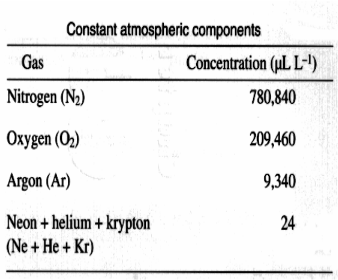
ESM 222

Structure of Environmental Media

Structure of Environmental Media

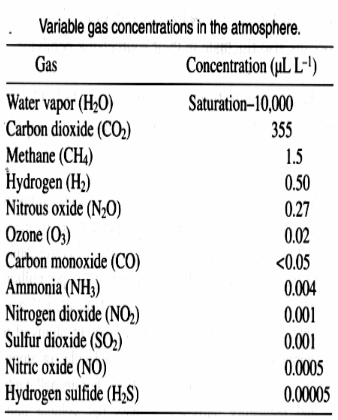
- Atmosphere
  - Structure
  - Aerosols
- Soils
  - Structure
  - Composition
  - Microbial activity
- Water Bodies
  - Rivers and Streams
  - Lakes
  - Oceans
  - Particulate Matter
  - Sediments

Atmospheric Composition



Constant atmospheric components

Gas	Concentration (μL L^{-1})
Nitrogen (N_2)	780,840
Oxygen (O_2)	209,460
Argon (Ar)	9,340
Neon + helium + krypton (Ne + He + Kr)	24



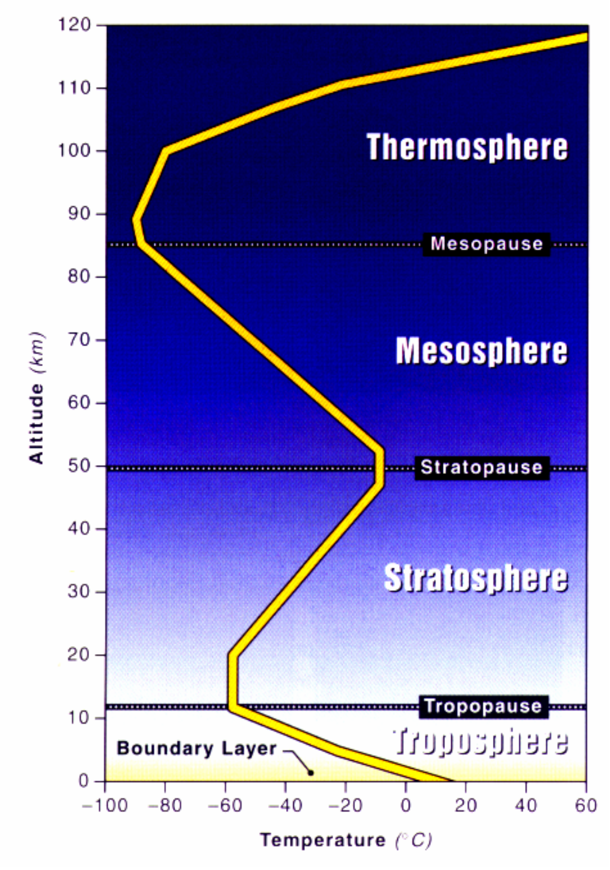
Variable gas concentrations in the atmosphere.

Gas	Concentration (μL L^{-1})
Water vapor (H_2O)	Saturation–10,000
Carbon dioxide (CO_2)	355
Methane (CH_4)	1.5
Hydrogen (H_2)	0.50
Nitrous oxide (N_2O)	0.27
Ozone (O_3)	0.02
Carbon monoxide (CO)	<0.05
Ammonia (NH_3)	0.004
Nitrogen dioxide (NO_2)	0.001
Sulfur dioxide (SO_2)	0.001
Nitric oxide (NO)	0.0005
Hydrogen sulfide (H_2S)	0.00005

Source: Pollution Science, Pepper et al 1996.

Atmosphere

- Pollutants of concern in the atmosphere are:
  - Urban air pollutants:
    - O_3 via NO_x and VOCs, CO, NO_x, SO_2, particulates, HAPs, …
  - Acid rain gases:
    - NO_x, SO_2, …
  - Greenhouse gases:
    - CO_2, CH_4, N_2O, CFCs, …
  - Ozone destroyers in stratosphere:
    - CFCs, …



Source: Pollution Science, Pepper et al, 1996.

Atmosphere

- For urban air pollution, troposphere is where all action occurs
- Surface layer
  - at bottom of boundary layer
  - ~1/10th of boundary layer, typically tens of meters
  - surface roughness and surface heat exchange affect properties (temperature, wind speed, humidity)

Atmosphere

- ❑ Atmospheric boundary layer
  - ❑ turbulence in this region may cause significant short-term mixing
  - ❑ interface between troposphere and ground
  - ❑ only a few hundreds of meters thick
  - ❑ large-scale airflow patterns affected by surface features, with large vertical gradients of temperature, wind speed and humidity

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Atmosphere

- ❑ Atmospheric boundary layer
  - ❑ Height of boundary layer varies throughout day, with maximum thickness by mid-afternoon
  - ❑ Boundary layer shrinks to about 100 to 200 m at night
  - ❑ Thermal “inversion” may cause trapping of pollutants in boundary layer, reducing the mixing depth

Wind Direction

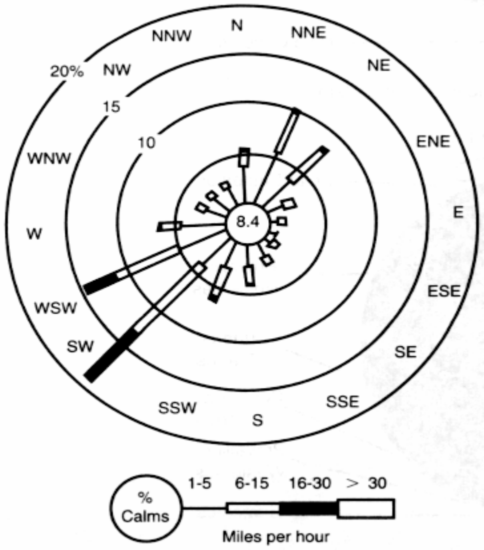

FIG. 5.6.3 Wind rose showing direction and velocity frequencies.

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

Wind Direction

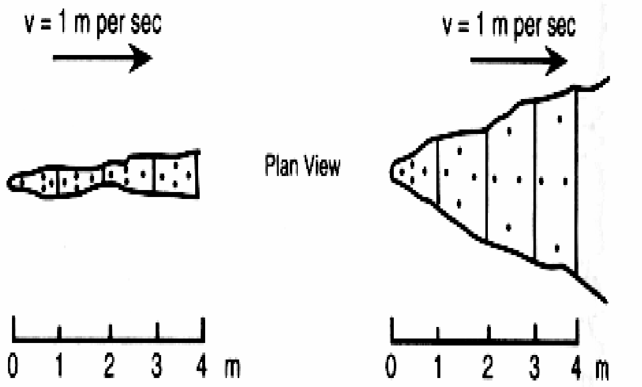

FIG. 5.6.5 Effect of wind direction variability or pollutant concentration from constant source. (Continuous emission of 4 units per sec.)

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

Turbulence

- Dispersion of pollutants due to:
  - wind speed
  - atmospheric turbulence
- Turbulence considers variations of more than 2 cycles/hr
- Most important are variations in the order of 1 to 0.01 cycles/sec

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Turbulence

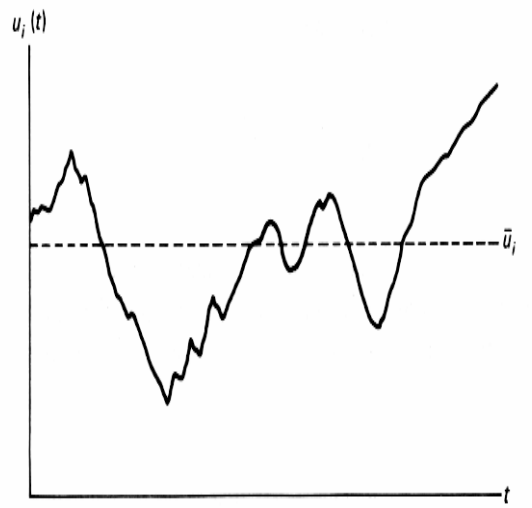

Figure 12.1. Typical record of the velocity in direction *i* at a point in a turbulent flow.

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

Inversions

- When temperature increases with altitude, lapse rate is negative or “inverted” from normal state
- Occurs when warm air “blankets” colder air: atmosphere is extremely stable
- Inversions limit vertical mixing, trapping pollutants in the lower region

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Inversions

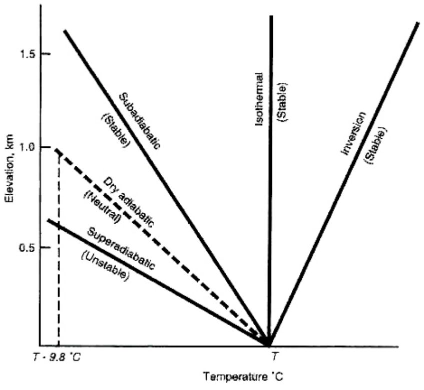


FIG. 5.6.7 Relationship of the ambient lapse rates to the dry adiabatic rate.

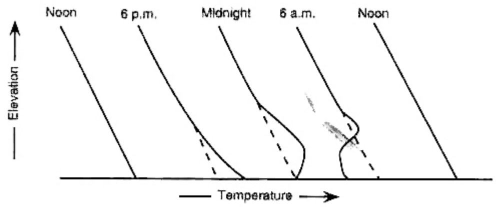


FIG. 5.6.8 Typical ambient lapse rates during a sunny day and clear night.

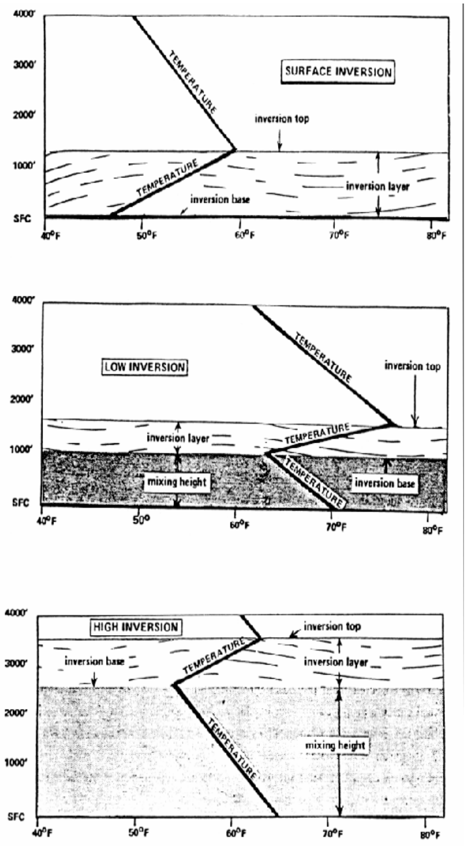


Figure 5.9. Typical inversions.

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

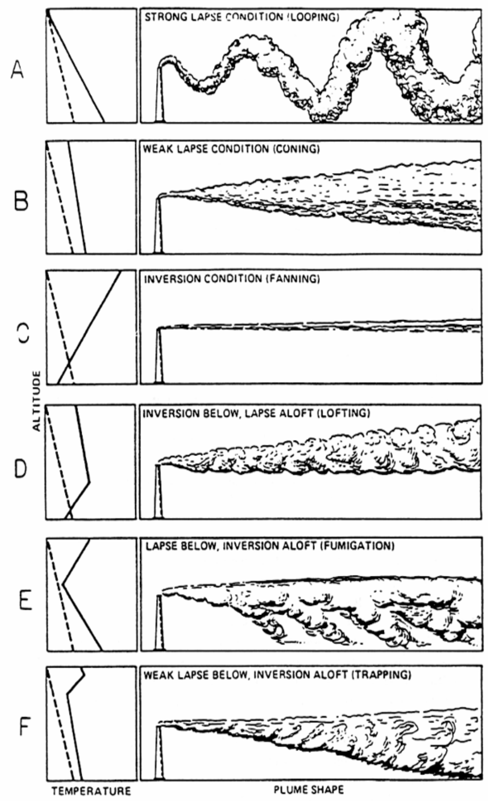


Figure 5.21. Plume structure as a function of temperature/stability.

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

Topography

- Features that affect small-scale circulation
  - natural: hills, tree foliage, lakes, rivers
  - anthropogenic: bridges, canals, roads, buildings, towers, airports
- Must be considered when modeling air pollutant dispersion

Wind Speed

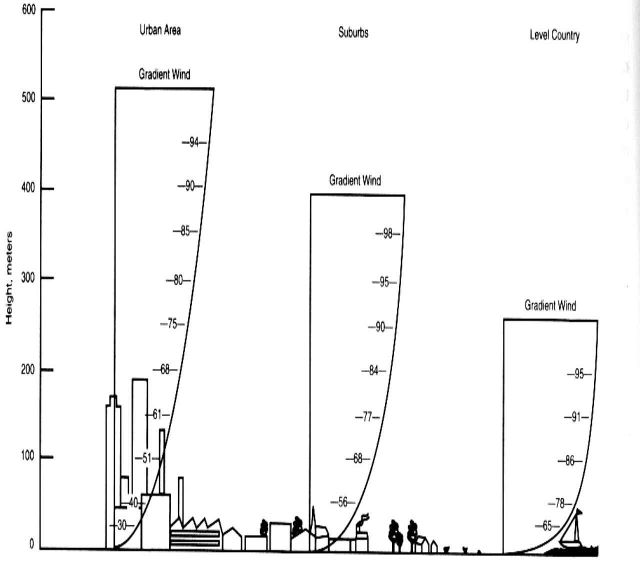


FIG. 5.8.9 Variation of wind with height for different roughness elements (figures are percentages of gradient wind). (Reprinted from D.B. Turner, 1970, *Workbook of atmospheric dispersion estimates (Revised)*, Office of Air Programs Pub. No. AP-26, Research Triangle Park, N.C.: U.S. EPA and based on A.G. Davenport, 1963, the relationship of wind structure to wind loading. Presented at Int. Conf. on the Wind Effects on Buildings and Structures, Nat. Physical Laboratory, Teddington, Middlesex, England, 26-28 June.)

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

Combined Effects

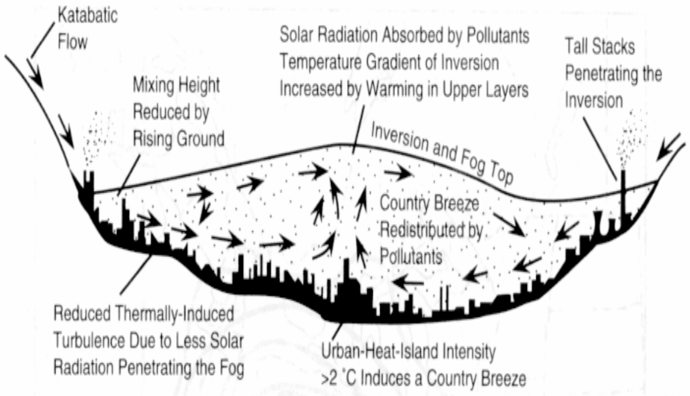


FIG. 5.6.11 Meteorology–pollution relationships during a smog in a valley location. (Reprinted, with permission, from D.M. Elsom, 1992, *Atmospheric pollution,* 2d ed., Oxford, U.K.: Blackwell Publishers.)

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

Downwash

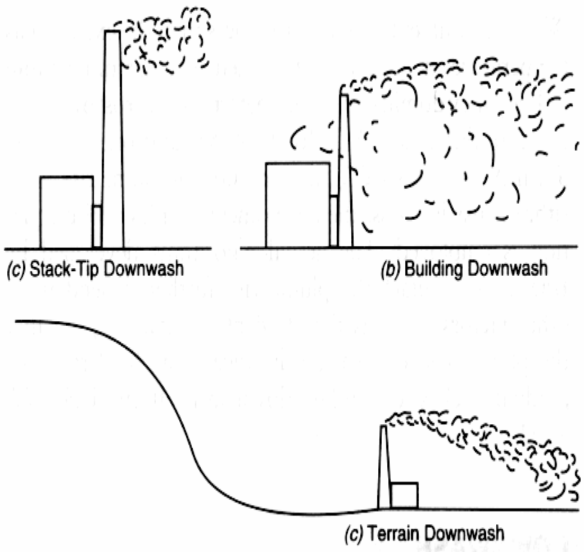


FIG. 5.8.10 Physical conditions that cause downwash. Reprinted from G.A. Briggs, 1969. *Plume rise,* U.S. Atomic Energy Commission Critical Review Series TID-25075, Clearinghouse for Federal Scientific and Technical Information.

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

Line Sources

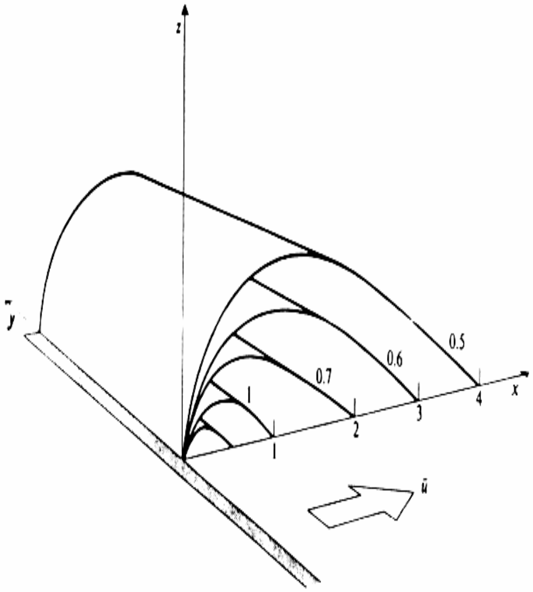
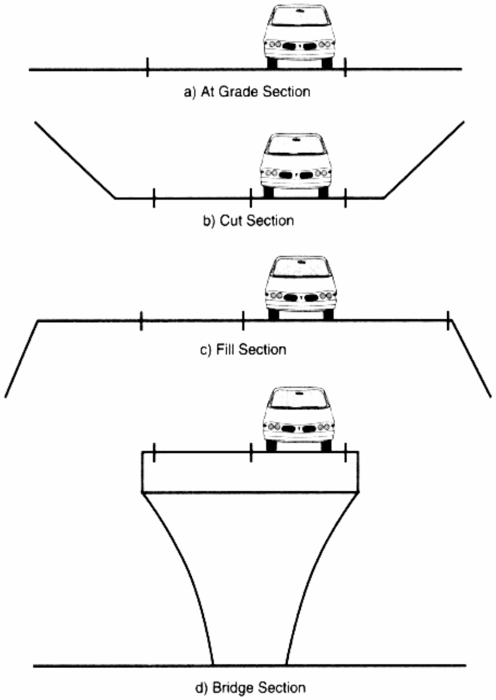


Figure 5.22. Line source relative cross wind concentration.

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996


a) At Grade Section

b) Cut Section

c) Fill Section

d) Bridge Section

FIG. 5.8.17 Four roadway cross sections treated by the CALINE3 model.

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

Dispersion Models

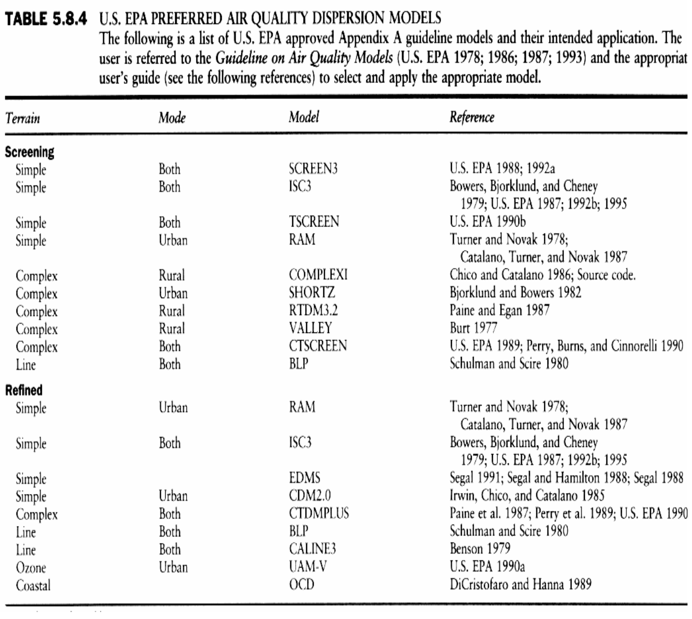


TABLE 5.8.4 U.S. EPA PREFERRED AIR QUALITY DISPERSION MODELS
The following is a list of U.S. EPA approved Appendix A guideline models and their intended application. The user is referred to the *Guideline on Air Quality Models* (U.S. EPA 1978; 1986; 1987; 1993) and the appropriat user's guide (see the following references) to select and apply the appropriate model.

Terrain	*Mode*	*Model*	*Reference*
Screening			
Simple	Both	SCREEN3	U.S. EPA 1988; 1992a
Simple	Both	ISC3	Bowers, Bjorklund, and Cheney 1979; U.S. EPA 1987; 1992b; 1995
Simple	Both	TSCREEN	U.S. EPA 1990b
Simple	Urban	RAM	Turner and Novak 1978; Catalano, Turner, and Novak 1987
Complex	Rural	COMPLEXI	Chico and Catalano 1986; Source code.
Complex	Urban	SHORTZ	Bjorklund and Bowers 1982
Complex	Rural	RTDM3.2	Paine and Egan 1987
Complex	Rural	VALLEY	Burt 1977
Complex	Both	CTSCREEN	U.S. EPA 1989; Perry, Burns, and Cinnorelli 1990
Line	Both	BLP	Schulman and Scire 1980
Refined			
Simple	Urban	RAM	Turner and Novak 1978; Catalano, Turner, and Novak 1987
Simple	Both	ISC3	Bowers, Bjorklund, and Cheney 1979; U.S. EPA 1987; 1992b; 1995
Simple		EDMS	Segal 1991; Segal and Hamilton 1988; Segal 1988
Simple	Urban	CDM2.0	Irwin, Chico, and Catalano 1985
Complex	Both	CTDMPLUS	Paine et al. 1987; Perry et al. 1989; U.S. EPA 1990
Line	Both	BLP	Schulman and Scire 1980
Line	Both	CALINE3	Benson 1979
Ozone	Urban	UAM-V	U.S. EPA 1990a
Coastal		OCD	DiCristofaro and Hanna 1989

Source: Environmental Engineering Handbook, 2nd ed., Liu & Liptak, 1996

Atmospheric Structure

- ❑ Aerosols & Particulate Matter
  - ❑ dust particles from soil
  - ❑ dust from combustion
  - ❑ water (fog to rain drops)
  - ❑ aggregated particles from conversion of gas species to aqueous species (e.g. SO_2 to HSO^-_4)
  - ❑ Concern with particles from ~1 to 10 microns

Aerosols

- Concentrations
  - Rural area typically 5 $\mu g/m^3$
  - Urban area may have more than 100 $\mu g/m^3$
- Density of particles: 1000 - 2600 kg/m^3
- Aerosols may be hydrophilic, hydrophobic (if mostly organic) or mixed
- Contribute significantly to dry or wet deposition of pollutants to ground surface, as well as reaction sites

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Aerosols

- Dry deposition velocity
  - typically 0.3 cm/s = 10.8 m/h
  - depends on wind conditions as well as nature of surface (i.e. may resuspend)
- Wet deposition velocity
  - rainfall rates from 0.1 to 1.5 m/yr
  - typical rate = 0.8 m/yr
  - each raindrop sweeps a volume of air ~ 200,000 its volume prior to landing

Sample Calculations

- Weight and volume of aerosols in atmosphere over an area of 1 km^2:
  - concentration = 50 $\mu\text{g/m}^3$ = 50 x 10^{-9} kg/m^3
  - volume of air = 6 km x 1 km^2 = 6 x 10^9 m^3
  - density of aerosols = 1500 kg/m^3

Weight = concentration x volume of air
= 300 kg

Volume = weight/density = 0.2 m^3
= 200 L

Sample Calculations

- Dry deposition rate:

$$\frac{\text{velocity}}{\text{length}} \text{ x volume aerosols} = 0.36 \text{ x } 10^{-3} \text{ m}^3\text{/h}$$

= 3.2 m^3/yr

- Wet deposition rate:

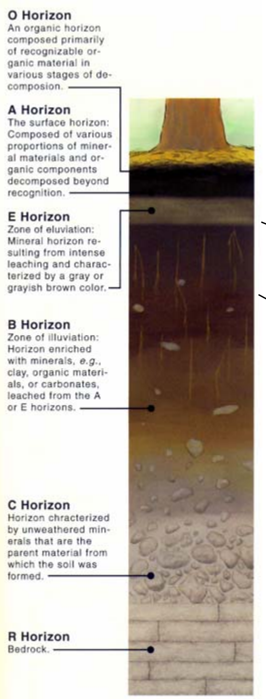
$$\frac{\text{velocity}}{\text{length}} \text{ x vol. aerosols x vol. swept by raindrop}$$

= 5.3 m^3/yr

Soil Structure

- ❑ Phases in the Soil
  - ❑ Solid phase (minerals, SOM)
  - ❑ Gas phase
    - ❑ same gases as in atmosphere, but may have very different concentrations
    - ❑ oxygen is lower and carbon dioxide may be > 1%
    - ❑ depending on microbial activity may have methane, hydrogen sulfide, ethylene, N_2O
  - ❑ Water phase

Lithosphere



Ground surface

Soil organic matter + mineral particles

Leached minerals

Mineral-enriched soil + organic materials

Gravel + Sand + Silt

Bedrock

Soil Structure

- ☐ Soil porosity
  - ☐ Defined as the volume of voids (= pore space) divided by the total volume of soil
  - ☐ Typically ranges from 20 to 50%
  - ☐ Depends on particle size distribution
  - ☐ Mixed large and small particles pack in better, leaving less pore space => lower porosity

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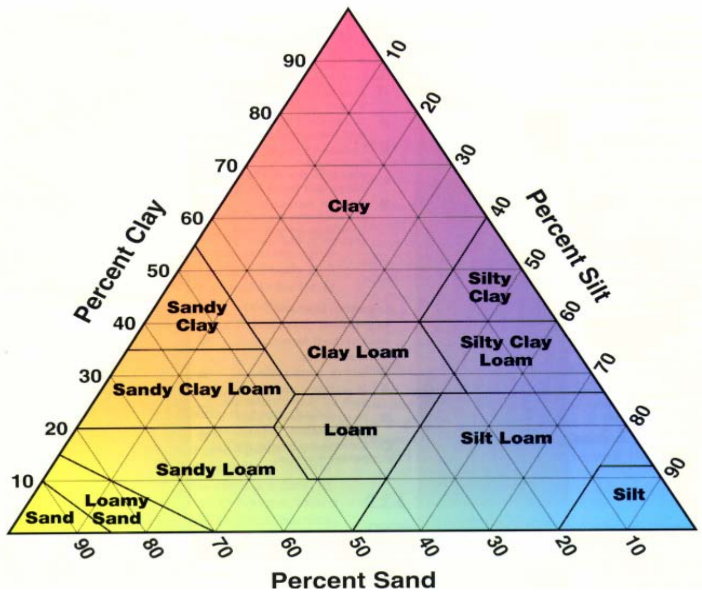
USDA classification



Source: Pollution Science, Pepper et al. 1996

Soil structure

USDA definition

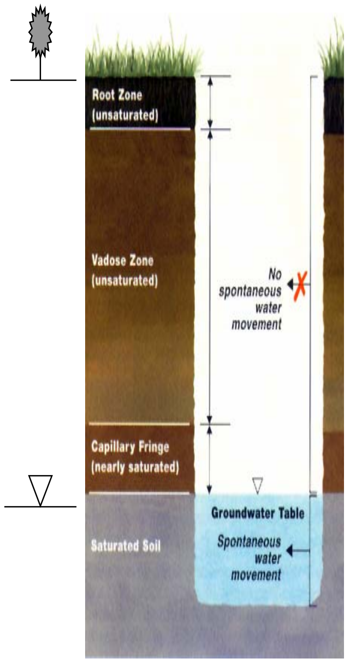
Particle	Size range (diameter)
Gravel	> 2 mm
Sand	0.05 to 2 mm
Silt	0.002 to 0.05 mm
Clay	< 0.002 mm (= 2 μm)

Soil Structure

- ☐ Typical soil minerals are silicates or carbonates
- ☐ Organic content in soil may be up to 5%, but typically around 2% for top soil and down to ~ 0.1% for sandy soils.
- ☐ Water content varies from very low saturation (5- 10%) to fully saturated with water, below the water table

Soil Structure

Water table (i.e. depth to first aquifer) fluctuates with recharge (rainfall or irrigation), pumping, and evapotranspiration



Source: Pollution Science, Pepper et al. 1996

Soil structure

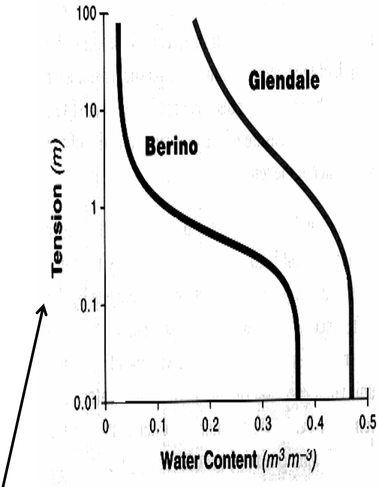
- ❑ Capillary force
  - ❑ Water is sucked up by dry soil above the water table (balanced by gravity pulling it down)
  - ❑ Clayey soils have a stronger capillary suction due to smaller pore sizes
  - ❑ Mixed soils (sand + clays) may have the highest capillary suction since the pores between sand grains are filled with clay particles => very small pore spaces

Soil Structure

Water retention curves are used to characterize the composition and behavior of soils.

Also useful to understand how pollutants may be sucked up by the soil matrix in the absence of water

Source: Pollution Science, Pepper et al. 1996



Can also be expressed in terms of saturation (%)

Tension = capillary force needed (units in meters of water)

Glendale: more clayey, requiring more tension to extract water from soil matrix

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Soil Structure

- Wettability
  - Clean sand and most mineral particles are water-wetting
  - Organic deposits on the particles are “oil-wetting”
  - Wetting properties may determine the path which an organic pollutant takes through the soil

Soil Structure

- ❑Soil Organic Matter (SOM)
  - ❑soil biomass (live bugs)
  - ❑organic residues (decaying plant and microbial biomass)
  - ❑humic substances (high molecular weight organic macromolecules, very slow decay ~ 2%/yr)
  - ❑amino acids, organic acids, carbohydrates, fats

Soil Structure

- ❑ Soil Organic Matter
  - ❑ In humid areas, SOM up to 5% on a dry-weight basis
  - ❑ In arid areas, with low inputs of plant residues, SOM typically < 1%
  - ❑ Significant natural recycling of nutrients via formation of SOM and its decomposition

Soil Structure - Biotic Activity

- Factors Affecting Growth of Microbes
  - Biotic stress - competition (e.g. pathogens)
  - Soil moisture
  - Temperature and its fluctuations
    - important in bioremediation at higher latitudes
  - Soil pH
  - Soil carbon, nitrogen and nutrients
  - Soil redox potential (i.e. aerobic or anaerobic conditions)

Structure of Water Bodies

- Rivers and streams
  - Hydraulic properties: flow, velocity, dispersion
  - Geometric properties: depth, width, slope
  - Properties change frequently over the course of river
  - Temporal distribution of water flow: annual hydrograph
  - Perennial vs. ephemeral flow; baseflow

Structure of Water Bodies

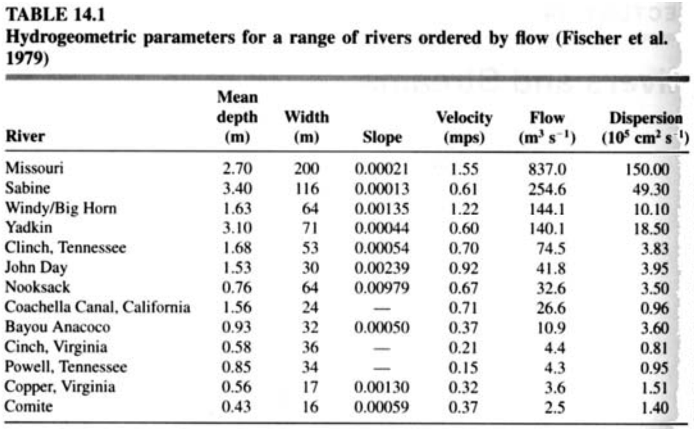
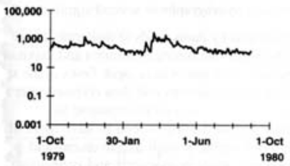


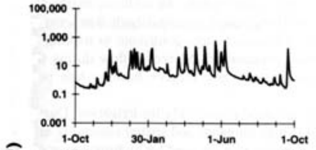
TABLE 14.1
Hydrogeometric parameters for a range of rivers ordered by flow (Fischer et al. 1979)

River	Mean depth (m)	Width (m)	Slope	Velocity (mps)	Flow ($m^3 s^{-1}$)	Dispersion ($10^5 cm^2 s^{-1}$)
Missouri	2.70	200	0.00021	1.55	837.0	150.00
Sabine	3.40	116	0.00013	0.61	254.6	49.30
Windy/Big Horn	1.63	64	0.00135	1.22	144.1	10.10
Yadkin	3.10	71	0.00044	0.60	140.1	18.50
Clinch, Tennessee	1.68	53	0.00054	0.70	74.5	3.83
John Day	1.53	30	0.00239	0.92	41.8	3.95
Nooksack	0.76	64	0.00979	0.67	32.6	3.50
Coachella Canal, California	1.56	24	—	0.71	26.6	0.96
Bayou Anacoco	0.93	32	0.00050	0.37	10.9	3.60
Cinch, Virginia	0.58	36	—	0.21	4.4	0.81
Powell, Tennessee	0.85	34	—	0.15	4.3	0.95
Copper, Virginia	0.56	17	0.00130	0.32	3.6	1.51
Comite	0.43	16	0.00059	0.37	2.5	1.40

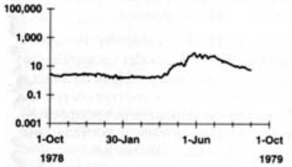
Source: Surface Water Quality Modeling, Chapra, 1997



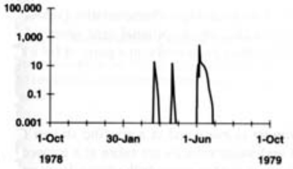
(*a*) Hudson River at Green Island, New York
(watershed area = 20,950 km²)



(*b*) Mill Creek near Belville, Texas
(watershed area = 974 km²)



(*c*) East River at Altmont, Colorado
(watershed area = 748 km²)



(*d*) Frio River near Uvalde, Texas
(watershed area = 1712 km²)

FIGURE 14.1
Annual streamflow hydrographs for (*a*) perennial temperate river, (*b*) perennial humid river, (*c*) snowfed river, and (*d*) ephemeral river.

Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

- Human activities modify the hydrographs
  - Impoundments (dams)
  - Urbanization and channeling
  - Water use for irrigation or drinking
  - Use for hydropower or cooling water
- Steady-flow model is an approximation with many exceptions

Structure of Water Bodies

- Stream geometry

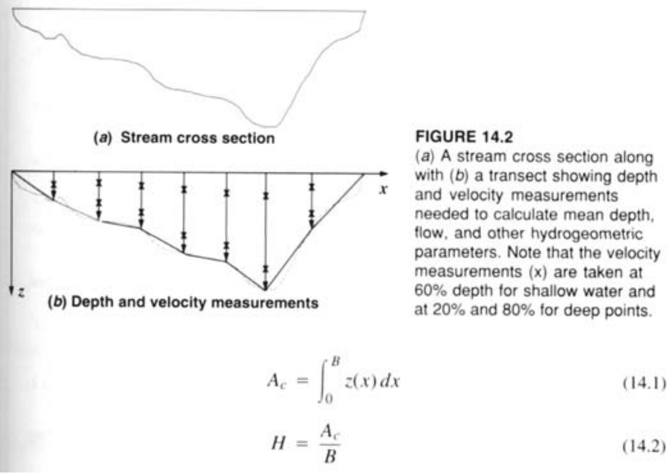


FIGURE 14.2
(*a*) A stream cross section along with (*b*) a transect showing depth and velocity measurements needed to calculate mean depth, flow, and other hydrogeometric parameters. Note that the velocity measurements (x) are taken at 60% depth for shallow water and at 20% and 80% for deep points.

$$A_c = \int_0^B z(x)\,dx \qquad (14.1)$$

$$H = \frac{A_c}{B} \qquad (14.2)$$

Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

- Water velocity profile is a function of depth:

$$U(z) = U_o \left(\frac{z_b - z}{z_b - z_o} \right)^{1/m}$$

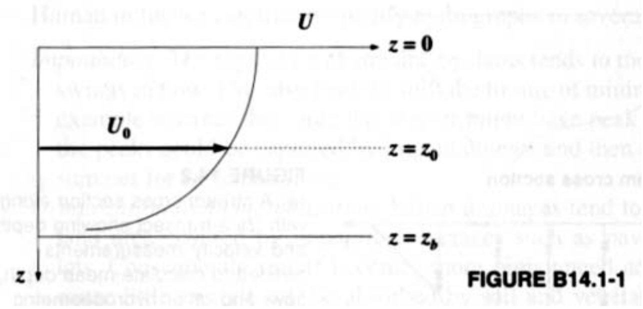


FIGURE B14.1-1

Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

- For modeling purposes, longitudinal flow is very similar to pipe flow, or a plumbing network
- Mixing in cross-section depends on flow velocity
- Typically at any cross-section significant mixing occurs, but mixing along the direction of flow is limited
- Short residence times for pollutants (days)

Structure of Water Bodies

- Reach estimates
  - Assumption that width is less variable than depth
  - Easier to measure width along river
  - Determine flow at a point along river
  - Measure travel time, t, using a tracer (dye)
  - Mean velocity is U = x/t
  - Average cross-sectional area from velocity and flow rate, A_c = Q/U
  - Mean depth, H = A_c/B

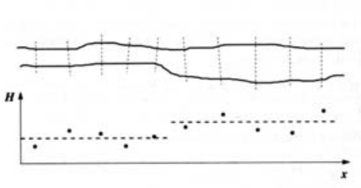
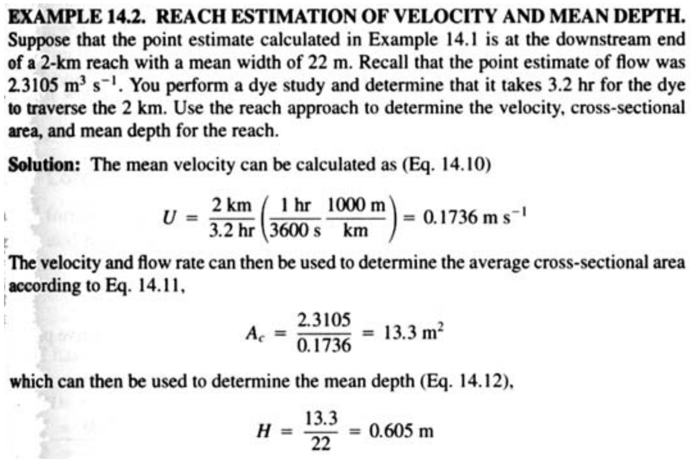


FIGURE 14.3
Data from individual transects can be plotted versus distance to develop average values of parameters for reaches.

Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies



EXAMPLE 14.2. REACH ESTIMATION OF VELOCITY AND MEAN DEPTH. Suppose that the point estimate calculated in Example 14.1 is at the downstream end of a 2-km reach with a mean width of 22 m. Recall that the point estimate of flow was 2.3105 $m^3\ s^{-1}$. You perform a dye study and determine that it takes 3.2 hr for the dye to traverse the 2 km. Use the reach approach to determine the velocity, cross-sectional area, and mean depth for the reach.

Solution: The mean velocity can be calculated as (Eq. 14.10)

$$U = \frac{2\text{ km}}{3.2\text{ hr}}\left(\frac{1\text{ hr}}{3600\text{ s}}\,\frac{1000\text{ m}}{\text{km}}\right) = 0.1736\text{ m s}^{-1}$$

The velocity and flow rate can then be used to determine the average cross-sectional area according to Eq. 14.11,

$$A_c = \frac{2.3105}{0.1736} = 13.3\text{ m}^2$$

which can then be used to determine the mean depth (Eq. 14.12),

$$H = \frac{13.3}{22} = 0.605\text{ m}$$

Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

- Low-flow conditions
  - Common design assumption
  - Obtain a long-term flow record
  - Express as a minimum 7-d average flow that would be expected to occur every 10 years
  - 7Q10 is based on probabilistic assumptions

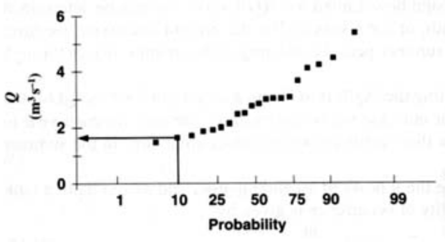


FIGURE 14.4 Frequency curve corresponding to the 7-d minimum flow for the river from Example 14.3.

10% probability that flow will be 1.75 m^3/s

Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

- Lakes
  - Very different mixing behavior than in rivers
  - Typically long residence times (years)
  - Light only penetrates 1-2 m, so photosynthetic activity limited to thin surface layer
  - Seasonal variation in temperatures has a significant effect on mixing

Structure of Water Bodies

- Major features
  - Origin: natural (lake) or artificial (impoundment)
    - impoundments typically have controlled outflow
  - Shape: Natural lakes tend to be more circular; impoundments (reservoirs) are more likely elongated or dendritic (flooded river valley)
  - Size: defined based on residence time (1 yr.) and depth (7m)

Structure of Water Bodies

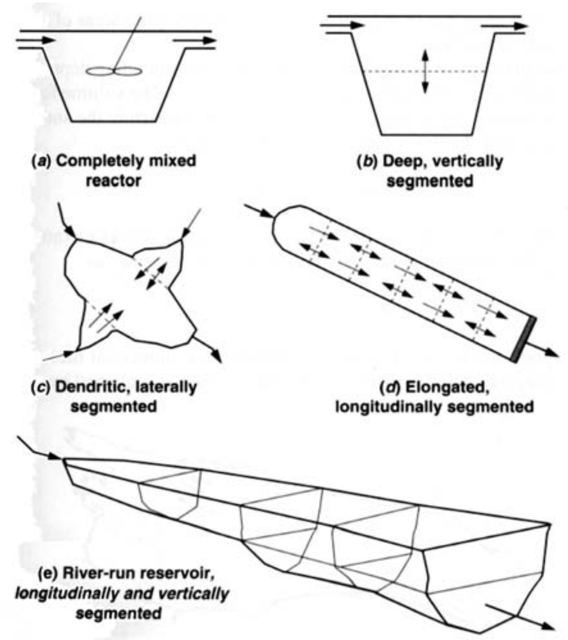


FIGURE 16.1
Typical segmentation schemes used for lakes and impoundments.

Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

- Lake morphometry (geometry)

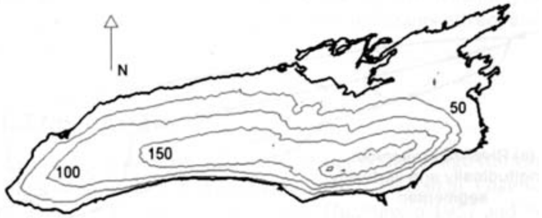


FIGURE 16.2
A bathymetric map of Lake Ontario (courtesy of Mike McCormick, GLERL/NOAA).

- Integrate cross-sectional area along depth to determine volume at a particular depth

Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

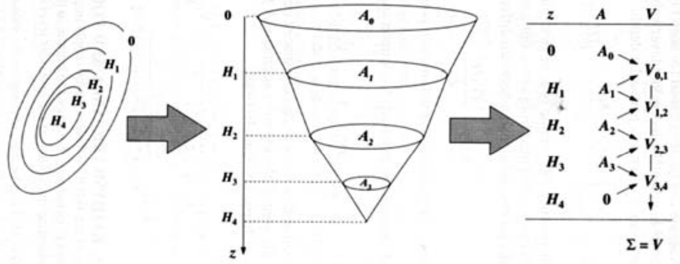


FIGURE 16.3
The process of calculating lake and reservoir morphometry consists of determining areas from a bathymetric map. These areas are then tabulated and used to determine volumes by numerical integration.

Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

- For many reservoirs, Q_{out} is a function of depth H
- No outflow may occur until depth reaches a minimum value
- Q_{in} depends on the hydrograph(s) of the tributary, with some base flow from groundwater recharge

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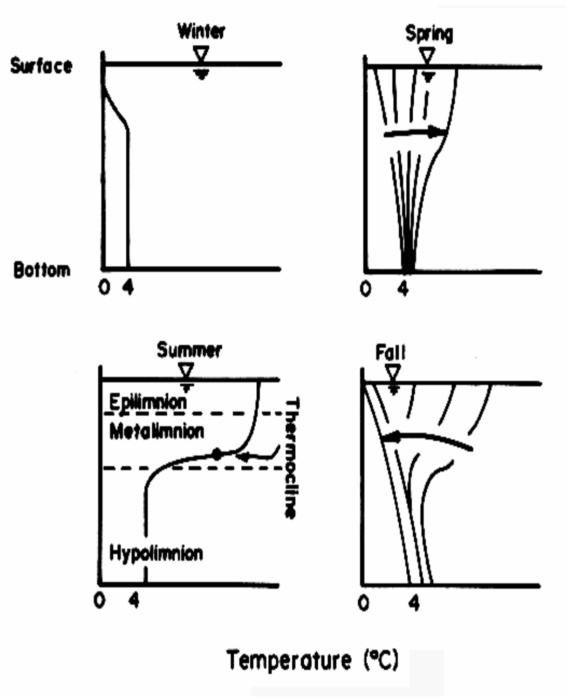
Structure of Water Bodies



Source: Environmental Pollution and Control (Vesilind et al), 1993

Structure of Water Bodies

- Stratification may last several months with little mixing among layers
- Bottom conditions may become anaerobic
- If organic matter, nitrogen and/or phosphorus loading is large, even epilimnion may become anaerobic resulting in eutrophication
- In autumn, turnover of lake may result in the remobilization of pollutants

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Structure of Water Bodies

- MTBE study findings
- Watercraft release up to 25% unburned gasoline with MTBE
- High concentrations only in surface layer (40-50 ppb)
- Bottom is below 5 ppb
- Can draw water from below but have problems with dissolved gases (H_2S) from anaerobic degradation

Structure of Water Bodies

- Estuaries & Bays

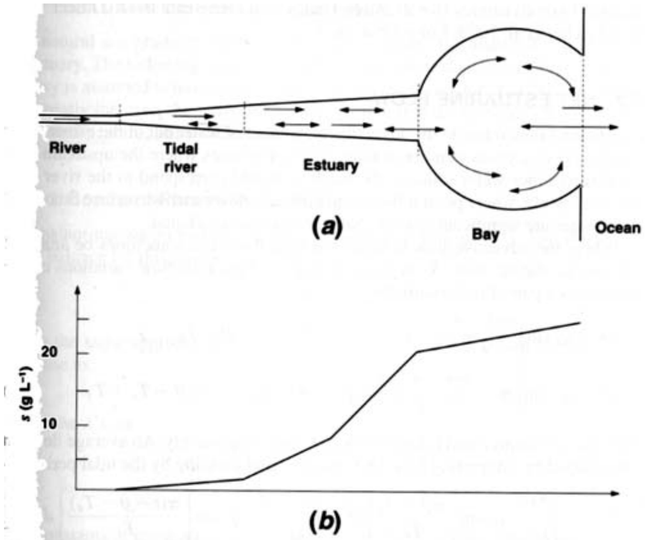


FIGURE 15.1
(a) A schematic of the various zones in an estuarine system. (b) Corresponding salinity concentration.

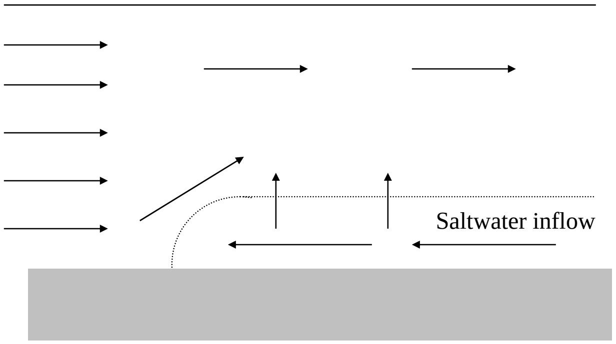
Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

- Tidal action is dominant feature
- Periodic full reversal of flow
- For short-scale problems (reactive pollutant), effect is mostly advective
- For long-scale problems, effect is mostly mixing (dispersion)
- Net flow corresponds to river flow

Structure of Water Bodies

- ❑Wide estuaries can exhibit lateral gradients of salinity and temperature
- ❑Deep bays can have vertical stratification

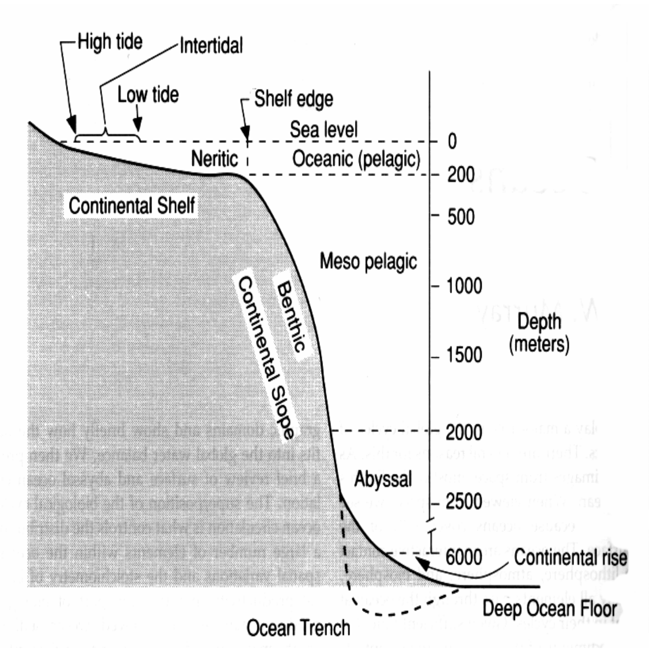


Source: Surface Water Quality Modeling, Chapra, 1997

Structure of Water Bodies

- ❑Oceans
  - ❑Large regional to global circulation patterns result in significant transport and mixing horizontally in short time
  - ❑Vertical currents may also result in significant mixing among layers but on very long time frames
  - ❑Topography and structure of ocean floor is a significant factor in mixing

Structure of Water Bodies



Source: Global Biogeochemical Cycles, Butcher et al., 1992

Structure of Water Bodies

- Oceans
  - Salinity and Temperature gradients serve to stratify the ocean so that vertical mixing is slow
  - Biota can contribute significantly to the “dispersion” of some pollutants due to uptake, accumulation and bioconcentration (e.g. DDT, PCBs)

Structure of Water Bodies

- ❑Sediments
  - ❑Bottom of lakes and oceans has a very active (fluffy) layer, the benthic region, typically 95% water and 5% particles, with high organic content
  - ❑At greater depths, water content decreases to ~50%
  - ❑The benthic region may be aerobic or anaerobic (anoxic), which has an impact on inorganic substances (metals, arsenic); organic material is decomposed by either microbial community, at different rates

Structure of Water Bodies

- ❑Sediments
  - ❑Most active area is top 5 cm, but deeper sediments also participate in degradation and/or storage of organic and inorganic pollutants (e.g. PCBs, metals)
  - ❑Deposition is a cyclic process, with frequent resuspension. Typical net rates are 1 mm/yr. For a sediment depth of 5 cm, this requires 50 years to bury an average particle.
  - ❑Toxic chemicals may desorb from the particles before burial

Sediments

- Particulate Matter
  - Chemicals may sorb into the particles
  - May consist of mineral matter (silica, clay, carbonates)
  - Usually contains decaying organic matter, which is usually lipophilic but may also contain some acidic portion (e.g. humic acids)
  - Sometimes arbitrarily distinguish between particulate and “dissolved” using a mesh or filter of around 0.45 μm

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Sediments

- Particulate Matter
  - Typically have about 7.5 g/m^3 of particulate matter, with 33% organic matter (density ~ 1000 kg/m^3) and 67% mineral (density ~ 2000 kg/m^3)
  - Deposition velocities vary significantly depending on water body and mixing conditions but typically range from 0.5 to 2 m/day
  - Biota (from plankton to fish and mammals) represent about 1 ppmv, with an average lipid (fat) content of ~ 5%

Sediments

- Sediment transport
  - Organic solids may be lost during settling due to decomposition
  - Residual organic particles and mineral solids are transported through the hydraulic system
  - Deposition zones form around low-energy regions: pools and inside of bends
  - Wind and current turbulence can “focus” deposition

Sediments

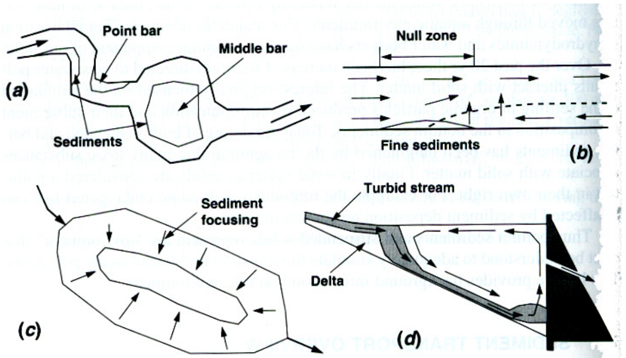


FIGURE 17.1
Patterns of deposition of fine sediments in natural waters. (*a*) Top view of river; (*b*) side view of estuary; (*c*) top view of lake; and (*d*) side view of impoundment.

Source: Surface Water Quality Modeling, Chapra, 1997

Sediments

TABLE 17.1
Suspended solids concentrations encountered in natural waters and sewage (from Di Toro et al. 1971, O'Connor 1988*c*, Lung 1994, Thomann and Mueller 1987)

System	Suspended solids (mg L^{-1})
Great Lakes:	
Superior/Huron	0.5
Saginaw Bay	8.0
Western Lake Erie	20.0
Flint River, Michigan	8–12
Rapid Creek, South Dakota	158
Clinton River, Michigan	10–120
Hudson River, NY	10–60
Potomac Estuary	5–30
James Estuary, Virginia	10–50
Sacramento–San Joaquin Delta, California	50–175
Raw sewage	300

TABLE 17.2
Densities of water and particulate matter

Substance	Density (g cm^{-3})
Water	1
Organic matter	
Wet-weight basis	1.02–1.1
Dry-weight basis	1.27
Siliceous minerals	2.65
Garnet sands	4

Source: Surface Water Quality Modeling, Chapra, 1997

Sediments

$$v_s = \alpha \frac{g}{18}\left(\frac{\rho_s - \rho_w}{\mu}\right) d^2 \qquad (17.1)$$

where v_s = settling velocity (cm s^{-1})
α = a dimensionless form factor reflecting the effect of the particle's shape on settling velocity (for a sphere it is 1.0)
g = acceleration due to gravity (= 981 cm s^{-2})
ρ_s and ρ_w = densities of the particle and water, respectively (g cm^{-3})
μ = dynamic viscosity (g cm^{-1} s^{-1})
d = an effective particle diameter (cm)

Thomann and Mueller (1987) have reexpressed Stokes' law in a convenient form,

$$v_s = 0.033634\alpha(\rho_s - \rho_w)d^2 \qquad (17.2)$$

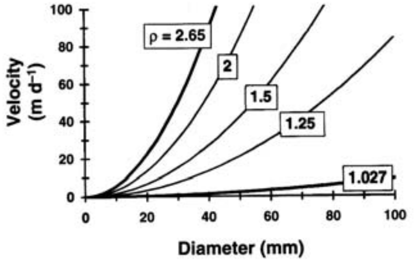
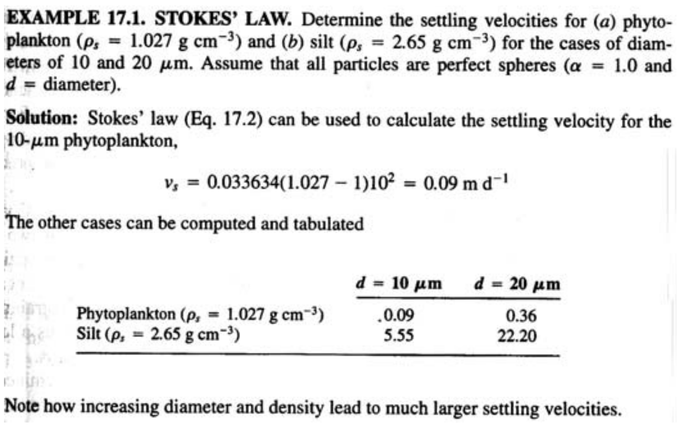


FIGURE 17.3
Plot of settling velocity versus diameter for various levels of particle density. This figure assumes that the particles are perfect spheres (α = 1.0 and d = diameter).

Source: Surface Water Quality Modeling, Chapra, 1997

Sediments



EXAMPLE 17.1. STOKES' LAW. Determine the settling velocities for (*a*) phytoplankton ($\rho_s = 1.027$ g cm^{-3}) and (*b*) silt ($\rho_s = 2.65$ g cm^{-3}) for the cases of diameters of 10 and 20 μm. Assume that all particles are perfect spheres ($\alpha = 1.0$ and d = diameter).

Solution: Stokes' law (Eq. 17.2) can be used to calculate the settling velocity for the 10-μm phytoplankton,

$$v_s = 0.033634(1.027 - 1)10^2 = 0.09 \text{ m d}^{-1}$$

The other cases can be computed and tabulated

	$d = 10\ \mu$m	$d = 20\ \mu$m
Phytoplankton ($\rho_s = 1.027$ g cm^{-3})	0.09	0.36
Silt ($\rho_s = 2.65$ g cm^{-3})	5.55	22.20

Note how increasing diameter and density lead to much larger settling velocities.

Source: Surface Water Quality Modeling, Chapra, 1997

Sediments

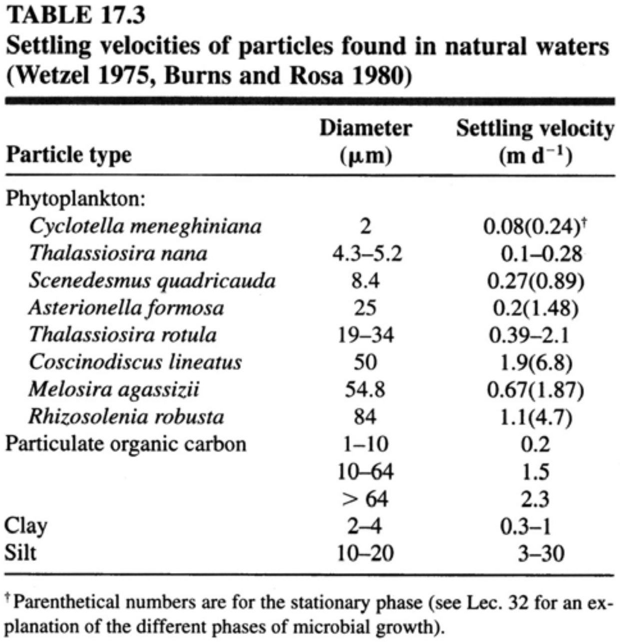


TABLE 17.3
Settling velocities of particles found in natural waters (Wetzel 1975, Burns and Rosa 1980)

Particle type	**Diameter (μm)**	**Settling velocity (m d^{-1})**
Phytoplankton:		
Cyclotella meneghiniana	2	0.08(0.24)[†]
Thalassiosira nana	4.3–5.2	0.1–0.28
Scenedesmus quadricauda	8.4	0.27(0.89)
Asterionella formosa	25	0.2(1.48)
Thalassiosira rotula	19–34	0.39–2.1
Coscinodiscus lineatus	50	1.9(6.8)
Melosira agassizii	54.8	0.67(1.87)
Rhizosolenia robusta	84	1.1(4.7)
Particulate organic carbon	1–10	0.2
	10–64	1.5
	> 64	2.3
Clay	2–4	0.3–1
Silt	10–20	3–30

[†] Parenthetical numbers are for the stationary phase (see Lec. 32 for an explanation of the different phases of microbial growth).

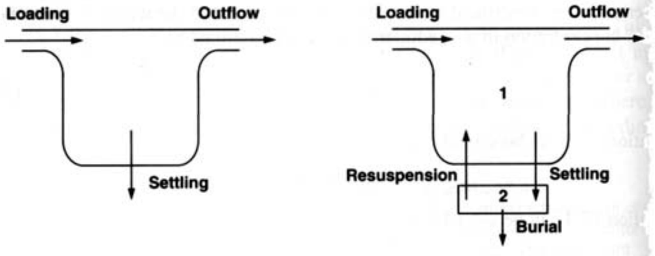
Source: Surface Water Quality Modeling, Chapra, 1997

Sediments

$$V_1 \frac{dm_1}{dt} = Qm_{\text{in}} - Qm_1 - v_s A_s m_1 + v_r A_s m_2 \qquad (17.12)$$

and

$$V_2 \frac{dm_2}{dt} = v_s A_s m_1 - v_r A_s m_2 - v_b A_s m_2 \qquad (17.13)$$



(*a*) No sediment-water interaction

(*b*) Sediment-water interaction

FIGURE 17.5
Schematic of a solids budget for a well-mixed lake (*a*) without and (*b*) with sediment feedback.

$$F_r = \frac{v_r}{v_r + v_b}$$

F_r = fraction resuspended

Source: Surface Water Quality Modeling, Chapra, 1997

Sediments

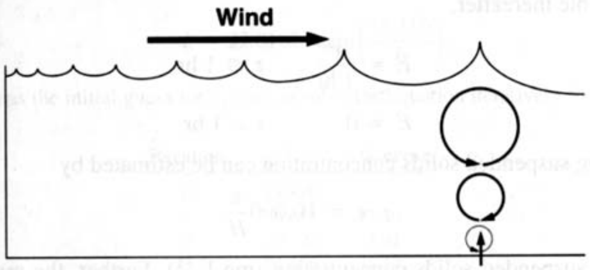


FIGURE 17.7
A simple model of how wind induces wave action that leads to sediment resuspension.

Source: Surface Water Quality Modeling, Chapra, 1997