Chapter 1 Concepts and Definitions

Contents

1.1 The Role of Hydrology and Hydraulic Engineering in Environmental Management

• Water quality = water quantity

+ hydrodynamics of transport and mixing

+ chemistry and biology of natural water systems

atmosphere - air motion

hydrosphere - water motion

Fluid motions transport and disperse disposal of residuals

- massive discharges of wastewater into rivers and oceans

Without fluid motion, there is no transport and dispersion

[Ex] estuarine modification or barriers → radically change the circulation patterns decreasing flushing of pollutants

1.1.1 Overall Framework for 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.

•Transport - Hydraulic engineer

Transformation - Chemist

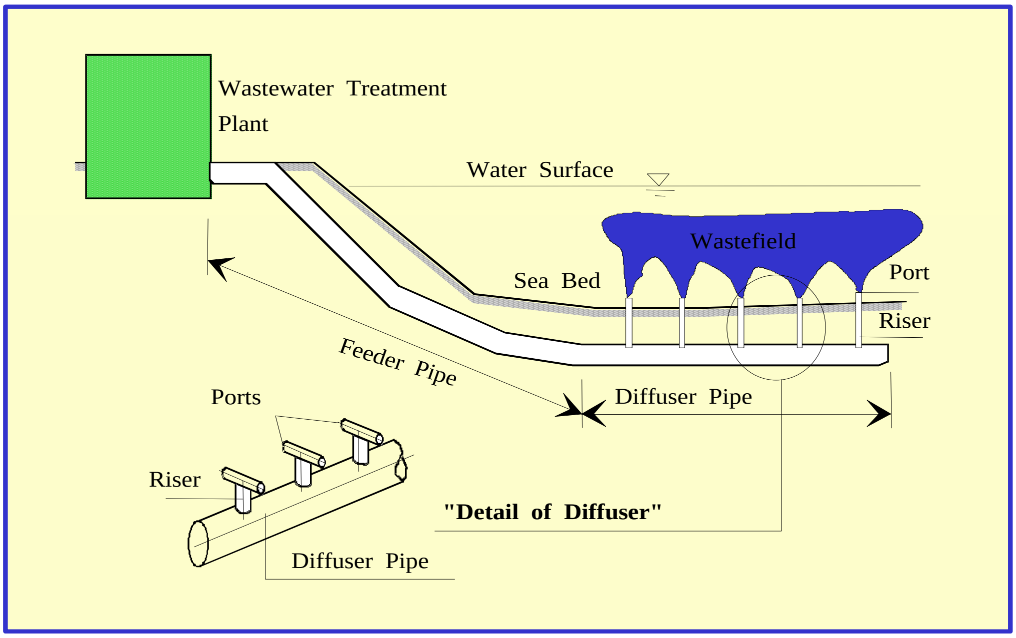
Accumulation - Biologist

⇒ 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.

• Role of hydraulic engineer in environmental management

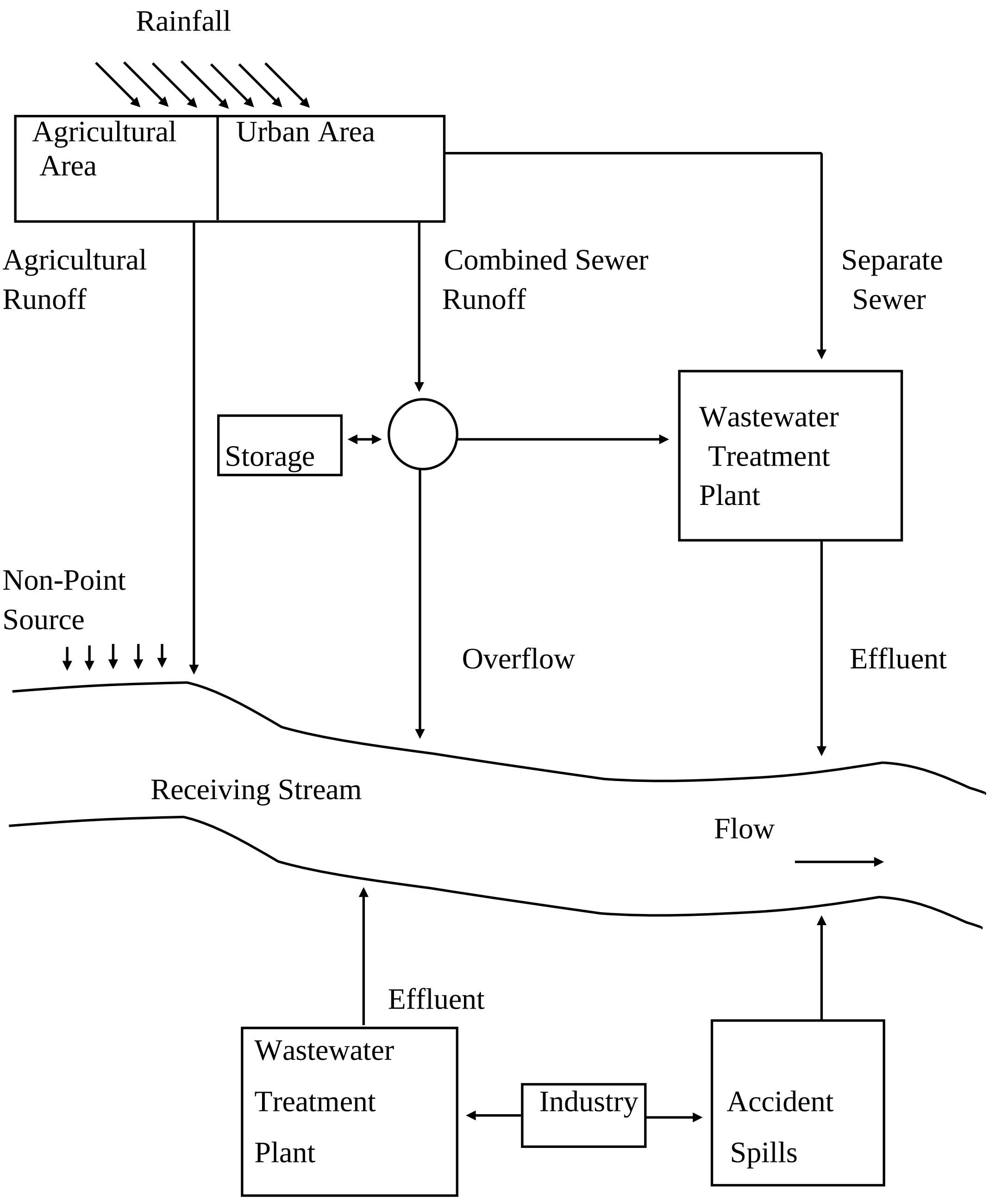
1) design of hydraulic structure (outfalls, diffusers)

-> **jets and plumes**



2) analyze water quality processes -> **diffusion and dispersion**

Conceptual View of Pollutant Inputs



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

• Environmental Control System

- Optimization of

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

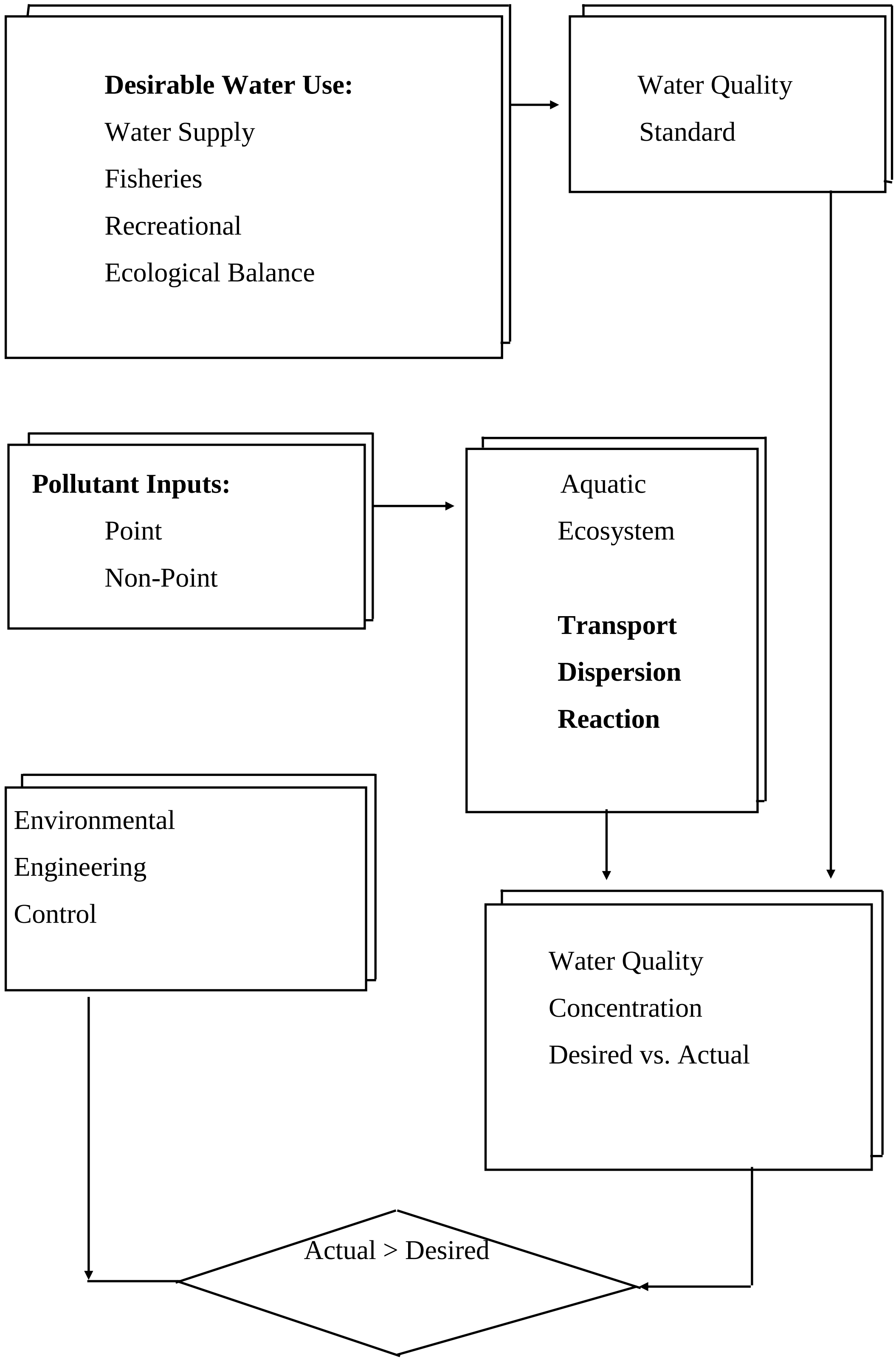
(b) wastewater treatment (primary, secondary treatment)

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

• 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

Flow Diagram of Water Quality Engineering



1.1.2 Using the Water Environment for Waste Assimilation

• Types of pollutant (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

(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

$$\text{Organic waste} + O_2 \xrightarrow{\text{bacteria}} CO_2 + H_2O$$

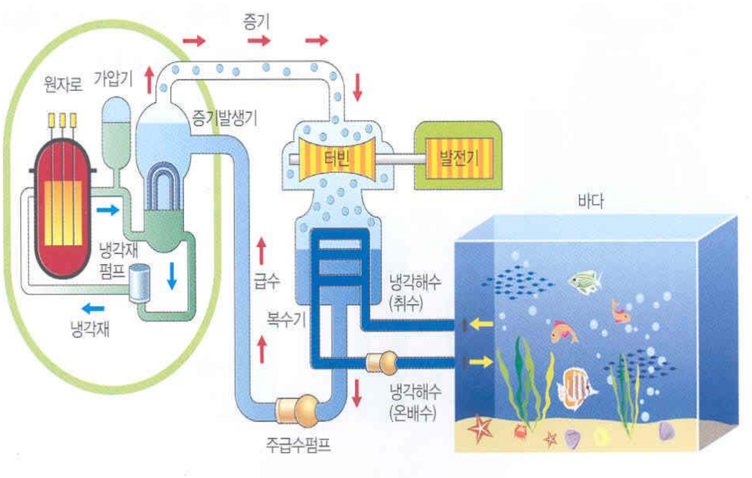
• COD

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

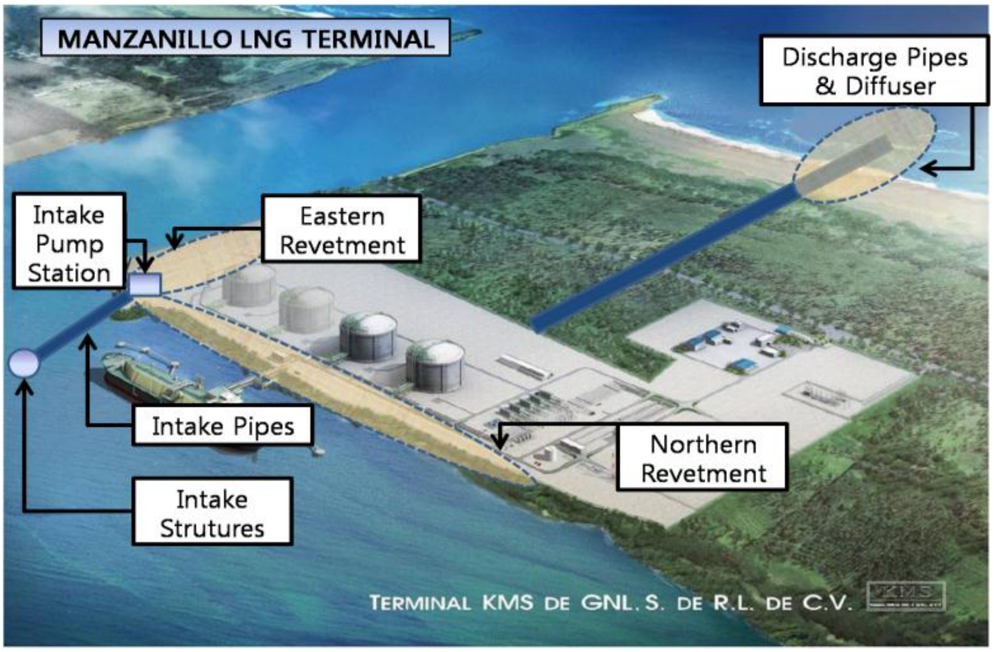
COD > BOD

Yangz River

Nakdong River



Cooling system for nuclear power plant



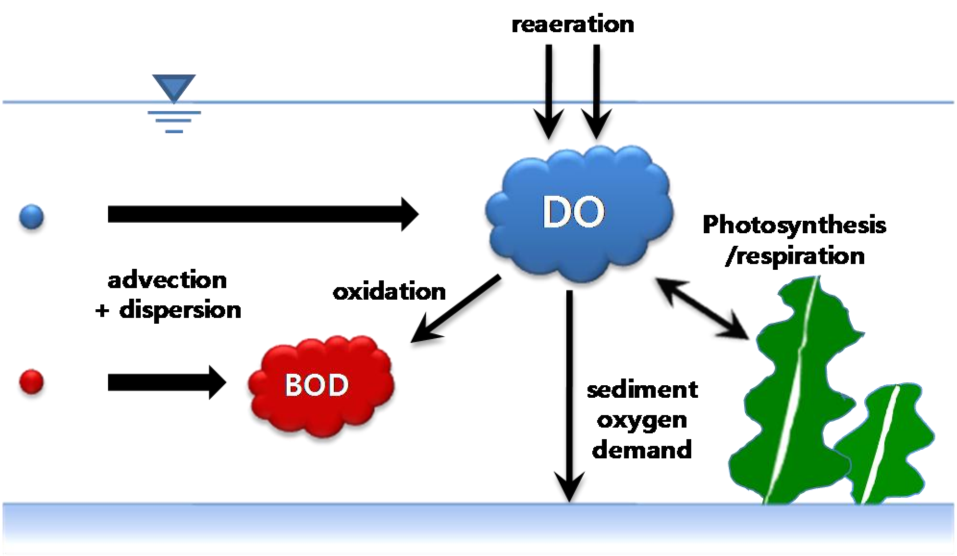
LNG plant (Manzanillo, Mexico)

• 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

(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)

(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] "Dilution is the solution to pollution."

- suitable only for heat and natural organic materials

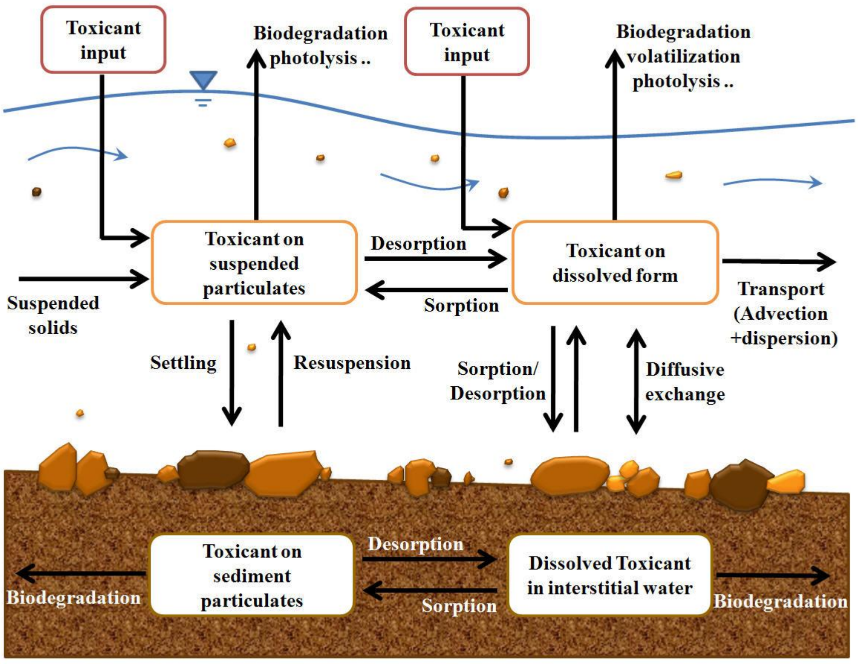
[Re] Toxic substances: trace metals, synthetic chemicals, radioactive materials

- 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 μg/l or ng/l

- tendency to be concentrated by aquatic organisms and transferred up the food chain



1.1.3 Mass Balance Concepts in Residual Management

• 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.

• **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

• Types of pollutant source

1) point source

- discharge from a structure which is specially designed for the outflow of wastewater or accidental spill

[Ex] - industrial and municipal sewerage system

- accidental spill of chemicals or oil from a ship

- release of heated water from power plant

2) nonpoint source

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

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

[Cf] classification by input period

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

instantaneous input - accidental spills

Effluent discharge channel (Tancheon STP)

1.1.4 Impacts of Some Traditional Activities of Hydraulic Engineers

• 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

(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

Panama Canal

Breakwater for harbors

SaemanGeum

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

$\Leftrightarrow$ 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)

(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

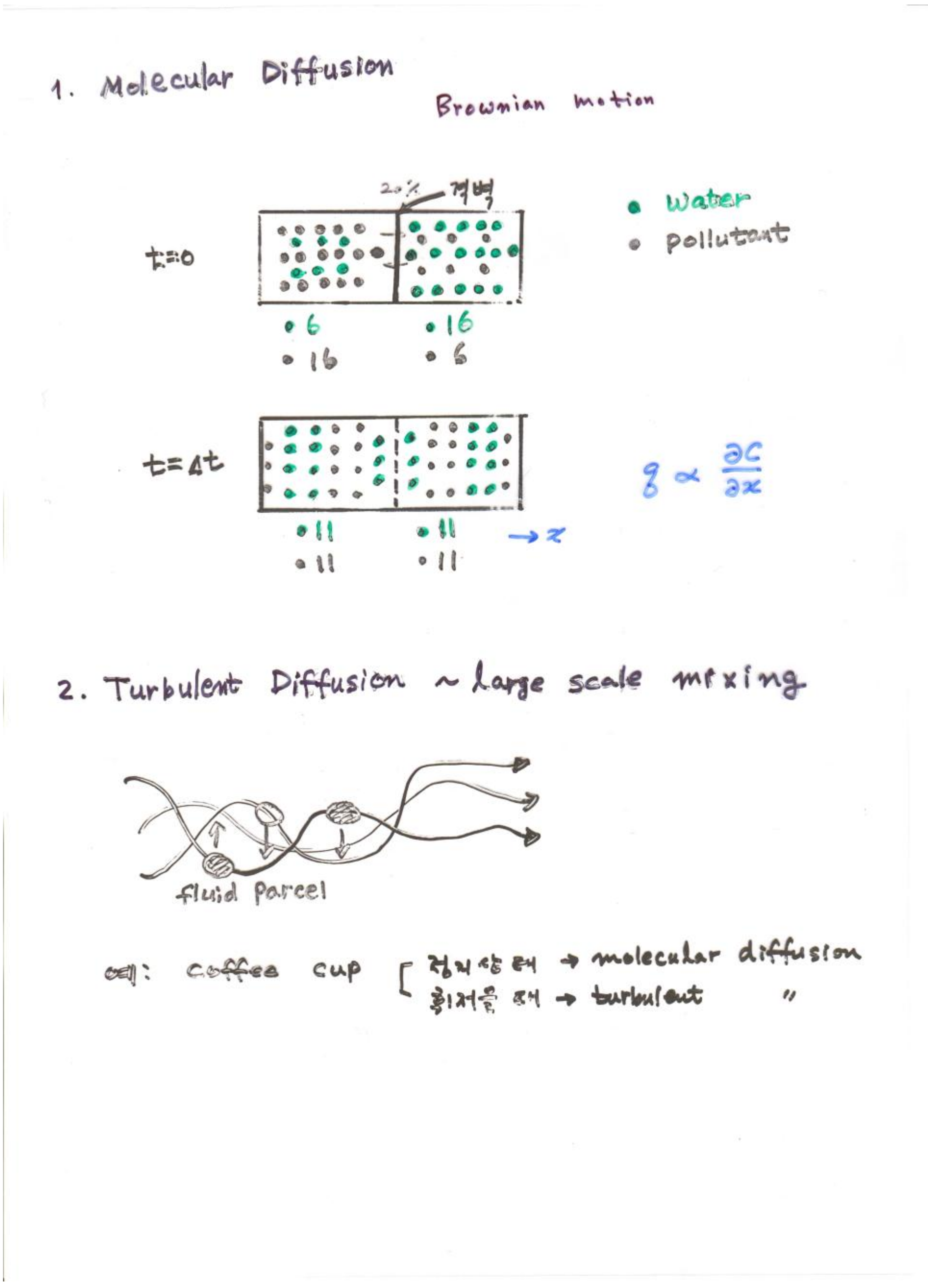
(4) Turbulent diffusion

- random scattering of particles by turbulent motion

- analogous to molecular diffusion

- molecular diffusion ≪turbulent diffusion

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

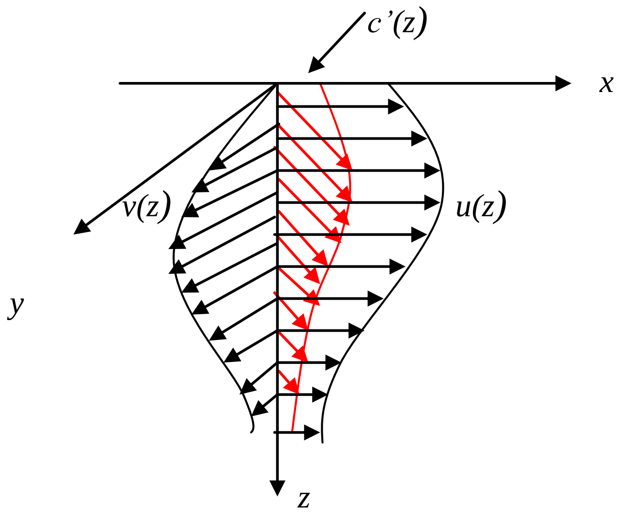


(5) Shear (shear flow)

- 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 diffusion

- molecular diffusion $\ll$ 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.

3. Shear Flow Dispersion

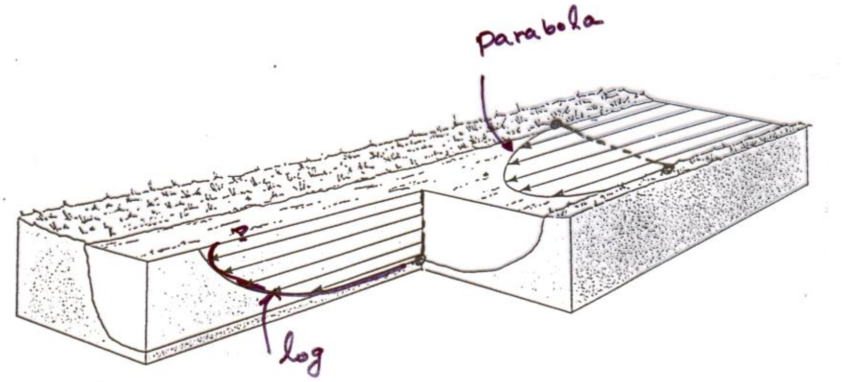
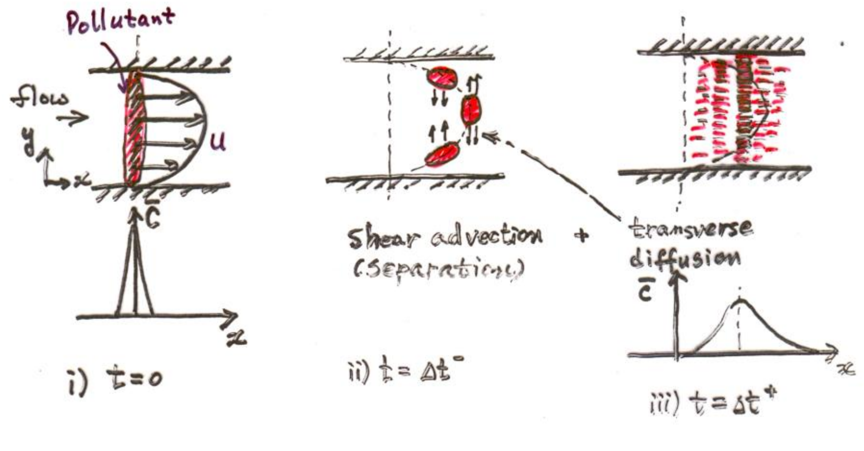


Figure 10.5
Variations in the velocity of flow in natural stream channels occur both horizontally and vertically. Friction reduces the velocity along the floor and sides of the channels. The maximum velocity in a straight channel is near the top and center of the channel.



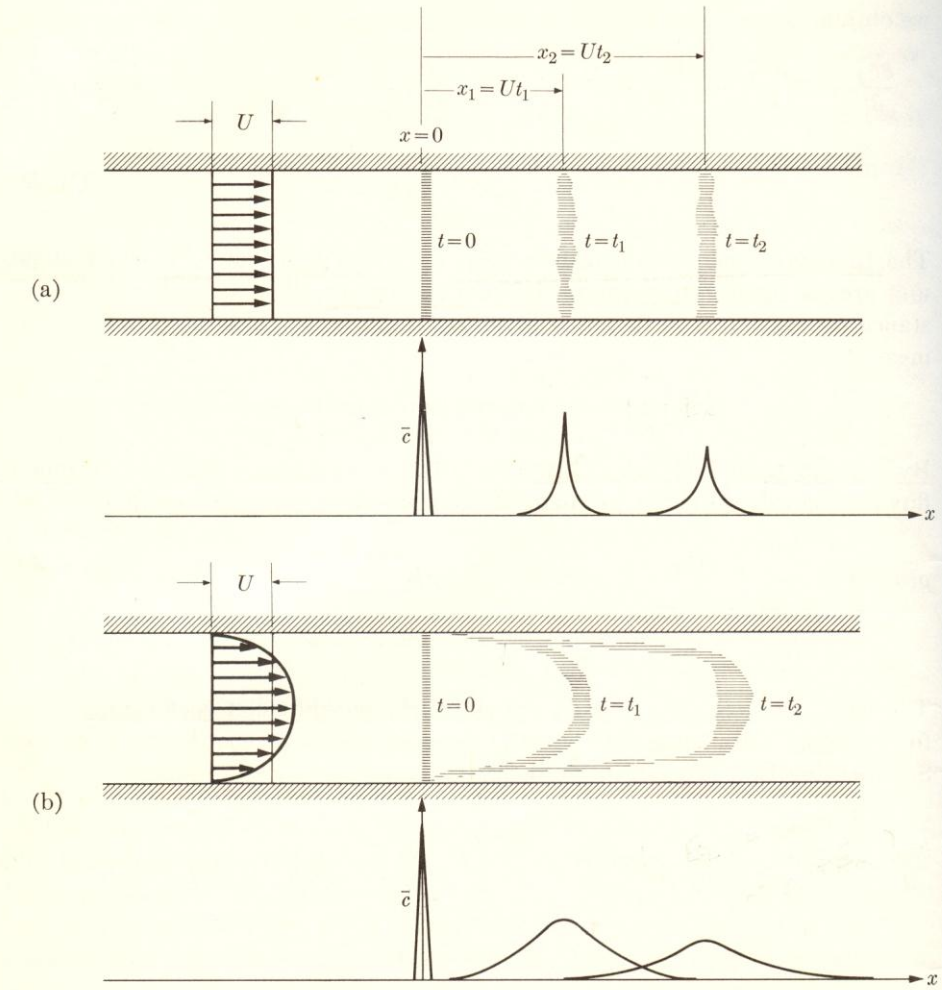


FIG. 16–10. Mechanism of longitudinal dispersion: (a) turbulent diffusion in uniform velocity flow; (b) turbulent dispersion due to nonuniform velocity distribution.

(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

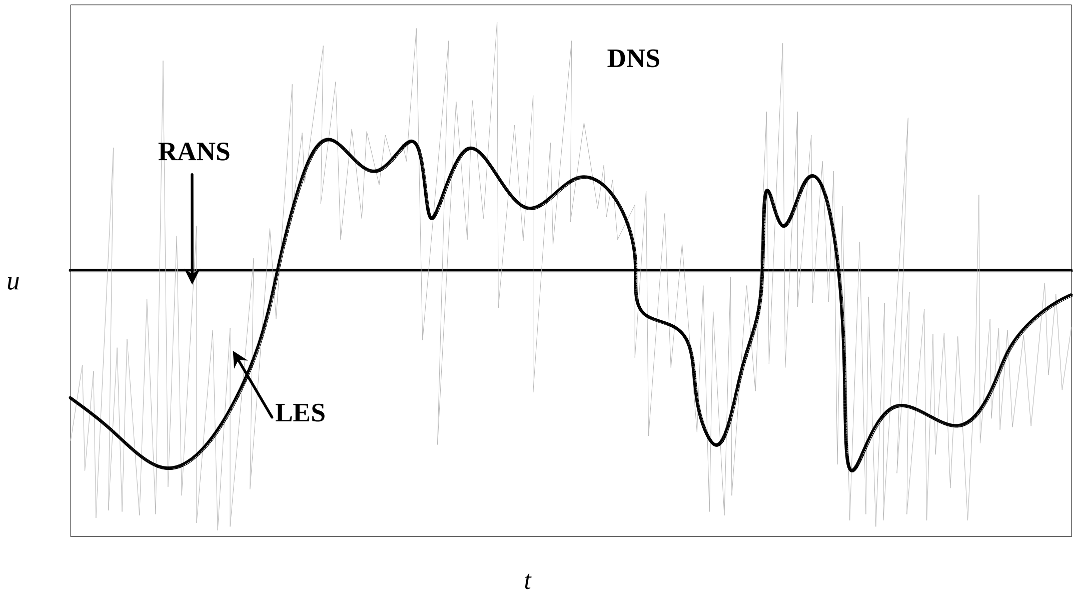
[Ex] sand grains, dead plankton → downward transport of nutrients in lakes and ocean

(11) Particle entrainment

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

• flow analysis - mean velocity is important

• pollutant analysis - fluctuation and irregularities in hydrologic systems are equally important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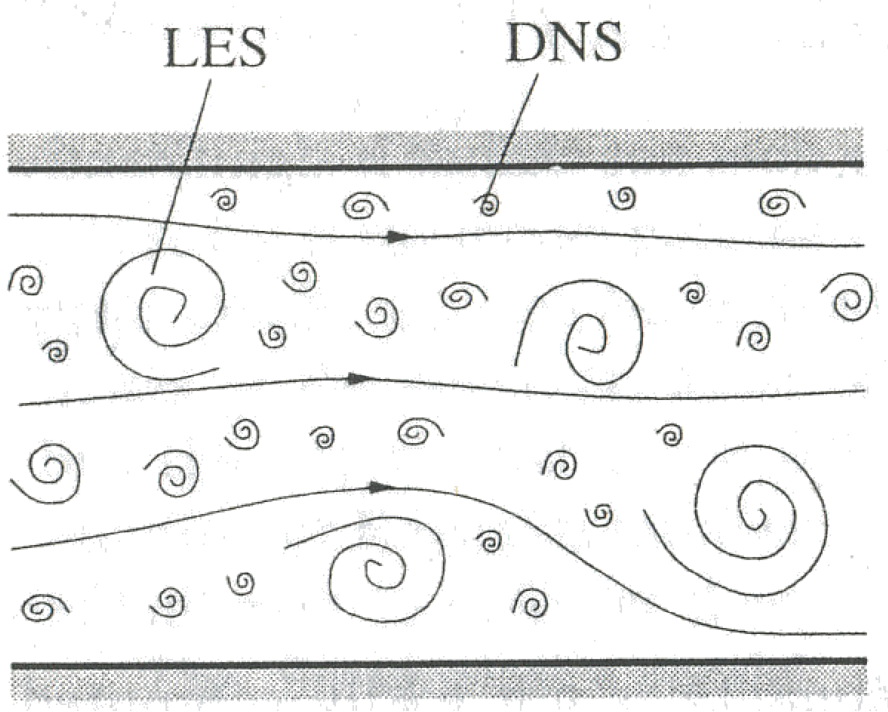
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DNS

1.2.2 Buoyant Jets and Plumes

• submerged (momentum) jet

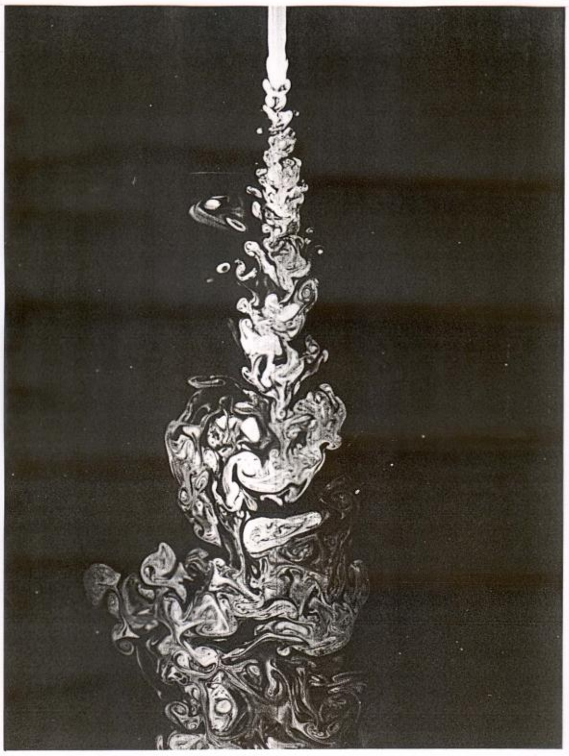
- increase the dilution of effluent discharge with the surrounding waters

• 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



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*

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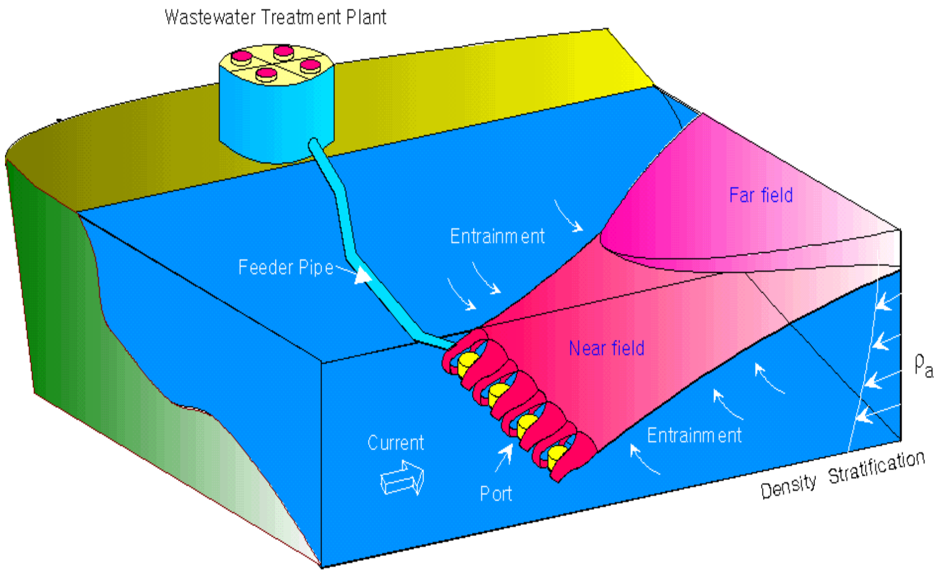
●Analysis of buoyant jets and plumes

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



1.2.3 Density-Stratified Flows in a Natural Environment and Geophysical Fluid Mechanics

• 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

1.2.4 Sedimentation and Erosion

• particle setting and entrainment, stream morphology

• erosion, transport and deposition → 『Advance River Engineering』

1.2.5 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 Strategies and Approaches for Problems Solving

1.3.1 Strategies

• Strategy:

a. Identify problems

b. For large complicated problems, break a problem (of mixing) into submodels (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

[Re] Approaches:

- computer modeling

- hydraulic modeling

- field experimentation

(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.

→ Table 1.1 Effluent flow from a sewer outfall (ocean)

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

(2) Definition of submodels

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:

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

(active mixing) → use hydraulic modeling

· far-field mixing:

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

→ use computer model

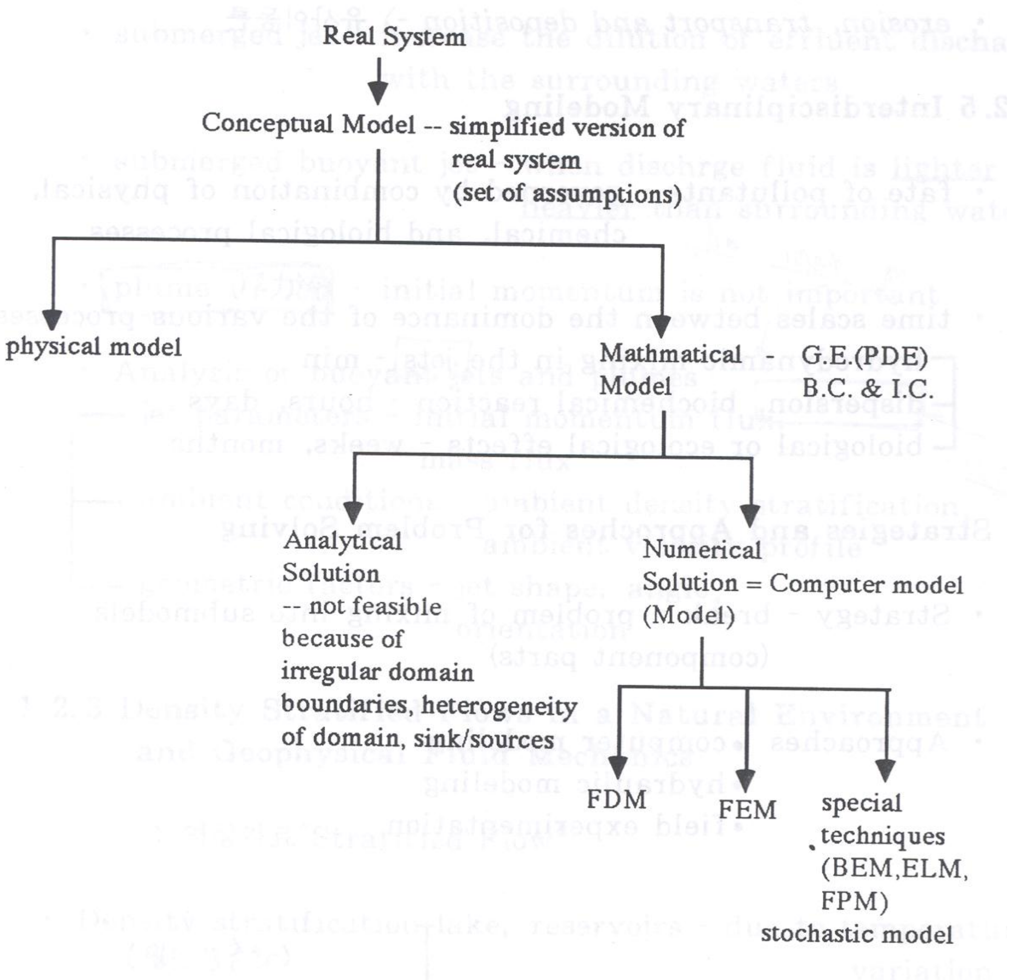
- results from near-field model are used as input of far-field model

[Re] Model

- idealized representations

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

- omit many secondary details or interactions



• 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

• 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

• Field Studies

-can be used to verify or adjust numerical models

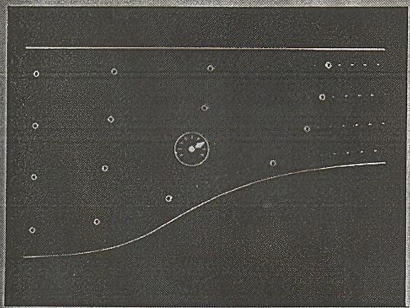
a. Eulerian-type measurements

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

b. Lagrangian experiments

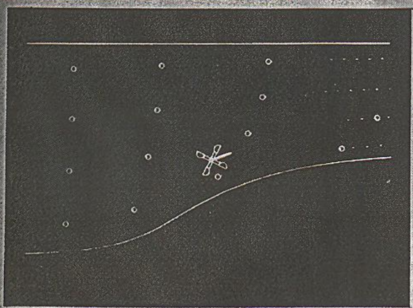
- follow drogues to track flow trajectories and dispersion → time series data for a given parcel of water motion, we would have to give the velocity of all the pieces of matter in the flow as a function of time and initial position.

Such a description, in terms of material points, is called a *Lagrangian* description of the flow. The identifying co-ordinates are called *Lagrangian*, or sometimes *material*, co-ordinates. Given the Lagrangian velocity field, we can easily calculate the Lagrangian displacement by integration in time, and the acceleration field by partial differentiation with respect to time.



7. A pressure gauge is attached to one of the moving points. (Lagrangian)

To make what we might call a Lagrangian measurement, we can imagine attaching an instrument like a pressure gauge to a fluid material point (Fig. 7). This sort of measurement is attempted in the atmosphere with balloons of neutral buoyancy. If the balloon does indeed move faithfully with the air, it gives the Lagrangian displacement, i.e. the displacement of an identified fluid "element." Such Lagrangian measurements are actually very difficult, particularly in the laboratory. We usually prefer to make measurements at points fixed in laboratory co-ordinates; it is relatively easy to hold an instrument at a fixed location.

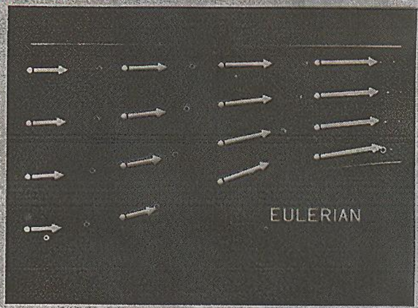


8. An anemometer is placed at a fixed position in the flow field.

(Eulerian)

Eulerian Description

Classically, the idea of a field, such as an electric, magnetic, or temperature field, is defined by how the response of a test body or probe, like the anemometer in Fig. 8, varies with time at each point in some spatial co-ordinate system. In Fig. 8 the fixed anemometer probes in laboratory co-ordinates. We will always use



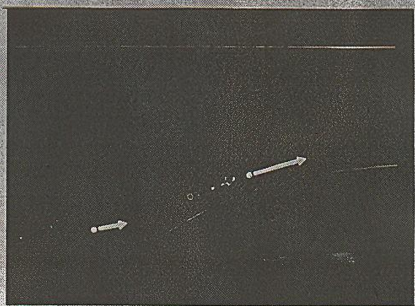
9. The solid vectors indicate the velocities at fixed points in the contraction.

solid points and solid arrows to indicate such probing positions, fixed in our laboratory, and the velocities measured there.

In Fig. 9 we have a grid of points fixed in space with an arrow at each to indicate the velocity at each point. A description like this which gives the spatial velocity distribution in laboratory co-ordinates is called an *Eulerian* description of the flow.

Relation Between Eulerian and Lagrangian Frames

Although the physical field is the same, the Eulerian and Lagrangian representations are not the same, be-



10. The open vectors indicate the Lagrangian velocity of the moving material point. The solid vectors indicate the Eulerian velocities at two fixed points. When the moving point coincides with a fixed point, the Eulerian and Lagrangian velocities coincide.

1.3.2 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

[Ex] complete vertical mixing

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

mixing time $T = \alpha \dfrac{d^2}{\varepsilon_v}$ (time scale)

d = depth (cm)

ε_v = vertical eddy diffusivity (m^2 / s)

set $\varepsilon_v = 0.07 u^* d$

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

f = Darcy – Weisbach friction factor

then $T = \alpha \dfrac{d^2}{0.07 d \bar{u}} \sqrt{\dfrac{8}{f}}$

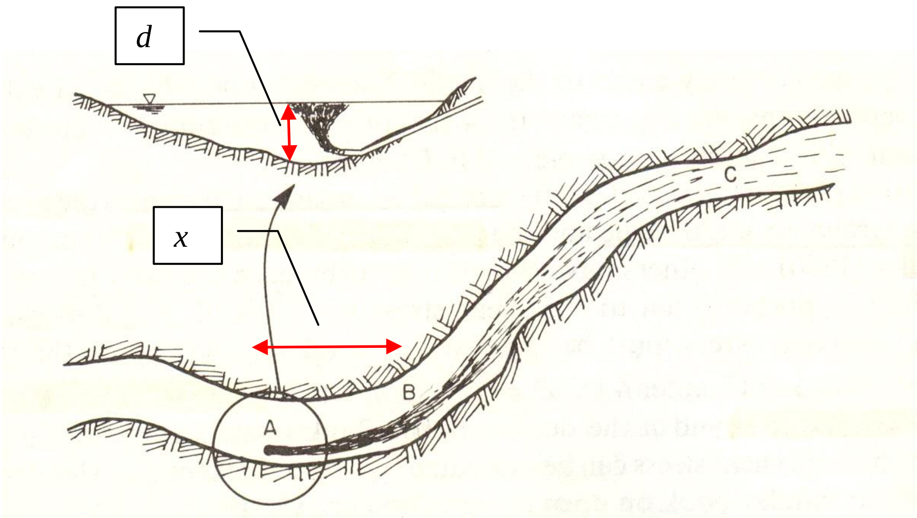
$$\sqrt{\frac{8}{f}} \approx 15\,; \quad \alpha \approx 0.35$$

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

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

$C = C(x, y, z, t)$

→ include turbulent fluctuations

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

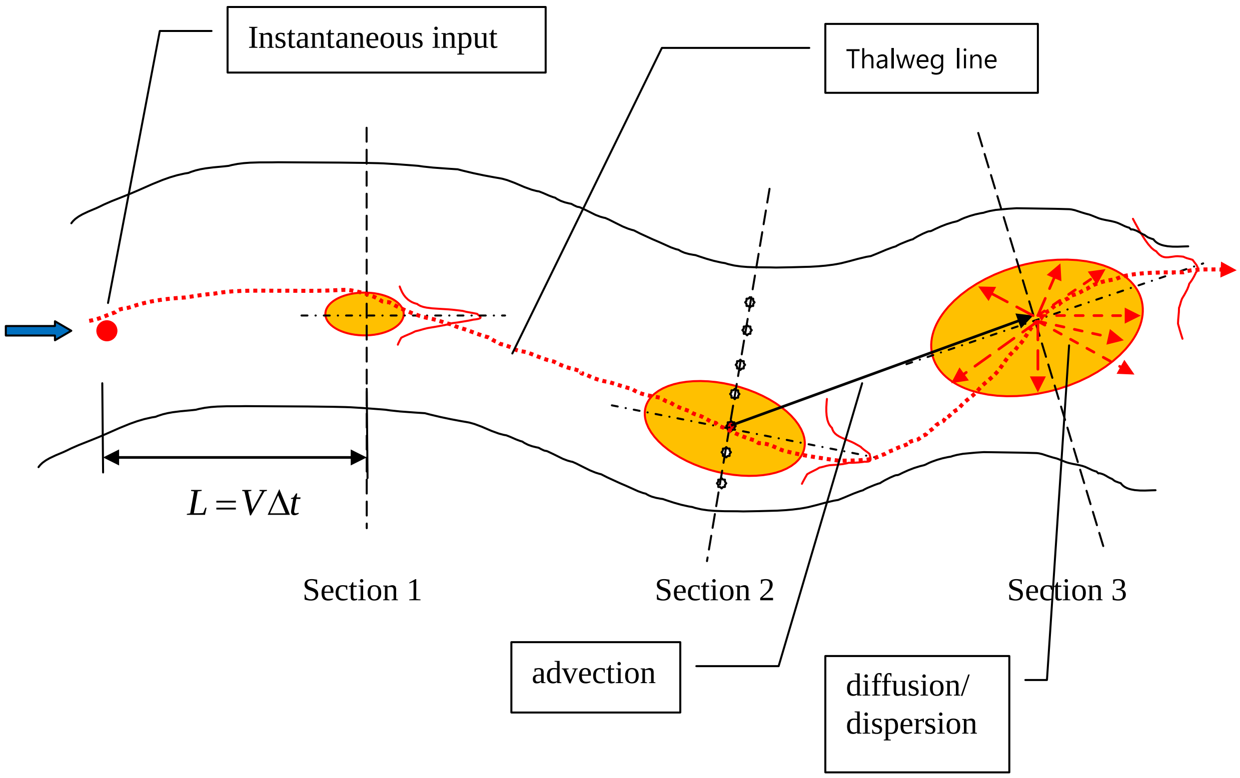
where T = averaging time interval

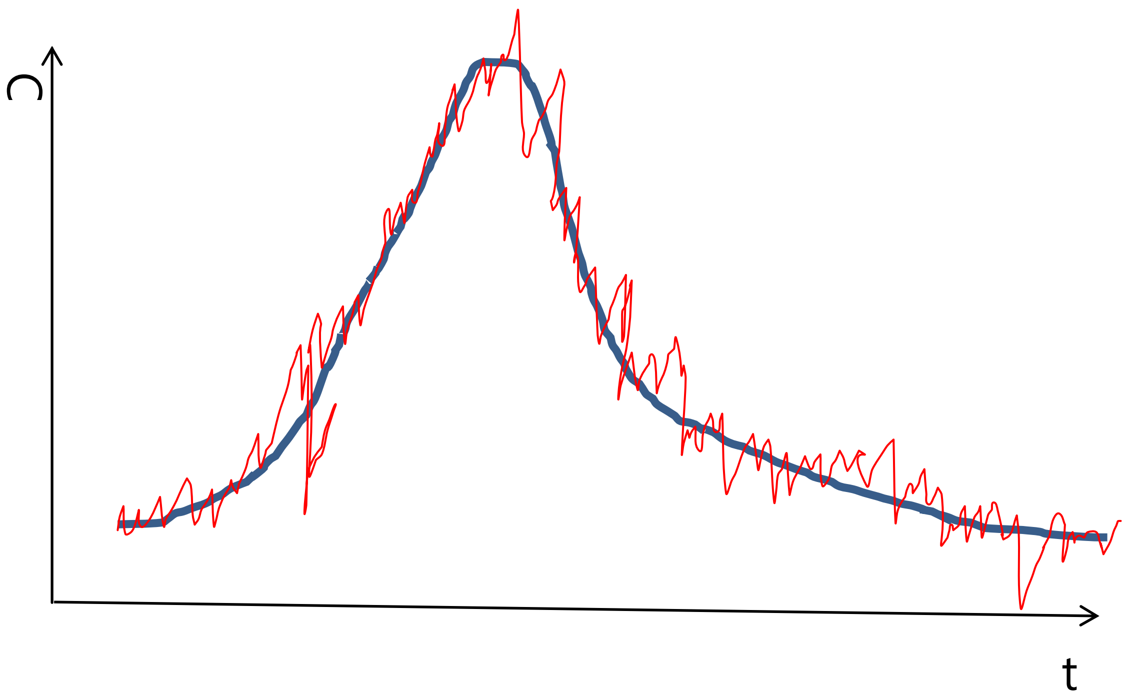
- sec, min for turbulence fluctuation

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

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

- hours, day for unsteady flow


Instantaneous input
Thalweg line
$L = V\Delta t$
Section 1
Section 2
Section 3
advection
diffusion/
dispersion


C
t

• 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)

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

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

• Total mass M

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

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

• mixture of effluent with ambient water of background concentration C_a

items	effluent	ambient water	mixture
vol.	vol_e	vol_a	$vol_e + vol_a$
conc. of contaminant	C_e	C_a	$\frac{vol_e C_e + vol_a C_a}{vol_e + vol_a}$ (harmonic mean)

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

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

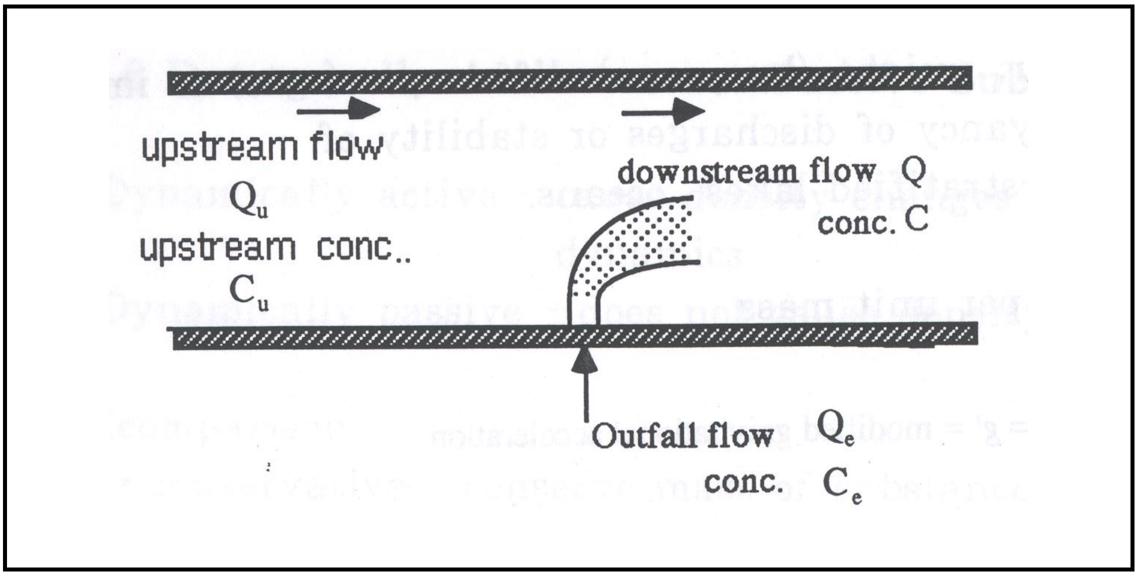
$$= C_a + P(C_e - C_a)$$

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

→ 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

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

$$S = \frac{C_e - C_a}{C - C_a}$$



Mass balance at effluent outfall

● 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]

• dilution of a composite sample

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

1.4.4 Density

• 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

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

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

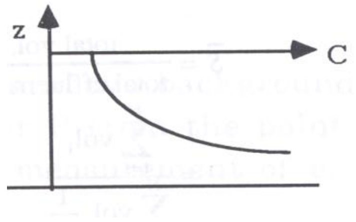
$$\rho = 1 + \frac{\sigma_t}{1000}\,(g/cm^3) = 1000 + \sigma_t (kg/m^3)$$

$$\sigma_t = \sigma - units$$

$$= f_n(temperature,\ salinity) \rightarrow See\ App.1$$

1.4.5 Density Stratification

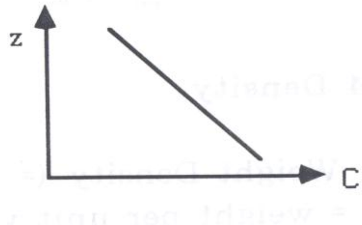
· density profile $\rho_a(z)$



z = vertical coordinates

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

· linear density stratification



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

1.4.6 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

• 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

1.4.7 Velocity Distribution in 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)

- $u = u(y, z)$

• Vertical velocity distribution

- approximated by a logarithmic function

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

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

where z = distance from the wall

R = pipe radius

d = channel depth

= Von Karman constant ≈ 0.4

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

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

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

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

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

define

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

• mean shear stress ← balance of force

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

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

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

[Re1]

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

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

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

[Re2]

Shear velocity $= u^* = \sqrt{\dfrac{\tau_o}{\rho}} = \sqrt{gRS}$ 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 τ_o

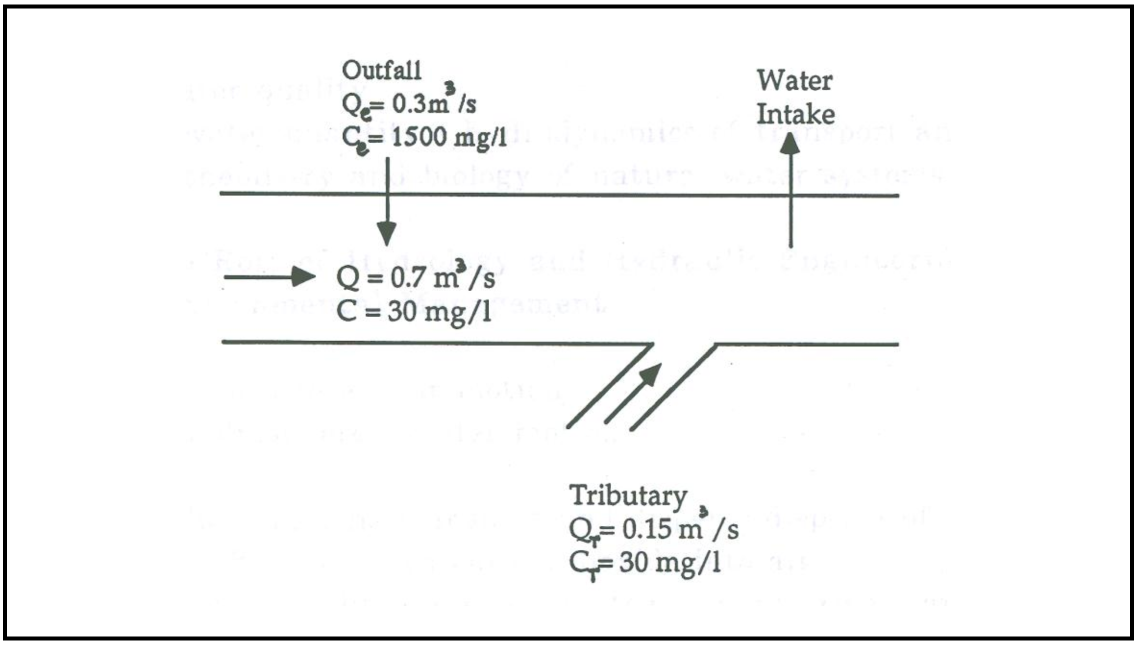
[Re3]

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

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 0.3m^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.