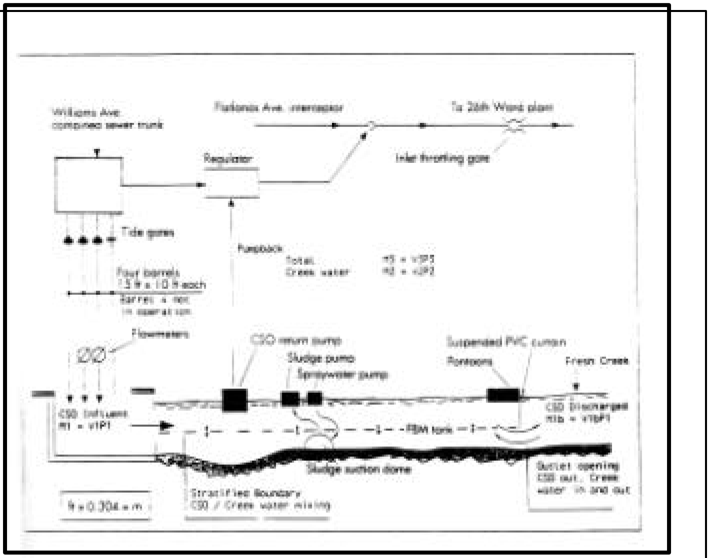
"Physical Transport in Surface Waters"

Module 2: Surface Waters, Lecture 1

Chemical Fate and Transport in the Environment, 2nd edition. H.F. Hemond and E.J. Fechner-Levy. Academic Press. London. 2000.

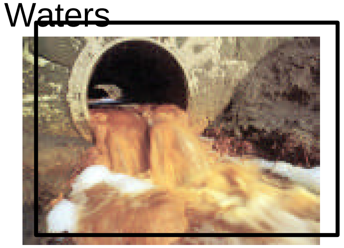
2.1.1 Nature of Surface Waters

- Rivers and streams are relatively long, shallow and narrow, and have obvious horizontal movement in the downstream direction.
- Lakes tend to be deeper and wider and are often stratified into distinct layers that impede vertical mixing.
- Estuaries are the interface between rivers and the ocean and are also commonly stratified due to salinity differences (the heavier salt water sinking and the lighter fresh water rising to the surface – see the attached paper in Module 1 where this feature was used to trap contaminated CSOs for pumpback treatment at the local wastewater treatment plant.)



2.1.2 Sources of Pollutant Chemicals to Surface Waters

- Point sources of water pollutants are discrete, localized, discharges, such as from industrial or municipal treatment operations
- They are regulated by the NPDES (National Pollutant Discharge Elimination System) program administered by most states) for the EPA.



- Nonpoint sources of pollutants are more difficult to measure because they cover a wide area or are composites of numerous smaller point sources.

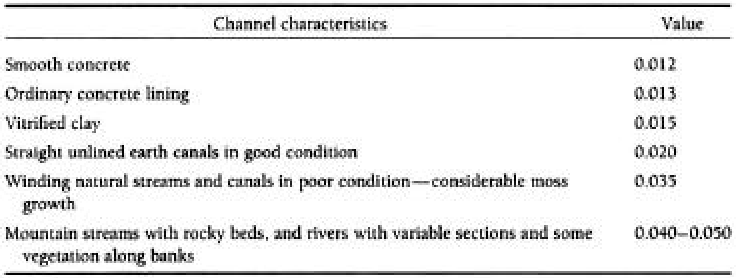
2.2.1 Physical Transport in Rivers

- Gravity-driven advection (water flows downstream by gravity).
- The Manning's equation is commonly used to predict this movement:

$$V = \frac{1.49R^{2/3}S^{1/2}}{n}$$

V is the water velocity [L/T]
R is the hydraulic radius = A/P [L]
S is the slope of the energy gradient
n is the Manning's roughness coefficient

Table 2-1. Manning's Roughness Coefficients



Channel characteristics	Value
Smooth concrete	0.012
Ordinary concrete lining	0.013
Vitrified clay	0.015
Straight unlined earth canals in good condition	0.020
Winding natural streams and canals in poor condition—considerable moss growth	0.035
Mountain streams with rocky beds, and rivers with variable sections and some vegetation along banks	0.040–0.050

Hemond and Fechner-Levy 2000

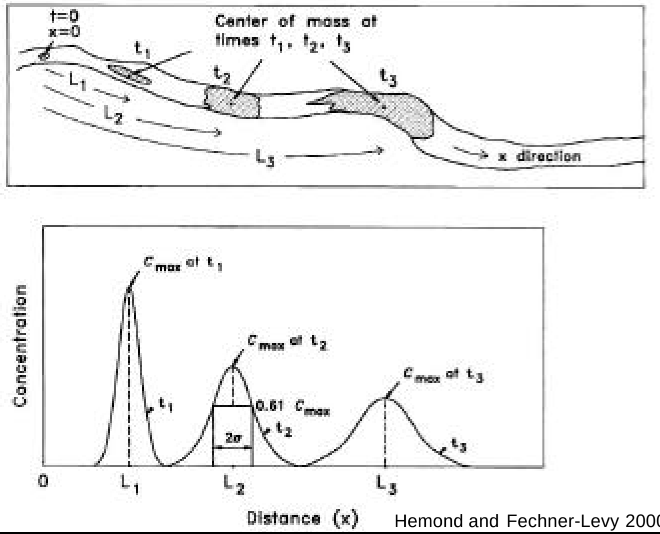
- Travel time along a river, after the release of a chemical, if given by:

$$t = \frac{L}{V}$$

Where L is the reach length and V is the average velocity. When the water velocity is not uniform, the travel time must be expressed as an integral:

$$t = \int_{x_1}^{x_2} \frac{1}{V(x)} dx$$

Dye releases are often used to directly measure travel time.



Hemond and Fechner-Levy 2000

- The mass of the chemical transported by a river past a given point per unit time is:

$$J_{tot} = Q \bullet C$$

Where J_{tot} is the total flux of the chemical and C is the average chemical concentration

Fickian Mixing Processes

- A mass of chemical released in a river will spread out as it moves downstream.
- This dispersion is caused by the velocity shear within the river, and turbulent diffusion.
- Water moves more rapidly down the center of the channel, near the surface, transporting chemicals faster, and elongating the “plume.”
- Plot of concentration vs. distance has the shape of a Gaussian (normal) curve:

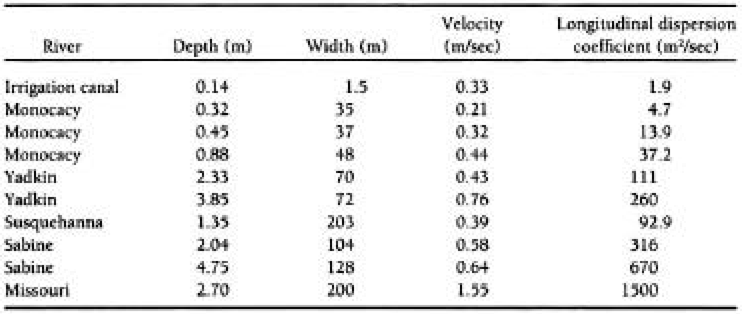
$$f(x) = \frac{1}{s\sqrt{2p}} e^{-x^2/2s^2}$$

- For a pulse injection, there is a close relationship between a Fickian mixing, or transport, coefficient D n a given direction and the standard deviation of the chemical distribution in that direction.
- D can be calculated from: $D=\sigma^2/2t$

  where σ^2 is the spatial variance (the square of the standard deviation) and t is the time since the injection.
- The concentration of a conservation tracer (C) at any time (t) after injection and any distance (x) downstream is:

$$C(x,t) = \frac{M}{\sqrt{4pD_L t}} e^{-(x-Vt)^2/(4D_L t)}$$

Where D_L is the longitudinal Fickian mixing coefficient [L^2/T]



River	Depth (m)	Width (m)	Velocity (m/sec)	Longitudinal dispersion coefficient (m²/sec)
Irrigation canal	0.14	1.5	0.33	1.9
Monocacy	0.32	35	0.21	4.7
Monocacy	0.45	37	0.32	13.9
Monocacy	0.88	48	0.44	37.2
Yadkin	2.33	70	0.43	111
Yadkin	3.85	72	0.76	260
Susquehanna	1.35	203	0.39	92.9
Sabine	2.04	104	0.58	316
Sabine	4.75	128	0.64	670
Missouri	2.70	200	1.55	1500

Hemond and Fechner-Levy 2000

- If the chemical undergoes a first-order decay, then the following predicts downstream concentrations:

$$C(x,t) = \frac{M}{\sqrt{4pD_L t}} e^{-(x-Vt)^2/(4D_L t)} \bullet e^{-kt}$$

At any given time t, the maximum concentration of the chemical (C_{max}) is found using:

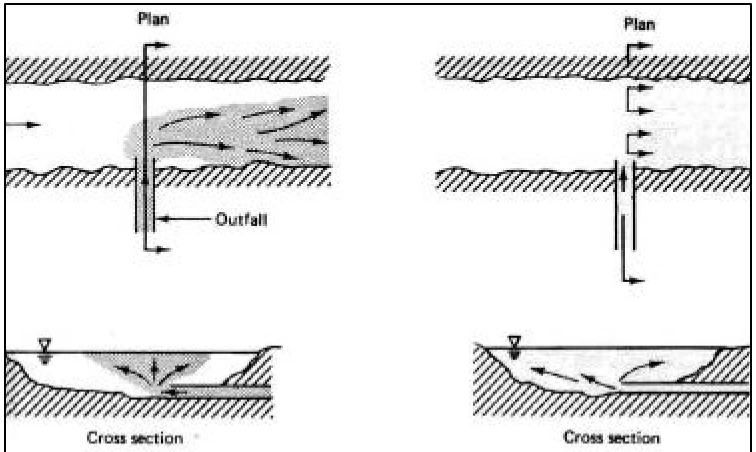
$$C_{\max} = \frac{M}{\sqrt{4pD_L t}} \bullet e^{-kt}$$

- If the chemical is not instantaneously mixed across the river, a “mixing” zone is created. The chemical must travel a certain distance before the chemical is uniform across the channel.
- The lateral standard deviation of the chemical’s concentration distribution can be estimated when this value is approximately equally to the river width (w):

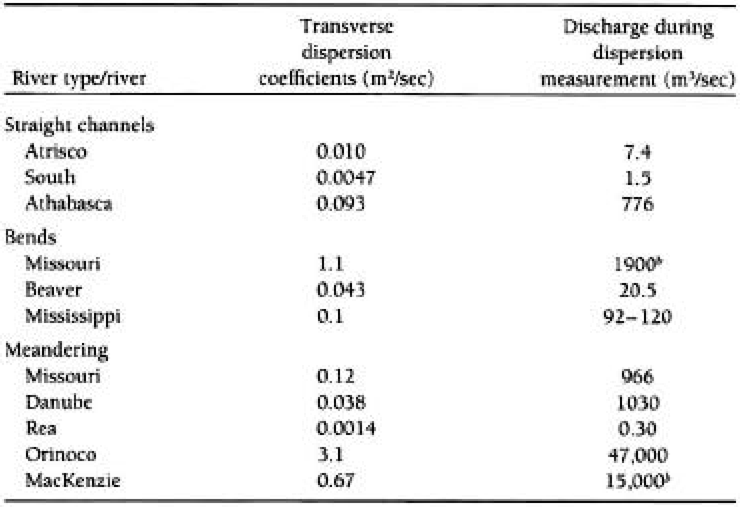
$$s_t = \sqrt{2D_t t} \approx w$$

Substituting the earlier expression for travel time, t, results in the following equation that can be used to predict the length of the transverse mixing zone:

$$L \approx \frac{w^2 V}{2D_t}$$



Thomann and Mueller 1987



River type/river	Transverse dispersion coefficients (m^2/sec)	Discharge during dispersion measurement (m^3/sec)
Straight channels		
Atrisco	0.010	7.4
South	0.0047	1.5
Athabasca	0.093	776
Bends		
Missouri	1.1	1900[b]
Beaver	0.043	20.5
Mississippi	0.1	92–120
Meandering		
Missouri	0.12	966
Danube	0.038	1030
Rea	0.0014	0.30
Orinoco	3.1	47,000
MacKenzie	0.67	15,000[b]

Hemond and Fechner-Levy 2000