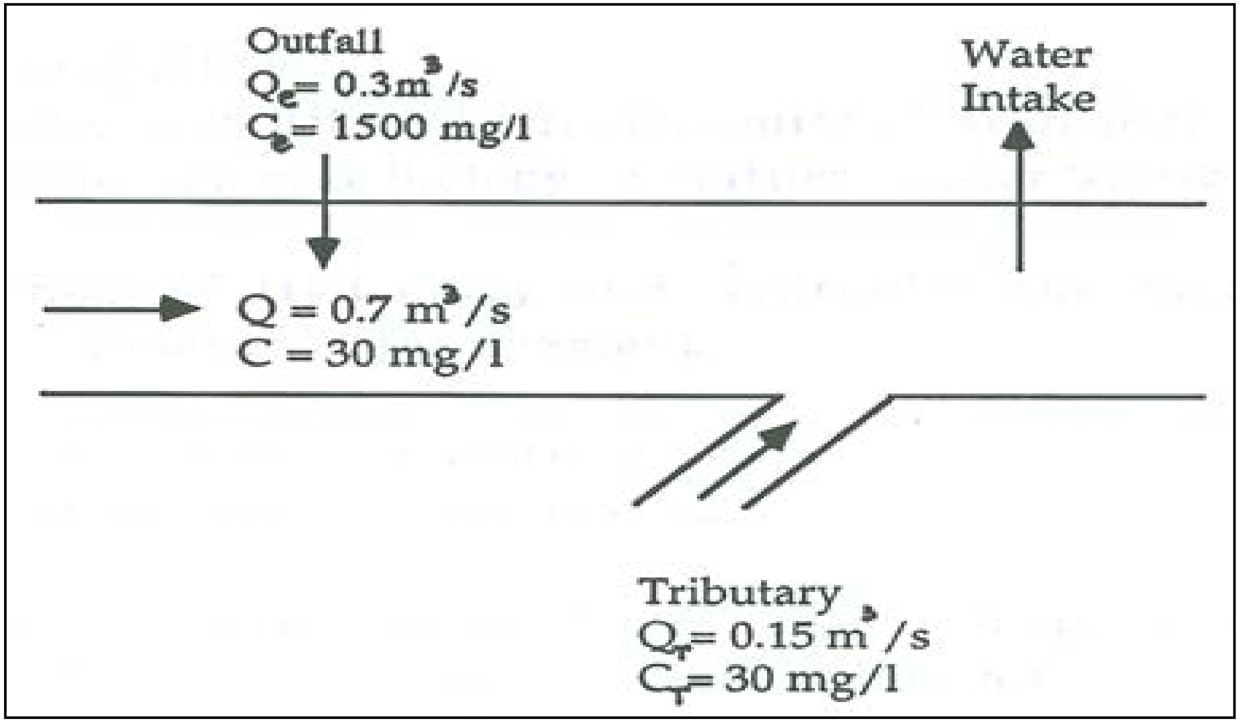
Homework #1

Due: 1 Week from Today

Upstream flow with a background level of chlorides, a conservative substance, of 30mg/ℓ is supplemented by an industrial discharge of 0.3m^3/s carrying 1,500mg/ℓ chlorides and a downstream tributary of 0.15m^3/s with background chlorides concentration of 30mg/ℓ. Assume downstream tributary chlorides concentration does not vary with flow.

To maintain a desired chlorides concentration of 250mg/ℓ at the water intake, determine: (a) the required industrial reduction in chloride concentration (b) the required increase in tributary flow.

Homework #1


Outfall
Qe= 0.3m³/s
Ce= 1500 mg/l
Water
Intake
Q = 0.7 m³/s
C = 30 mg/l
Tributary
QT= 0.15 m³/s
CT= 30 mg/l