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River Pollution

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Introduction

River pollution is the contamination of river so that it becomes unfit for usage. Rivers are often used as disposal sites for unwanted biological or industrial products, usually referred to as waste. When such waste enters river ecosystem and possesses a potentially threat or a detrimental effects on its health, then it is known as a pollutant. Asian rivers are the most polluted in the world. They have three times as many bacteria from human waste as the global average and 20 times more lead than rivers in industrialized countries. There are two different types of pollutants.

1. Conservative Pollutant
2. Non-conservative Pollutant

In conservative pollutant the unit mass remains the same over the time period for example the transportation of sediments from upstream to downstream. On the other hand, non-conservative pollutants are those types of pollutant where unit mass change with time as a result of decay.

The project looks at the pollutant concentration of a river stream with respect to time and distance for point source pollutants (conservative and non-conservative ones) to obtain the concentration-distance and concentration-time profiles. Since it is difficult to predict non-point sources pollution in comparison to point source pollution therefore the focus of this project was mainly concentrated on point source pollutants. An ideal and simplified hydraulic parameters with necessary assumptions were made for the project and then simulated with the real case such as Songhua river of China where an accidental chemical spilled took place in the year 2003.

Objectives of the project

1. Construct concentration-distance and concentration time profiles of the fate and transport of the spill.
2. Repeat (1) assuming that the toxic material is non-conservative and has a decay constant of 0.1/day
3. Calculate the dispersion coefficient using empirical formula and check its validity using Change of Moment and Routing method.

4. Simulate the scenario that happened in Songhua River China when about 100 tons toxic chemicals were spilled.

Assumptions

For the project, the following assumptions were made:

1. The river is of uniform cross section all throughout its length with uniform velocity.
2. The pollutant is evenly dispersed within the river at all times
3. Water flows into and out of the river at the same constant rate (so that all seasonal effects have been ignored)
4. All other water gains and losses (e.g. rainfall, evaporation, extraction and seepage) have been ignored
5. The volume of water in the river is constant

Methodology

In order to find the concentration profiles with respect to distance and time, at first the parameters such as width, depth, Manning's roughness coefficient, slope of the bed and mass of the pollutant were assumed. The velocity was determined using Manning's Eq. as given below:

$V=1/n\ R^{2/3}S^{1/2}$ ……………………………….(i)

Where V is the velocity in m/s

R is Hydraulic Radius, A/P = Cross-sectional Area / Wetted Perimeter

Once we have computed the velocity we can calculate the Flow rate Q as

$Q = AV$ ………………………………………..(ii)

The Dispersion coefficient of the river is estimated using the empirical formula given by Fischer et al. in 1979

Dispersion Co-efficient $D = 0.011\ V^2B^2/HU^*$ ……………………………………(iii)

Where U^* = shear velocity = $(g\ R\ S_f)^{(1/2)}$

B = width of the river

The concentration with respect to distance and time can calculated using the following Eq.

$$C(x,t) = \frac{M}{A(4\pi Dt)^{(1/2)}} \exp\left[\frac{-(x-Ut)^2}{4Dt} - Kt\right]$$

…..…..(iv)

Where

C= *Concentration*

M= M*ass of pollutant*

D- *Dispersion coefficient*

K- *Decay constant*

x- *Distance*

t- *Time*

The concentration with respect to time at different sections of the river such as 300, 600, 900 m from the upstream were calculated and plotted. Similarly, concentrations with respect to distance at various time steps were also plotted considering two cases:

1. Case I - Conservative Pollutant
2. Case II – Non-conservative Pollutant

Now the dispersion coefficient for the river is computed using Fisher's et al. Eq. and it is compared with change of moment and routing method for validation.

Method of Moments: In this method the dispersion coefficient is recalculated based on the equation described by Fischer (1968).

$D = U^2/2\ [(\sigma_{t2}^2 - \sigma_{t1}^2)/(t_2 - t_1)]$ ……………………………………………………(v)

Routing Method: The routing method (Fischer, 1966, 1968) of estimating the dispersion coefficient consists of matching the measured concentration-time profile with a predicted concentration-time profile for an assumed value of the dispersion coefficient until the mismatch between the two profiles as measured by the sum of squared differences is a minimum. Using the properties of the underlying linear theory in the bulk diffusion process, the principle of superposition is invoked to obtain the concentration distribution profile at any given time if the profile at some initial time is known. If at $t = t_0$, the initial concentration profile $c = c_0(\xi, t_0)$, then at any subsequent time, the concentration profile is given by

$$c(\xi,t) = \int_{-\infty}^{\infty} c_0(\xi',t_0)\frac{e^{-\frac{(\xi-\xi')^2}{4D(t-t_0)}}}{\sqrt{4\pi D(t-t_0)}}\,d\xi' \qquad \text{..................(vi)}$$

However, in practice, it is difficult to measure the concentration-distance profile in the field. Therefore, the concentration-distance profile is obtained from the concentration-time profile by the following transformation which is approximate:

$$c(\xi,\bar{t}_0) = c(x_0,t)$$

Where

$$\xi = \bar{u}(\bar{t}_0 - t)$$

Then the distance integration of Eq. (vi) becomes the following time integration:

$$c(x_1,t) = \int_{-\infty}^{\infty} c(x_0,\tau)\frac{\exp\left[\frac{-(\bar{u}(\bar{t}_1-t)+\bar{u}(\tau-\bar{t}_0))^2}{4D(\bar{t}_1-\bar{t}_0)}\right]}{\sqrt{4\pi D(\bar{t}_1-\bar{t}_0)}}\bar{u}\,d\tau \qquad \text{....................(vii)}$$

In Eq. (vii), $c(x_1,t)$ is the concentration-time profile at station x_1, $c(x_0,t)$ is the concentration-time profile at station x_0, $\bar{t}_0$ and $\bar{t}_1$ respectively are the mean times of passage of the tracer cloud past stations x_0 and x_1, and $\bar{u}$ is the mean velocity of flow. In deriving Eq. (vi), $c(\xi,t)$ is replaced by $c(x_1,t)$, ξ by $\bar{u}(\bar{t}_1 - t)$, ξ' by $\bar{u}(\bar{t}_0 - \tau)$, $c_0(\xi',t_0)$ by $c(x_0,\tau)$, $(t-t_0)$ by $(\bar{t}_1 - \bar{t}_0)$, and $d\xi$ by $\bar{u}\,d\tau$.

The routing method assumes that no dispersion takes place while the tracer cloud passes through the measuring station. In actual practice, the concentration profiles at two stations are measured, and the upstream concentration profile is used as an input and the corresponding concentration profile at a downstream station is determined for an assumed value of *D*. It is then compared with the measured concentration profile at the downstream station, and the dispersion coefficient is adjusted iteratively until the two concentrations match within a certain specified tolerance.

The data regarding the width, depth, Manning's roughness coefficient and bed slope of Songhua River was obtained from available sources. The concentration profile for the River Songhua was simulated based on the proportionality and linearity of the obtained results from the initial ideal condition.

Finally, instead of an instantaneous discharge or impulse input a continuous and constant discharge of sewage is assumed and the BOD concentration of the river is calculated using the following Eq.

$C(t) = C_0 (1 – e^{–kt})$ ……………………………………………(vii)

Where C_0 = Initial Concentration in mg/L

K = Decay constant

Results and Discussion

Table – 1: Dissolved Oxygen and Water Quality (Source: Eugene R. Weiner, 2000)

Dissolved Oxygen (mg/L)	Water Quality
> 8.0	Good
6.5-8.0	Slightly Polluted
4.5-6.5	Moderately Polluted
4.0-4.5	Heavily Polluted
< 4.0	Severely Polluted

For Case 1 and Case 2, the following parameters were calculated and assumed

Calculated parameters using the empirical formulas	***Parameters assumed***
Velocity (V) = 0.29743977 m/s	Width of the river (b) = 48.8 m
Shear Velocity (U*) = 0.034499 m/s	Depth of the river (h) = 8.07
Dispersion Coefficient (D) = 11.07922 m^2/s	Length of the river (L) = 1000 m
Area = 393.816 m^2	Roughness Coefficient (n) = 0.05
Wetted Perimeter = 64.94 m	Bed slope of the river (So = Sf) = 0.00002
Hydraulic Radius = 6.0643055 m	Mass of pollutant (m) = 5 kg

Case 1: Conservative pollutant

The concentration-distance graphs (Figure 1) of the pollutant were derived using the Delphi program. The graphs show that at the first few seconds, the pollutant undergoes logarithmic decrease as distance from the source increases. However as time passes, the trend gradually reverses. The concentration at the point source gradually decreases while the concentration downstream gradually increases.

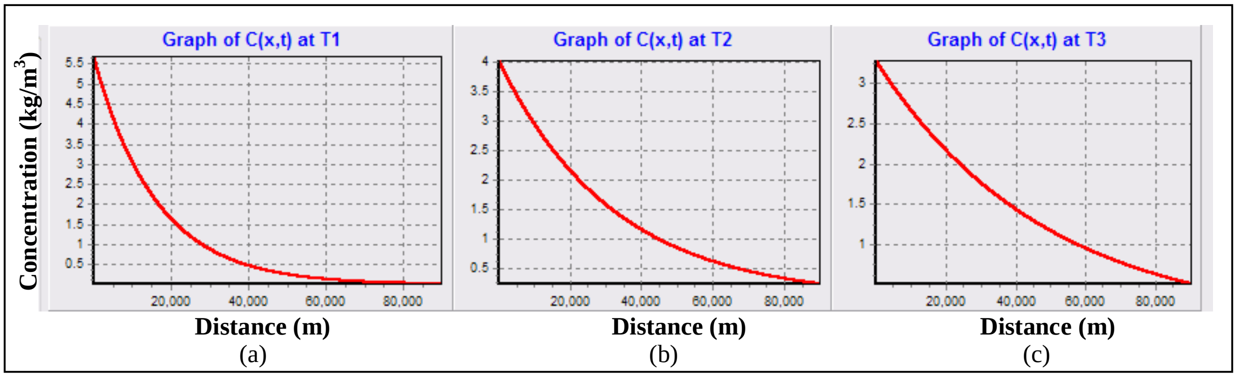


Figure 1. Graphs showing the concentration of the 5 kg conservative pollutant as distance increases from the point source plotted at different time frames; (a) at T1 = 500s, (b) at T2 = 1000s and (c) at T3=1500s.

On the other hand, the concentration-time graphs (Figure 2) show a different trend. While all of the graphs show a Gaussian distribution curve, the peak amount decreases as time passes. P1 is the point 300m downstream from the point source and shows the highest peak concentration 4kg/m^3 compared to points P2 (600m) which is 2.8kg/m^3 and P3 (900m) at 2.2kg/m^3.

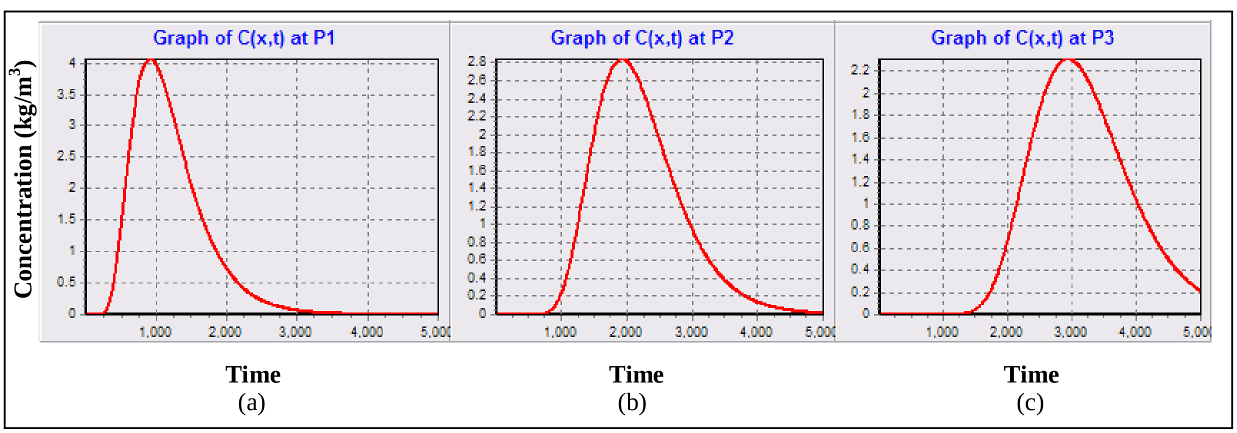
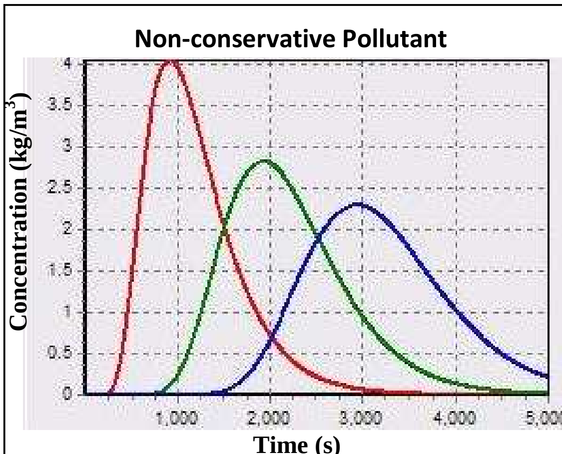


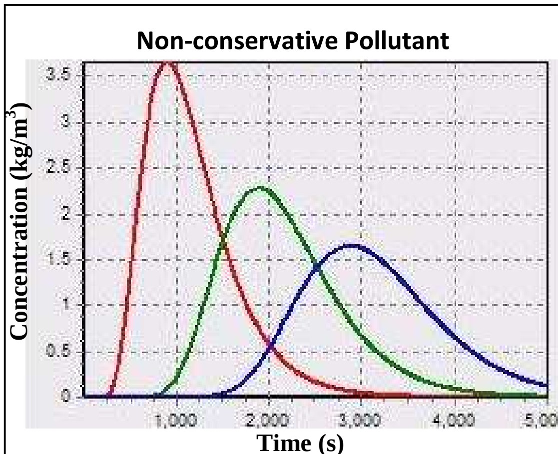
Figure 2. Graphs showing the concentration of the 5 kg conservative pollutant as time elapses plotted at different points x from the point source; (a) at P1 x= 300m, (b) at P2 x= 600m and (c) at P3 x= 900m.

Case 2: Non-conservative pollutant

The two graphs below (Figure 3) show the comparison of the concentration-time curves between non-conservative pollutants with different decay constants, K=0.1/day and K=10/day. As anticipated, the pollutants with higher decay constant shows lower concentration than the one with lower decay constant, with peak concentration 4kg/m^3 and 3.6kg/m^3 respectively.



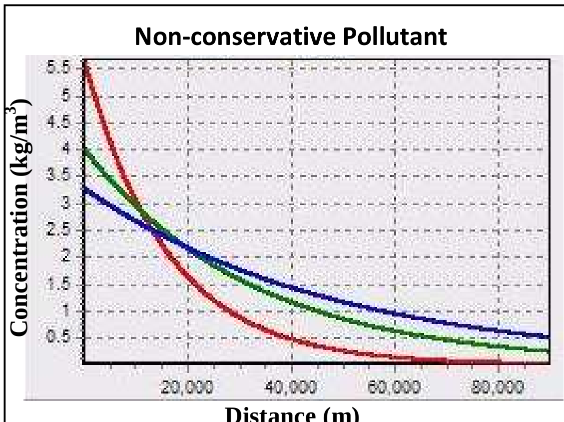
(a)K = 0.1/day



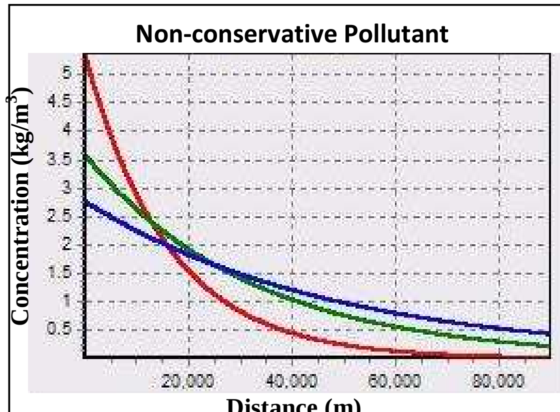
(b) K= 10/day

Figure 3. Concentration of pollutant as time elapses taken at three different points x down the river from the point source (red x= 300m, green: x= 600m, blue: x=900m)

The concentration-distance curves (Figure 4) of the pollutants with different decay constant show similar trends but have a slight difference in concentration. Pollutant with K=0.1/day has a peak concentration of 5.6 kg/m^3 while pollutant with K= 10/day has 5.4kg/m^3.



(a) K=0.1/day



(b) K=10/day

Figure 4. Concentration of pollutant as distance increases downstream from the point source taken at three different times t (red : t= 500s, green: t= 1000s, blue: t=1500s)

Recalculation of Dispersion Coefficient Using Method of Moments

The dispersion coefficient D was recalculated using the method of moments (Eq. v) to verify the validity of the dispersion coefficient used. Using the concentration time curve, the following calculations were undertaken:

Variance at T2 (σ_{t2}) = 827677.4001 s ; T2 = 2000 s

Variance at T1 (σ_{t1}) = 827666.6667 s ; T1 = 995 s

$$D = \frac{(0.034499)^2}{2} \left[(827677.4001)^2 - (827666.6667)^2/(2000 - 995)\right]$$

D = 10.51745215 m^2/s

The value D used is 11.07922 m^2/s which is relatively close to the recalculated value. This shows that the D used for the calculations is valid.

Case 3: Songhua River, China spill

The Songhua river spill in China happened in November 2005. An approximately 100 tons of toxic substances made up of a mixture of benzene, aniline and nitrobenzene (UNEP, 2005) entered the Songhua River and a plume of contamination started flowing downstream. The toxic substances are from an explosion occurred at a petrochemical plant of the Jilin Petrochemical Corporation in Jilin Province, China. The simulation that was done in the case of China spill is in principle the same as the previous simulations. However in this case, some of the parameters are changed such as the length, and the roughness coefficient to capture the nearest to actual configuration of the Songhua River. The pollutant was classified to be as conservative and due to lack of data on the amount of each of the three identified pollutants, the bulk mass which is 100 tons was used for the simulation.

Similar to the previous simulations, the trends of the concentration-distance and concentration-time graphs of the Songhua River pollution are the same (Figures 5 and 6). However, in this case the concentrations are much larger since the input mass is much higher than the previous cases.

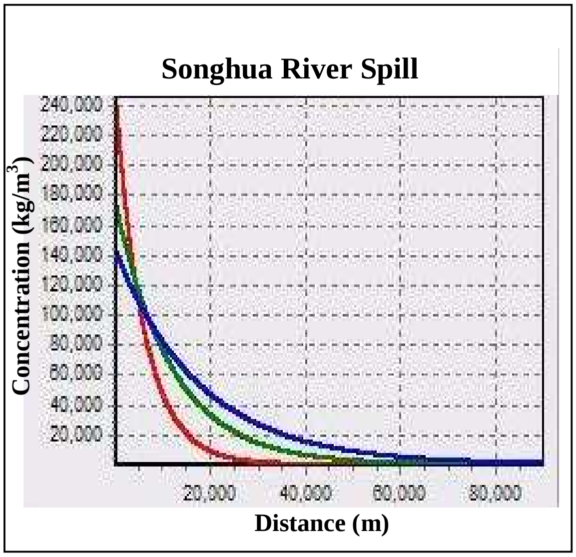


Figure 5. Concentration of pollutant as distance increases downstream from the point source taken at three different times t (red: t= 500s, green: t= 1000s, blue: t=1500s)

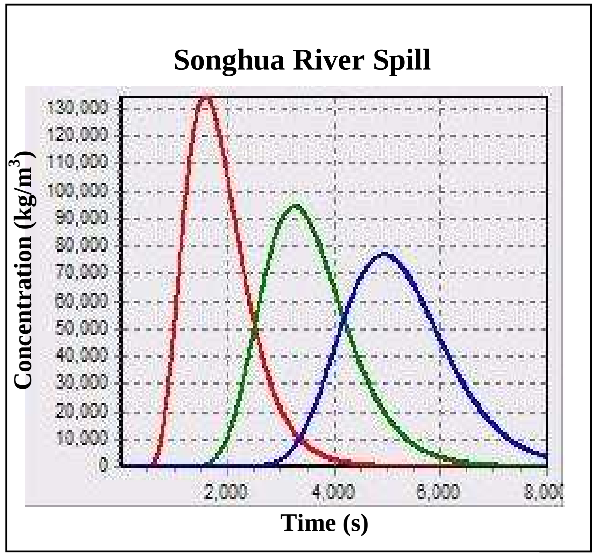


Figure 6. Concentration of pollutant as time elapses taken at three different points x down the river from the point source (red x= 300m, green: x= 600m, blue: x=900m)

Conclusions

The simulation of the fate and concentration of the pollutant in the river show parallel trends of results whether it is conservative or non-conservative. In general, for a pollutant from a point source, the concentration tends to decrease from the point source downstream as time elapses. However there is a time when the concentration increases downstream. This happens when all of the pollutants from the point have all been transported down and no recharge of pollutant happens. It must also be noted that the conservative pollutant show higher concentration than the non-conservative pollutant. This is because the mass of the former is conserved while the latter decays via various factors such as oxygen, water and so on. Furthermore, the higher the decay constant, the lower the concentration with respect to time becomes.

Recommendations

Like any other models, this project is ephemeral. Hence, it is imperative that the model should be validated through actual data and actual spill events. This is because many of the parameters such as the river cross section, length and Manning's roughness have been assumed and these assumptions might yield completely different results from the actual scenario. However, the basic ideas and methods are sufficient enough to be used as a guide when modeling such events.

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