1. Introduction - Tutorials

1.1 Considering a pipe (0.5 m ∅) discharging 0.1 L/s of sewage (1,230 g/L, 0.001 Pa.s), calculate the Reynolds number.

1.2 Considering a rectangular drain (0.04 m wide) discharging 0.8 L/s of water as an open channel flow (3 cm depth), calculate the Reynolds number and predict the flow regime.

1.3 Considering a plane Couette flow between a fixed wall and a conveying belt. The distance between the wall and belt is 0.05 m. The conveying belt travel at a constant speed of 0.092 m/s and the fluid is air at standard conditions. Calculate the Reynolds number, the boundary shear stress at the wall and on the centreline. If the belt is 20 m long and 0.5 m wide, calculate the shear force.

1.4 Rhodamine WT dye (50 ppm) is released in a 10 m^3 water container. Calculate the mass of dye released.

1.5 Cooling water (35 Celsius) is discharged from a power plant in a natural system (average temperature: 290 Kelvin). The outfall is discharged at the bottom of the 2.2 m deep river where the characteristic velocity is about 0.3 m/s while the free-surface velocity equals 1.05 m/s. Calculate the buoyancy per unit mass and the Richardson number.

2. Turbulent shear flows - Tutorials

2.1 A circular jet (0.5 m diameter) discharges 0.6 m^3/s of water in the middle of a lake. Assuming that the flow is driven by the initial jet momentum, calculate the flow velocity: (a) 15 m downstream on the jet centreline, and (b) 20 m downstream and 8-m away from the centreline (i.e. x = 20 m, r = 8 m).

2.2 During a storm, the wind blows over a sandy beach (0.5-mm sand particle). The wind boundary layer is about 100-m high at the beach and the free-stream velocity at the outer edge of the wind boundary layer is 35-m./s. Calculate the shear velocity, the displacement and momentum thickness.

2.3 For the above problem (wind storm), calculate the virtual origin of the turbulent boundary layer.

2.4 The free-surface velocity in a river is 0.65 m/s and the water depth is 0.95 m. Assuming a Darcy friction factor f = 0.03, calculate the water discharge per unit width.

2.5 Considering a stream flow in a wide rectangular channel, the discharge per unit width is 0.41 m^2/s and the water depth is 1.9 m. Plot the velocity profile and momentum exchange coefficient profile. Calculate the velocity and momentum exchange coefficient at 0.6 m above the bed.
Calculate the shear velocity as CHANSON (1999, pp. 74). Assume f = 0.041.

3. Diffusion : basic theory - Tutorials

3.1 A 3.1 kg mass of dye is injected in the centre of large pipe. In absence of flow and assuming molecular diffusion only, calculate the time at which the mass concentration equals 0.1 g/L at the injection point. *Assume* $D_m = 0.89$ *E-2* m^2/s.

3.2 Considering a one dimensional semi-infinite reservoir bounded at one end by a solid boundary (e.g. a narrow dam reservoir), a 5 kg mass slug of contaminant (D_m = 1.1E-2 m^2/s) is injected 12 m from the straight boundary (e.g. concrete dam wall). Calculate the tracer concentration at the boundary 5 minutes after injection. Estimate the maximum tracer concentration at the boundary and the time (after injection) at which it occurs.

3.3 A 10 km long pipeline is full of fresh water. At one end of the pipeline, a contaminant is injected in such a fashion that the contaminant concentration is kept constant and equals to 0.14 g/L. Assuming D_m = 1.4 E-3 m^2/s and an infinitely long pipe, calculate the time at which the pollutant concentration exceeds 0.007 and 0.01 g/L at 4.2 km from the injection point.

4. Advective diffusion - Tutorials

4.1 An initial mass slug (mass M = 1) is introduced suddenly at the origin at t = 0. Assuming D_m = 0.2 and V = 1, (1) calculate the maximum mass concentration at t = 0.3; (2) calculate the mass concentration for x= 0.07 and t = 0.3.

4.2 A pipeline is initially filled with clear-water. At t = 0, contaminated waters (C_o = 55 ppm, D_m = 2E-9 m^2/s) is flushed into the pipeline at one end and the average flow velocity is 0.95 m/s. Estimate the width of the interface (defined between 5% and 95% of the initial concentration) 50 km downstream.

4.3 A one-dimensional stream (V = 0.35 m/s) is suddenly contaminated with a steady concentration (C_o = 185 ppm, D_m = 1.8E-1 m^2/s) introduced at t = 0. Estimate the time at which the tracer concentration will be 20 ppm at 12 m from the injection.

Note : In the above exercises, large values of diffusion coefficients were used for simplicity of calculations and more meaningful results. Such values are not representative of solutes in water.

5. Turbulent dispersion and mixing. (1) Vertical and transverse mixing - Tutorials

5.1 Considering a wide rectangular channel, the water depth is 3.2 m and the flow rate is 2.8 m^2/s. Assuming a gravel bed (k_s = 12 mm), calculate the boundary shear stress and the shear velocity.

5.2 Water flows at uniform equilibrium in a 4.5 m wide, concrete-lined rectangular channel. The observed water depth is 0.85 m and the bed slope is 0.0011. Calculate the flow rate, the shear velocity and the vertical mixing coefficient.

5.3 A natural stream discharges 4.9 m^3/s at equilibrium down a sandy bed slope (k_s = 2 mm, slope: 0.0004). The channel width is 27 m. (a) Calculate the water depth and the shear velocity. (b) Estimate the vertical and transverse mixing coefficient.

5.4 A sewage plant releases 250 m^3 per day of effluents containing 195 ppm of a chemical near the right bank of a wide, slowly meandering stream. The creek is 2.4 m deep and the bed slope is 0.00011. Calculate the flow rate and the shear velocity. Assuming that the effluent is completely mixed over the vertical, determine the width of the plume, the maximum concentration 1,200 m downstream of the discharge point and its location

Assume uniform equilibrium flow conditions in the river (k_s = 5 mm).

5.5 A barrel of arsenic (2.1 Tonnes) falls accidentally from a trailer crossing a 1 km long wide river. The river flows at 0.12 m/s and the water depth is 4.6 m. (it is assumed that the container falls on the river centreline.) Calculate the contaminant concentration 500 m downstream of the injection point : (a) on the centreline, 1 hour after the accident, (b) on the centreline, 1 hour 20 min. after the accident, and (c) 100 m from the centreline, 1 hour 20 minutes after the accident.

Assume V_* = 0.0062 m/s. 1 Tonne = 1 metric ton = 1,000 kg.

5.6 Generate a random walk model using a spreadsheet (App. 5B). Assuming V = 1.2, D_X = 0.8 and δt = 1, study the dispersion of 100 particles in a one-dimensional flow. At a time T = 90, calculate the probability distribution function of the tracer concentration. (Perform the random walk computation using δt = 1. Plot the PDF using bins of Δx = 0.2.)

6. Turbulent dispersion and mixing. (2) Longitudinal dispersion - Tutorials

6.1 A natural stream has the following channel characteristics :

flow rate : 18.5 m^3/s, water depth : 0.786 m, width: 15 m, bed slope: 0.001, gravel: k_s = 5 mm

Assume uniform equilibrium flow conditions in a rectangular channel. Neglect vertical mixing and assume a slowly meandering stream.

A barrel of dye (2.2 kg) is suddenly released in the natural stream from the channel bank (i.e. side). A measurement station is located 18 km downstream of the injection point.

(a) Calculate the maximum mass concentration in the cross-section located at 500 m downstream of the injection point. (b) Calculate the maximum tracer concentration at that station and the arrival time. (c) The detection limit of the chemical is 0.3 mg/m^3. Calculate the length of time during which the chemical will be detectable at the measurement station.

6.2 The flood plain of Oxley Creek, in Brisbane, has the following channel characteristics during a flood event: water depth : 1.16 m, width: 55 m, bed slope: 0.0002, short grass: k_s = 0.003 m

Assume uniform equilibrium flow conditions in a rectangular channel. Neglect vertical mixing. Assume a slowly meandering stream.

During a test, a barrel of dye (7.5 kg) is released in the natural stream on the channel centreline (from a bridge). A measurement station is located 15 km downstream of the injection point. (a) Calculate the basic hydraulic, mixing and dispersion parameters. (b) Calculate the maximum tracer concentration at that station and the arrival time. (c) The detection limit of the chemical is 0.2 mg/m^3. Calculate the length of time during which the chemical will be detectable at the measurement station.

8. Mixing in estuaries - Tutorials

8.1 The estuary of the Flora river is 240 m long and 17 m wide. At high tide, the average water depth is 3.5 m. Calculate the wind setup for a 25 m/s wind blowing along the main axis of the estuary. Estimate the cross-sectional mixing time and compare the result with the tidal period. Estimate the bottom current assuming a bottom roughness k_s = 5 mm.

The tidal regime is semi-diurnal. The transverse mixing coefficient is assumed to be 0.007 m^2/s.

8.2 A lagoon on the north coast of Papua New Guinea extends along 15 km of the shoreline and is about 250 m wide in average. The mean water depth is 0.9 m. Calculate the wind setup for a 22 m/s wind blowing parallel to the shoreline and perpendicular to the coast. Estimate the resonance frequencies of the lagoon.

The resonance frequency of a water body is the "sloshing" frequency of the seiche.

8.3 The estuary of the Loup river, Nice (France) is affected by a salt wedge system. The river width is about 25 m. For a 4.8 m^3/s flow rate, the water depth is about 1.5 m. Calculate the length of the salt wedge, the height of the wedge at the river mouth, and the saline wedge height at 90 m upstream of the river mouth.

Use KEULEGAN's theory. Assume Var river density of 1012 kg/m^3 (because of suspended sediments).

8.4 A river flow into a tideless sea. The river flow velocity is 0.15 m/s and the mean water depth is 1.35 m. A salt barrier is to be built 50 m upstream of the river mouth to prevent salt intrusion into the river system and on the water table. Calculate the minimum salt barrier height.

8.5 A reasonably well-mixed estuary is about 1200 m long. The depth-averaged density varies between 1005 and 1022 kg/m^3 over that distance, and the average water depth 2.4 m. Calculate the required longitudinal free-surface gradient. Plot the velocity profile in the estuary (assuming ν_T = 0.001 m^2/s). Estimate the free-surface velocity and the maximum negative velocity.

8.6 The Knysna Bay Estuary in the Southern Cape (South-Africa) is 230 m wide with an average channel depth of approximately 10 m. The longitudinal gradient in average density $\partial\rho/\partial x$ is about 0.0027. Near the river mouth, the average density is 1016 kg/m^3 and the free-surface velocity is 0.226 m/s. Plot the velocity profile. Calculate the mass flux in the upstream direction and the upper-surface mass flux in the downstream direction.

8.7 Cabbage Tree Creek, Queensland (Australia)

Cabbage Tree Creek is a small water system in the northern suburbs of Brisbane (Australia). The creek is affected by local traffic (trawlers and boats) in its estuarine zone. Field measurements were conducted in Cabbage Tree Creek on 12 Feb. 2003 in the estuarine zone (Fig. 8-13). The data are summarised below.

AMD	Depth	Temp.	DO	Turbidity	Conductivity	pH	Remarks
km	m below f/s	Celsius	(%)	NTU	mSiemens /cm		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2	0.2	26.8	0.884	12	37.6	7.9	From a drifting boat
2	0.5	26.8	0.879	12	38.5	7.9	
2	1	26.7	0.819	14	40	7.9	
2	1.25	26.8	0.803	14	41.3	7.95	
2	1.5	26.8	0.752	20	47.9	8.1	
2	1.75	26.85	0.761	17	46.3	8.1	
2	2	26.9	0.795	14	48.9	8.1	
2	2.5	26.9	0.806	15	50.2	8.2	
2	3	26.9	0.817	18	50.7	8.2	
2	3.5	26.8	0.817	19	51.1	8.2	
2	4	26.8	0.813	26	51.1	8.2	Just above the bottom
3.2	0.2	25.7	0.566	25	12.3	7	From a bridge
3.2	0.5	25.8	0.574	25	12.5	7.1	
3.2	1	26.5	0.556	20	33.3	7.5	
3.2	1.5	26.9	0.484	22	42.3	7.7	
3.2	2	26.8	0.464	35	43	7.7	Just above the bottom

Notes : AMD = Adopted Middle Thread Distance measured upstream from the mouth; Source : field data collectged by the writer and the Queensland Environment Protection Agency.

(a) Calculate the slope of the mean water surface to counterbalance the mean density gradient between AMD = 2000 and 3200 m. (b) Predict the velocity profile at AMD 2.8 km.

Neglect the bed slope. Assume an average water depth of 4.2 m and 2.2 m at AMD 2.0 and 3.2 km respectively, and ν_T *= 0.003 m*^{2}*/s.*

Fig. 8-13 - Cabbage Tree Creek, Brisbane, Queensland on 12 Feb. 2003 near AMD 2.0 km, looking upstream

Fig. 8-14 - Vertical distribution of conductivity and dissolved oxygen content