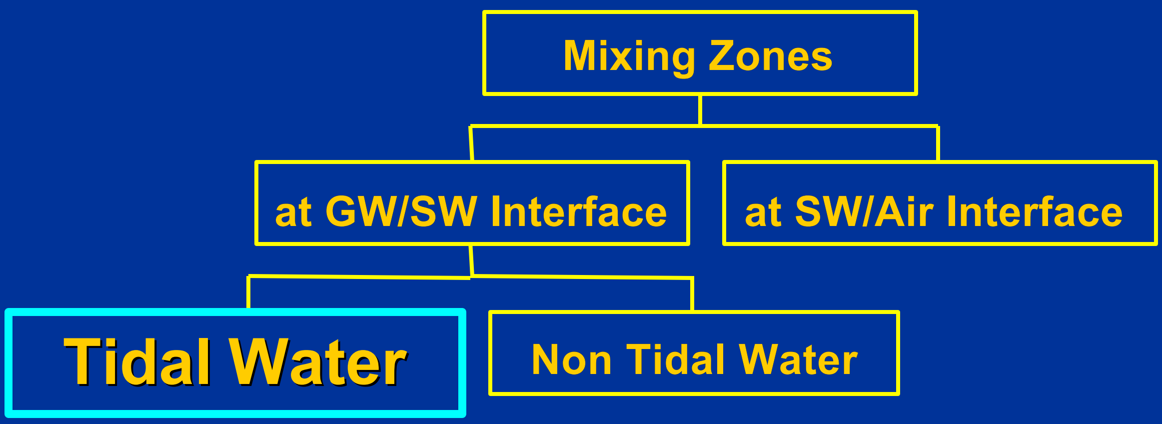
Exit Concentration in Ground Water Discharging into Tidal Waters

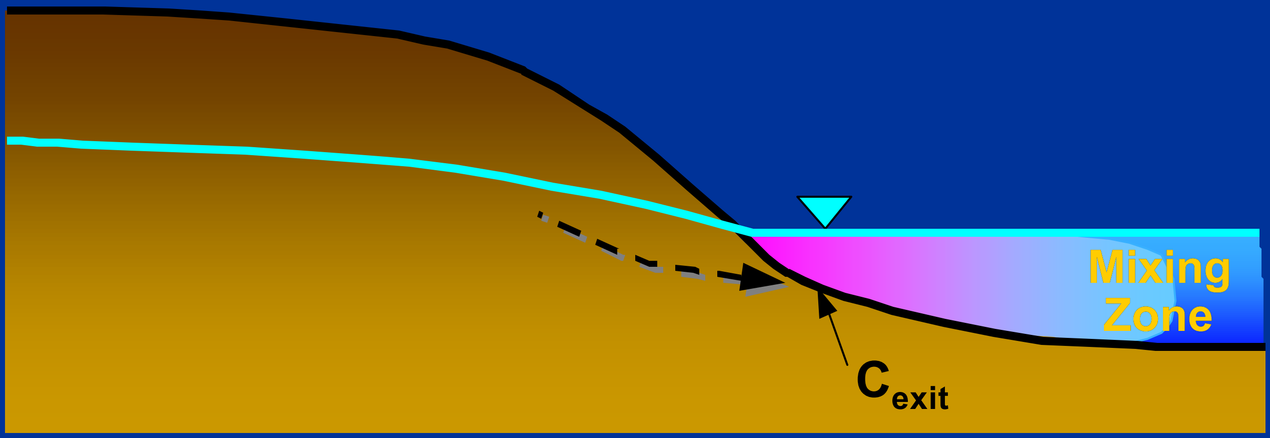
Gannett Fleming

Mixing Zones



- Disproportionately large number of industrial facilities are located close to tidal waters
- The results of numerical study suggest significant lowering of exit concentration by tidal flushing

EXIT CONCENTRATION IN GROUND WATER DISCHARGING INTO TIDAL WATERS



- Since concentration in mixing zone = f(C_{exit}), it is important to get a good understanding of C_{exit} before we can understand/predict concentration in the mixing zone

- Relatively, much more studies have been conducted to estimate C_{exit} for discharge into non-tidal water than to tidal water

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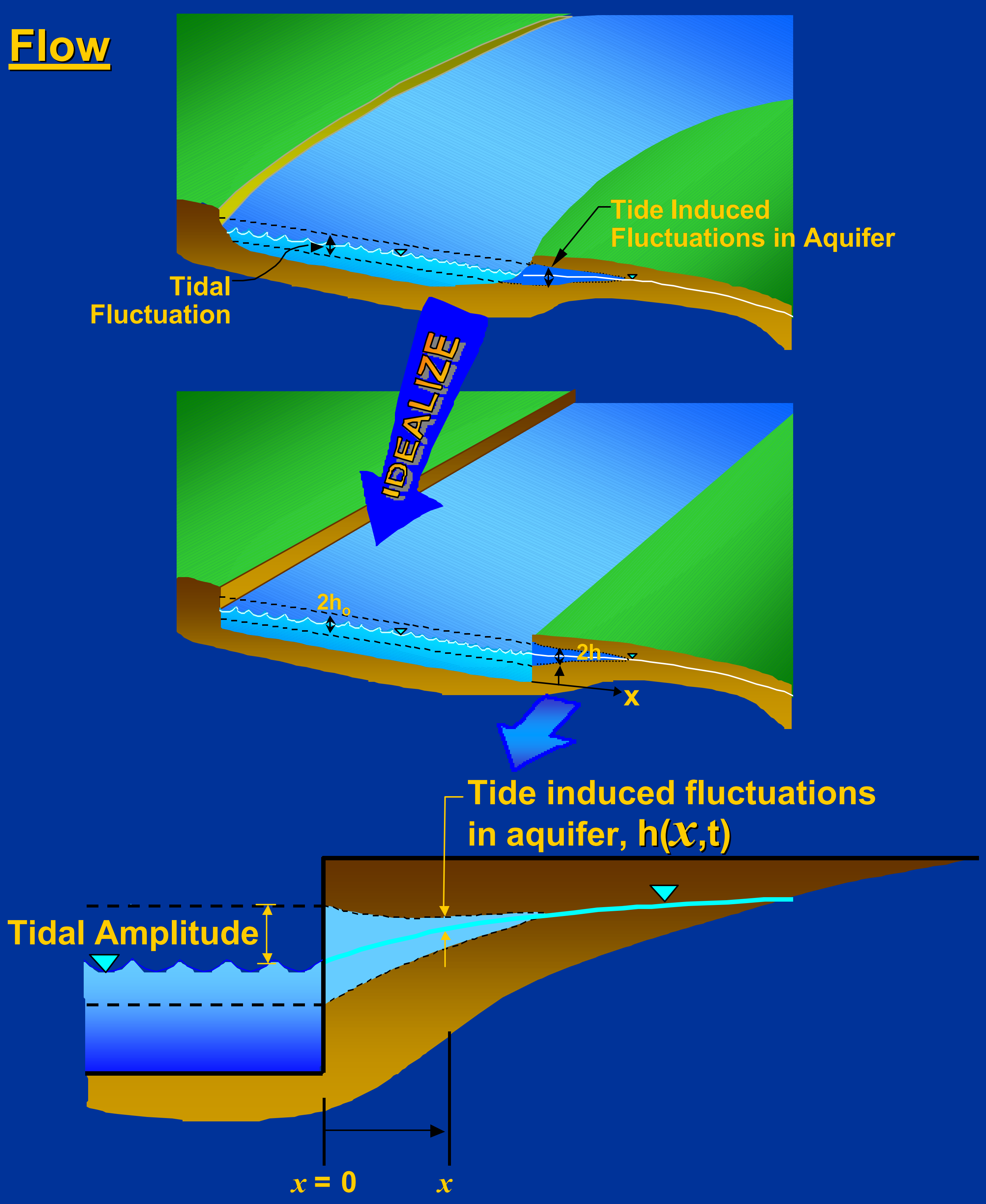

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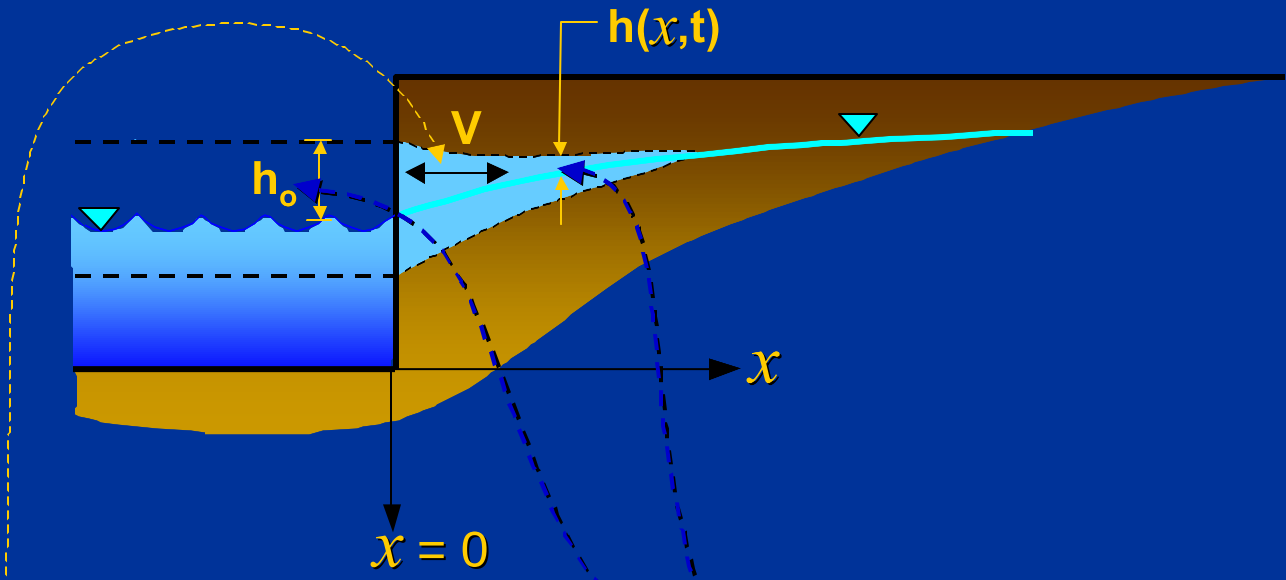
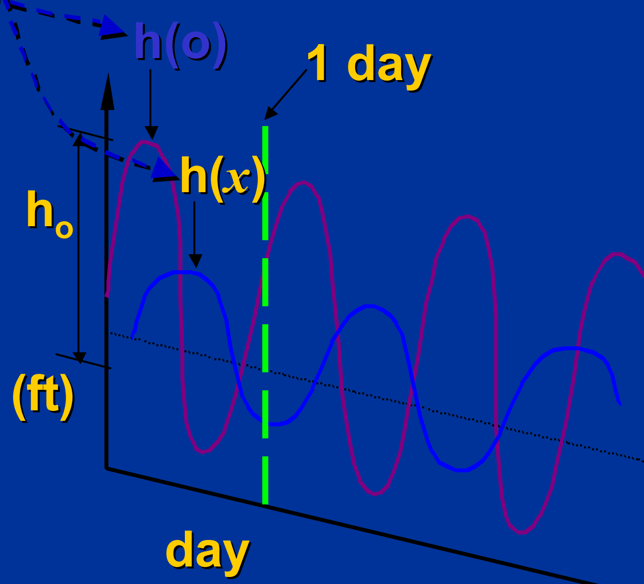




$$h = h_o \exp(-x\beta)\ \mathrm{Sin}\left[\frac{2\pi t}{t_o} - x\beta\right] \text{ (ft)}$$

t = time (days)

t_o = tidal period ≈½ day

$$\beta = \sqrt{\frac{\pi S}{t_o T}}\left(\frac{1}{\text{ft}}\right)$$

S = Storage Coefficient

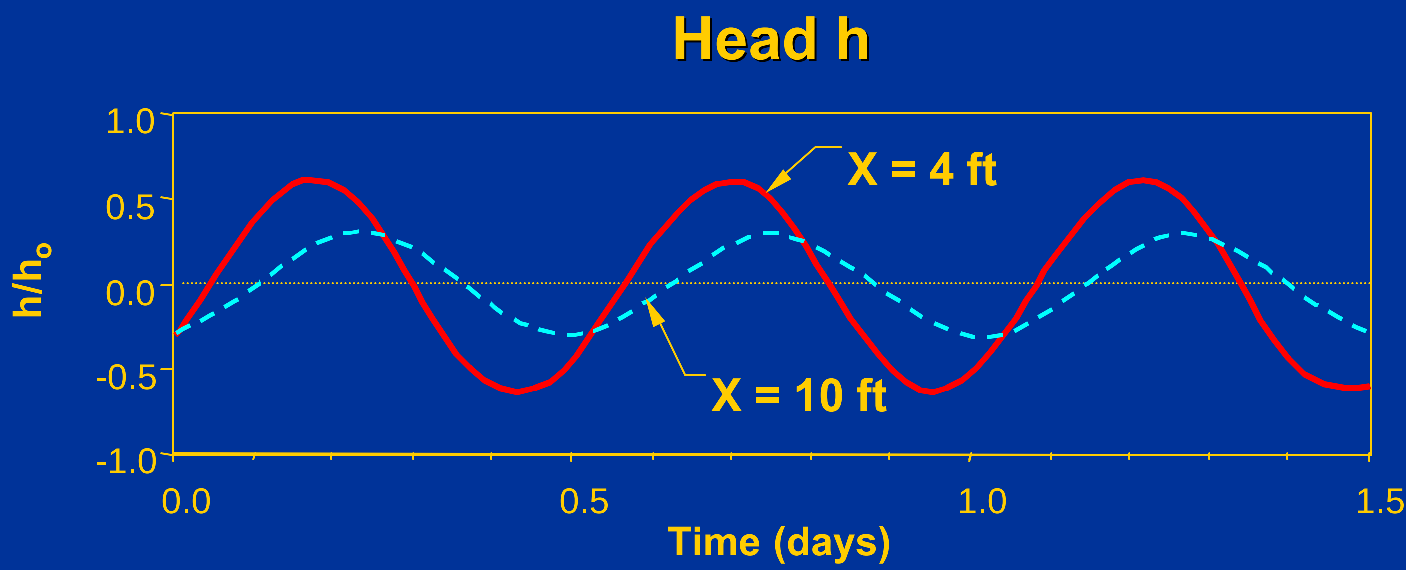
T = Transmissivity (ft^2/day)

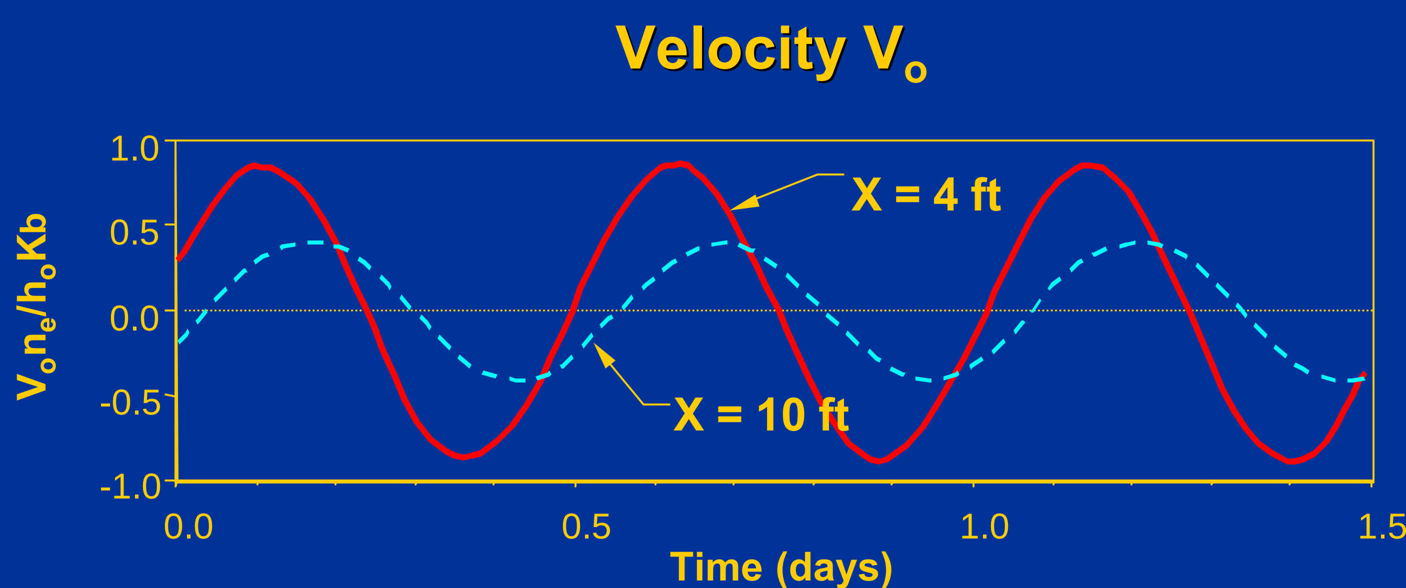
$$V_o = \frac{\partial h}{\partial x} = h_o \frac{K}{n_e} \beta \exp(-x\beta) \sqrt{2}\ \mathrm{Sin}\left[\frac{2\pi t}{t_o} - x\beta + \frac{\pi}{4}\right] \text{ ft/day}$$

n_e = effective porosity

EXIT CONCENTRATION IN GROUND WATER DISCHARGING INTO TIDAL WATERS

Periodic Variation of h and V_o at x=4 ft and 10 ft





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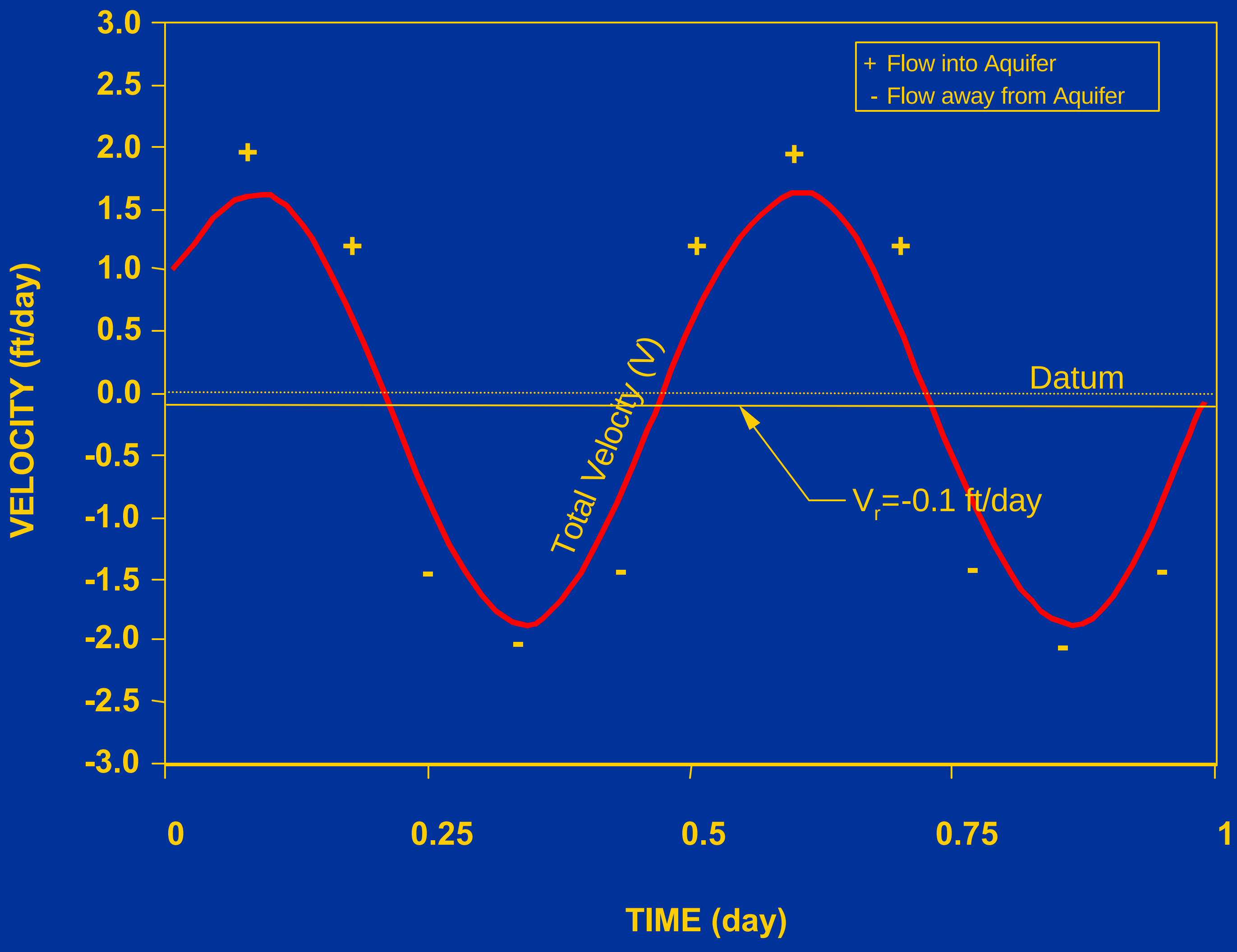
Ground-water flow velocity variation at x=0



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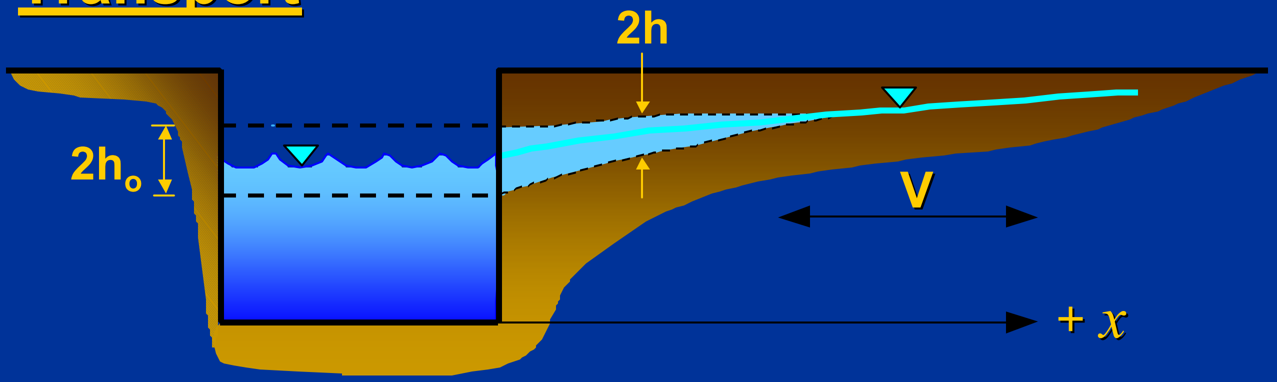
Transport



$$h = h_o \exp(-x\beta)\ \mathrm{Sin}\left[\frac{2\pi t}{t_o} - x\beta\right]$$

$$V = Vo + Vr$$

tidal — regional

$$= \frac{K}{n_e}\frac{\partial h}{\partial x} - \frac{K}{n_e} i_r$$

$$\frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right) - \frac{\partial (VC)}{\partial x} = R_d \frac{\partial C}{\partial x}$$

D = α |V|

α = Dispersivity (ft)

R_d = Retardation Coefficient

n_e = Effective Porosity

Oscillating Boundary Conditions

$V \geq 0$ (Stream → GW) $C|_{x=0} = C_o$

(flush with clean water)

Where C_o = Concentration in estuary

$V \leq 0$ (GW → Stream) $\frac{\partial c}{\partial x}\Big|_{x=0} = 0$

(conc. gradient '0')

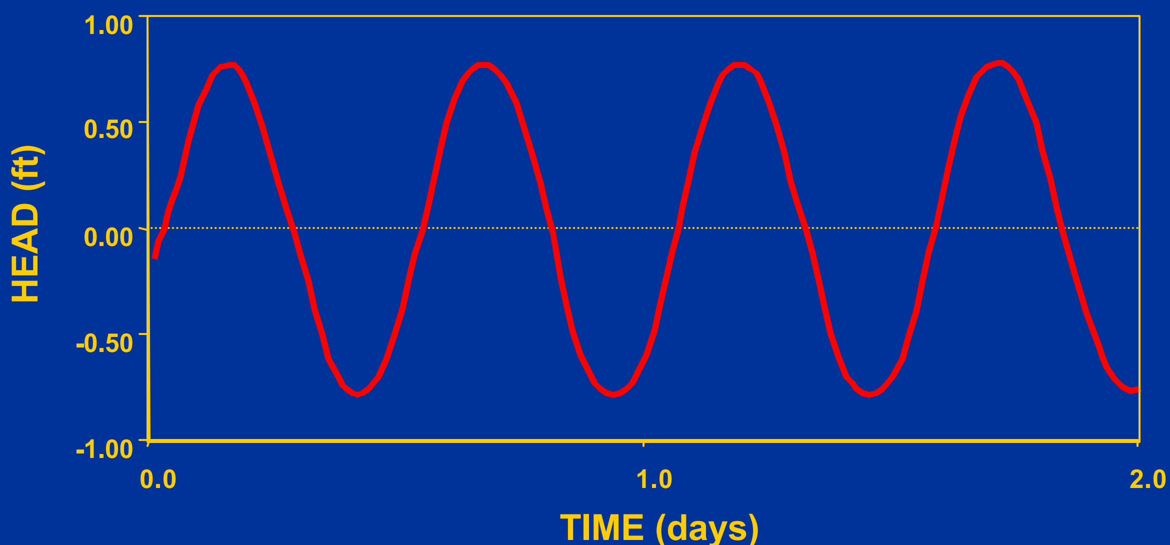
Computer Code (TransTia)

- One-dimensional
- Finite difference

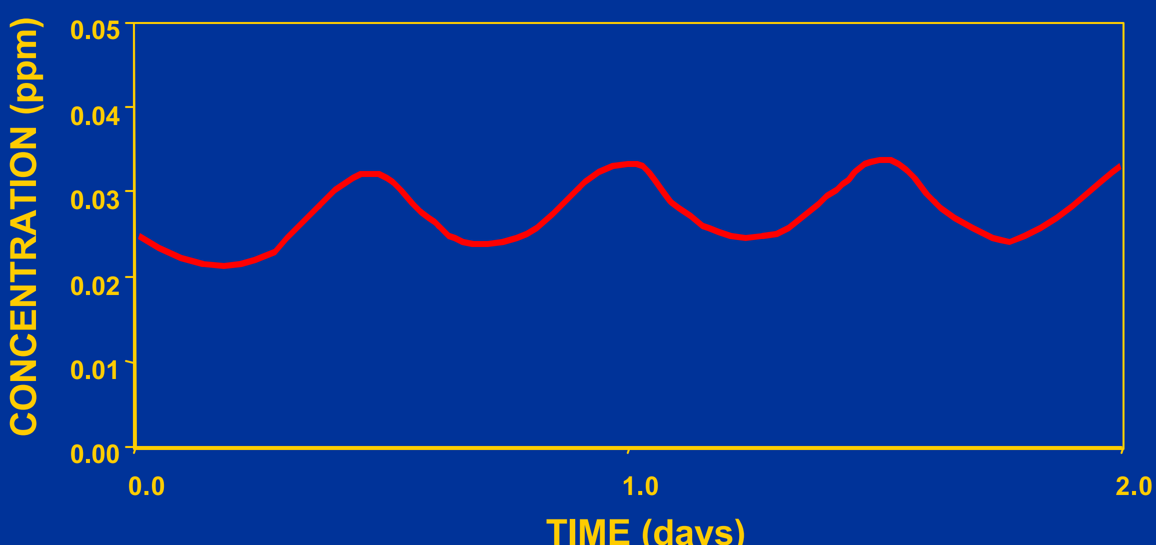
EXIT CONCENTRATION IN GROUND WATER DISCHARGING INTO TIDAL WATERS

Head and Concentration Variations Near the Exit Boundary

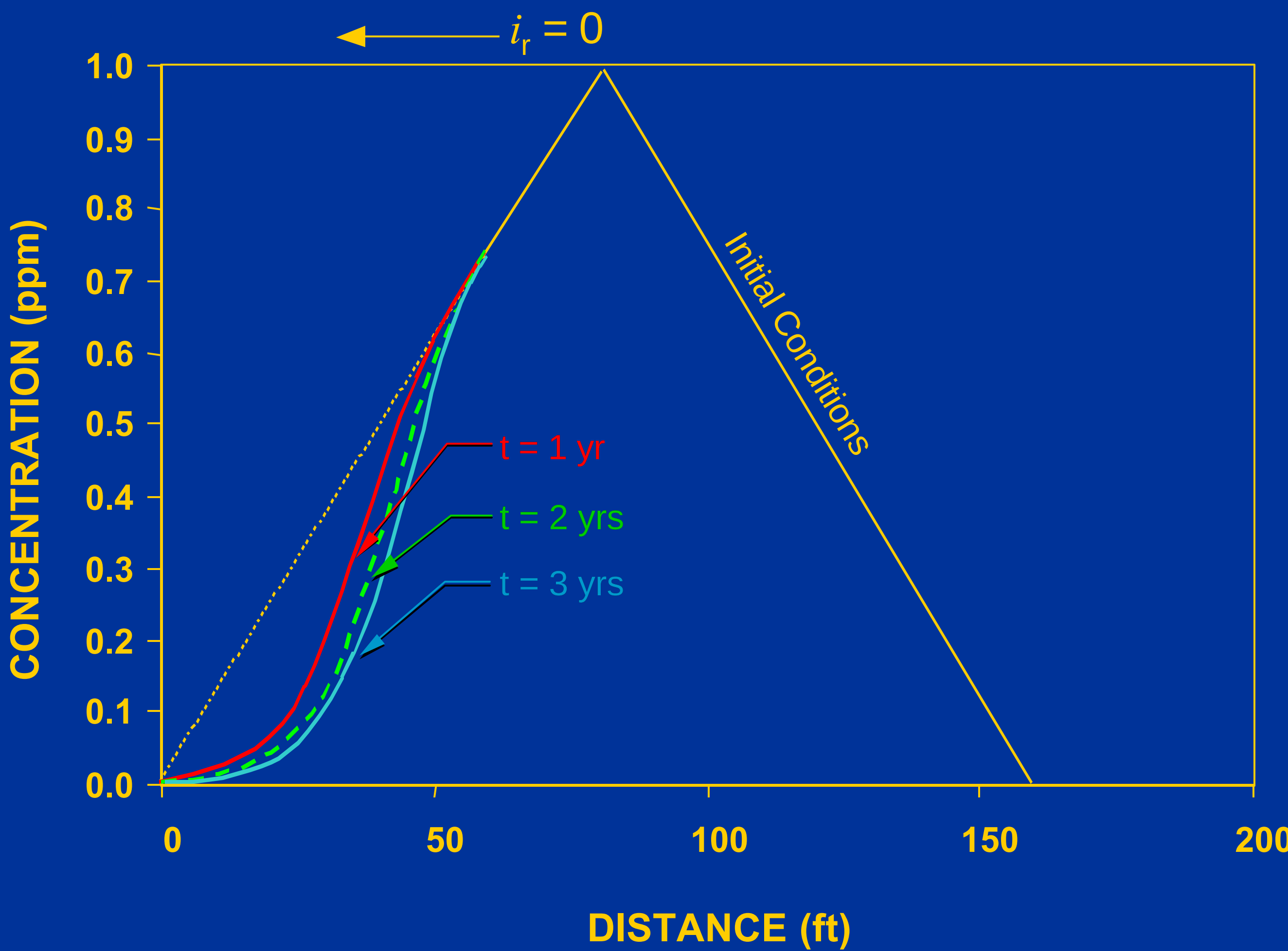
(A) Head Variation at x=2 ft



(B) Concentration Variation at x=2 ft

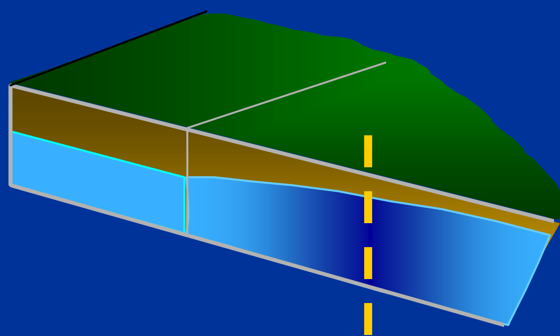


Results of the Base-case Simulation without Regional Gradient

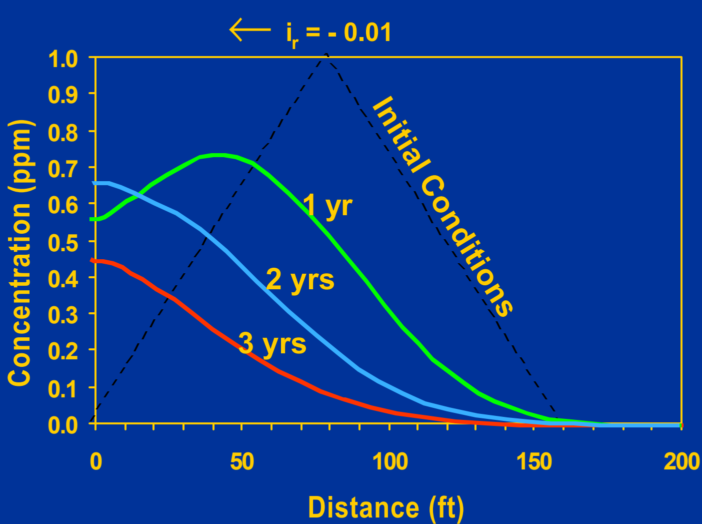


EXIT CONCENTRATION IN GROUND WATER DISCHARGING INTO TIDAL WATERS

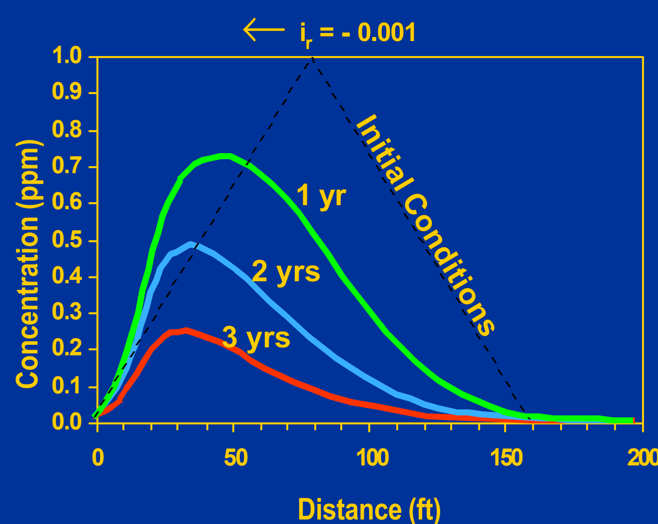
Illustrative Example

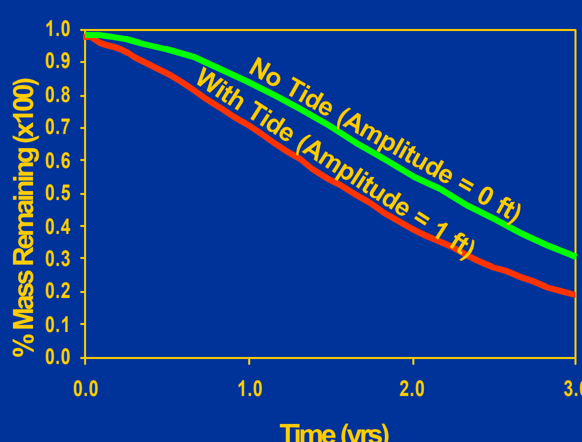


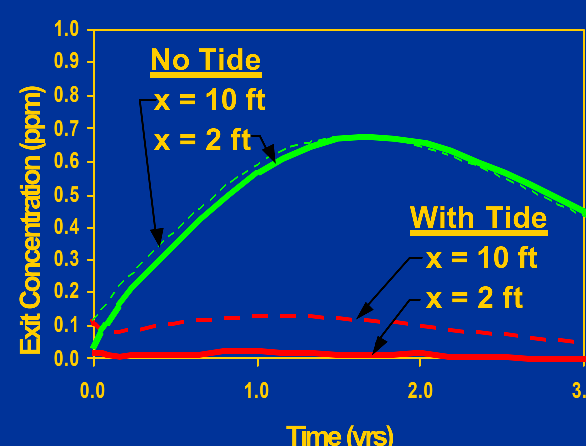
Without Tide



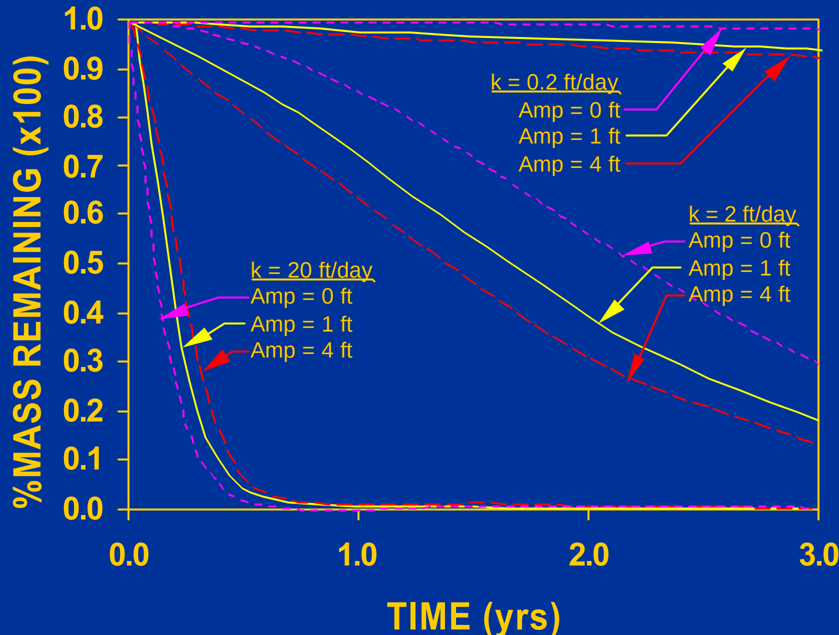
With Tide



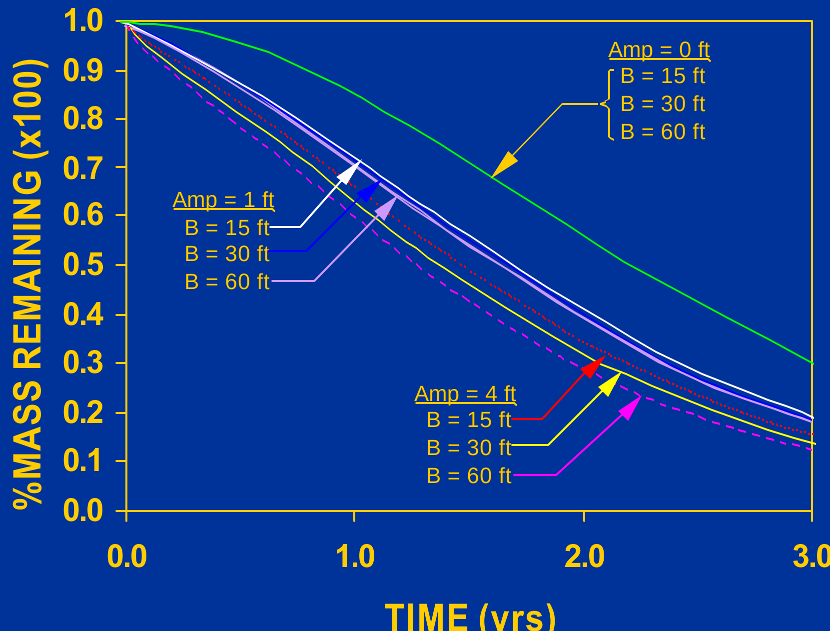




EXIT CONCENTRATION IN GROUND WATER DISCHARGING INTO TIDAL WATERS



Sensitivity of hydraulic conductivity (k) on mass reduction process



Sensitivity of the saturated depth (B) on mass reduction process

Sensitivity of Transport

① Tidal Parameters

- Amplitude → high

② Aquifer Parameters

- Regional gradient → high
- Hydraulic conductivity → high
- Saturated thickness → relatively low

Subsequent Research

① Field Measurement: USGS Tracer test at Aberdeen Proving Ground

② Numerical Study: Sensitivity of exit concentration to Regional Velocity at DuPont's Chambers Works Facility

Subsequent Research #1

Presented on June 2, 2000 at the AGU Spring Meeting in Washington D.C. Abstract in "Design and preliminary results of a small scale tracer test, Aberdeen Proving Ground, Maryland, Maryland, J. C. Johnson, L. D. Olsen, AGU 2000 Spring Meeting, Eos, May 9, 2000, p S249

- Tracer study in a wetland on bank of a creek at the Aberdeen Proving Ground, Maryland
- 96 sampling piezometer at approximately 4,4,28 inch diameter with vertical sampling at 0.5 ft interval to 5 feet
- Sodium bromide and sulfur hexaflouride dye
- 15 sampling events over 1 year

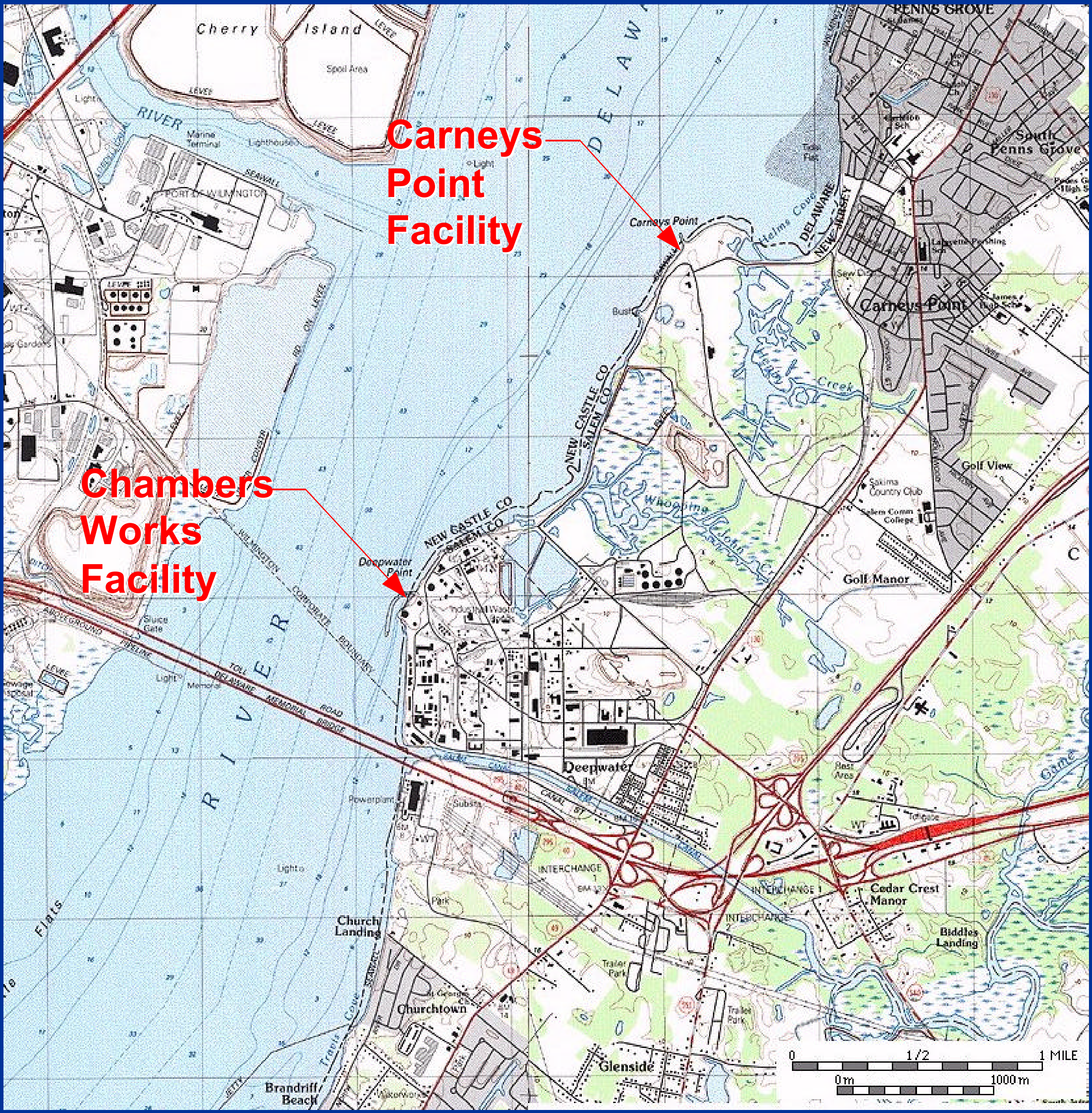
Objective: Estimate ground water velocity and dispersivity.

Conclusion relevant to present work: Measured concentrations compared significantly better to numerical predictions with tide than without.

EXIT CONCENTRATION IN GROUND WATER DISCHARGING INTO TIDAL WATERS

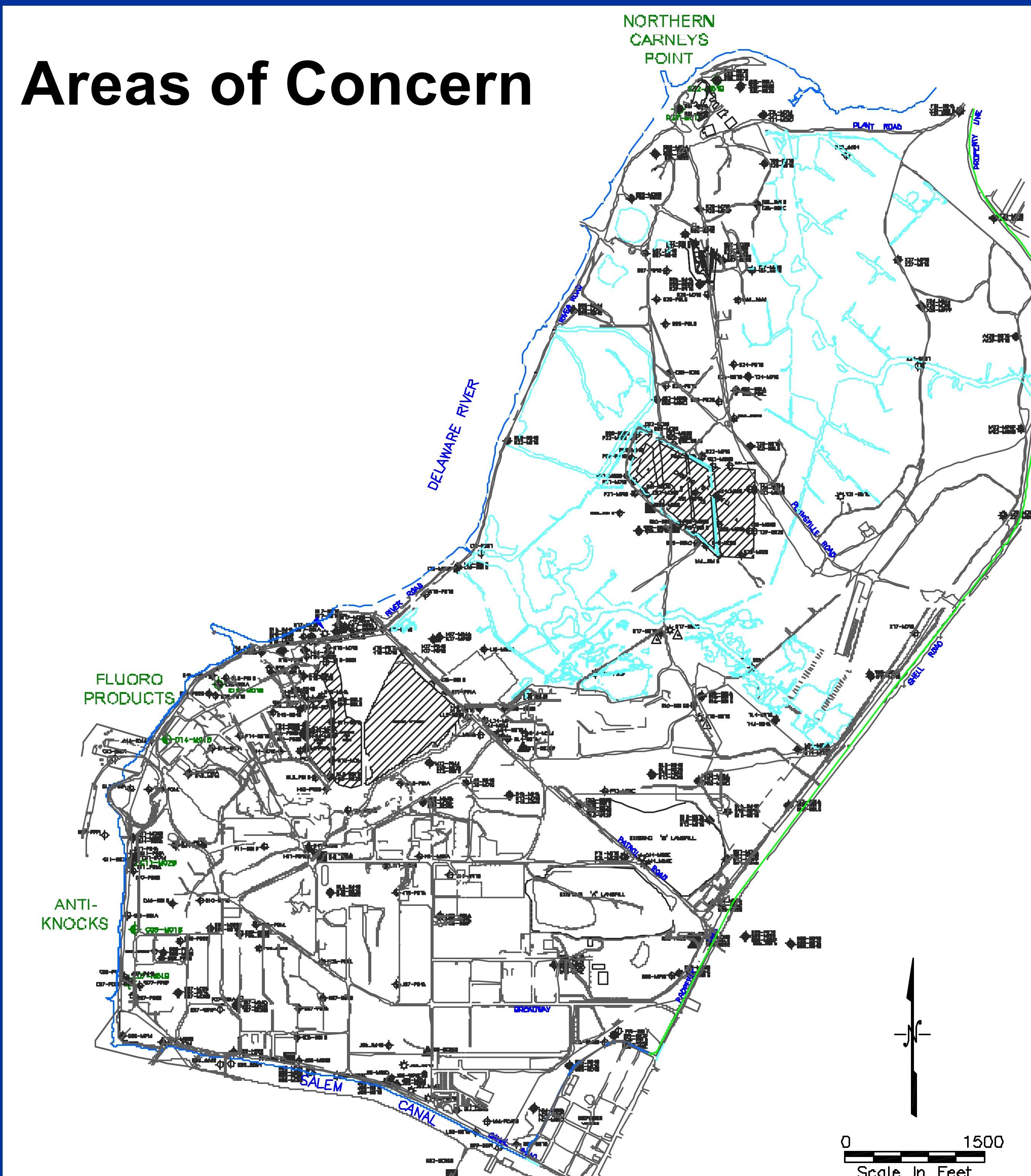
Subsequent Research #2

Site Location



EXIT CONCENTRATION IN GROUND WATER DISCHARGING INTO TIDAL WATERS

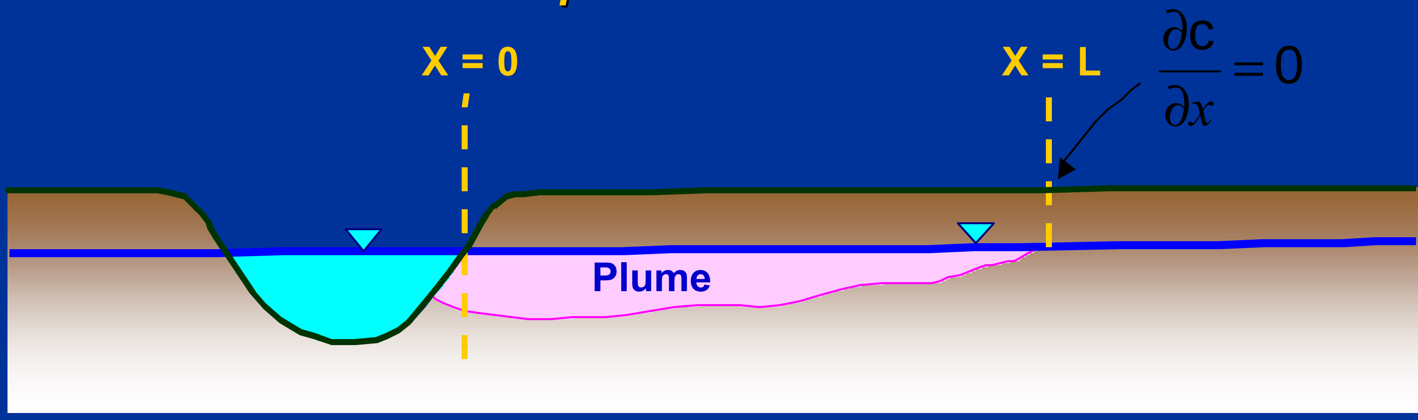
Subsequent Research #2



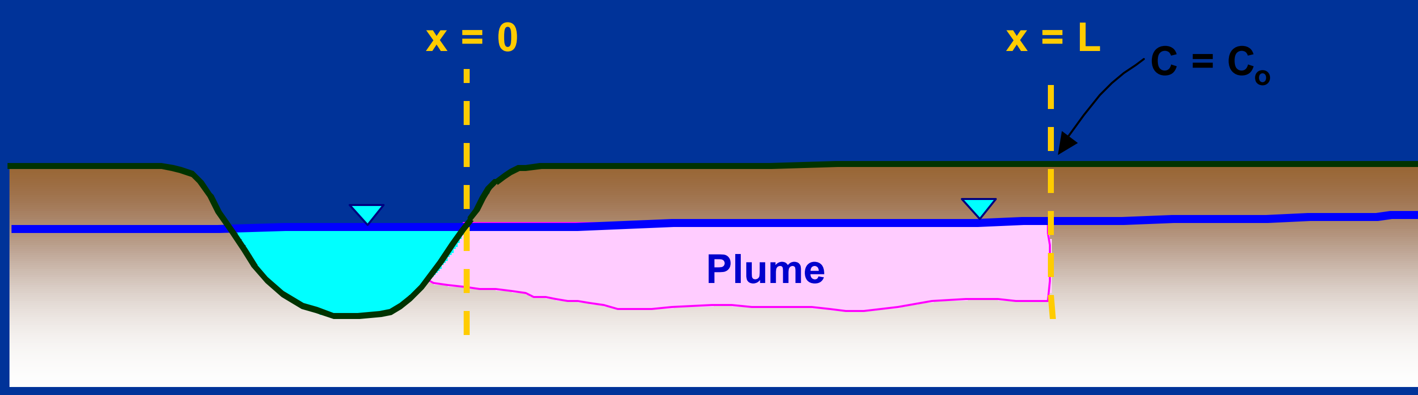
EXIT CONCENTRATION IN GROUND WATER DISCHARGING INTO TIDAL WATERS

Boundary Condition Modified for Site Conditions

- *Boundary Condition in Published Paper*



- *Modified Boundary Condition*



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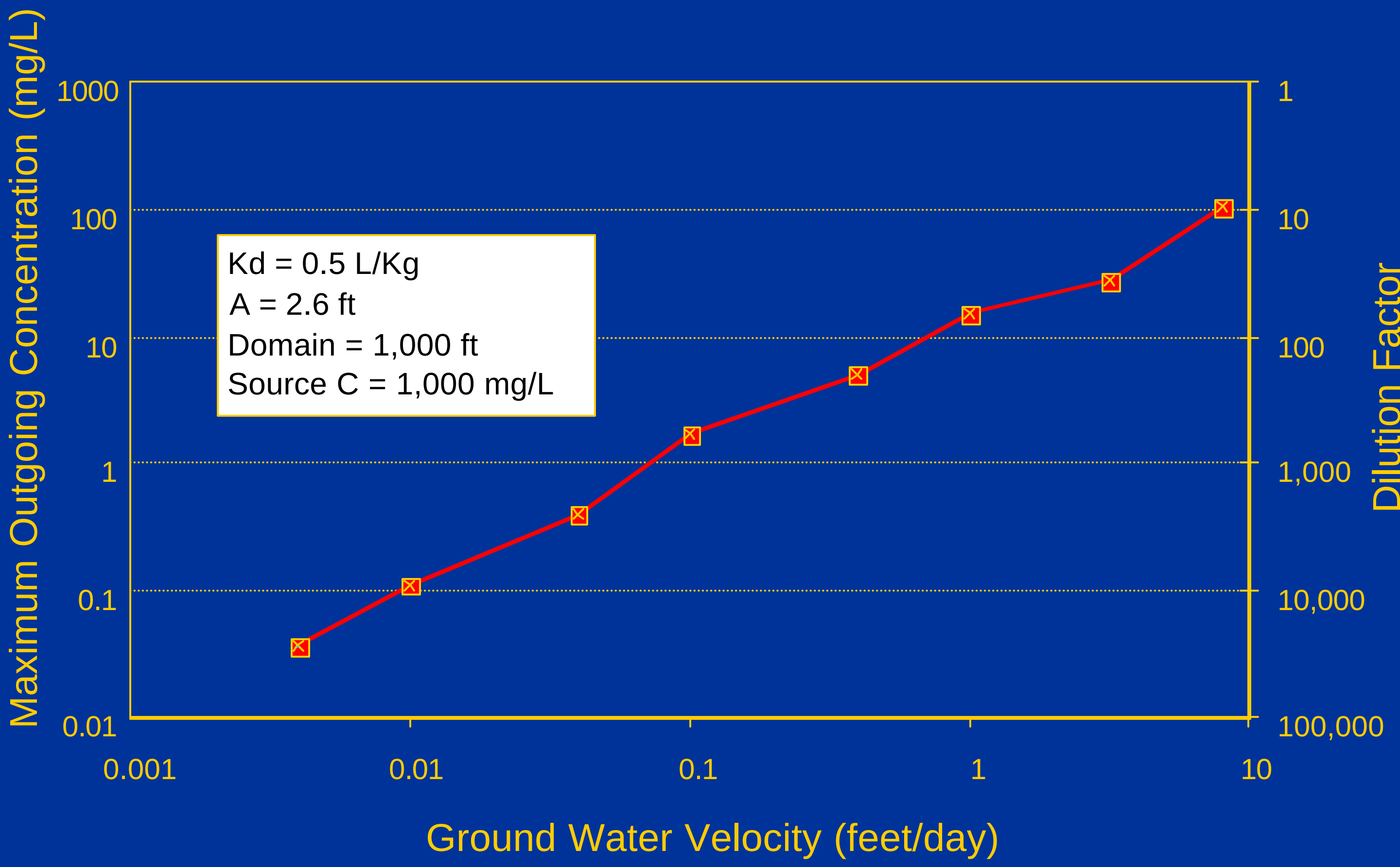
Regional Velocity Sensitivity



Conclusions

① Tides in general lower exit concentration

② Transport in a tidal aquifer is sensitive to:

- Regional gradient
- Hydraulic conductivity
- Tidal Amplitude

(Regional gradient and Hydraulic conductivity: **Regional Velocity**)