Simulation of 2D Transport of Phenol through a Confined Aquifer

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Abstract : Groundwater is one of the components of the hydrological cycle from which humanity gets the supply of water for domestic, industrial and agricultural use. The need for groundwater is increasing with the increase of population, industrialization, agriculture and navigation. Hence the conservation of the groundwater resources in quality and quantity deserves utmost attention. The quality of groundwater is judged by amount of the dissolved or suspended solutes present in it. The occurrences of groundwater contamination and quality of groundwater have become major issues. To understand the movement of contaminant in the groundwater, a physical model is developed and experiments were carried out. The experiment is conducted to study the transport of Phenol through groundwater aquifer under different slope conditions. The contaminant concentrations that are tested in above experiments were 100ppm, 75 ppm and 50 ppm. The slopes for the aquifer are 1:75 and 1:60. Graded sand in defined proportions was used as porous media. To understand the transport of Phenol in the aquifer, samples are collected at the time intervals of 24hrs after the introduction of contaminant into the aquifer and contours of transport of Phenol are plotted and compared.

***Keywords*:** Groundwater Aquifer, Physical Model, Phenol, Contaminant, Flow, Transport

I. INTRODUCTION

Groundwater is the most valuable source of potable water in world and groundwater aquifers are the storehouses. Since the beginning of civilization, mankind has thrived around the areas where groundwater resources are available. In 21st century, major irrigation and industrial projects are planned considering the availability of groundwater. Groundwater resource is judged by the criteria of quality and quantity. The quality of groundwater is judged by the amount of the dissolved or suspended solutes present in it [5].

The occurrences of groundwater contamination and quality of groundwater have become major issues since the discovery of numerous hazardous waste sites in the late seventies. Some of the important sources of groundwater contamination are: landfills, surface waste ponds, underground storage tanks, pipelines, and land applications of pesticides, radioactive waste disposal sites, salt water intrusion and mine drainage [3]. From these sources the pollution may be in the form of dissolved salts, domestic and industrial waste from distributed or point source, heat, radioactive materials, pesticides, manure etc.

Phenol is a major contaminant in groundwater aquifers and is designated as an extremely hazardous substance. EPA regulates Phenol under the Clean Water Act (CWA) and the Clean Air Act (CAA) [8]. Phenol contaminated water when used for human consumption results in diarrhea, mouth sores, dark urine and burning of mouth [8]. Groundwater investigations will help in understanding the flow and transport of such contaminants in spatial and temporal conditions.

The objective of a groundwater contamination investigation is to determine the presence and extent of dissolved or free-phase contaminants, as well as likely rate and direction of contaminant migration within the groundwater flow system. Any groundwater pollution study involves identification of the source of pollution, the movement of the pollutants in the groundwater environment once they are introduced, proper management of resource utilization and preventive measures to ensure suitable development and remediation of polluted sites [2]. A better understanding of the ways in which the spatial and temporal dynamics of physical habitat determines the groundwater flow, and how these elements can be incorporated, into assessment methods, is the key requirement for groundwater management [1]. Groundwater management involves making of decisions for achieving quality goals without violating site specified constraints and requires in depth information on the response of the managed system to proposed activities[9]. Any planning of mitigation or control measures, once contamination is detected in the saturated or unsaturated zones, requires the prediction of the path and the fate of contaminants, in response to the planned activities. Any monitoring or observation network must be based on the anticipated behavior of the system [6]. For generating the anticipated behavior of the contaminant in groundwater, numerical and physical models are prepared for the calculations of heads and flow and concentrations of contaminant.

In this study, a physical model of the aquifer is developed to understand the flow and transport of Phenol in groundwater aquifer. Porous media for the experimental work is selected. Slope conditions are introduced. Experiments are conducted for various conditions of slopes and Phenol concentrations of 100ppm, 75ppm and 50ppm. Experiments are conducted to study groundwater flow and transport of Phenol in the porous media for two different slope conditions (1: 60 and 1: 75) and graphs are plotted based on the readings taken.

II. Physical Model Development

To understand the flow and transport of Phenol in groundwater aquifer, physical model of the aquifer is fabricated. Initially, sand is selected as the porous medium for conducting experiments. Sand is washed and sundried and separated into fractions of 4.75mm, 2.36mm, 1.18 mm, 600 micron, 300 micron and 150 micron by sieving. The selected fractions are stored in different bags for further use. The selected porous media is 10% retained on 4.75mm sieve and 90% passing. The composition of the porous media is given in the Table 1.

The experiments are conducted to understand the transport of Phenol. A transparent tank is fabricated with glass tray of 1.5mX0.5mX0.07m. An Acrylic Sheet with laser cut grid 1.5mX0.5mX0.01m is installed in it [4]. Glass Tubes of 4mm diameter, 7cm long are inserted in it with rubber stops and one Acrylic Tap is attached at the downstream. The schematic diagram of the model and cross section are given in Fig. 1 and 2.

The porous media is spread upto 2cm thick at the bottom. Acrylic sheet with the glass tubes grid is placed in the tank. The glass tubes are arranged such that each tube is inserted 1cm into the porous media [7]. The tank is saturated with water. After 24 hrs, the level of water is reduced till 2cm. 50ml of contaminant solution with 100 ppm Phenol concentration is added at a fixed point in the tank. After 24 hrs, contaminant concentrations are recorded using colorimetry. Similar 2 more tests are performed in the tank with addition of 50ml of contaminant solution with 100 ppm for durations of 48hrs and 72 hrs, respectively. Contaminant concentrations were recorded using colorimetry. The experimental variations are given in the Table 2.

Results and Discussion

Groundwater pollution is observed at global level and its impact if felt across all the continents and demographics. Groundwater remediation methods like pump and treat or pump and use are commonly implemented. Contaminant like Phenol is being prominently noted in developed and developing countries. In order to understand the flow and transport of Phenol in porous media, a physical model is developed and results are taken for 100ppm, 75ppm and 50ppm concentrations of Phenol with injection rate of 50ml/day. The properties of the media are derived from the conventional methods. The transport conditions are observed for two bottom slope (1:60 and 1:75) in a simulated confined aquifer.

The injection and monitoring wells are laid out on the physical model in the form of a grid. It is shown in Fig.2. For the simulation of groundwater flow, two slope conditions of 1:60 and 1:75 are introduced as shown in Fig.3. Grid pattern used for the study is shown in Fig. 4. The results of 100ppm, 75ppm and 50ppm for two slopes of 1:60 and 1:75 with injection rate of 50ml/day are shown in Fig.5.

It is observed that the spread of contaminant deceases with reduction in the contaminant concentration and insertion of Phenol. For all the results, the distance of travel of transport is also measured. These results are compared for the transport of Phenol from the injection well to the distance covered for Phenol to be in 40ppm, 30ppm, 20ppm, 10ppm and 5ppm concentrations. The results are shown in Table 3 and Table 4.

Spread of 40ppm and 5ppm concentrations for initial concentration of 100ppm Phenol in 1:60 slope is 0.83m and 1.216m while for the slope 1:75 was 0.52m and 1.16m. Similarly, the spread of 40ppm and 5ppm concentrations for initial concentration of 75ppm Phenol in 1:60 slope is 0.75m and 1.23m and 0.788m and 1.124m for 1:75. As well, the spread of 40ppm and 5ppm concentrations for initial concentration of 50ppm Phenol in 1:60 slope was 0.13m and 0.77m and for 1:75 slopes it was 0.21m and 0.75m respectively. It is observed that the spread of contaminant increases with the increase of the slope.

The percentage increase in the spread of Phenol with respect to time progressed after injection is shown in Table 5.

It is observed that percentage of Phenol spread is the highest in 1:60 slope. As the contaminant Phenol is injected after every 24hr time interval, it is observed that higher the concentration of Phenol more is the percentage spread.

With the use of the physical model developed, further studies on contaminants can be conducted with different types with variations in concentrations, slope conditions and porous media. The decay rate of contaminant with respect to the spread of plume can also be studied using the developed physical model. Also this study was a pre-requisite to see the effectiveness of *in situ* bioremediation of Phenol.

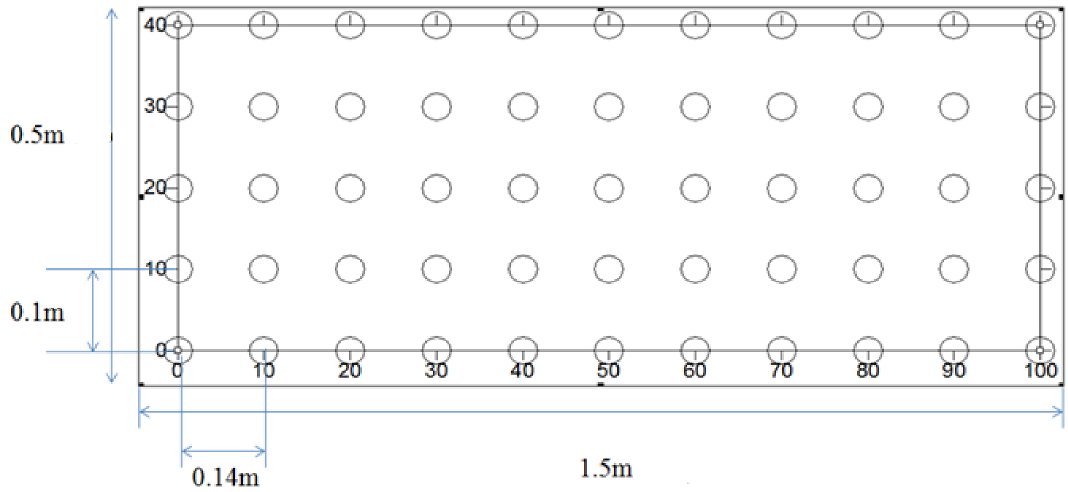


Fig.1 Schematic of the Physical Model

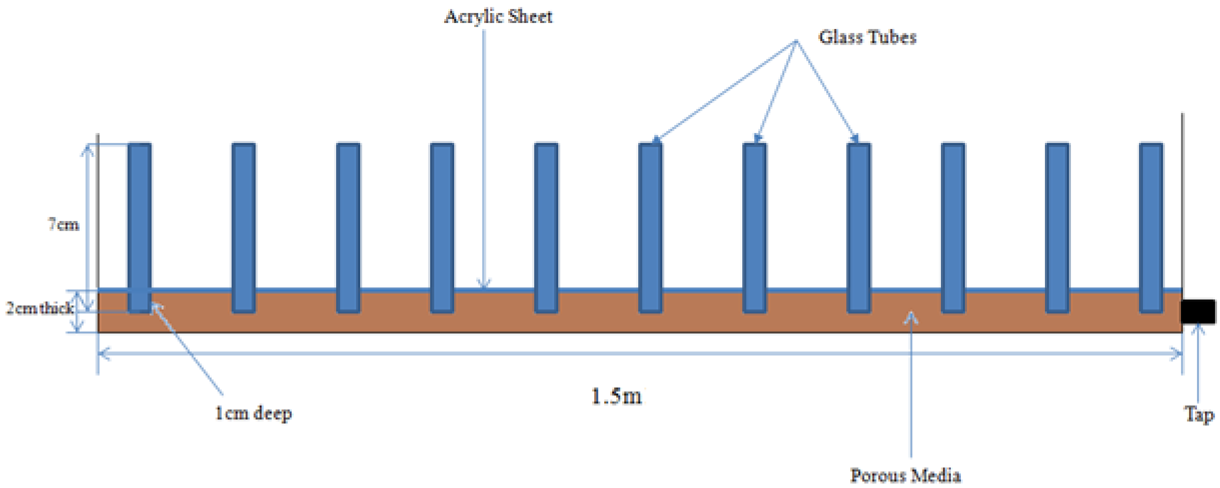
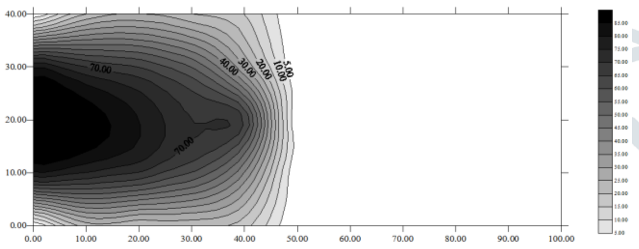
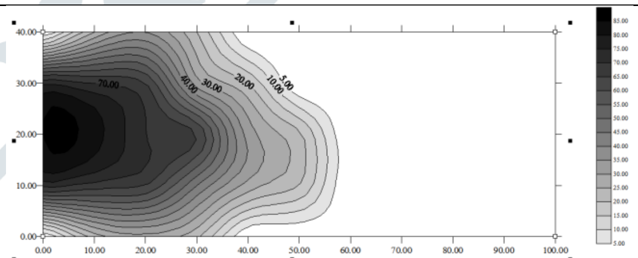
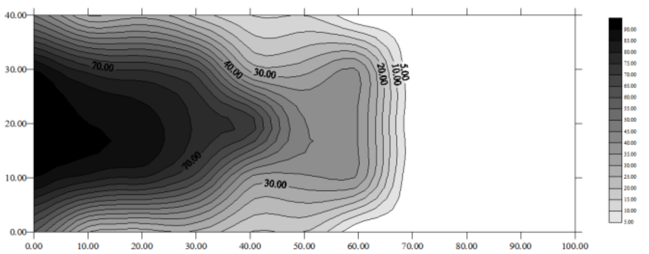
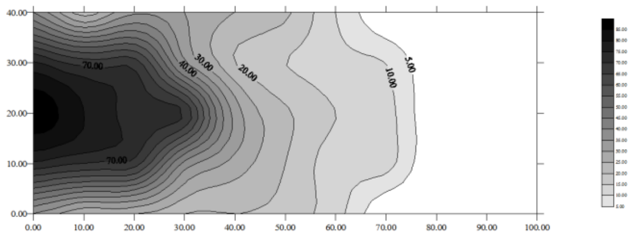
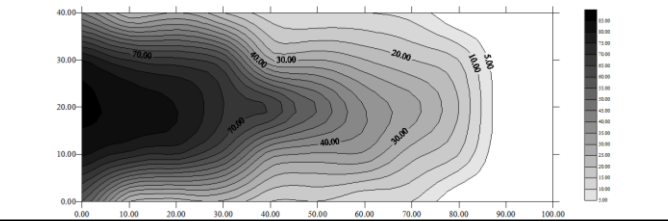
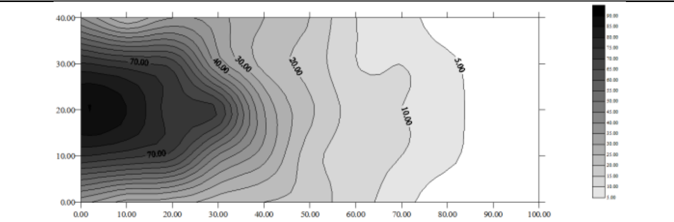
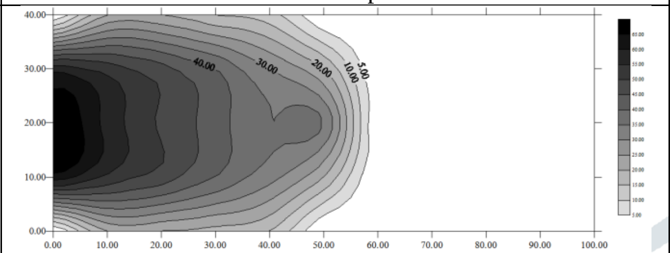
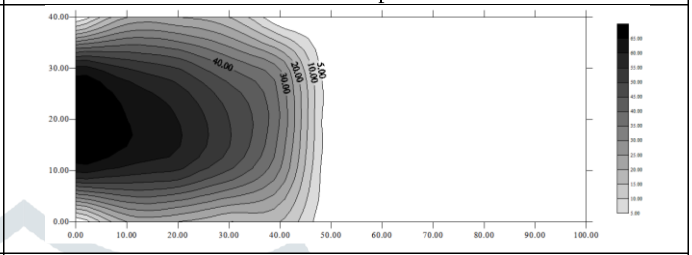
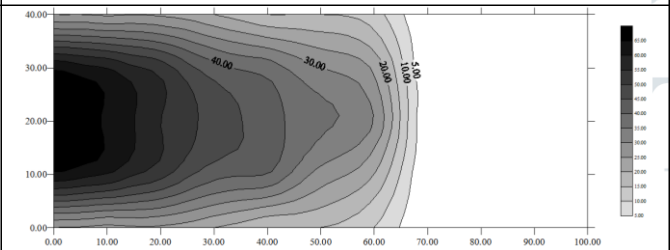
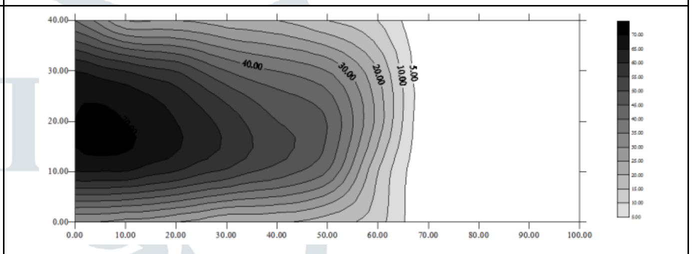
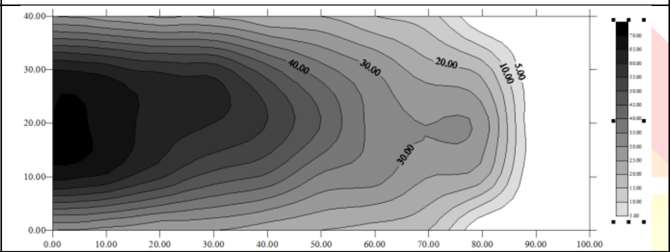
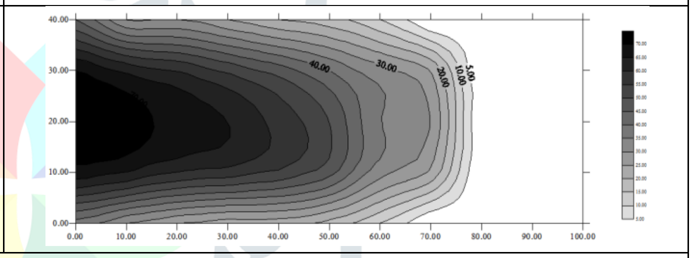
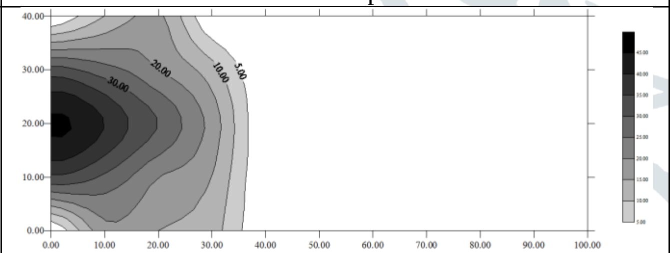
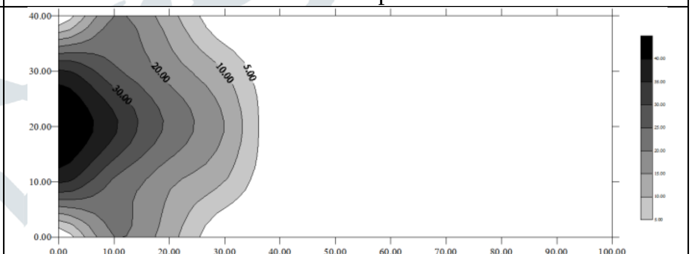
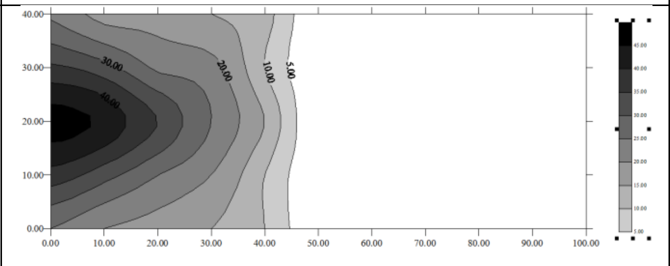
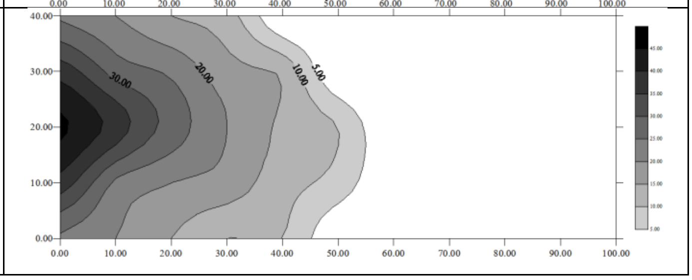


Fig. 2 Cross Section of the Physical Model

	Grid Patter of Injection wells and Monitoring wells for Simulated Groundwater Aquifer											
	A	B	C	D	E	F	G	H	I	J	K	*Marked Corner
1	A1	B1	C1	D1	E1	F1	G1	H1	I1	J1	K1	
2	A2	B2	C2	D2	E2	F2	G2	H2	I2	J2	K2	
3	A3	B3	C3	D3	E3	F3	G3	H3	I3	J3	K3	* Tap outlet
4	A4	B4	C4	D4	E4	F4	G4	H4	I4	J4	K4	
5	A5	B5	C5	D5	E5	F5	G5	H5	I5	J5	K5	

. Fig. 3: Grid Pattern used in the study

	Contours for transport of 100ppm Phenol in 1:60 and 1:75 Slope	
Set No	1:60 Slope	1:75 Slope
24hrs		
48hrs		

72hrs		
	Contours for transport of 75 ppm Phenol in 1:60 and 1:75 Slope	
	1:60 Slope	1:75 Slope
24hrs		
48hrs		
72hrs		
	Contours of contaminant transport for 50 ppm Phenol under 1:60 and 1:75 Slopes	
	1:60 Slope	1:75 Slope
24hrs		
48hrs		

72hrs

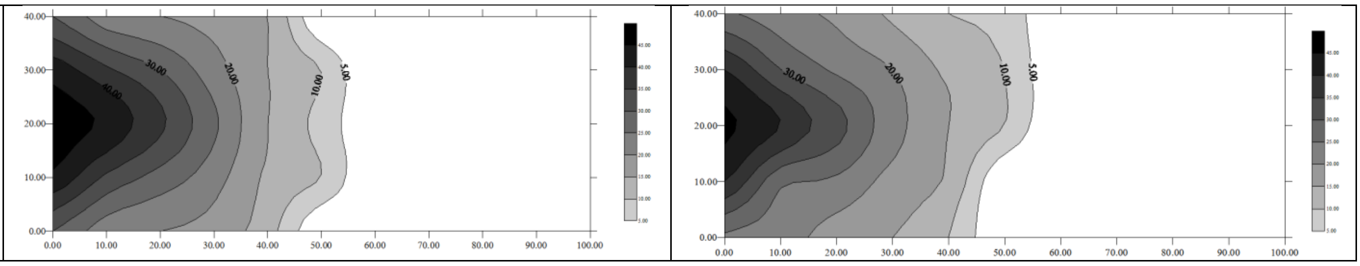


Fig. 5 Contours of contaminant transport for100ppm, 75ppm and 50 ppm Phenol under 1:60 and 1:75 Slopes

Table 1: Weight Percentage for Porous Media

Sieve	Weight	%
4.75 mm	3kgs	10%
2.36mm	1.5kgs	5%
1.18mm	12kgs	40%
600	12kgs	40%
150	1.5kgs	5%
Total:	30kgs	100%

Table 2: Experimental Variations for Transport of Phenol

Sr No.	Contaminant Solution Concentration (ppm)	Contaminant Solution Quantity (ml)	Slope
1	100ppm	50ml	1:60
2	100ppm	50ml	1:75
3	75ppm	50ml	1:60
4	75ppm	50ml	1:75
5	50ppm	50ml	1:60
6	50ppm	50ml	1:75

Table 3: Comparison of transport of 100 ppm and 75 ppm Phenol in 1:60 and 1:75 Slope

Sr No	Initial Concentration	Concentration	Slope	Distance from Entry Point	Slope	Distance from Entry Point
1	100 ppm after 24hrs	40 ppm	(1:60)	0.612m	(1:75)	0.52m
2		30 ppm		0.63m		0.58m
3		20 ppm		0.65m		0.64m
4		10 ppm		0.66m		0.73m
5		5 ppm		0.68m		0.79m
6	100 ppm after 48hrs	40 ppm	(1:60)	0.72m	(1:75)	0.51m
7		30 ppm		0.86m		0.58m
8		20 ppm		0.9m		0.72m
9		10 ppm		0.937m		0.1m
10		5 ppm		0.96m		1.06m
11	100 ppm after 72hrs	40 ppm	(1:60)	0.83m	(1:75)	0.52m
12		30 ppm		1m		0.58m
13		20 ppm		1.1m		0.72m
14		10 ppm		1.17m		0.98m
15		5 ppm		1.216m		1.16m
1	75 ppm after 24hrs	40 ppm	(1:60)	0.45m	(1:75)	0.52m
2		30 ppm		0.72m		0.58m

3		20 ppm		0.75m		0.61m
4		10 ppm		0.78m		0.55m
5		5 ppm		0.81m		0.77m
6	75 ppm after 48hrs	40 ppm	(1:60)	0.59m	(1:75)	0.73m
7		30 ppm		0.82m		0.79m
8		20 ppm		0.87m		0.849m
9		10 ppm		0.92m		0.902m
10		5 ppm		0.94m		0.936m
11	75 ppm after 72hrs	40 ppm	(1:60)	0.75m	(1:75)	0.788m
12		30 ppm		1.08m		0.972m
13		20 ppm		1.15m		1.024m
14		10 ppm		1.2m		1.068m
15		5 ppm		1.23m		1.124m

Table 4: Comparison of transport of 50 ppm Phenol in 1:60 and 1:75 Slope

Sr No	Initial Concentration	Concentration	Slope	Distance from Entry Point	Slope	Distance from Entry Point
1	50 ppm after 24hrs	40	(1:60)	0.09m	(1:75)	0.14
2		30		0.2m		0.28
3		20		0.34m		0.41m
4		10		0.47m		0.47m
5		5		0.51m		0.516m
6	50 ppm after 48hrs	40	(1:60)	0.1m	(1:75)	0.2m
7		30		0.23m		0.33m
8		20		0.42m		0.49m
9		10		0.69m		0.59m
10		5		0.75m		0.65m
11	50 ppm after 7hrs	40	(1:60)	0.13m	(1:75)	0.21m
12		30		0.31m		0.37m
13		20		0.45m		0.49m
14		10		0.69m		0.66m
15		5		0.77m		0.75m

Table 5: Percentage increase in the spread of Phenol with time

	1:60 Slope			1:75 Slope		
	100ppm	75ppm	50ppm	100ppm	75ppm	60ppm
5 ppm	78.8	51.9	51.0	46.8	46.0	45.3
10 ppm	77.3	53.8	46.8	34.2	94.2	40.4
20 ppm	69.2	53.3	32.4	12.5	67.9	19.5
30 ppm	58.7	50.0	55.0	0.0	67.6	32.1
40 ppm	35.6	66.7	44.4	0.0	51.5	50.0

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