Stream Pollution Remediation

A Freshman Engineering Design Project

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Overview:

Student teams are faced with a stream pollution scenario. Each team will be asked to develop a plan to respond to citizen complaints concerning phenol in the drinking water, which is creating a "disinfectant" taste. Each group will be assigned a perspective from which to view the situation. Teams will also be provided with three plans that have already been developed to respond to citizen complaints. Teams may adapt these plans or develop completely original plans.

Learning Objectives or Student Outcomes:

By the end of this lesson or activity, student teams will be able to

1. develop or modify a remediation plan to respond to a stream pollution scenario;
2. prepare a short written report to present and support their plan; and
3. make a brief oral presentation to introduce and justify the remediation plan before a mock public hearing.

Prior Knowledge Needed to Ensure Student Preparation:

- A basic understanding of conservation (accounting) principles
- A basic knowledge of general chemistry and general biology
- An understanding of analytical geometry and calculus principles

Team Size/Composition:

Teams of 4 work best; if necessary, a few teams of 3 or 5 students may be formed.

How is *positive interdependence* ensured?

Each team works together to develop one stream pollution remediation plan, one written report and one team oral presentation on that plan.

How is *individual accountability* ensured?

Individual accountability is ensured through the participation of **all** team members in the oral presentation of the remediation plan; in addition, peer assessments may be used.

Components of Assessment:

Students will be assessed based on the team written report and oral presentation and on any peer assessments conducted.

Team Skills Needed for Success:	
All team members must have the ability to communicate, cooperate and collaborate; they must also feel free to share their own ideas and to give and receive constructive feedback.	
How Are These Skills Emphasized?	
Team members are expected to be able to question and to discuss issues in an open-minded manner and to see perspectives other than those that have been self-formed. The assignment of roles (plant representatives, State Department of Environmental Quality, citizens, and mediator) in particular will help them to accomplish this. Team members should also be able to explore solutions that are innovative or creative, taking all different ideas into consideration. Students are also expected to have the willingness to expand their knowledge (and responsibility) beyond course (or job) requirements.	
Materials Needed by Students: • A computer and spreadsheet software • Handouts (see below)	**Materials Needed by Instructor:** • Handouts for students (see below)

Instructions to Students:

1 Project Description

Persons have complained that their drinking water has had a slight "disinfectant" taste to it. Samples indicate that a trace amount of phenol has indeed entered the treatment complex and that as little as 1 ppb can be detected by taste. The State Department of Environmental Quality [SDEQ], in cooperation with three plants whose discharges contain phenol-type compounds which might cause the problem, conducted three surveys along the stream course; one before and two just after two separate modifications at Plant 2.

The results of these surveys are shown in Table 1. The plant locations, relative to the drinking water intake, are shown in Figure 1. A segmented creek/river model is proposed to analyze this system. The segments used are also depicted in Figure 1.

In order to simulate chemical transport and fate in this stream course, a mathematical model is developed having the form of a partial differential equation:

$$[dC/dt] = - U [dC/dx] + R \qquad (1)$$

where C is the concentration of chemical (phenol), M/L^3
t is time, t
x is distance or stream mile, L
U is the stream velocity, L/t
R is the rate of disappearance of chemical from the stream, M/tL^3

In words, this equation states that the rate of change of chemical concentration with time is proportional to the rate of physical transport down the river course as measured at some location plus the rate of disappearance by reaction.

If the flow rates and plant discharges remain relatively constant over a given time frame, then equation (1) can be simplified to a steady state (time invariant) form expressed as an ordinary differential equation:

$$U\,[dC/dx] = R \qquad (2)$$

In words, this equation states that the change in concentration of a chemical as a function of stream distance is proportional to the rate of disappearance by reaction. In such streams the rate of disappearance by reaction can occur by either chemical or biological mechanisms.

Therefore, the value for R can be expressed as:

$$R = -(Ke + Kb)\,C \qquad (3)$$

where K_e is a rate constant controlled by biophysical extraction, (1/t), and
K_b is the rate constant associated with BOD satisfaction, (1/t)

In the absence of detailed stream data that would allow separating these mechanisms, it is often necessary to treat them as a lumped or overall rate constant, K, such that equation (3) simplifies to:

$$R = -K\,C \qquad (4)$$

Substitution into equation (2) results in:

$$U\,[dC/dx] = -K\,C \qquad (5)$$

This equation can be integrated between the limits $x = 0$, $C = C_o$ and $x = \infty$, $C = 0$ resulting in the following:

$$C = Co \exp[-Kx/U] \qquad (6)$$

where C_o is the initial concentration of chemical entering a segment, M/L^3.

When there is merging of two (or more) streams in a segment, C_o can be calculated as the average of the chemical composition after the streams merge:

$$C_o = [Q_rC_r + Q_tC_t]/[Q_r + Q_t] \qquad (7)$$

where C_r is the concentration of chemical in the main stream, M/L^3
Q_r is the volumetric flow rate in the main str
Q_t is the volumetric flow rate of the tributary or the plant discharge, L^3/t

Therefore, using equations (6) and (7), and data (See Table 2) that allows one to

	calculate the rate constants (usually from stream survey and laboratory analysis plans), the concentration of chemical in the stream at any location can be found.
2	**Developing a Model** Develop a spreadsheet that will allow you to calculate the concentration of chemicals throughout the stream (creek/river) course. Example headings for your spreadsheet are shown below. **Column** — **Label** 1 — Segment No. or Plant discharge location 2 — Stream Location, miles 3 — Reaction Rate Constant (k), 1/sec 4 — Stream Velocity, ft/sec 5 — Inlet Volumetric Flow to Segment (Q_{in}), cfs 6 — Inlet Concentration to Segment (C_{in}), ppb 7 — Mixed Concentration (C_o), ppb 8 — Exit Volumetric Flow from Segment (Q_{out}), cfs 9 — Exit Concentration from Segment (C_{out}), ppb Assume that the river and branch background concentrations of chemical are zero, but the creek background level upstream from the Plant 1 location is 5 ppb. *What would cause this chemical to have a background concentration of 5 ppb before the water reaches any man-made facility?* Compare your spreadsheet results with those given in Figure 2. If they are reasonably close, then proceed to the next exercise. If they are not, see instructor.

3	**Developing a Remediation Plan** You are now asked to develop a plan to respond to citizen complaints concerning phenol in the drinking water. Your group will be assigned the perspective of one of the following organizations: a) Plant 1, b) Plants 2 & 3, or c) the SDEQ Use your phenol transport model from step 1 to predict the effects of changing the plant discharge concentrations and discharge rates. Three plans (Scenarios A, B, and C) have already been developed to respond to citizen complaints. Teams may adapt these plans or develop completely original plans. More information for use in developing the remediation plan • Role Playing Considerations • What You Should Learn from this Special Problem • Questions and Ideas that Are Related to this Problem
4	**Deliverables** Your team will be asked to prepare a short written report to present and support your mitigation plan. Your reports will be graded on how well you search the literature, develop a logical solution, and concisely present your solution. Also, each team will make a brief (8-10 minute) oral presentation to introduce and justify the remediation plans before a mock public hearing. The purpose of your presentation is to persuade the “judge” and audience to adopt your plan. Members of competing teams will ask your team questions regarding your plan. Each member of the team is expected to contribute during this presentation.

Handouts:

- Table 1: Compilation of Creek and Stream Surveys
- Figure 1: Plant Locations, Relative to Drinking Water Intake
- Table 2: Reaction Rate Constant , K, as a Function of Creek Flow and Segment Number
- Figure 2: Concentration of Chemicals throughout the Stream
- Scenarios
- Role Playing Considerations
- What You Should Learn from this Special Problem
- Questions and Ideas that Are Related to this Problem

Table 1. Compilation of Creek and Stream Surveys

SURVEY 1 [1991]	PLANT PARAMETERS	1	2	3
RIVER FLOW = 20,000cfs	DISCHARGE RATE, Mgal/day	325	706	85
CREEK FLOW = 500cfs	DISCHARGE CONC, ppm	150	120	150
BRANCH FLOW = 50cfs	LOAD, lb/hr	16.8	29.4	4.4

SURVEY 2 [1992]	PLANT PARAMETERS	1	2	3
RIVER FLOW = 7,000cfs	DISCHARGERATE, Mgal/day	325	994	85
CREEK FLOW = 150cfs	DISCHARGECONC, ppm	150	19	150
BRANCH FLOW = 15cfs	LOAD, lb/hr	16.8	6.6	4.4

SURVEY 3 [1993]	PLANT PARAMETERS	1	2	3
RIVER FLOW = 15,000cfs	DISCHARGE RATE, Mgal/day	325	650	85
CREEK FLOW = 400cfs	DISCHARGE CONC, ppm	150	10	150
BRANCH FLOW = 40cfs	LOAD, lb/hr	16.8	2.2	4.4

NOTES:

Survey 1 was completed before any modifications were made at Plant 2.

Survey 2 was completed just after Plant 2 modifications which increased capacity (and therefore discharge rate from 706 to 994 Mgal/day), but decreased discharge concentration (from 120 to 19 ppm) as a result of the installation of a secondary treatment facility.

Survey 3 was completed just after Plant 2 installed a Discharge Reduction Modification (which reduced the rate from 994 to 650 Mgal/day) and improved the efficiency of the secondary treatment unit (reducing the concentration from 19 to 10 ppm).

Figure 1: Plant Locations, Relative to Drinking Water Intake

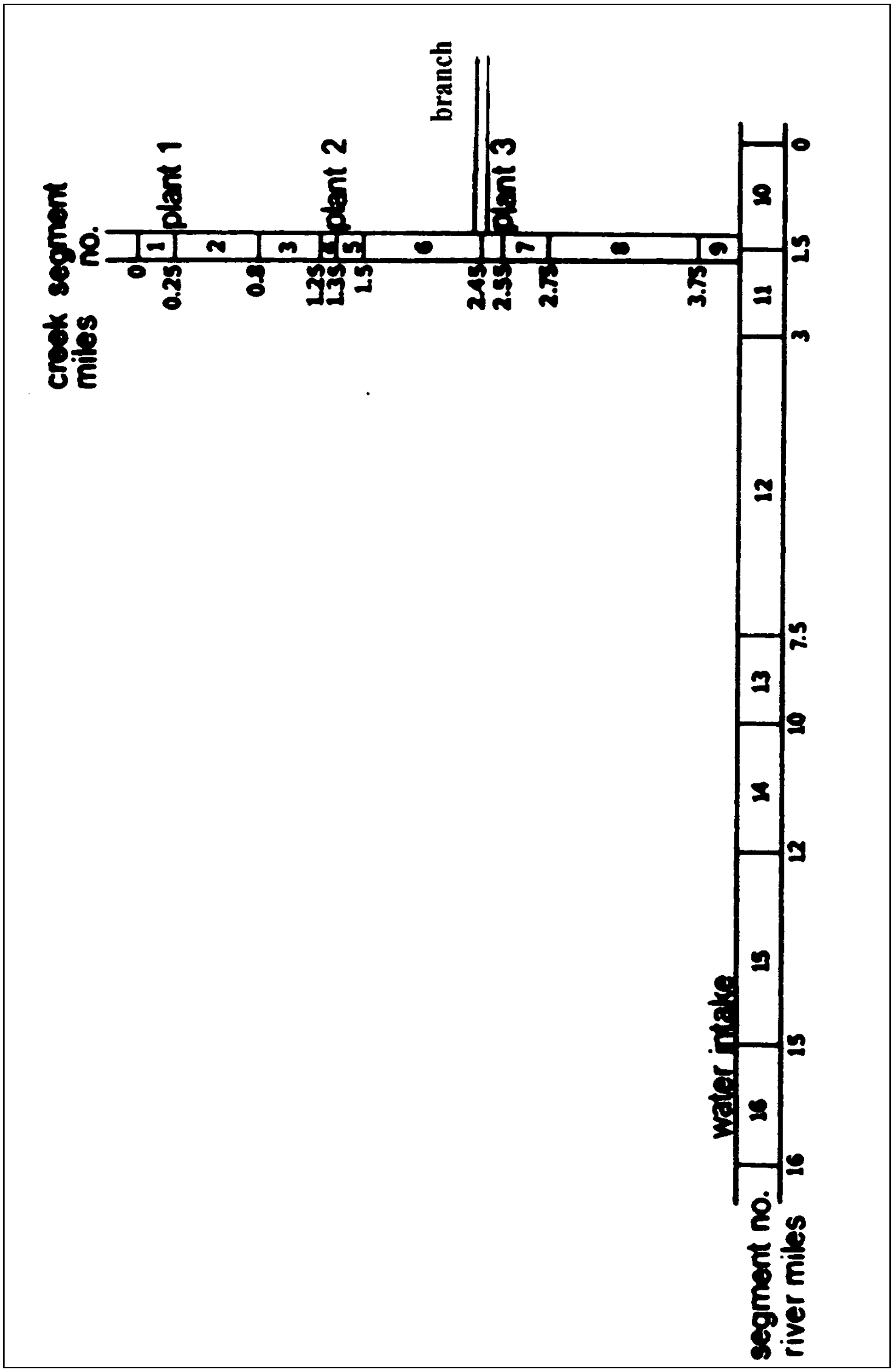
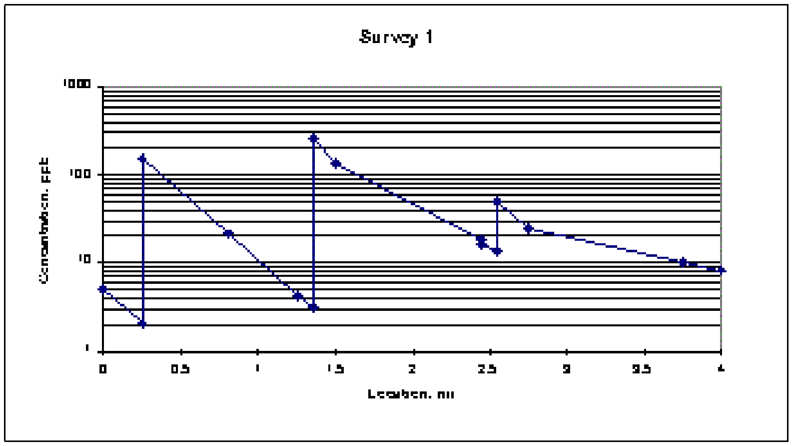


Table 2. Reaction Rate Constant , K, as a Function of Creek Flow and Segment Number

	CREEK FLOW, cfs	500	400	150	500	400	150
SEGMENT	CREEK PHYSICAL CONDITION	K VALUES			CREEK FLOW AREA		
		(1/sec x10^5)			(ft^2)		
1	shallow, rocky, plants	95	75	33	357	188	333
2	shallow, rocky, plants	95	75	33	358	188	334
Plant 1	shallow, rocky, plants	95	75	33			
3	shallow, rocky, plants	95	75	33	358	188	334
4	shallow, rocky, plants	99	77	34	250	188	250
5	shallow, rocky, plants	99	77	34	418	253	402
Plant 2	shallow, rocky, plants	99	77	34			
6	deep, smooth, no growth	44	34	15	460	278	442
7	shallow, rocky, plants	99	77	34	368	209	368
Branch	deep, smooth, no growth	44	34	15	63	38	50
Plant 3	shallow, rocky, plants	99	77	34			
8	deep, smooth, no growth	13	10	6	690	418	552
9	deep, smooth, no growth	13	10	6	690	418	552
River	deep, smooth, no growth	20	15	7			

NOTE: K values are interpolated from field data taken during March-September, 1991

Figure 2: Concentration of Chemicals throughout the Stream



Scenarios

Scenario A

Because of the chemical compositions noted at the creek/river location during the surveys (>5 ppb), the SDEQ proposes the following corrective action:

All plants along the creek must reduce their chemical discharge concentration by 90% below their current levels, that is:

Plant	1	2	3
CurrentConc,ppm	150	10	150
ReducedConc,ppm	15	1	15

such that the 5 ppb level is not exceeded at the 7 day-10 year low flow conditions (Survey 2 flowrates in Table 1).

Scenario B

Plant 2 challenges this action plan by stating that they have already met the reductions in 1992-1993 modifications (actually exceeded) that would be reached by Plant 1 and Plant 3 by this action. They say, for product sales price equity (prevention of unfair pricing for the same chemical among plants regulated at different discharge levels), Plant 1 and Plant 3 should first be required to reduce their concentration levels to that achieved by modifications at Plant 2.

Scenario C

The SDEQ counter proposes, after Plant 1 and Plant 3 representatives protest Scenario B, that the maximum chemical discharge per plant should not exceed 2 pounds of chemical per hour; with maximum target values for flow rate and concentration set at 0.5 cfs and 15 ppm, respectively. Therefore, based on this last action plan, the current operating level of each plant shows:

Plant	Target	1	2	3
Q,Mgal/day	325	325	[650]	85
Q,cfs	0.5	0.5	1.0	0.13
C,ppm	15	[150]	10	[150]
Discharge,lb/hr	2	[16.8]	[2.2]	[4.4]

Values in [ ] represent levels in excess of suggested maximums by the SDEQ
Mgal refers to thousands of gallons.

Therefore, each of the plants would have the following options available to them in order to meet the SDEQ rules (Scenario C):

	Current Levels	**Option A**	**Option B**
Plant1			
Q,Mgal/day	325	325	
C,ppm	150	15	
Discharge,lb/hr	16.8	2	
Plant2			
Q,Mgal/day	650	[591]	325
C,ppm	10	10	10
Discharge,lb/hr	2.2	2	1.2
Plant3			
Q,Mgal/day	85	85	85
C,ppm	150	[70]	15
Discharge,lb/hr	4.4	2	0.44

Consider these options as you develop your arguments for or against a given scenario.

Also consider in all scenarios in a qualitative sense, the economic factors that would ultimately need to be used to evaluate the cost/benefit of each scenario. For example the costs associated with reducing chemical from 1000 ppm to 100 ppm is far less expensive (secondary treatment) than in going from 100 ppm to 10 ppm (tertiary treatment) or even from 10 ppm to 1 ppm. Similarly, the cost of reducing volumetric discharges are tied directly to plant production and processing requirements. One might be able to reduce flows from 650 Mgal/day to 600 Mgal/day and accept slightly higher operating temperatures in the plant. But to go from 650 Mgal/day to 325 Mgal/day may require an entirely different process or major equipment changes.

Role Playing Considerations

Plant Representatives:
- What factors produce the most cost effective approach?
- Will changes result in unexpected improvements or just meet environmental standards?
- What is "fair" with regard to all plants since they are direct competitors?

State Department of Environmental Quality:
- Is plant regulation the only way to control taste problem in this system?
- Should the objective of the SDEQ be solely to keep the people happy?
- Can a "fairer" way be found that recognizes the concerns of the plants?

Citizens:
- Is the desire for clean drinking water a higher goal than other water uses?
- How will resulting changes in plant operations and costs impact on prices to the consumer?
- Who ultimately pays for the plant changes?

Mediator:
- Are there any other solutions that have not been considered?
- Are all of the important factors contributing to this problem identified?
- Is the model and the regulatory plan realistic?

What You Should Learn from this Special Problem

- The application of the conservation of mass law.
- The formulation of mathematical expressions representing the exchange of mass in a system.
- The method used to simplify a partial differential equation to an ordinary differential equation.
- The method used to solve the ordinary differential equation using boundary conditions.
- The application of the solution equations (or model) to a segmented grid system representing a stream.
- The concept of a reaction rate describing mass consumption by chemical/biological reaction.
- The implementation of the model using a spreadsheet.
- The limitations of the model and what it can and cannot describe about the system.
- The way that the model might be expanded to include more terms needed to describe a more complex array of system features.
- The kinds of data needed to implement a more sophisticated model.
- The reasons for implementing the model that is used.
- The analysis of the results produced by the model.
- The way that the results are used to address concerns of citizens, plant representatives and DEQ personnel.
- The way that consensus is reached through discussion of various environmental protection options.
- The role of perspective or point of view and its impact on the decision process.
- The method of presenting results and the way a technical report is used to implement a plan.
- The realization that real-world problems are seldom well defined (like textbook problems).
- The need to consider different points of view to arrive at a viable solution.
- The role of the engineer in addressing issues raised by different groups.
- The alternatives that might be used as a substitute for this method of analysis.

Questions and Ideas that Are Related to this Problem:

1. The disinfectant taste has been reported even though the model calculations show that the maximum concentration achieved under all the scenarios is less than 1 ppb. How does one explain this contradiction? How good is the model? What are the model limitations? Can phenol concentrations lower than 1 ppb be detected through taste? Are there other possible sources of phenol contamination in this system making the levels exceed 1 ppb?
2. In identifying the stream velocity, which is important in the model calculations, what is the best way to approximate the cross-sectional area of the stream? How does one measure the volumetric flow rate and the velocity of a stream?
3. What are the different things that the plants can do to improve phenol discharge levels? What are the economic implications involved with each choice? When should a process be changed to meet environmental standards in a stream?

