# Chapter 1

# Introduction to Environmental Hydraulics

## Contents

# Chapter 1 Introduction to Environmental Hydraulics

## 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

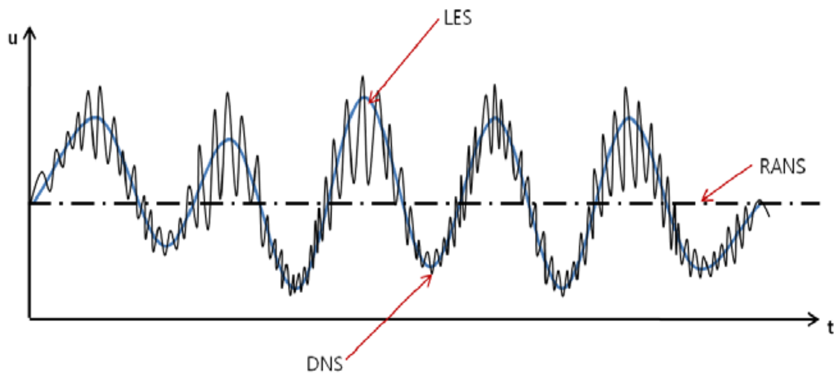
## *1.1.1 Water Quality Management*

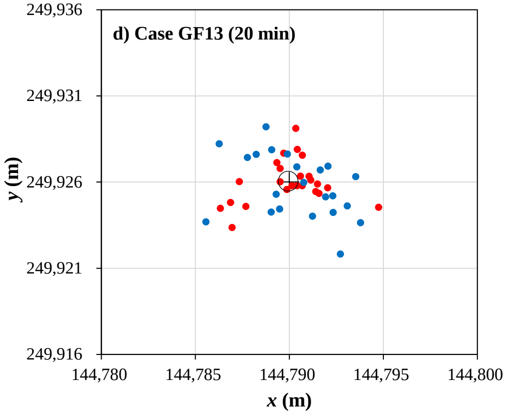
- To study water quality [$C(x, y, z, t)$] in surface waters, we need to study

- 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 [$k, \alpha$ ]



# 1.1 Environmental Management

## *1.1.1 Water Quality 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.

# 1.1 Environmental Management

## *1.1.1 Water Quality Management*

•**Fate of pollutants depends on**

Transport (Hydraulic engineer) + Transformation (Chemist) + Accumulation (Biologist)

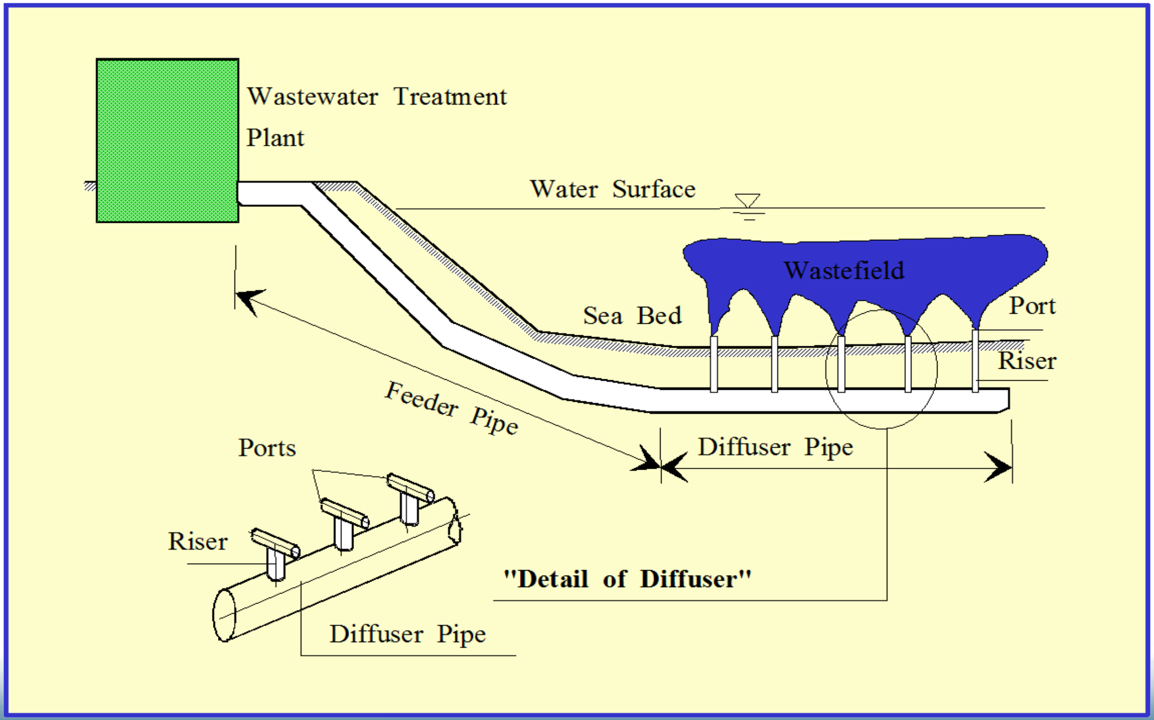
⇒ Processes that takes places between the point where a pollutant is discharged into the water environment and some other sites (downstream site in rivers) where the ambient water quality is observed.

# 1.1 Environmental Management

## *1.1.1 Water Quality Management*

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

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



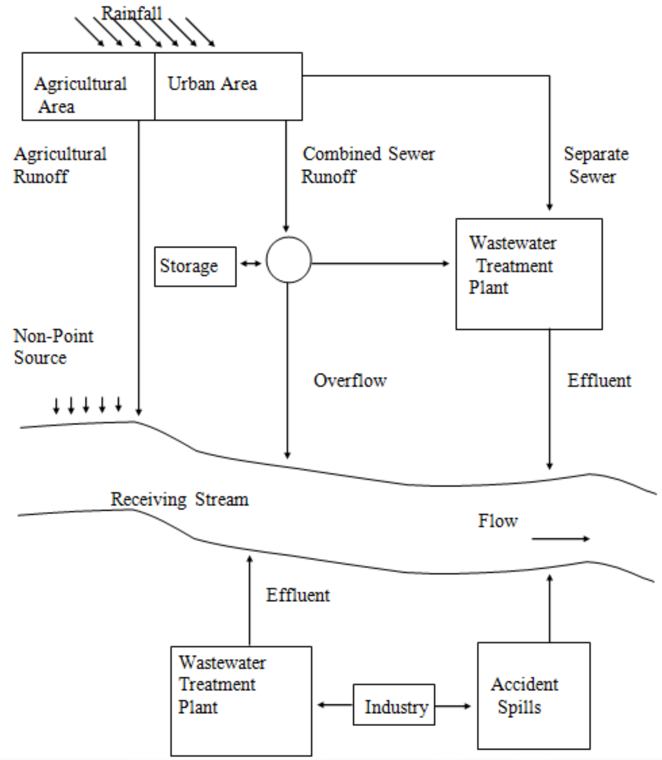
# 1.1 Environmental Management

## *1.1.1 Water Quality Management*

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

2) Analyze water quality processes

-> **diffusion and dispersion**



# 1.1 Environmental Management

[Re] Classification of pollutants sources

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

# 1.1 Environmental Management

## *1.1.1 Water Quality Management*

• **Environmental Control System**

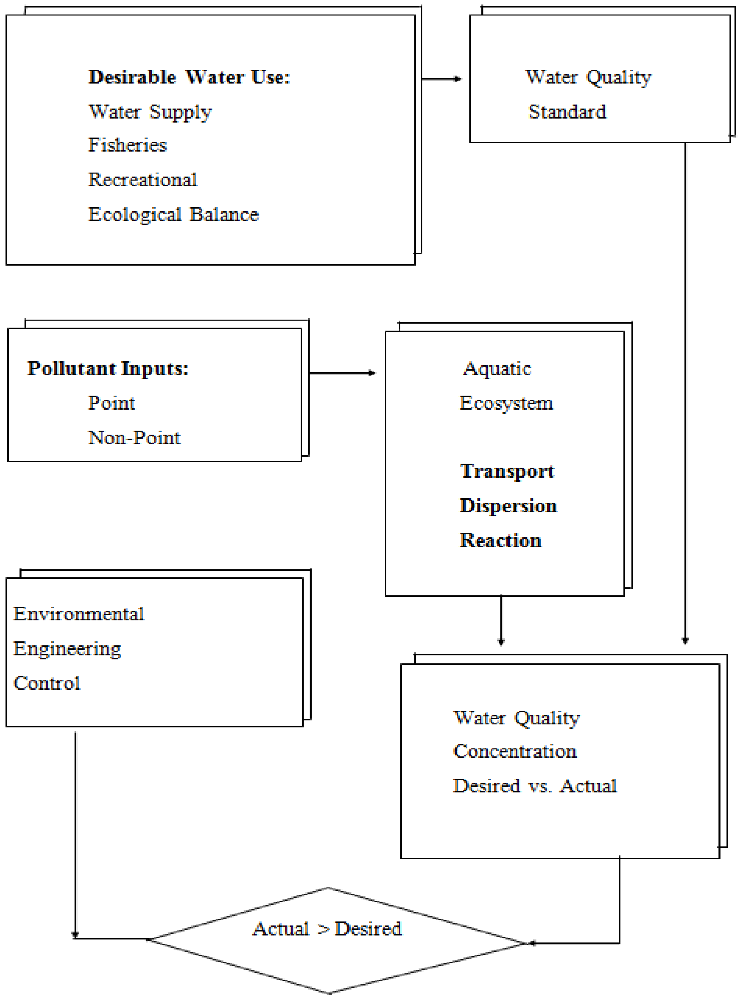
- Optimization of

(a) control of pollutants at the source (pre-treatment, clean technology)

(b) wastewater treatment (primary, secondary treatment)

(c) disposal in the environment (post-treatment, wastewater outfalls)

# 1.1 Environmental Management



# 1.1 Environmental Management

## *1.1.1 Water Quality Management*

- **Role of hydraulic engineer (Environmental Hydraulics)**

- make interface between man's activities and the natural environment

- draw water supply from natural water bodies

- develop technology how wastewater is returned → design of outfalls

# 1.1 Environmental Management

## *1.1.2 Types of Pollutants*

### 1.1.2.1 Classification of Pollutants

**(1) Mass conservation**

- Conservative pollutants

- Non-conservative pollutants ~ decaying pollutants

# 1.1 Environmental Management

## 1.1.2 Types of Pollutants

### 1.1.2.1 Classification of Pollutants

**(1) Mass conservation**

[Re] Conservation of mass

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

# 1.1 Environmental Management

## *1.1.2 Types of Pollutants*

### 1.1.2.1 Classification of Pollutants

**(1) Mass conservation**

**[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

## *1.1.2 Types of Pollutants*

### 1.1.2.1 Classification of Pollutants

**(2) 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

# 1.1 Environmental Management

## *1.1.2 Types of Pollutants*

### 1.1.2.1 Classification of Pollutants

**(2) Pollutant source**

• Nonpoint source

- Widely distributed points where pollutants are introduced into the hydrologic cycle

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

# 1.1 Environmental Management

## *1.1.2 Types of Pollutants*

### 1.1.2.1 Classification of Pollutants

### (3) Classification by input period

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

Instantaneous input - accidental spills

**Fig. 1.4 Effluent discharge through open channels (Tancheon STP)**

# 1.1 Environmental Management

## *1.1.2 Types of Pollutants*

### 1.1.2.1 Classification of Pollutants

**(4) Dynamically Active versus Passive Substances**

• 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

# 1.1 Environmental Management

## 1.1.2 Types of Pollutants

### 1.1.2.1 Classification of Pollutants

**(4) Dynamically Active versus Passive Substances**

• 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

## *1.1.2 Types of Pollutants*

### 1.1.2.1 Classification of Pollutants

• Typical pollutants (from the least dangerous to the most hazardous)

(1) Natural inorganic salts and sediments

- not toxic unless in excessive doses

# 1.1 Environmental Management

## *1.1.2 Types of Pollutants*

### 1.1.2.1 Classification of Pollutants

• Typical pollutants (from the least dangerous to the most hazardous)

(2) Waste heat or heated water discharges

- cooling water for electric generating plants

- decrease water's assimilative capacity for oxygen

# 1.1 Environmental Management

## 1.1.2 Types of Pollutants

Fig. 1.3 Yangz River


Fig. 1.4 Nakdong River

# 1.1 Environmental Management

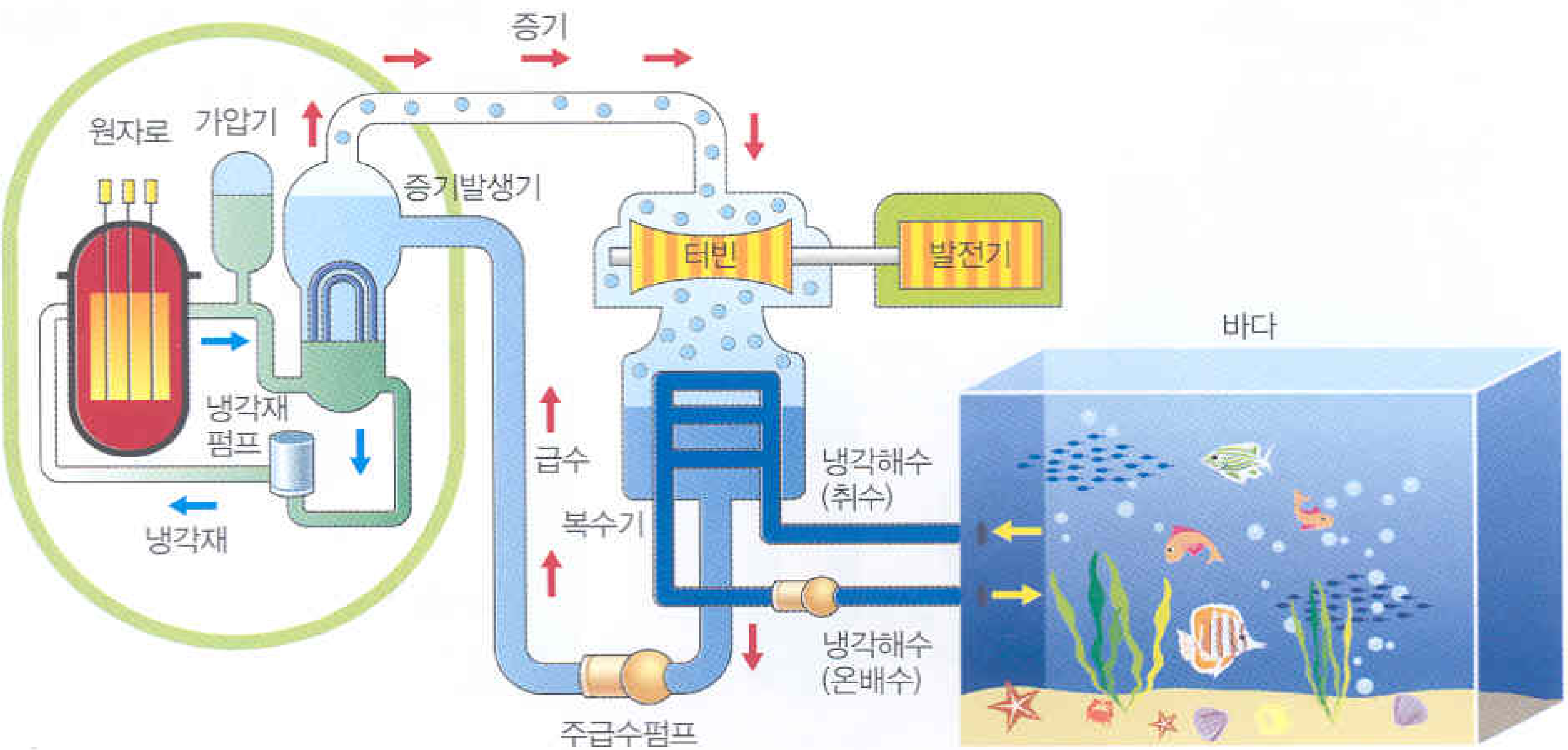



**Fig. 1.5 Cooling system for nuclear power plant**

# 1.1 Environmental Management

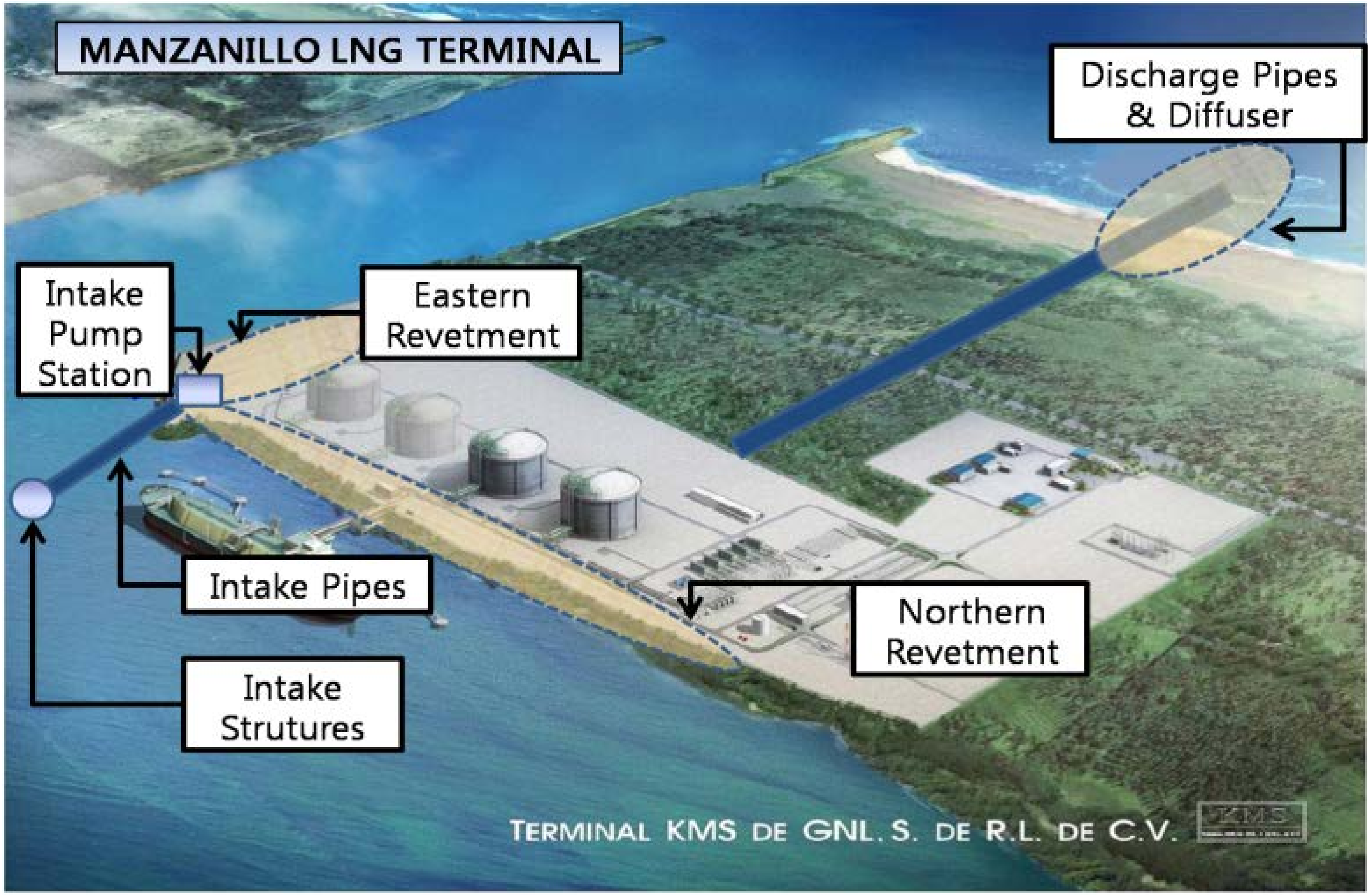



**Fig. 1.6 LNG plant (Manzanillo, Mexico)**

# 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

Organic waste $+ O_2 \rightarrow CO_2 + H_2O$

# 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

# 1.1 Environmental Management

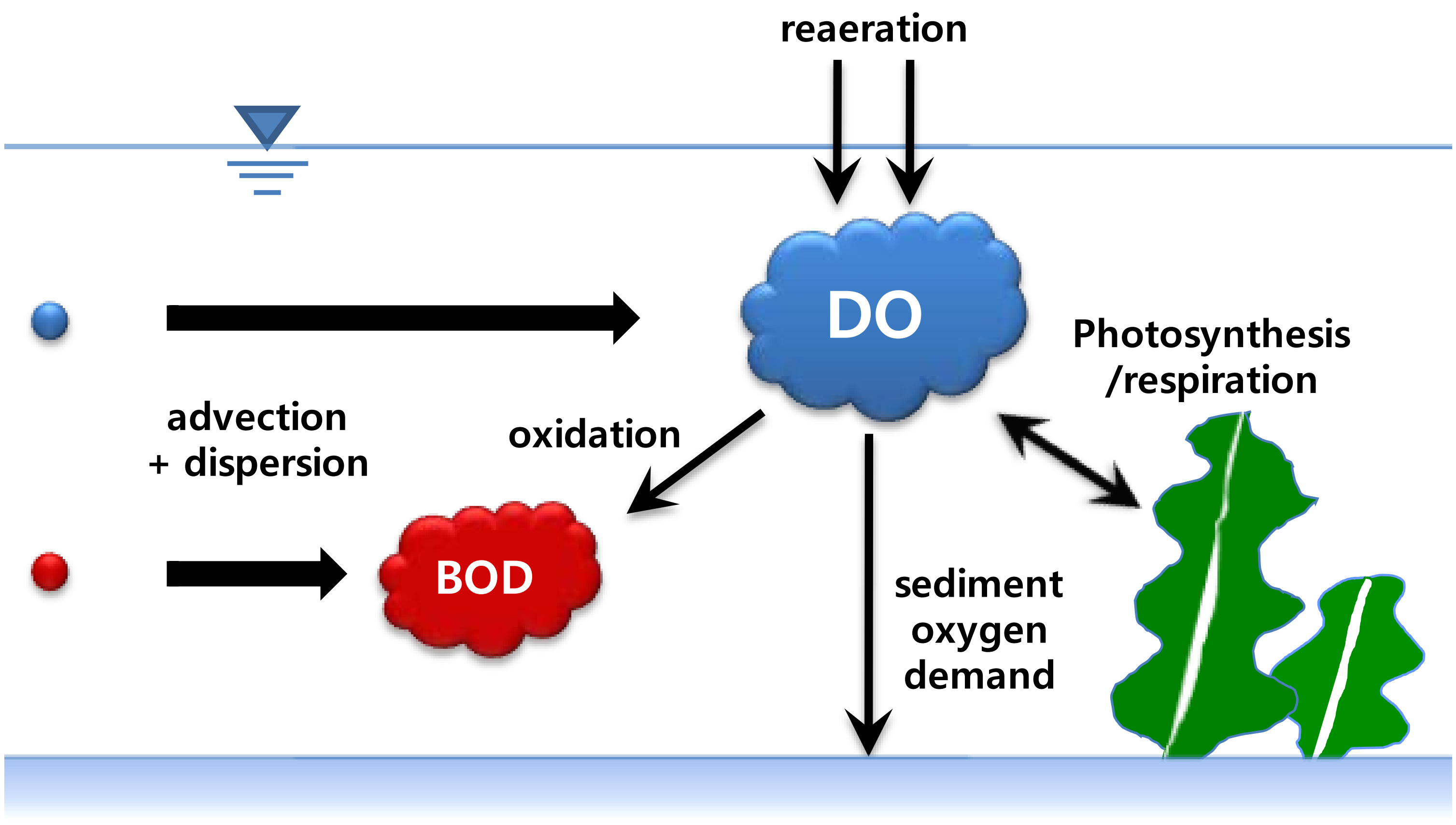



Fig. 1.7 BOD-DO coupled system

# 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)

# 1.1 Environmental Management

**(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)

# 1.1 Environmental Management

## (7) Chemical and biological warfare agents

- exceedingly toxic; cannot be dispersed in the environment

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

- suitable only for heat and natural organic materials

[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

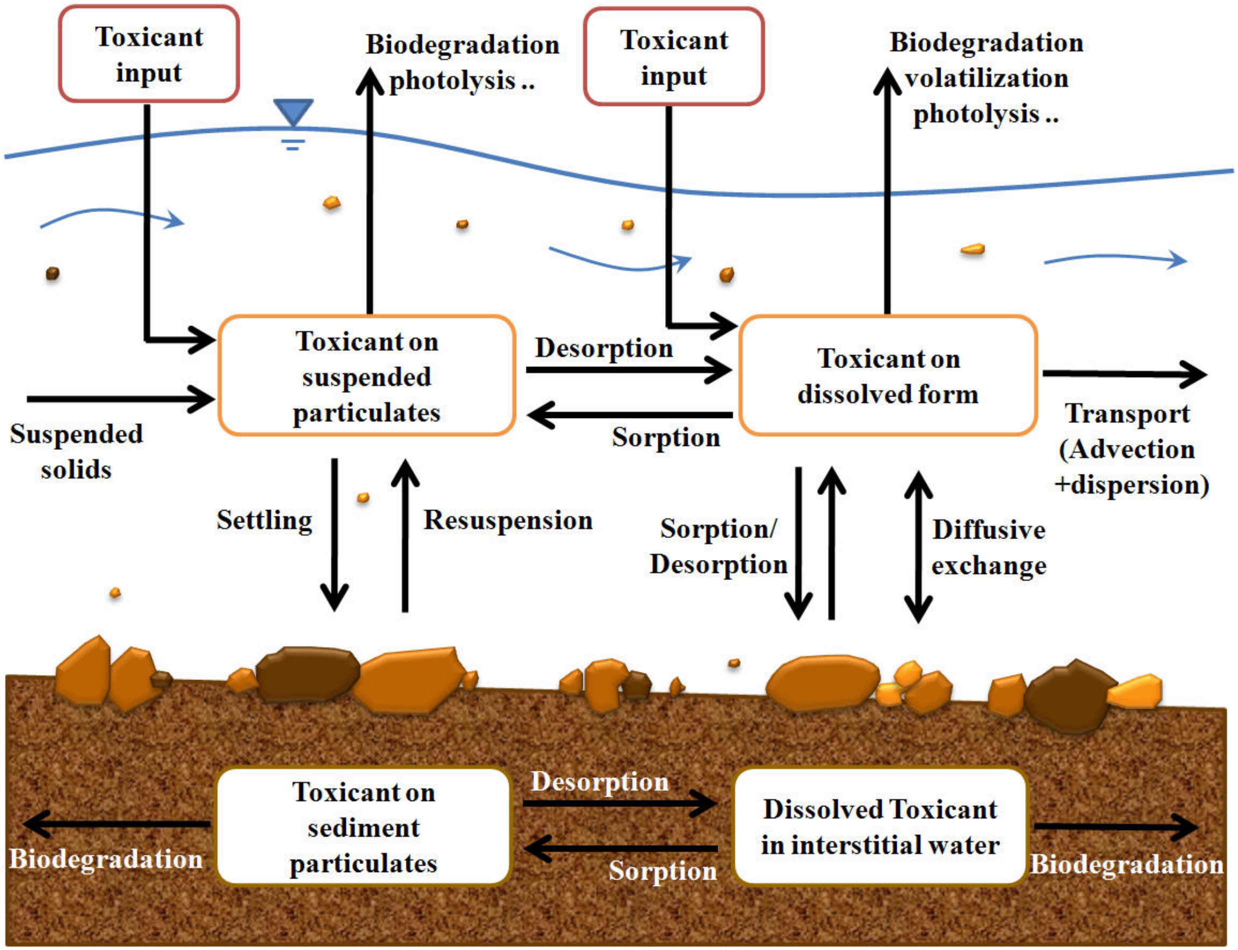



Fig. 1.8 Transport of toxic materials

# 1.1 Environmental Management

## *1.1.3 Impacts of Hydraulic Works*

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

(1) man-made reservoirs → summertime thermal stratification → oxygen depletion in the lower layer

(2) diversion water for consumptive uses → reduce river flow (inflow) and its ability to provide natural flushing

(3) canals → transport huge amount of dissolved salts, sediment, nutrients and parasites

# 1.1 Environmental Management

*1.1.3 Impacts of Hydraulic Works*

(4) agricultural drainage system → accelerate the leaching of nutrients and salts from land to natural hydrologic systems

(5) breakwater for harbors → interfere with natural nearshore circulation which could otherwise carry away pollutants

(6) estuarine modification or barriers → radically change the circulation patterns decreasing flushing of pollutants

# 1.1 Environmental Management

Fig. 1.9 Panama Canal

Fig. 1.10 Breakwater for harbors

# 1.1 Environmental Management

Fig. 1.11 Saemangeum sea dike

Fig. 1.12 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)

# 1.2 Environmental Hydraulics

(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

# 1.2 Environmental Hydraulics

(4) Turbulent diffusion

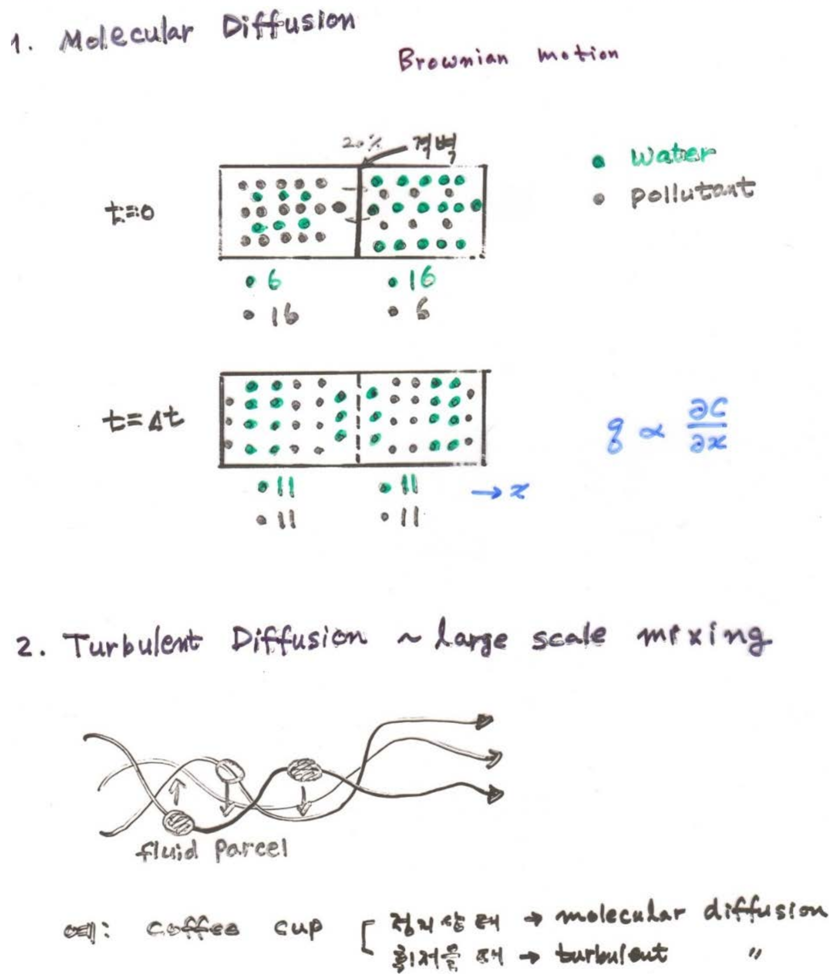
- random scattering of particles by turbulent motion

- 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

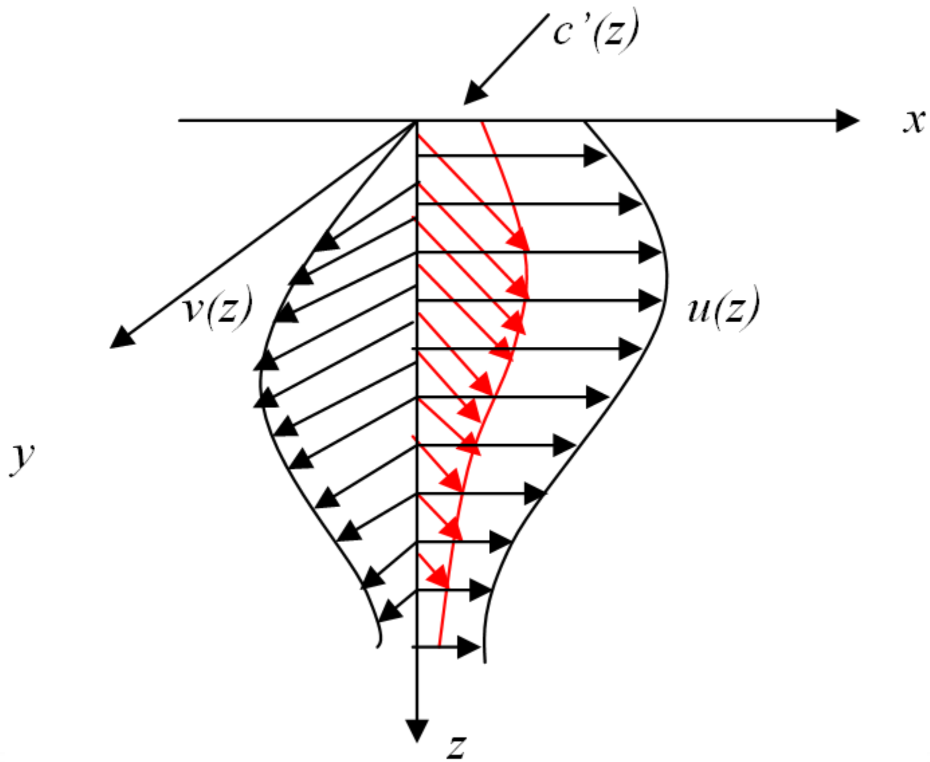
# 1.2 Environmental Hydraulics

(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



# 1.2 Environmental Hydraulics

(6) Dispersion

- scattering of particles or cloud of contaminants by the combined effects of shear and diffusion

- shear advection + vertical and/or transverse diffusion

- 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

## 3. Shear Flow Dispersion

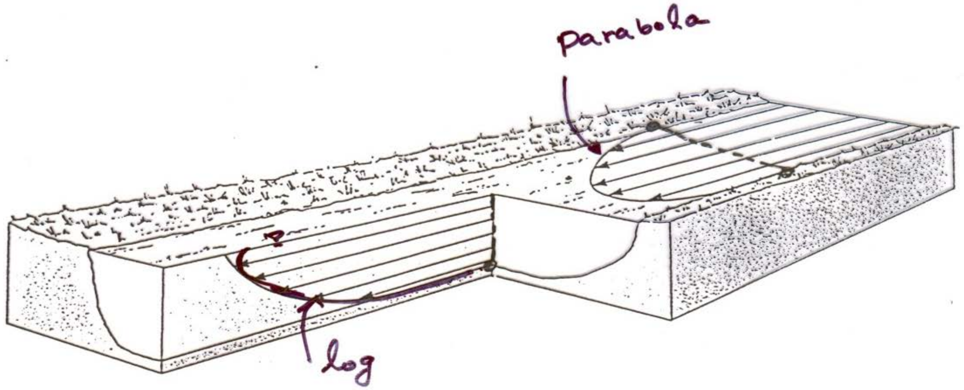



**Figure 10.5**
Variations in the velocity of flow in natural stream channels occur both horizontally and vertically. Friction reduces the velocity along the floor and sides of the channels. The maximum velocity in a straight channel is near the top and center of the channel.

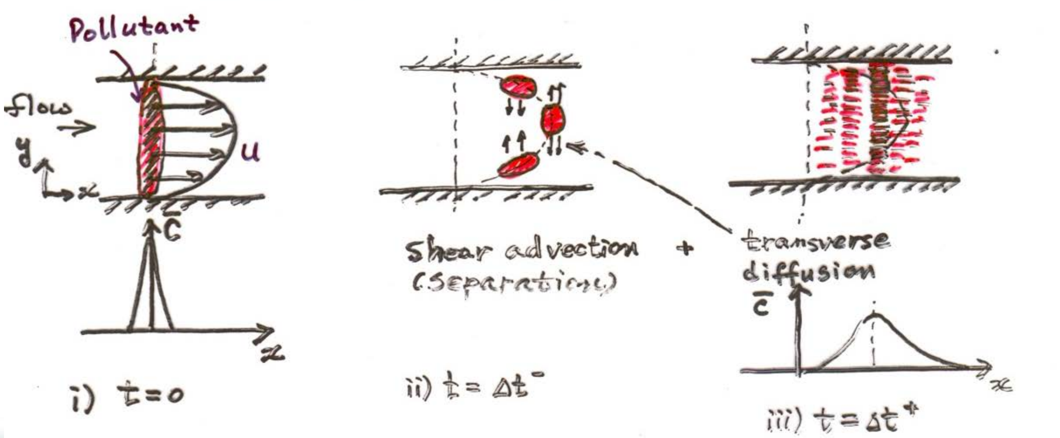
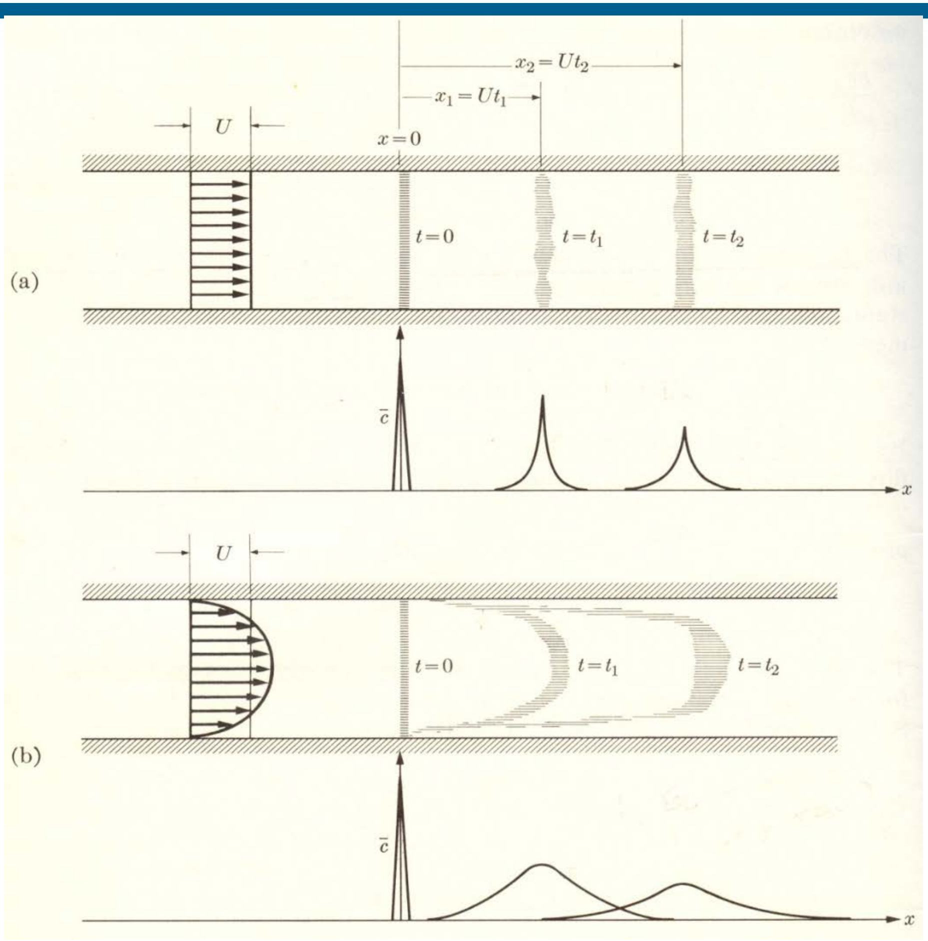



Fig. 1.14 Shear flow dispersion

# 1.2 Environmental Hydraulics




(a) turbulent diffusion in uniform velocity flow;
(b) turbulent dispersion due to nonuniform 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

# 1.2 Environmental Hydraulics

(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

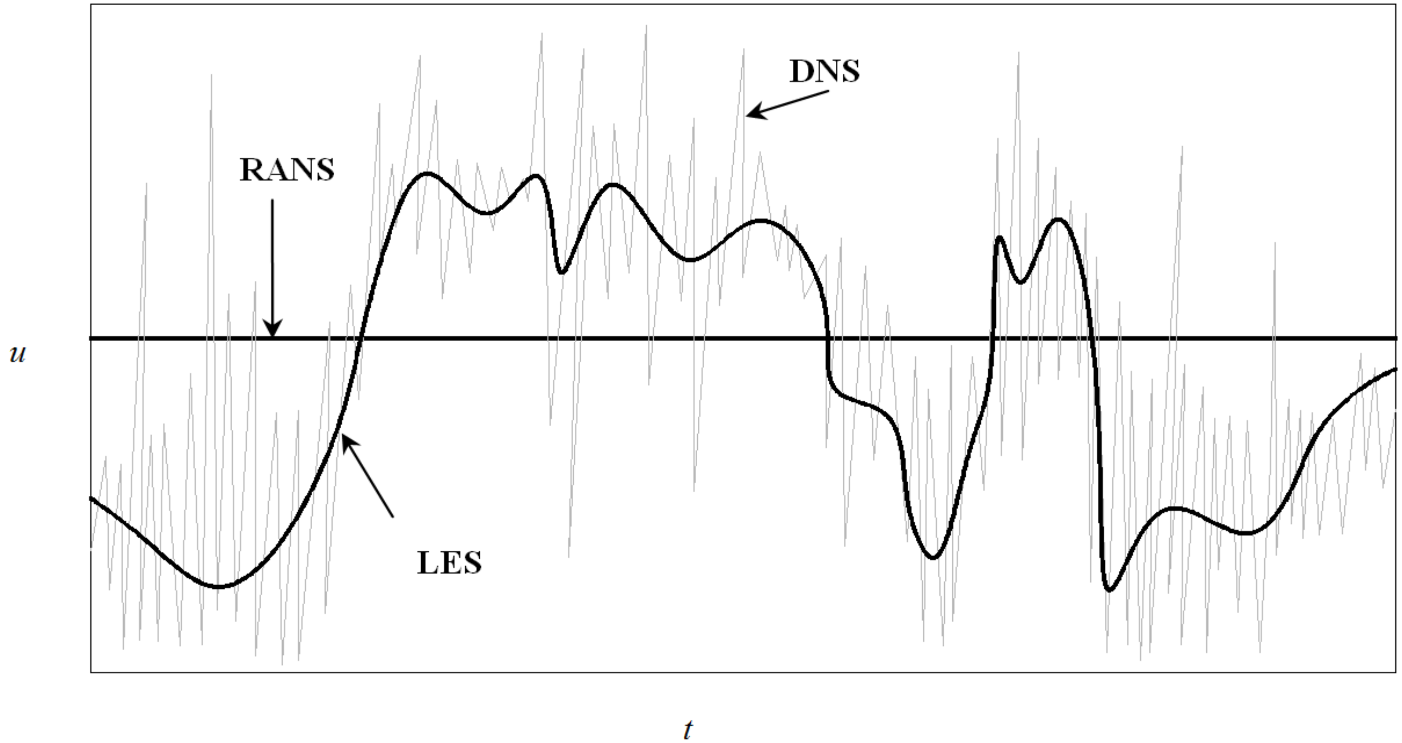
(11) Particle entrainment

- 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

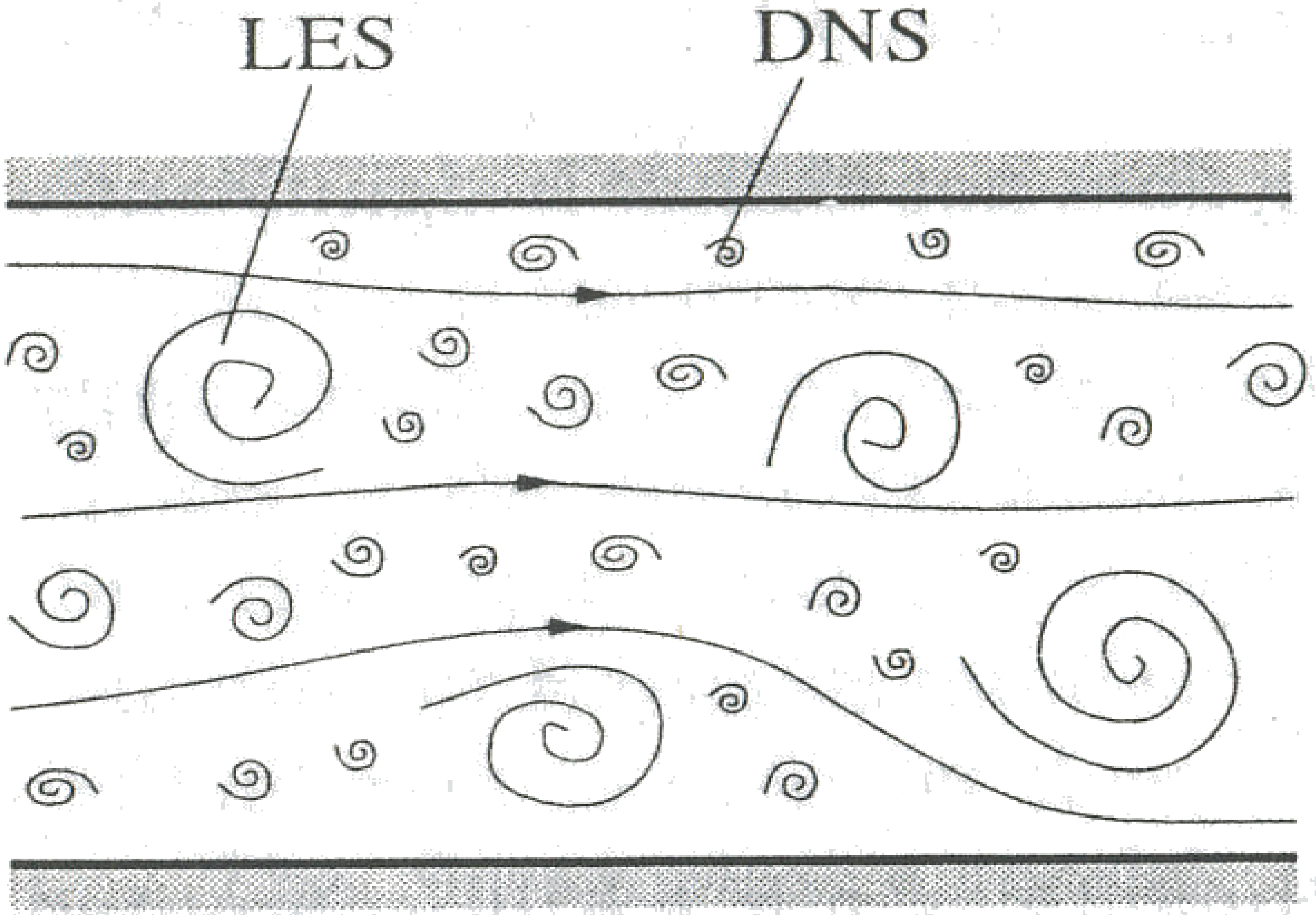



Fig. 1.17 LES versus DNS

# 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

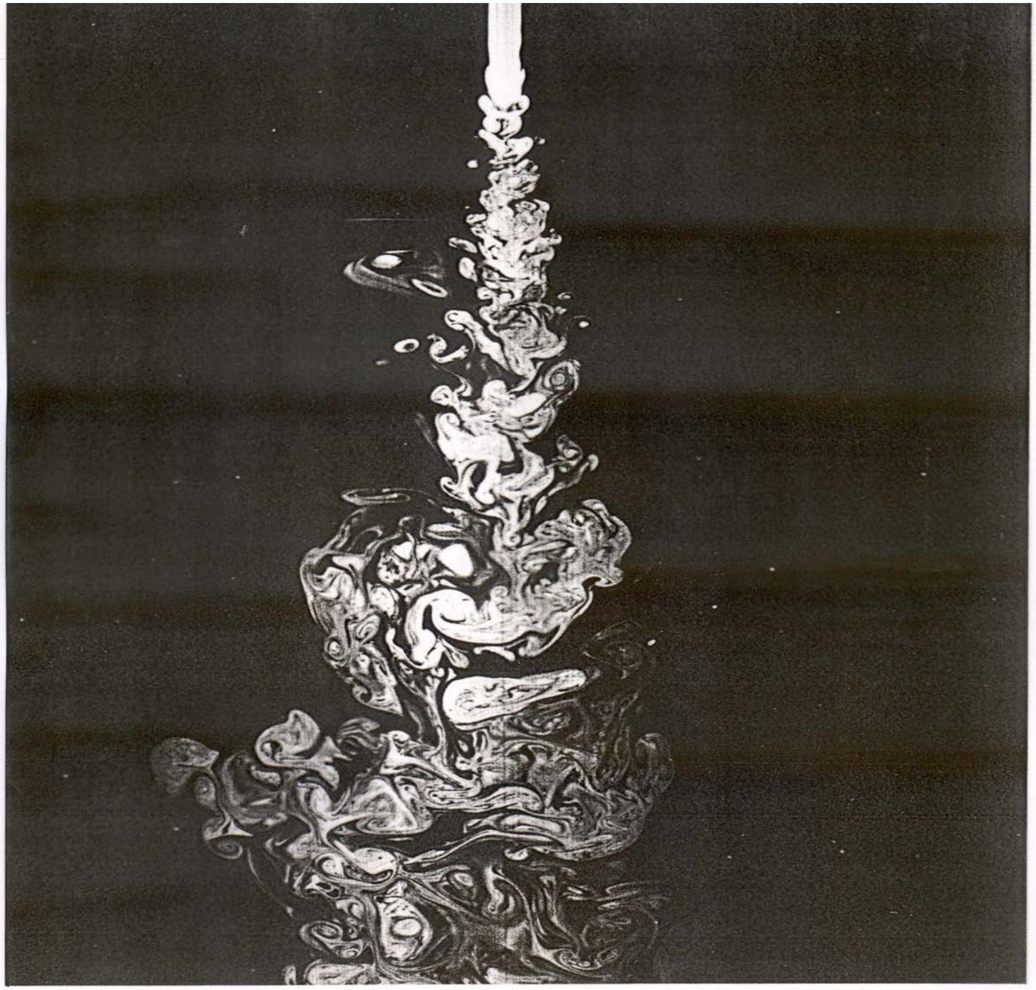
- when discharge fluid is lighter or heavier than surrounding waters

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

• plume

- initial momentum is not important

# 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*

# 1.2 Environmental Hydraulics

- Analysis of buoyant jets and plumes

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

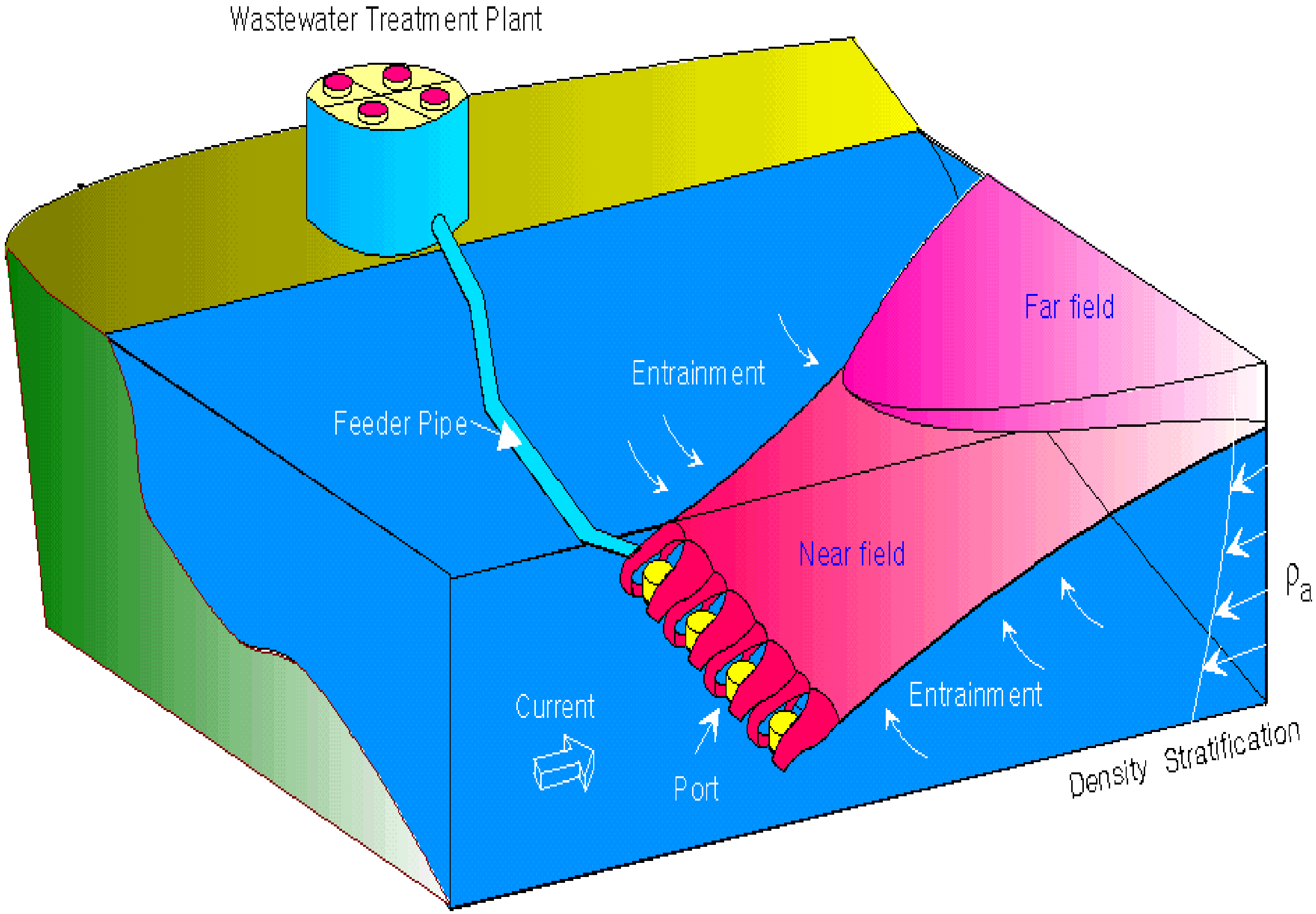



Fig. 1.19 Analysis of buoyant jets and plumes

# 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 = $\rho g$ = weight/vol.

where $\rho$ = mass density = *M/vol.*

$g$ = gravitational acceleration

# 1.2 Environmental Hydraulics

• Variation of $\rho$ 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

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

$$\begin{aligned} \sigma_t &= \sigma - units \\ &= f_n(temperature,\ salinity) \rightarrow See\ App.1 \end{aligned}$$

# 1.2 Environmental Hydraulics

• Density stratification

→ lake, reservoirs - due to temperature variation

→ estuary - salinity profiles

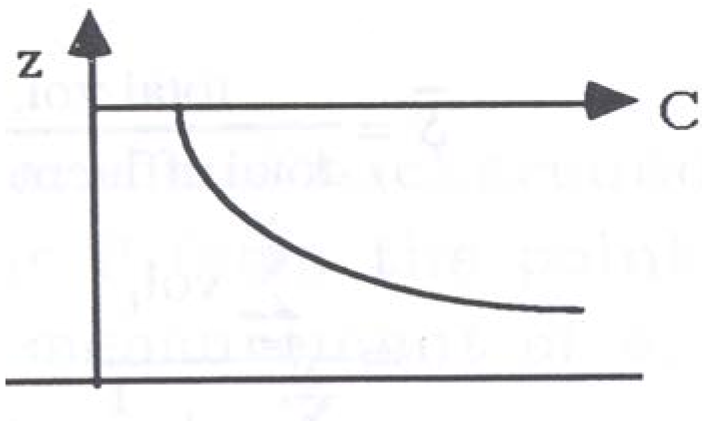
- internal structure causes effect on both mean flow fields and turbulent mixing and dispersion

# 1.2 Environmental Hydraulics

- density profile $\rho_a(z)$

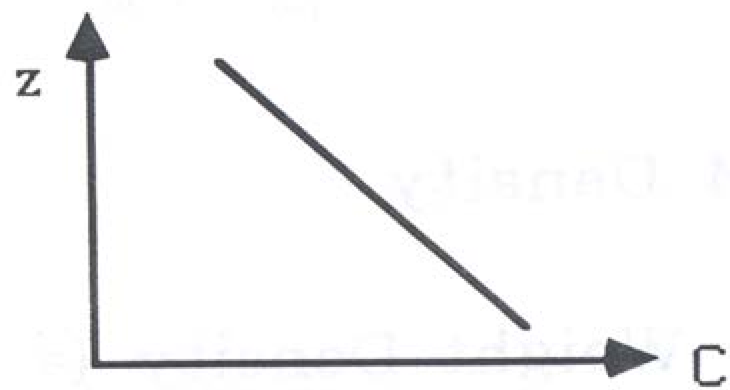
  $z$ = vertical coordinates

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




- linear density stratification

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



# 1.2 Environmental Hydraulics

## *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:

a. Identify problems

b. For large complicated problems, break a problem (of mixing) into <u>sub-models</u> (component parts)

c. Use two or more approaches (mixed approaches/hybrid modeling)

- interweaving of all of the approaches

- better than single approach, computer model, hydraulic model, and field studies

# 1.3 Mixing Analysis

## *1.3.1 Strategies*

- Strategy:

a. Identify problems

b. For large complicated problems, break a problem (of mixing) into <u>sub-models</u> (component parts)

c. Use two or more approaches (mixed approaches/hybrid modeling)

- interweaving of all of the approaches
- better than single approach, computer model, hydraulic model, and field studies

# 1.3 Mixing Analysis

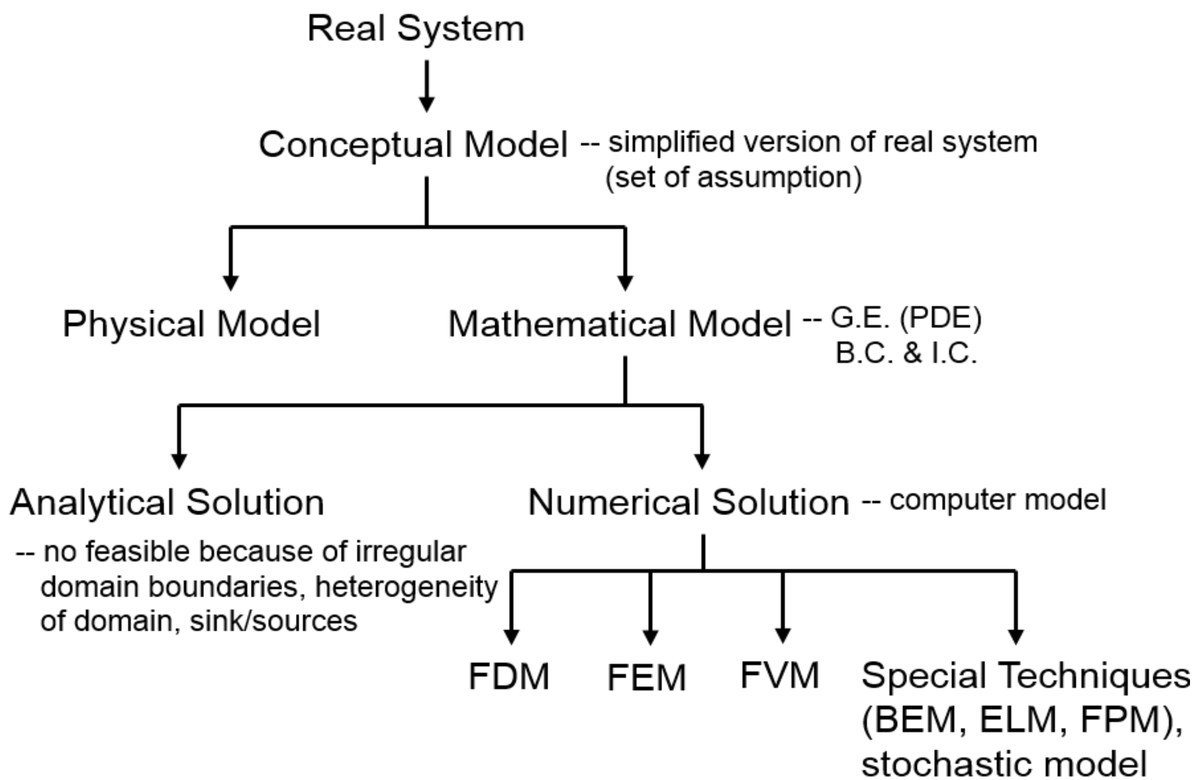
## *1.3.1 Strategies*

[Re] Approaches:

- computer modeling

- hydraulic modeling

- field experimentation



# 1.3 Mixing Analysis

## *1.3.2 Interdisciplinary Modeling*

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

- different time scales between the dominance of the various processes

  - hydrodynamic mixing in the jets - min

  - dispersion, biochemical reaction - hours, days

  - biological or ecological effects - weeks, months

# 1.3 Mixing Analysis

(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.

# 1.3 Mixing Analysis

| 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

**(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

# 1.3 Mixing Analysis

• Near-field mixing:

- initial jet and plume mixing occurs; momentum and buoyancy of the jet are important (active mixing)

→ 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

# 1.3 Mixing Analysis

• 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

| 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 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

[Re] Model

• Conceptual model:

- idealized representations

- concentrate on the dominant processes and important features of the water domain

- omit many secondary details or interactions

# 1.3 Mixing Analysis

• 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

• 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

# 1.3 Mixing Analysis

[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

• Field Studies

-can be used to verify or adjust numerical models

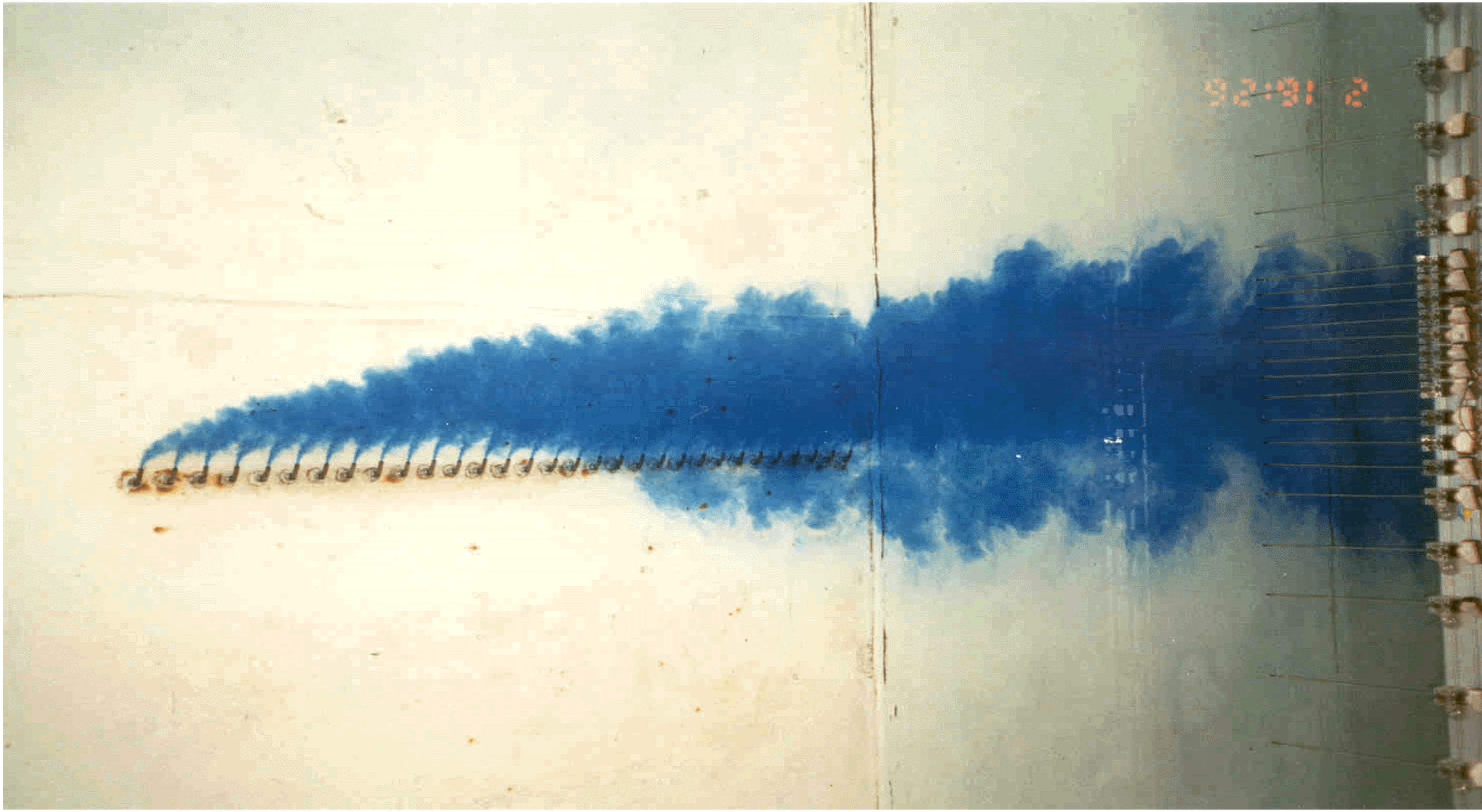
a. Eulerian-type measurements

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

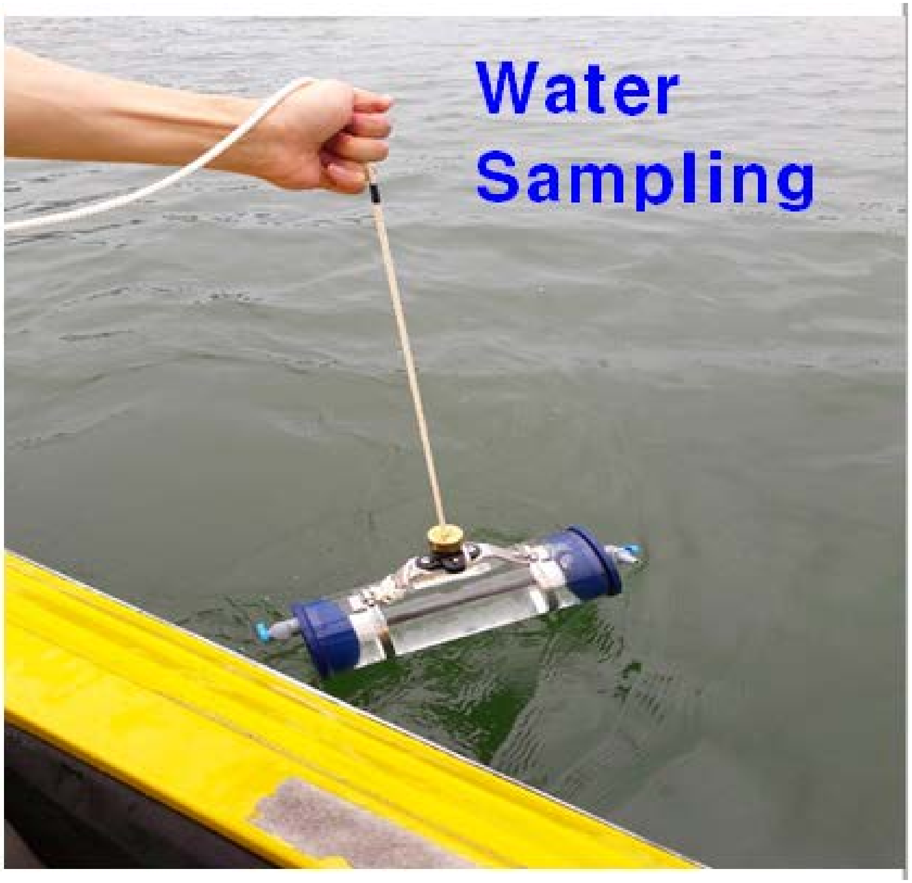
b. Lagrangian experiments

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

# 1.3 Mixing Analysis



# 1.3 Mixing Analysis

# 1.3 Mixing Analysis

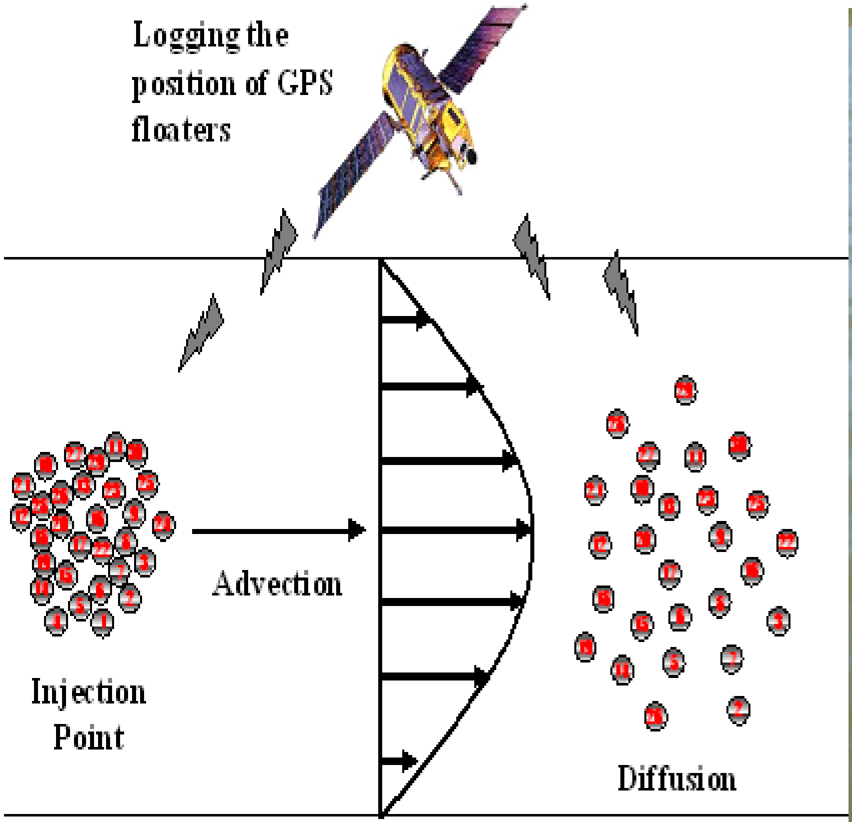



Fig. 1.21 Eulerian versus Lagrangian measurements

# 1.3 Mixing Analysis

## *1.3.3 Approaches*

• 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

[EP] Complete vertical mixing

→ Find longitudinal distance required for complete vertical mixing of <u>surface discharge</u> pollutants

# 1.3 Mixing Analysis

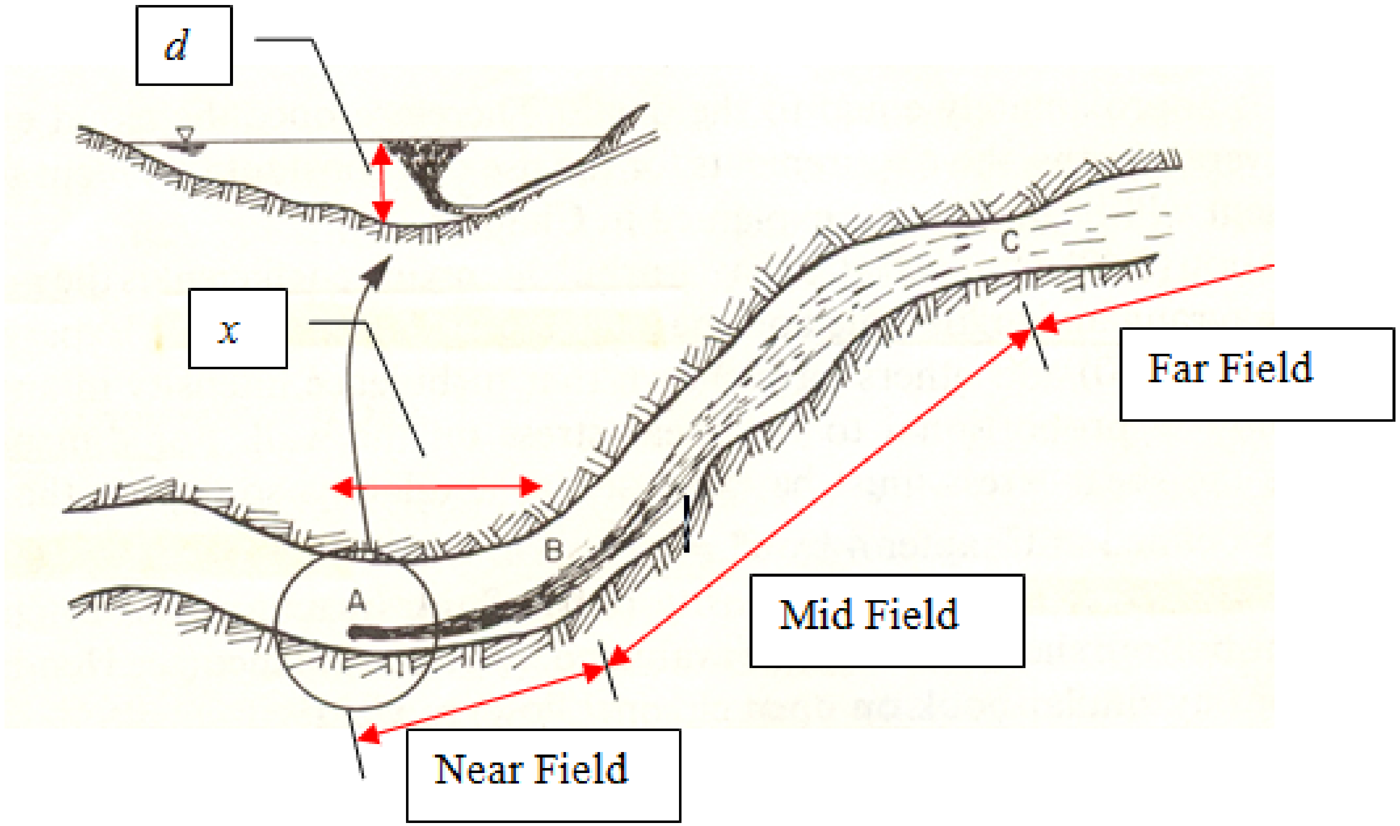



Fig. 1.22 Stages of pollutant mixing in rivers

# 1.3 Mixing Analysis

[Solution]
Mixing time; $T = \alpha \dfrac{d^2}{\varepsilon_v}$ (time scale)

where $d$ = depth (cm); $\varepsilon_v$ = vertical eddy diffusivity $(m^2/s)$

set $\varepsilon_v = 0.07 u^* d$

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

where $f$ = Darcy-Weisbach friction factor

then $T = \alpha \dfrac{d^2}{0.07 d \bar{u}} \sqrt{\dfrac{8}{f}}$ assume $\sqrt{\dfrac{8}{f}} \approx 15$ ; $\alpha \approx 0.35$ $\therefore T \approx 75 \dfrac{d}{\bar{u}}$

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

$x$ = 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 $\Delta M$ = tracer mass in elemental volume $\Delta V$

# 1.4 Basic Definitions and Concepts

## 1.4.1 Concentration

• 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

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

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

- hour, day for unsteady flow

# 1.4 Basic Definitions and Concepts

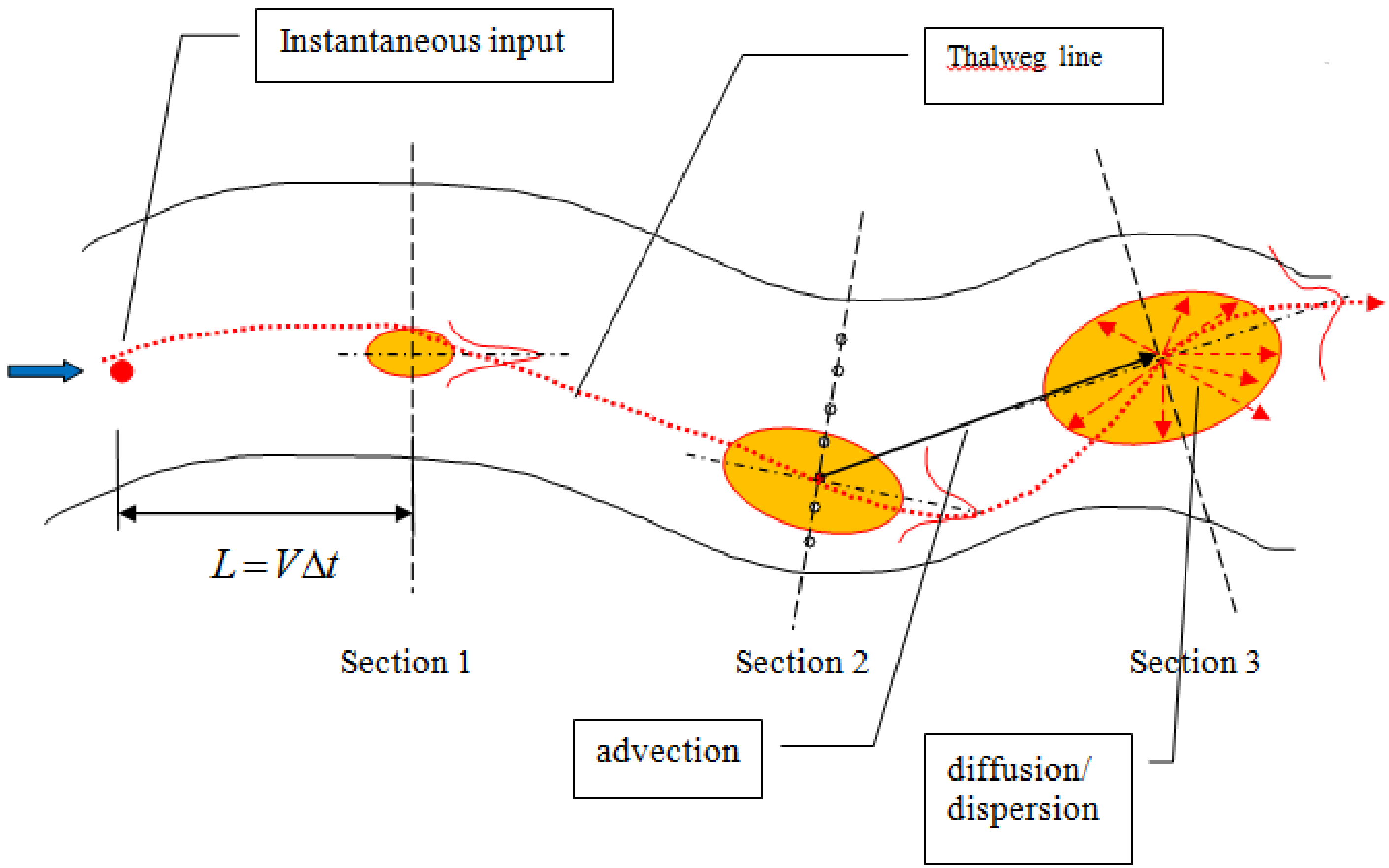



Fig. 1.23 Advection and diffusion

# 1.4 Basic Definitions and Concepts

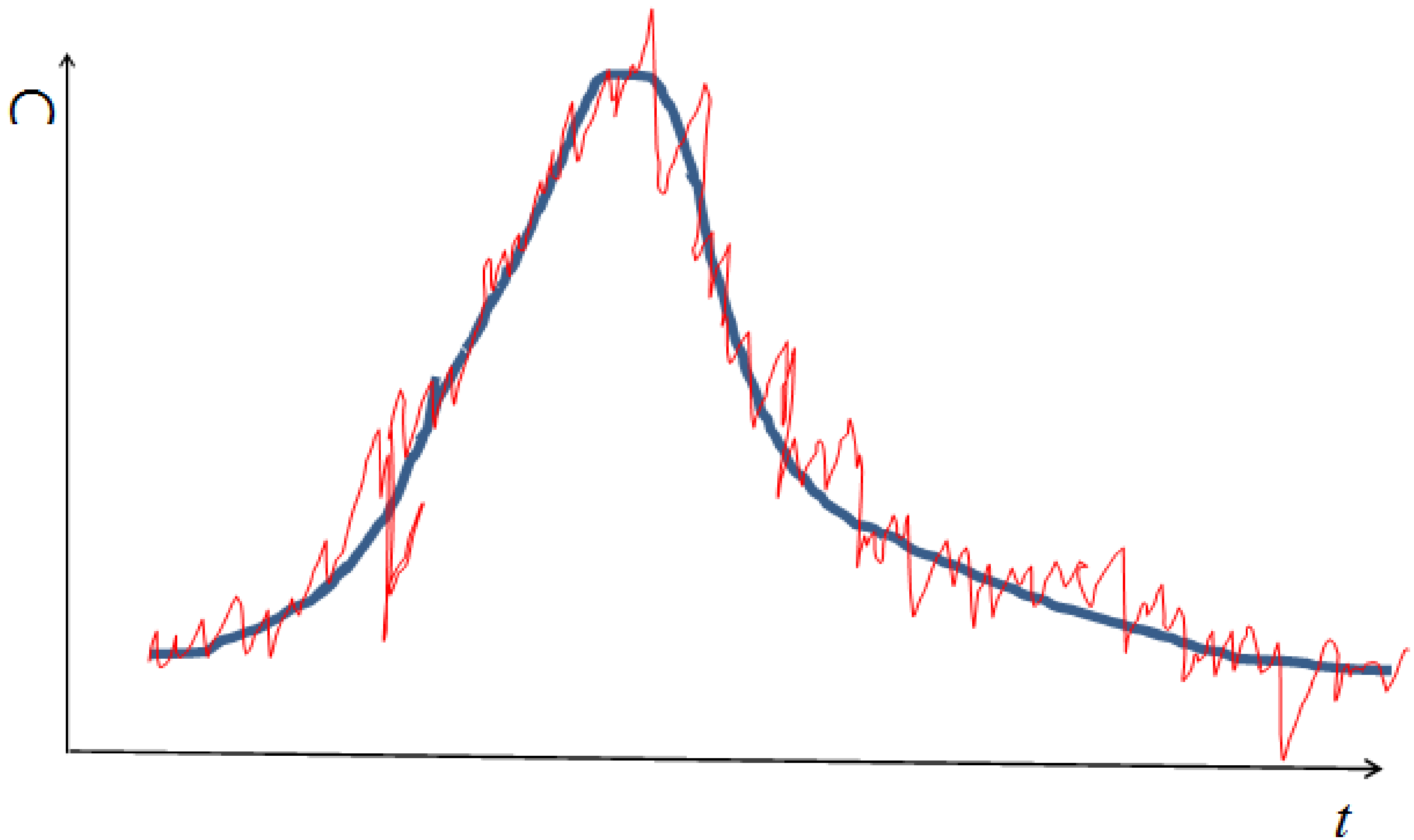



Fig. 1.24 Concentration fluctuation

# 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 = mass per unit area per unit time

Flux of contaminant mass through AA

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

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

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

# 1.4 Basic Definitions and Concepts

[Re] mass flux

$$M = CVol = CQt = CuAt$$

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

- Total mass *M*

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

# 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

# 1.4 Basic Definitions and Concepts

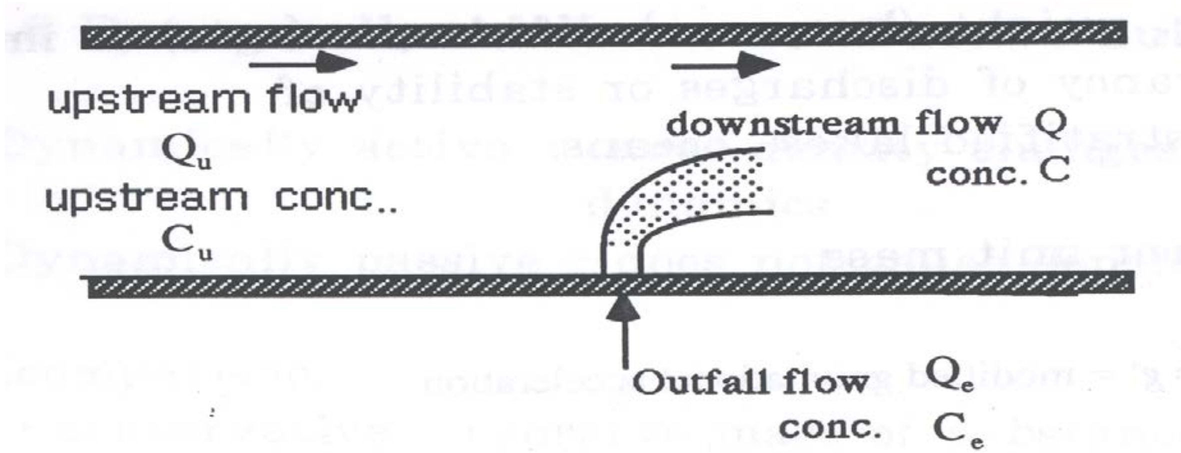
After effluent is fully mixed across the section,

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 $C_a$

| tems | effluent | ambient water | mixture |
|---|---|---|---|
| vol. | $vol_e$ | $vol_a$ | $vol_e + vol_a$ |
| conc. of contaminant | $C_e$ | $C_a$ | $\dfrac{vol_e C_e + vol_a C_a}{vol_e + vol_a}$ (harmonic mean) |

# 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 <u>reduced by the dilution</u> factor *S* or *p*

from the point of discharge to the point of measurement of effluent

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

# 1.4 Basic Definitions and Concepts

- dilution of a composite sample

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

# 1.4 Basic Definitions and Concepts

## *1.4.3 Turbulent Shear Flow*

• turbulent shear flow in a long pipe or channel

- driving force: pressure gradient and gravity

- resisting force: shear stresses at the wall

• velocity contour map (Fig.5.11)

$$u = u(y, z)$$

# 1.4 Basic Definitions and Concepts

• Vertical velocity distribution

- approximated by a logarithmic function

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

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

# 1.4 Basic Definitions and Concepts

where $z$ = distance from the wall

$R$ = pipe radius

$d$ = channel depth

$\kappa$ = Von Karman constant ≈ 0.4

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

$$\tau_o = \frac{1}{8} f \rho \bar{u}^2 \rightarrow \text{[Re1]}$$

# 1.4 Basic Definitions and Concepts

where $\tau_o$ = 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

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

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

define

$$\sqrt{\frac{\tau_o}{\rho}} \equiv u^* =$$ shear (friction) velocity → [Re2]

# 1.4 Basic Definitions and Concepts

- mean shear stress ← balance of force

$$\tau_o = \rho g R_h S$$

$$\therefore\ u^* = \sqrt{g R_h S} \qquad \rightarrow \text{[Re3]}$$

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

# 1.4 Basic Definitions and Concepts

[Re1]

$$h_L = f\frac{L}{D}\frac{v^2}{2g}, \quad h_L = \frac{\tau_0 L}{\gamma R_h}$$

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

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

# 1.4 Basic Definitions and Concepts

[Re2]

Shear velocity $= u^* = \sqrt{\frac{\tau_o}{\rho}} = \sqrt{gRS}$ for steady unsteady flow

$$= \sqrt{gD\ (S_o - \frac{\partial D}{\partial x} - \frac{v}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial x})}$$ for

unsteady flow

- dimensions of velocity

- varies with the boundary friction $\tau_o$

# 1.4 Basic Definitions and Concepts

[Re3]

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

$S_0$ = channel slope for uniform flow

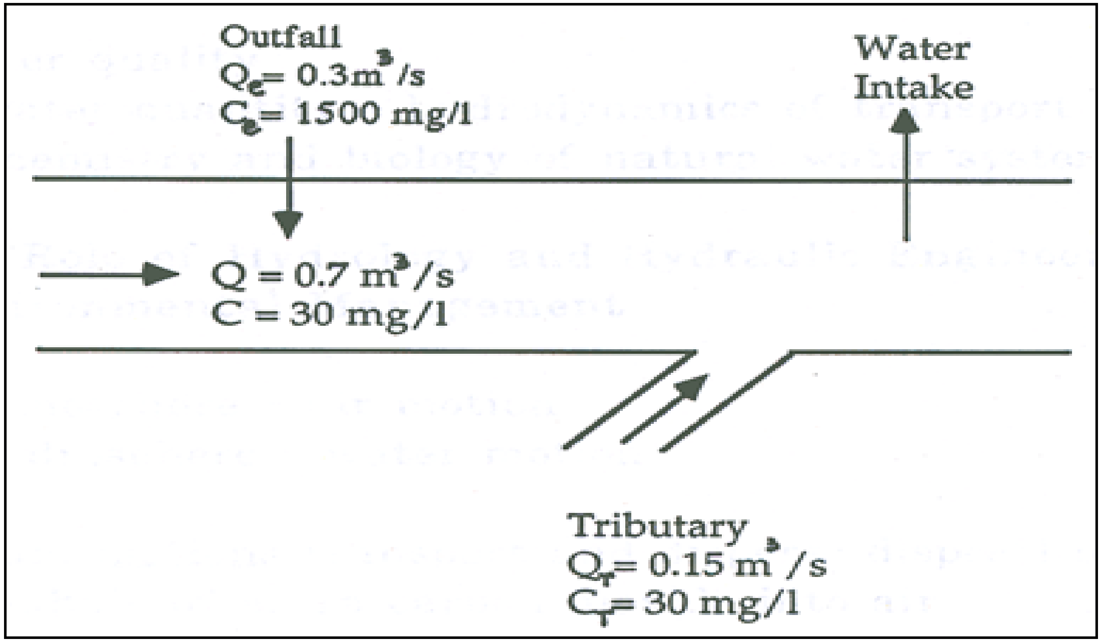
# Homework #1

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 $0.3 m^3/s$ carrying 1,500mg/ℓ chlorides and a downstream tributary of $0.15 m^3/s$ 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