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Optimal Quantitave and Distributive Analysis of Thermal Pollution due to Heated Water Released to Rivers

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Abstract

To reduce the effects of discharging heated water disposed into a river flow by a single thermal source, two parameters were changed to get the minimum effect using optimization. The first parameter is to distribute the total flow of the heated water between two disposal points (double source) instead of one and the second is to change the distance between these two points. In order to achieve the solution, a two dimensional numerical model was developed to simulate and predict the changes in temperature distribution in the river due to disposal of the heated water using these two points of disposal.

MATLAB-7 software was used to build a program that could solve the governing partial equations of thermal pollution in rivers by using the finite difference technique. The distribution of temperature in the river was presented by using the SURFER software that was used to draw the temperature contour lines and computing the areas of critical temperature (The area where the temperature exceed a certain selected value, which is believed to be critical for aquatic life). The optimum case was that which gave the minimum critical area.

The decision variables are the subdivided flow of the two disposal points, and the distance between these two points. The result had indicated that the optimum case can be achieved when the flow of first point was 0.1 from the total flow of heated water and the second was 0.9 from this total flow. The optimal distance between the two points was found to be 30 m.

Introduction

In many technological processes water is used as a cooling medium. Thermal pollution occurs when heated water is discharged into rivers, lakes, oceans, or other bodies of water. The heated water raises the temperature of water above its normal level and can harm animals and plants living in water. The major waste heat producing industries are: Steam electric generating plants (thermal or nuclear), Petroleum refineries, Steel mills, Chemical plants and etc.

Special attention is paid to electric generating plants where cooling water are mixed with the river. Steam generation of electric power plant requires rejection of tremendous quantities of waste heat typically 58% to 67% of the energy input to the plant from the generation units to the surrounding.

The heated water discharged directly to the river may increase the temperature of the water approximately more than 10 °C Andrzej [3].

Eugene R.Gilliland (1983) studied thermal pollution in Soonner Lake in April and found that the maximum difference in water temperature between heated and unheated area had warmed to 17 °C. In Iraq many studies of thermal pollution mentioned that the difference may reach more than 10 °C especially at summer season, Joody [8].

The heat discharged into a river or other moving water systems is mixed and dispersed within the receiving water; the heat is eventually transferred to the atmosphere by evaporation, radiation and/or as conduction of sensible heat. The temperature distribution downstream from the point of thermal discharge is determined by the hydrodynamic characteristics of the stream and the meteorological condition prevailing at the site.

The heated water discharged directly to the river can be more dangerous to the health of the receiving water than organic pollution. Higher temperature reduces solubility of oxygen and chemical reactions proceed at a faster pace Masters, [10]. Water temperature has an effect on the saturated oxygen value, which can be approximated as, APHA, [4]:

$$Cs=14.16-0.3943T+0.007741T^2-0.0000646T^3 \qquad (1)$$

<u>Where:</u>

Cs concentration of saturated oxygen soluble in water (mg/l) and T is the water temperature in (°C).

Iraqi legislations [14] do not mention allowable temperature of heated water discharge to the rivers but the minimum concentration of soluble oxygen is limited by 5 mg/l. According to Eq. 1, this value required that the temperature of the river should not exceed 50 °C. National Environmental health Forum Monographs [11] recommended that the temperature should not exceed 37 °C, in addition any change of aquatic environment due to the change in temperatures was considered as pollution and should be treated, Richard[13].

From above it can be concluded that removal of waste heat prior to discharge to a body of water has became necessary. One of the treatment methods that can be used to reduce the effects of heated water discharge is to change the mode of discharge, to reduce the effects to the minimum.

Many studies dealt with the problem of thermal pollution in water bodies. Some of these studies had presented and developed mathematical model to describe the thermal pollution in rivers.

Dea Geun Kim et. al. [6] studied the mixing of heated water which is discharged from a submerged multiport diffuser by using the three-dimensional grid-based numerical model. The laboratory experimental work has been conducted to investigate mixing characteristics of the coflowing diffuser. The following figure shows the schematic diagram of laboratory flume and experimental setup.

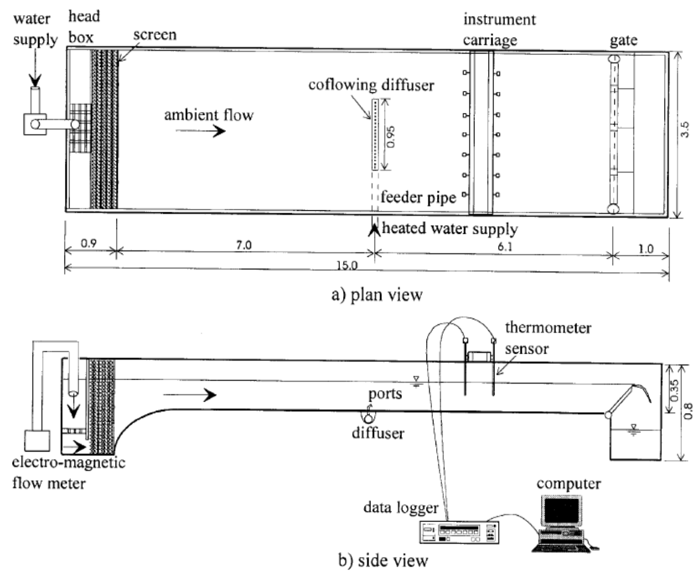


Fig. 1: Dea Geun Kim and et.al. (2000) Physical Modeling Apparatuses of Thermal Pollution.

A comparison of the model simulations with the laboratory experiments results showed that the proposed model properly simulated the shapes of thermal plumes and the distributions of excess temperature.

Li-Ren Yu et. al [9] had presented unsteady state two dimensional numerical models to simulate the velocity and temperature fields in the estuary of the Yangtza River in Brazil. Variations of bottom topography and water surface elevation were included. The distribution of velocity and temperature computed by turbulence model (k-ε) was compared with experimental results and field data. It was found that the simulation using the (k-ε) model can provide more details of flow and temperature distribution than the simulation by using the model of eddy viscosity and diffusivity.

Cakiroglu. C and Yurteri **.C** [5] presented mathematical models to predict the long- term effect of thermal pollution on local fish population. The fish life cycle model simulates different life stages of fish by using appropriate expressions represented by growth and mortality rates. The model was applied to a local fish species, githead (Sparus aurata), for the cause of a proposed power plant in Aegean region of Turkey. The simulation indicated that population reduction of about 2 % to 8 % in the long run, was observed.

Joody, Ali [8] developed one and two dimensional numerical models for simulation of the spread and mixing of thermally polluted water (single source) disposed into the river flow released from the Al-Doura Power Station starting from the outfall up to 1000 m downstream but the results showed that the effected river reach is within 150 m from the disposal point. A computer program was written by using Quick Basic language for computer programming. Comparison of the observed data on 3rd,Feb,2001 up to 27th,July,2001 with the data computed by the two dimensional model showed good agreement with a percentage error of 0.57 and 1.95 respectively.

Al-Mosewi, Tariq [1] studied the effect of the heated water released by a single source pipe from South Baghdad Electric Power Station to the Tigris River; for this purpose, a two dimensional numerical model was developed to simulate and predict the temperature distribution of the heated water. Momentum conservation equation and thermal energy equation were used to describe the distribution and diffusion of temperature along the river reach. Furthermore the model incorporated the (k-ε) model to calculate the distribution of turbulent viscosity along this reach. Fortran-77 programming language was used to write a program that solved the governing equations by using the (ADI) method.

The models mentioned in the above two references will be modified and developed to be used for solving *double-source* of heated water that is discharged into river flows. All the equations, assumptions, initial and boundary conditions in these models will be considered in the present study.

Al-Suhaili Rafa and Mohsin Jasim [2] applied two dimensional numerical model for estimating temperature distribution in a river. This model was found to be sensitive to the wind speed. A laboratory physical model was built to find experimental data. The comparison of the observed results from Al-Doura Power Station and laboratory physical model with those computed by the numerical model showed a good agreement and the maximum absolute difference percentage were 16.2 %, 8.6 % respectively.

Governing Equations and Mathematical Model of Thermal Pollution in Rivers

The proposed problem to be solved is shown in Fig.2. The thermal pollution source flow is qo, with to temperature level. This flow is to be subdivided into two flow fractions q1 and q2, the flow of the two disposal points respectively. The disposal points are L distance apart

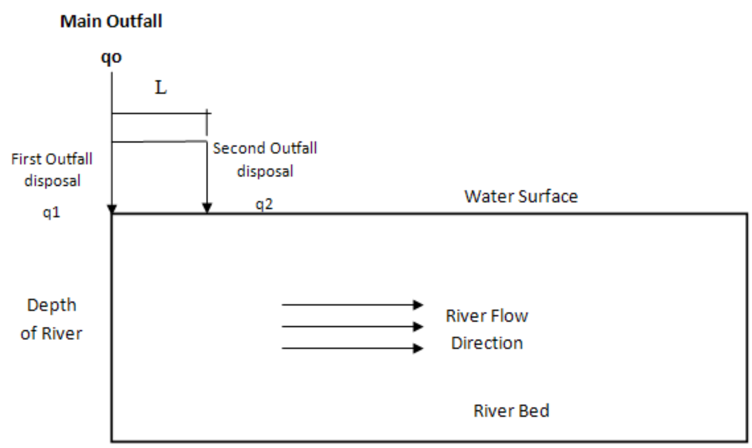


Fig. 2: Thermal Distribution Proposed Model.

The determination of the transport, mixing and dilution of heated water is important for the environmental impact study. In this case, it is very important to know the governing equations concerned with the mathematical model that describes the temperature and velocity distribution in a river. The equations that will be used in this research are (Rastogi and Rodi [12]):

1. Momentum Conservation equations (Navier-Stokes equation).
2. Thermal- energy equation.
3. K-ε turbulence model.
4. Density – temperature relationship of water.
5. Pressure distribution.

Eq. 1, 2 and 3 are considered as the governing differential equations, while the eq. 4 and 5 are the auxiliary equations.
By expanding the above equations to directional equations in Cartesian system the following can be obtained (Joody [8]):

Horizontal momentum equation:

$$\rho\frac{\partial U}{\partial t}+U\frac{\partial\rho U}{\partial X}+W\frac{\partial\rho U}{\partial Z}=\frac{\partial}{\partial X}\left(\mu\frac{\partial U}{\partial X}\right)+\frac{\partial}{\partial Z}\left(\mu\frac{\partial U}{\partial Z}\right)\qquad(2)$$

Vertical momentum equation:

$$\rho\frac{\partial W}{\partial t}+U\frac{\partial\rho W}{\partial X}+W\frac{\partial\rho W}{\partial Z}=\frac{\partial}{\partial X}\left(\mu\frac{\partial W}{\partial X}\right)+\frac{\partial}{\partial Z}\left(\mu\frac{\partial W}{\partial Z}\right)-\frac{\partial P}{\partial Z}+\rho g\qquad(3)$$

Thermal-Energy Equation:

$$\rho\frac{\partial T}{\partial t}+U\frac{\partial\rho T}{\partial X}+W\frac{\partial\rho T}{\partial Z}=\frac{\partial}{\partial X}\left(\frac{\mu}{\sigma}\frac{\partial T}{\partial X}\right)+\frac{\partial}{\partial Z}\left(\frac{\mu}{\sigma}\frac{\partial T}{\partial Z}\right)-\frac{\alpha(T-T_r)}{C_w.H}\qquad(4)$$

K- ε Turbulence Model:

$$\rho\frac{\partial K}{\partial t}+U\frac{\partial\rho K}{\partial X}+W\frac{\partial\rho K}{\partial Z}=\frac{\partial}{\partial X}\left(\frac{\mu}{\sigma_k}\frac{\partial K}{\partial X}\right)+\frac{\partial}{\partial Z}\left(\frac{\mu}{\sigma_k}\frac{\partial K}{\partial Z}\right)+G-\rho\varepsilon\qquad(5)$$

$$\rho\frac{\partial\varepsilon}{\partial t}+U\frac{\partial\rho\varepsilon}{\partial X}+W\frac{\partial\rho\varepsilon}{\partial Z}=\frac{\partial}{\partial X}\left(\frac{\mu}{\sigma_\varepsilon}\frac{\partial\varepsilon}{\partial X}\right)+\frac{\partial}{\partial Z}\left(\frac{\mu}{\sigma_\varepsilon}\frac{\partial\varepsilon}{\partial Z}\right)+C_1\frac{\varepsilon}{K}G-C_2\rho\frac{\varepsilon^2}{K}\qquad(6)$$

Equations 5 and 6 can be solved together with the mean flow equations to determine the two turbulence parameters and then to evaluate turbulent viscosity and diffusivity.

Where

$$G=\mu\left[2\left(\frac{\partial U}{\partial X}\right)^2+2\left(\frac{\partial W}{\partial Z}\right)^2+\left(\frac{\partial W}{\partial X}+\frac{\partial U}{\partial Z}\right)^2\right]\qquad(7)$$

The Pressure Distribution along the river depth can be presented as:

$$P=g\int_0^Z\rho dz\qquad(8)$$

The two dimensional numerical model includes the above partial differential equations, which takes into account momentum, buoyancy, diffusion, density stratification and surface heat exchange. These parameters will be presented in order to obtain an algebraic equation form to be solved by numerical solution. In this research, the unsteady spread and mixing processes of heated water disposed into a river flow will be studied. The governing equations are solved numerically using the Finite Difference method. This model is to be completed with the optimization model presented hear after to find the optimum flow fraction between the two disposed points and the optimal distance between these two disposal points.

Computer Program Description

A computer program is an essential research tool used to perform the computations of the simulation model. A computer program is written by MATLAB-7 that is considered as a powerful language for technical computing. The input data for the model is the length of the river, the average depth, slope of the river, roughness height, river velocity….etc.
The results will be printed as temperature distribution along the study reach after the run of the following steps for the first outfall pipe:

1. Reading the input data.
2. Calculating the density of Water River and heated water.
3. Calculating the viscosity of Water River and heated water.

4. Reading initial condition where time equals zero for each grid point and for all variables.
5. Reading boundary conditions for each grid point and for all variables.
6. Calculating the pressure, density and viscosity for each grid point.
7. Calculating velocity components and temperature at each grid point.
8. Calculating the distribution of turbulent viscosity at each grid point.
9. Return to steps from 6 to 8 after increasing time step.
10. Printing temperature at each grid point after reaching the final time.

The results of the temperature distribution in the river due to the double source thermal pollution will be plotted by using the SURFER program to draw the temperature contour lines.

The heat discharge into a river or other moving water system is mixed and dispersed within the receiving water; the equation of mixing is used to find the temperature of the mixing zone (tmix), which is an input variable required for the model.

$$\mathbf{tmix} = \frac{\mathbf{tr} * \mathbf{qr} + \mathbf{to} * \mathbf{qo}}{\mathbf{qr} + \mathbf{qo}} \qquad (9)$$

Where: tr=temperature of river, qr=flow of river, to=temperature of heated water, qo=flow of heated water.

Eventhough the model is for a double source thermal pollution, it can also be used as a single source pollution model. This can be done when the input data to the model simulate this case. This is by setting q2 and L as zero and q1=qo.

The Optimization Model

As mentioned above the aim is to find the optimal flow subdivision of the thermal source into two disposal points instead of one disposal point. These two disposal points are set at L distance apart.

The objective function of the optimization model is:

f(q1,q2, L)= Minimum (Area of critical water temperature)

= Minimum (Area of water temperature greater than the critical temperature)

= Minimum ($A_T > T_c$)

Subject to the following constraints:

$q1 \le qo$

$q2 \le qo$

$q1 + q2 = qo$

$t1 = t2 = to$

For the case of the double disposal point the mixing eq. (9) could be modified by substituting q1 and/or q2 instead of qo. The optimum solution could be found by computing the temperature distribution using the numerical model, and hence, the area of critical temperature for different sets of input values of the decision variables q1, q2 and L that satisfies the constraints.

Results and Discussion

Fig. 3 shows the temperature distribution along the river due to a single source thermal pollution, i.e. q1=qo , q2=0, L=0. This case was selected to allow for comparison with the cases of double source thermal pollution with different flow subdivision and different distance between the two thermal source pollution disposal points.

Table 1 Thermal Polluted Area for Different Critical Temperature value of the Single Source Pollution,q1=qo=2 m^3/sec, tr=35 ºC,to=48 ºC,q2=0,L=0, U=2 m/sec, qr=5 m^3/sec, time=100 sec

Temperature Critical T_c (ºC)	39	38	37
Thermal Polluted Area A_T (m^2)	57	83	59
Total Area (m^2)	199		

As mentioned before, the reduction of the effected areas (high temperature area) to the minimum value will be done by changing two parameters; the first is the division of the original heated water flow between two disposal points instead of one, and the second by changing the length between these two points. These parameters will be optimized to get the optimum decision. Before that the numerical model should be modified to describe the temperature distribution with two outfall pipes. The reduction of the high temperature area will be helpful in the reduction of the soluble oxygen depletion area.

The mathematical model will be applied on two disposal points instead of one. In other words the computer program will be applied for two points and this requires considering the data of the first disposal point result of step 10 of the computer program as an input data for the second outfall (disposal point), then repeating steps 1 to 10 of the computer program to compute the temperature distribution for the case of two disposal points.

The total flow of the heated water will be subdivided between these two disposal points with increments from 0.1 to 0.9 fractions. In addition the distance between these two points (L) will be selected as 10 m, 20 m, and 30 m. To study the effect of distance between the two disposal points the distance must begin with 10 m or more. The reason of choosing the lowest length of 10 m was arised from the fact gained from the application of the mathematical model, that within a distance less than 10 m little variation in temperature distribution was found due to the single source point.

Fig. 4 to 12, show the temperature distribution within the river reach resulting from different fraction divisions of the heated water flow between the two disposal points for a distance of (10 m) between them. Where q1 is the flow of the first disposal point and q2 is the flow of the second one, the total flow of the two pipes is qo as mentioned before, tr=35 ºC, qo=2 m^3/sec=q1+q2 , and time to reach these conditions=100 sec.

Table 2 shows the area of thermal pollution for three different critical temperatures 39, 38 and 37 °C calculated using the contours shown in the above figures; the cells that have minimum area value are shaded.

Table 2 Area of Critical Temperature for Different Flow Subdivisions and 10m Distance between the Two Disposal Points.

	Flow Increments	Occupied Area for each Contour			Total Area
		39 °C	38 °C	37 °C	
L=10 m	q1= 0.9, q2= 0.1	16.3	117.7	62.5	196.5
	q1= 0.8, q2= 0.2	10.2	114.5	68.3	193
	q1= 0.7, q2= 0.3	8.2	102	86	188
	q1= 0.6, q2= 0.4	6.8	52.2	122.5	181.5
	q1= 0.5, q2= 0.5	5.6	33.3	132.7	171.6
	q1= 0.4, q2= 0.6	4.5	24.5	126.8	155.8
	q1= 0.3, q2= 0.7	3.4	19.9	66.9	90.2
	q1= 0.2, q2= 0.8	2.4	**12.4**	51	63.4
	q1= 0.1, q2= 0.9	**1.54**	13.3	**34.8**	**48.1**

The above table shows that the area of critical temperature 39 °C contour line varied from 16.3 to 1.54 m^2 in which the minimum area occured at q1=0.1qo and q2=0.9qo while the minimum area of temperature 38 °C contour line was 12.4 m^2 at q1=0.2qo and q2=0.8qo, in addition the minimum area of temperature 37 °C was at q1=0.1qo and q2=0.9qo. So that it became obvious that the optimum case is obtained at q1=0.1qo and q2=0.9qo that gave he minimum critical area.

Figures (13, to 21) show the temperature distribution within the river reach resulting from different fraction divisions of the heated water flow between the two disposal points for distance of (20 m) between them.

Table 3 shows the area for three different critical temperatures 39,38 and 37 °C calculated using the contours shown in the above figures, the cells that have minimum area value are shaded. It can be concluded from table 3 that the minimum critical area will be at q1=0.1qo and q2=0.9, this may be due to the reason that the water river will retain its normal temperature before reaching to the second disposal point.

Table 3 Area of Critical Temperature for Different Flow Subdivisions and 20m Distance between the Two Disposal Points.

	Flow Increments	Occupied Area for each Contour			Total Area
		39 °C	38 °C	37 °C	
L=20 m	q1= 0.9, q2= 0.1	7.3	123.7	70	201
	q1= 0.8, q2= 0.2	6.38	113.2	77	197
	q1= 0.7, q2= 0.3	5.8	95.2	90	191
	q1= 0.6, q2= 0.4	5.24	46	131.6	183
	q1= 0.5, q2= 0.5	4.6	30.2	140.2	175
	q1= 0.4, q2= 0.6	3.8	23.5	127.5	151
	q1= 0.3, q2= 0.7	3	19.3	62.8	85.1
	q1= 0.2, q2= 0.8	2.2	16	43.6	61.7
	q1= 0.1, q2= 0.9	**1.45**	**13.1**	**33**	**47.5**

Figures (22, to 30) show the temperature distribution within the river reach resulted from different fraction divisions of the heated water flow between the two disposal points for distance of (30 m) between them.

Table 4 shows the area for three different critical temperatures 39,38 and 37 °C calculated using the contours shown in the above figures, the cells that have minimum area value are shaded.

Table 4 Area of Critical Temperature for Different Flow Subdivisions and 30m Distance between the Two Disposal Points.

L=30 m	Flow Increments	Occupied Area for each Contour			Total area
		39 °C	38 °C	37 °C	
	q1= 0.9, q2= 0.1	**0**	118	85	203
	q1= 0.8, q2= 0.2	0.9	101	95	197
	q1= 0.7, q2= 0.3	1.8	52.2	136	190
	q1= 0.6, q2= 0.4	2.4	32.8	143.8	179
	q1= 0.5, q2= 0.5	2.5	25.3	136	164
	q1= 0.4, q2= 0.6	2.4	21.1	88.5	112
	q1= 0.3, q2= 0.7	2.1	18	55	75
	q1= 0.2, q2= 0.8	1.73	15.3	41	58
	q1= 0.1, q2= 0.9	1.3	**12.7**	**32**	**46**

The above table shows that the area occupied by 39 C contour line varies from 0 to 2.5 m^2 and these values are considered small but the minimum area occupied by 38

L=20 m	**Flow increments**	**Occupied area for each contour**		**Total area**
		22 °C	21 °C	
	q1= 0.9, q2= 0.1	133	102	235
	q1= 0.8, q2= 0.2	122	110	232
	q1= 0.7, q2= 0.3	103	125	228
	q1= 0.6, q2= 0.4	82.5	148.5	231
	q1= 0.5, q2= 0.5	31.6	184	215.8
	q1= 0.4, q2= 0.6	25.7	179.3	205
	q1= 0.3, q2= 0.7	21	167.5	188.5
	q1= 0.2, q2= 0.8	17	104	121
	q1= 0.1, q2= 0.9	**13.8**	**67.8**	**81.6**

and 37 C contours lines are 12.7 and 32 m^2 respectively, so these values of occupied areas will assign the optimum associated decision variables qo, q1 for L=30 m.

From the above figures and tables it could be concluded that the optimum solution to reduce the effects of heated water discharge into rivers by the division of the heated water flow into two disposal points, the first one has 0.1 from total flow and the second has 0.9 from total flow and the distance between these two pipes of 30 m.

For winter season the average river water temperature

L=10 m	**Flow increments**	**Occupied area for each contour**		**Total area**
		22 °C	21 °C	
	q1= 0.9, q2= 0.1	134	93	227
	q1= 0.8, q2= 0.2	124	101	225
	q1= 0.7, q2= 0.3	109	113	222
	q1= 0.6, q2= 0.4	56	161	217
	q1= 0.5, q2= 0.5	33.8	177.8	211.6
	q1= 0.4, q2= 0.6	26.6	175.4	202
	q1= 0.3, q2= 0.7	22	171	193
	q1= 0.2, q2= 0.8	17.5	107	124.7
	q1= 0.1, q2= 0.9	**14**	**68.4**	**82.4**

could reach 20 °C and the temperature of heated water reach to 30 °C. So another difference of temperature data was used as input data for mathematical model, the following tables show the occupied area for water river temperature where the total affected area case of single outfall disposal point was equal to 228 m^2.

Table 5 Area of Critical Temperature for Different Flow Subdivisions and 10m Distance between the Two Disposal Points.

Table 6 Area of Critical Temperature for Different Flow Subdivisions and 20m Distance between the Two Disposal Points.

Table 7 Area of Critical Temperature for Different Flow Subdivisions and 30m Distance between the Two Disposal Points.

L=30 m	**Flow increments**	**Occupied area for each contour**		**Total area**
		22 °C	21 °C	
	q1= 0.9,q2= 0.1	120.7	120	241
	q1= 0.8,q2= 0.2	105	132	237
	q1= 0.7,q2= 0.3	55.5	177.5	233
	q1= 0.6,q2= 0.4	32	194	226
	q1= 0.5,q2= 0.5	26	191	217
	q1= 0.4,q2= 0.6	22.3	181.5	203.8
	q1= 0.3,q2= 0.7	18.9	161	180
	q1= 0.2,q2= 0.8	16	94.6	110.6
	q1= 0.1,q2= 0.9	**13.3**	**65.7**	**79**

Form the above tables the optimum case that gave the minimum area affected was still at distance 30 m between disposal points where flow of first point was equal to 0.1 from total flow and the second was 0.9 from the total flow.

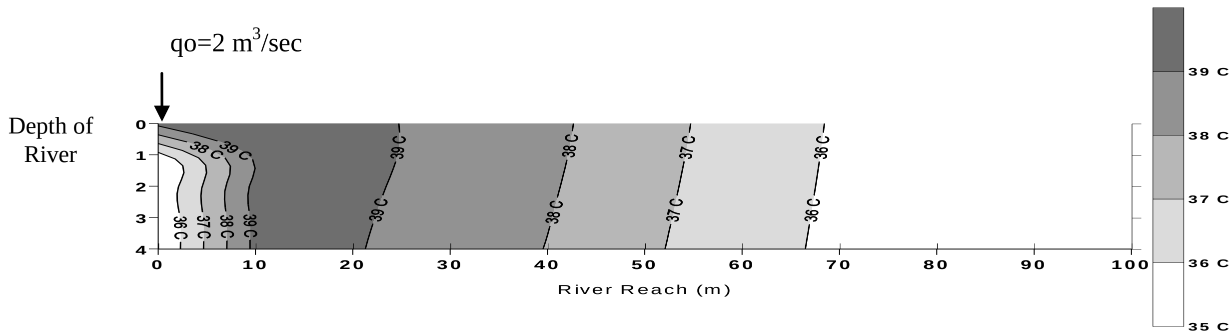


Fig. 3: Temperature Distribution from a Single Source Where tr=35 ºC and tmix=39.3 ºC.

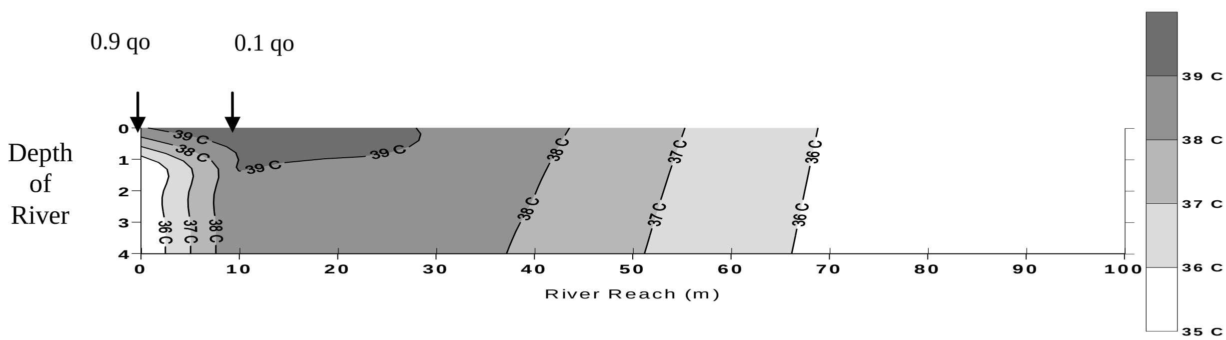


Fig. 4: Temperature Distribution where q1=0.9qo,q2=0.1qo.

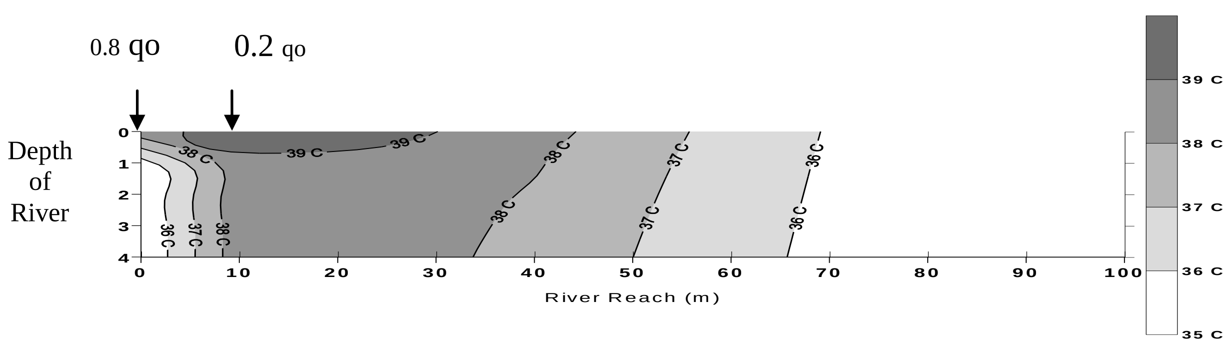


Fig. 5: Temperature Distribution where q1=0.8qo,q2=0.2qo.

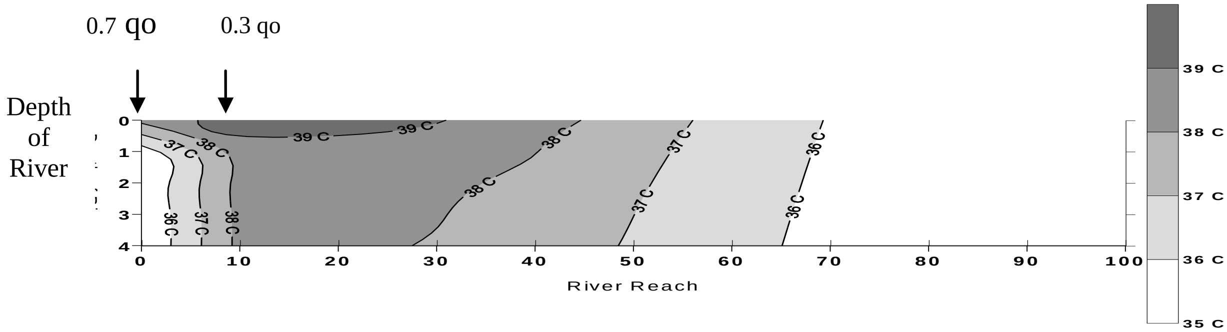


Fig. 6: Temperature Distribution where q1=0.7qo,q2=0.3qo.

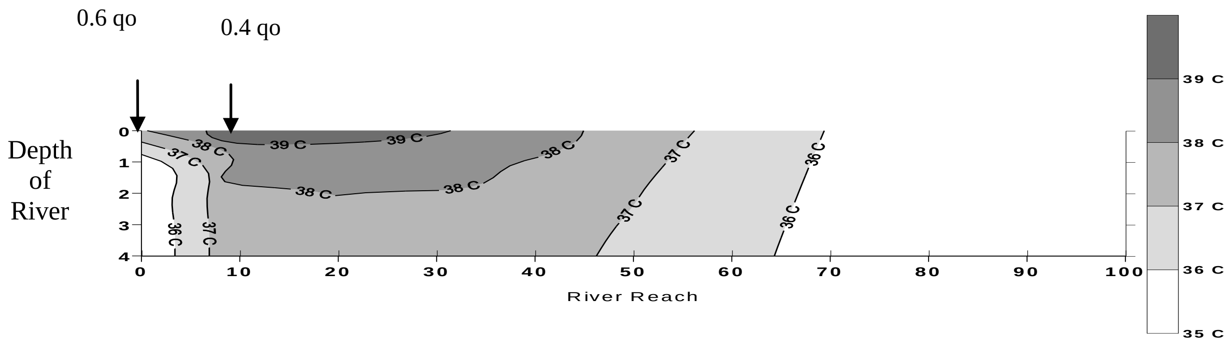


Fig. 7: Temperature Distribution where q1=0.6qo,q2=0.4qo.

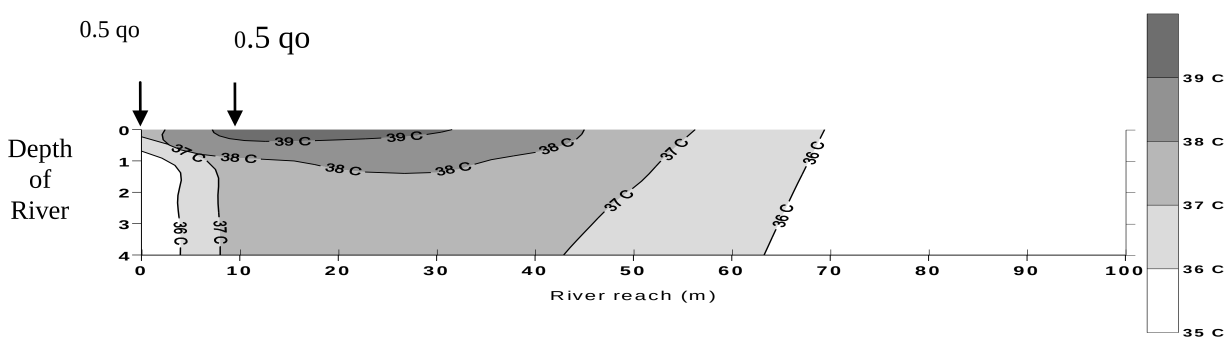


Fig. 8: Temperature Distribution where q1=0.5qo,q2=0.5qo.

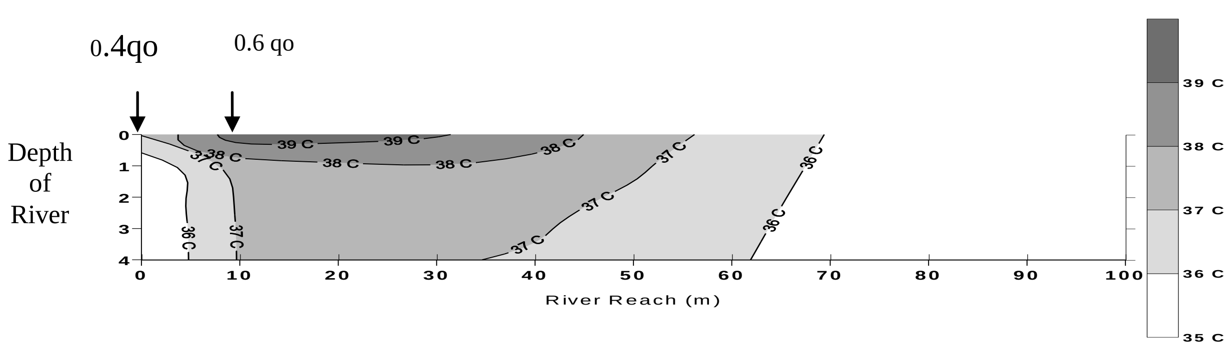


Fig. 9:Temperature Distribution where q1=0.4qo,q2=0.6qo.

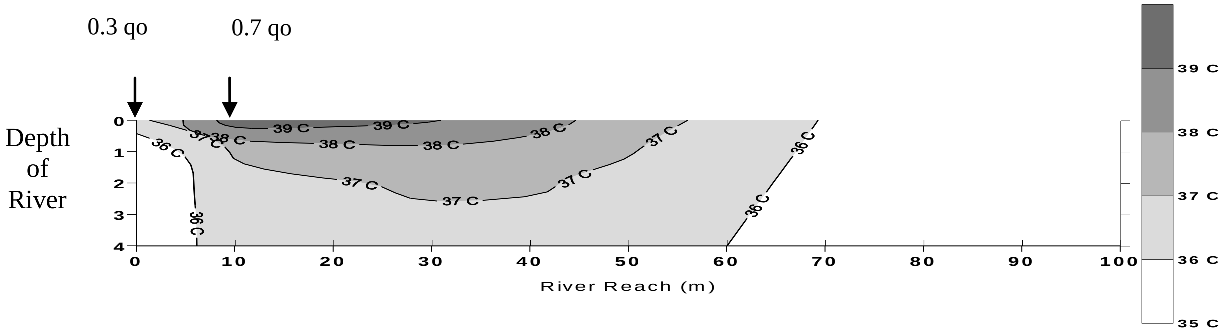


Fig. 10: Temperature Distribution where q1=0.3qo,q2=0.7qo.

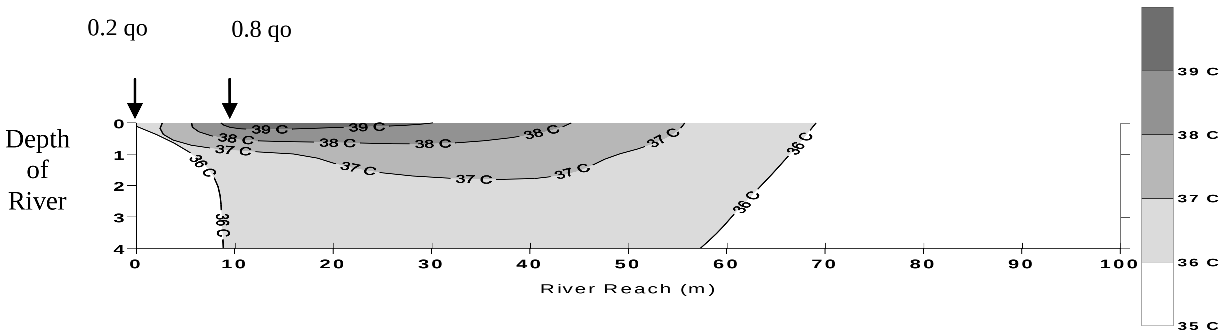


Fig. 11: Temperature Distribution where q1=0.2qo,q2=0.8qo.

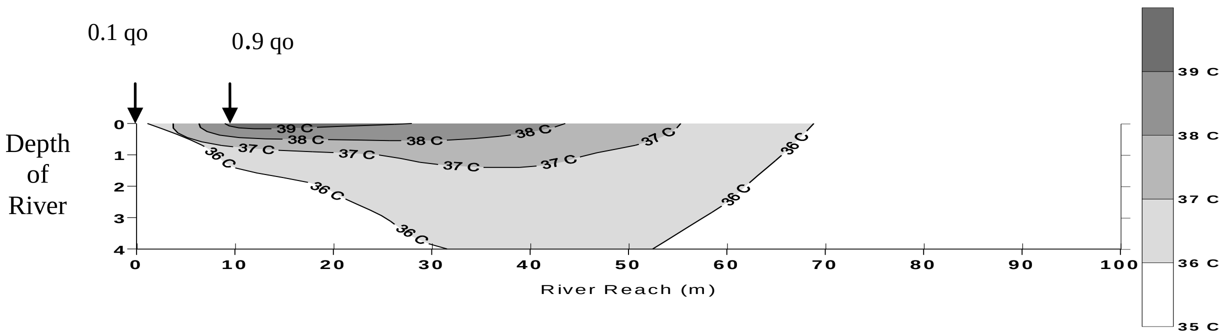


Fig.12: Temperature Distribution where q1=0.1qo,q2=0.9qo.

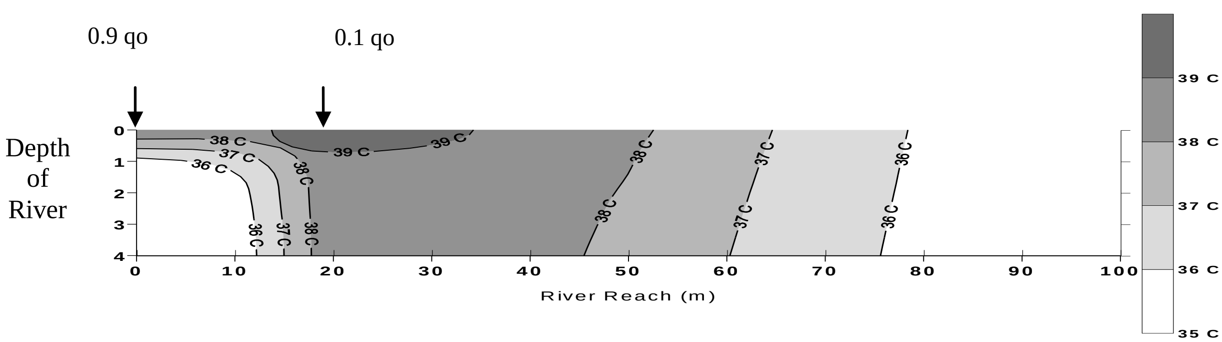
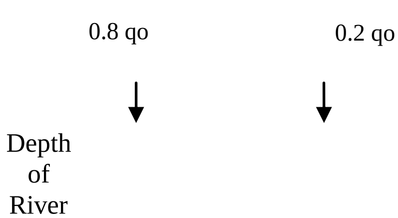


Fig. 13: Temperature Distribution where q1=0.9qo,q2=0.1qo.



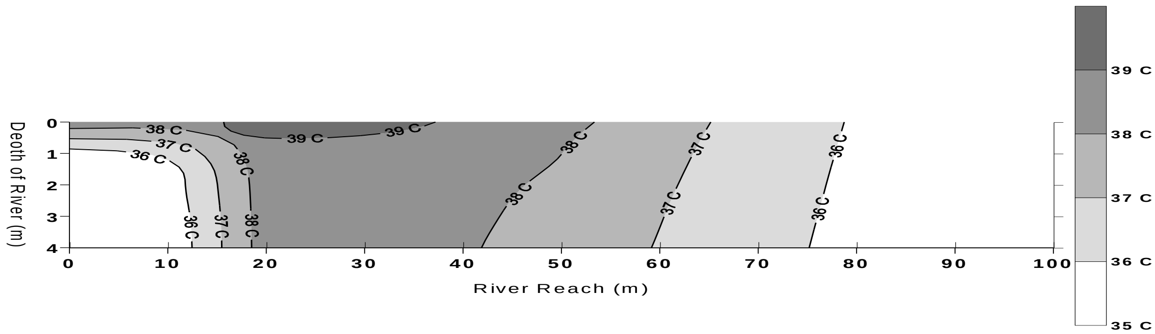


Fig. 14: Temperature Distribution where q1=0.8qo,q2=0.2qo.

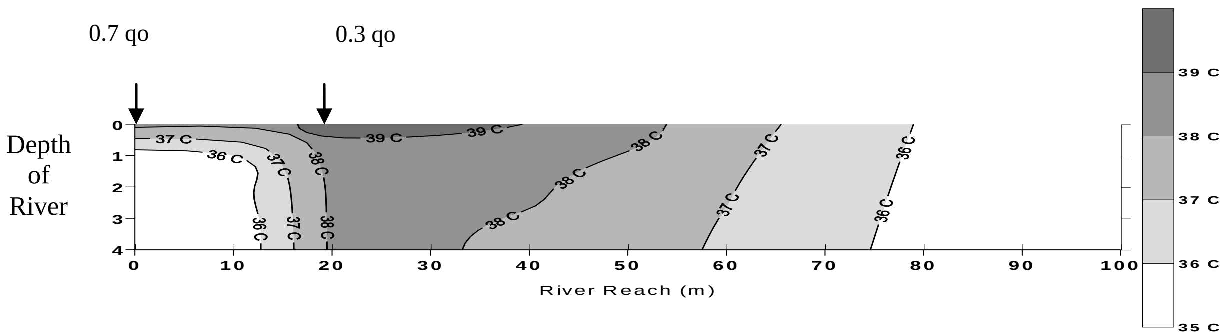


Fig. 15: Temperature Distribution where q1=0.7qo,q2=0.3qo.

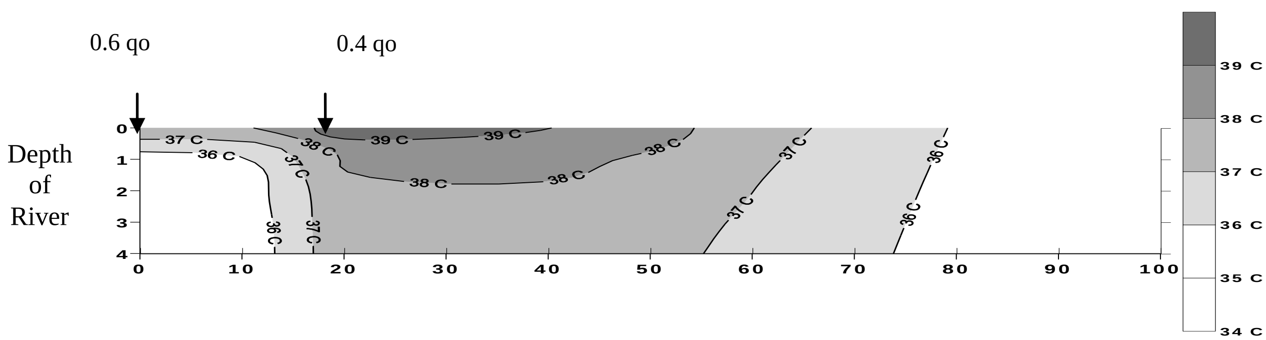


Fig. 16: Temperature Distribution where q1=0.6qo,q2=0.4qo.

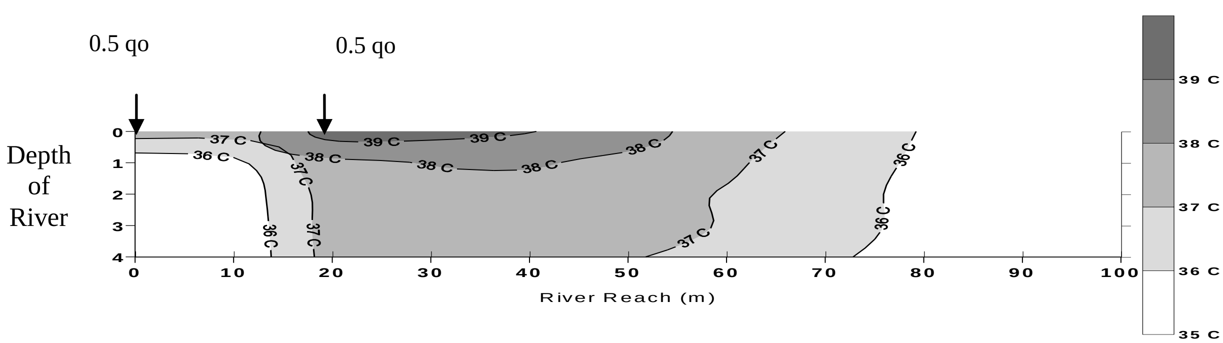


Fig. 17: Temperature Distribution where q1=0.5qo,q2=0.5qo.

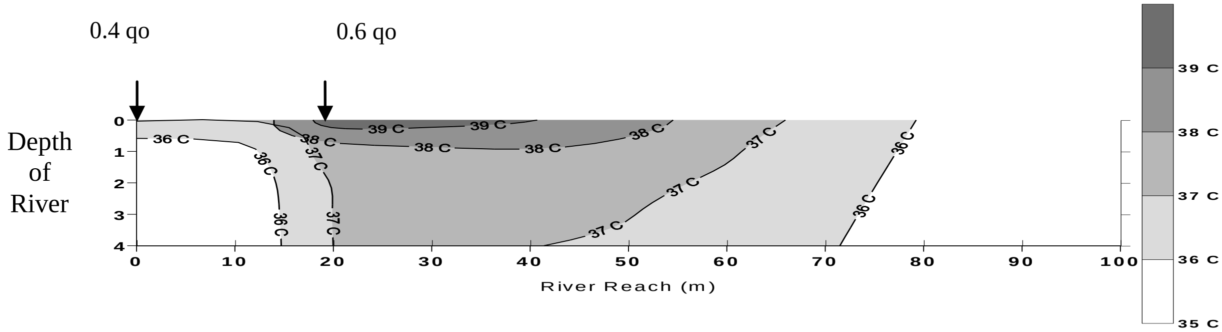


Fig. 18: Temperature Distribution where q1=0.4qo,q2=0.6qo.

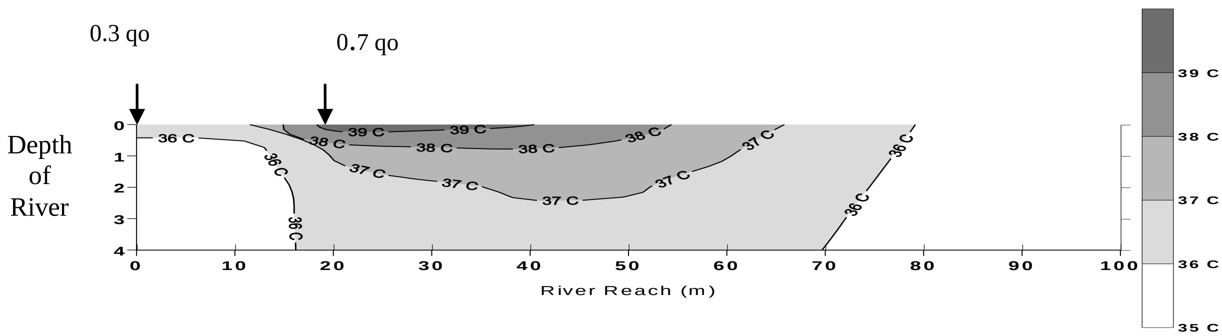


Fig. 19: Temperature Distribution where q1=0.3qo,q2=0.7qo.

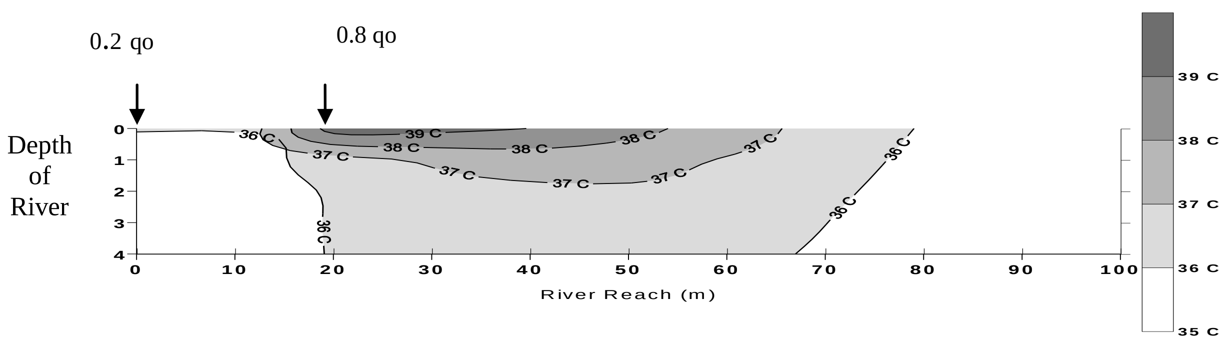


Fig. 20: Temperature Distribution where q1=0.2qo,q2=0.8qo.

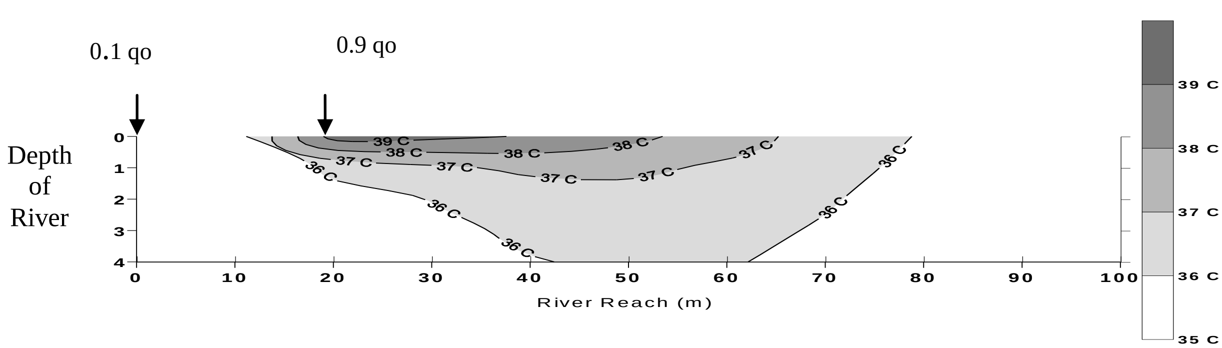


Fig. 21: Temperature Distribution where q1=0.1qo,q2=0.9qo.

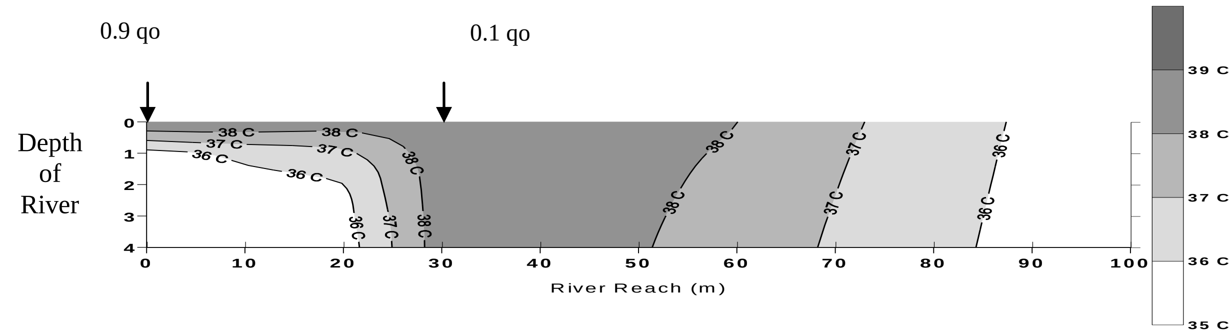


Fig. 22: Temperature Distribution where q1=0.9qo,q2=0.1qo.

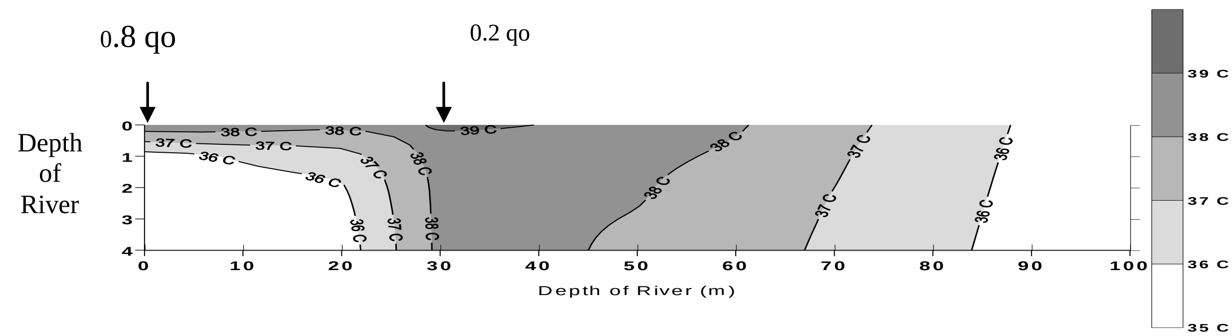


Fig. 23: Temperature Distribution where q1=0.8qo,q2=0.2qo.

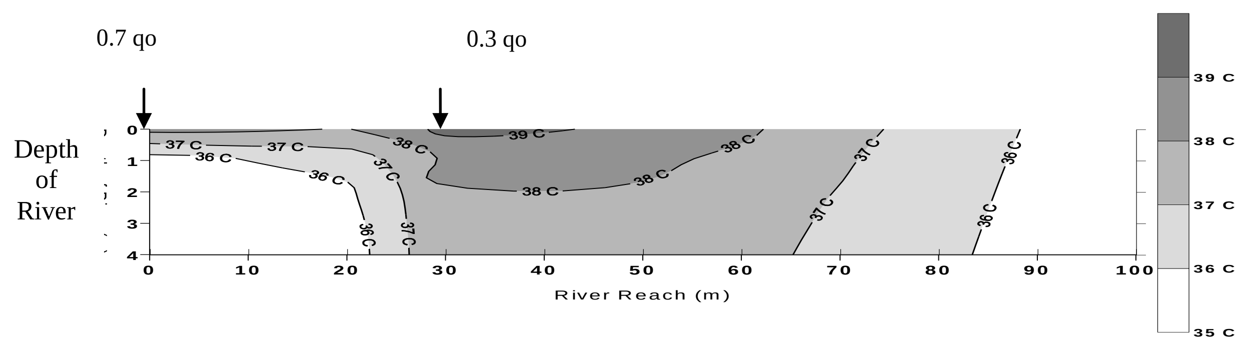


Fig. 24: Temperature Distribution where q1=0.7qo,q2=0.3qo.

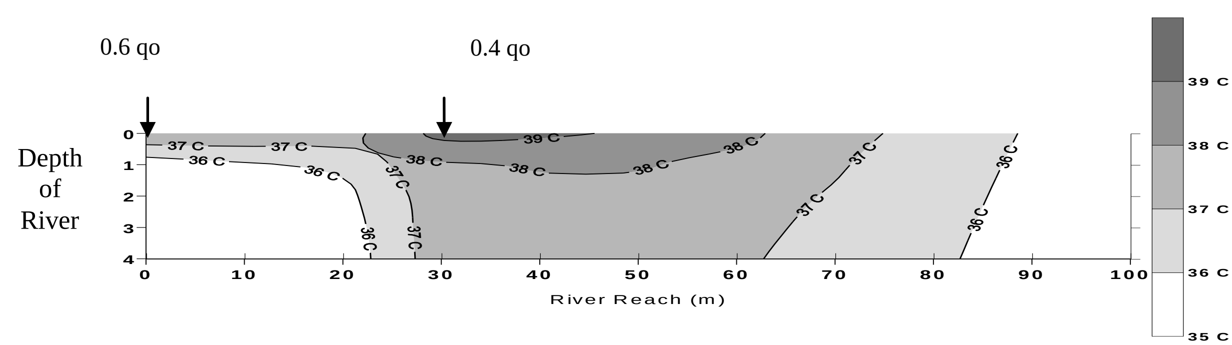


Fig. 25: Temperature Distribution where q1=0.6qo,q2=0.4qo.

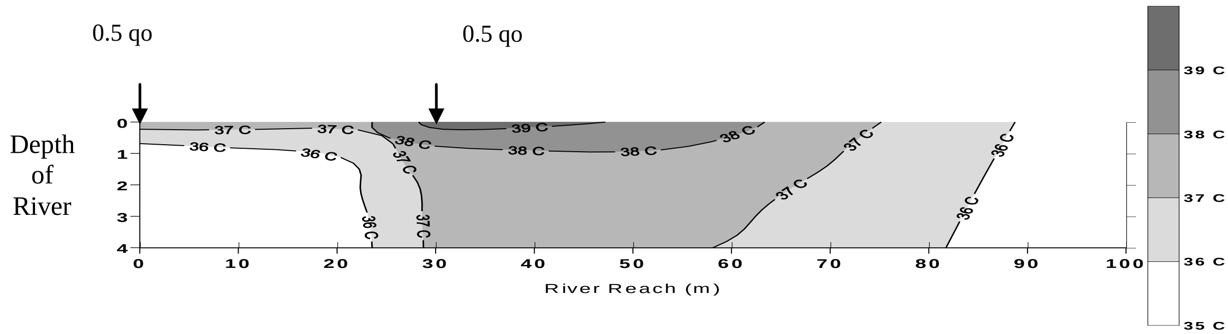


Fig. 26: Temperature Distribution where q1=0.5qo,q2=0.5qo.

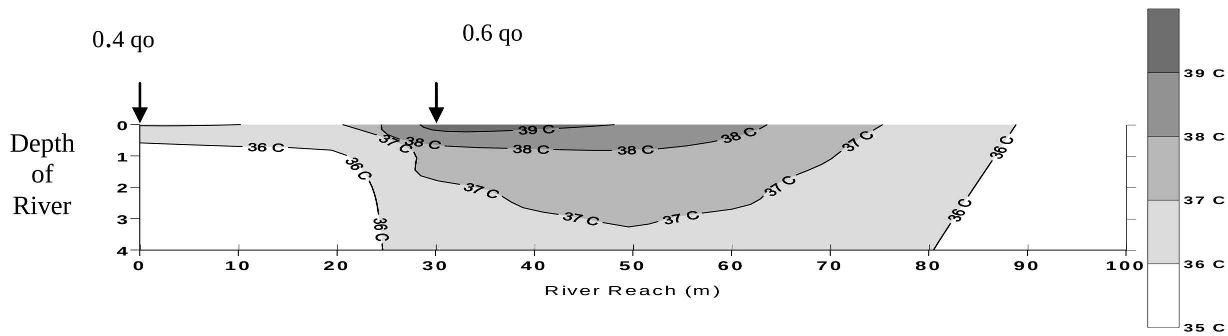


Fig. 27: Temperature Distribution where q1=0.4qo,q2=0.6qo.

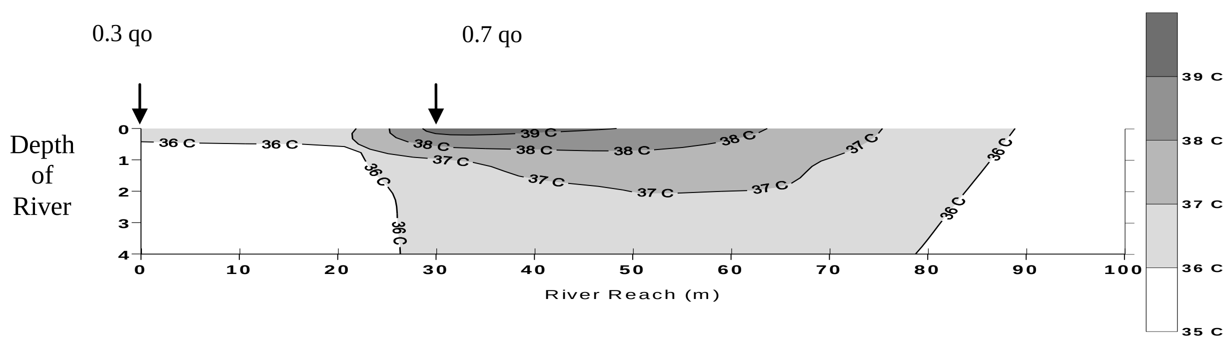


Fig. 28: Temperature Distribution where q1=0.3qo,q2=0.7qo.

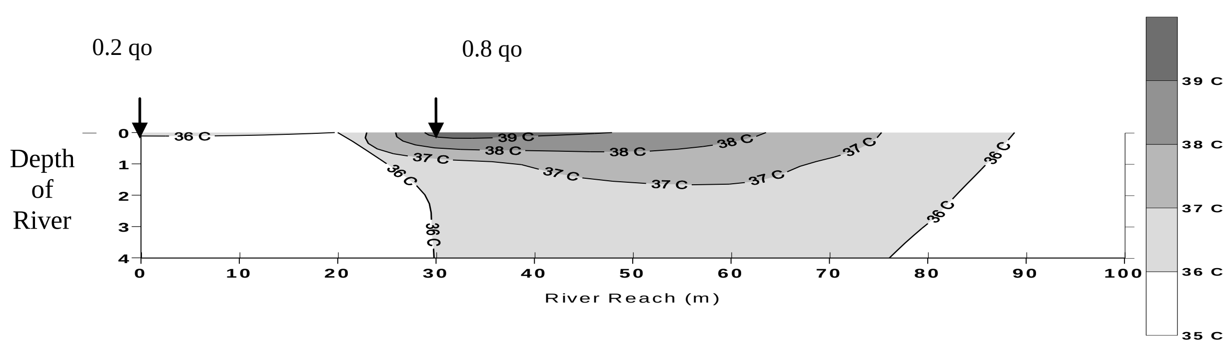


Fig. 29: Temperature Distribution where q1=0.2qo,q2=0.8qo.

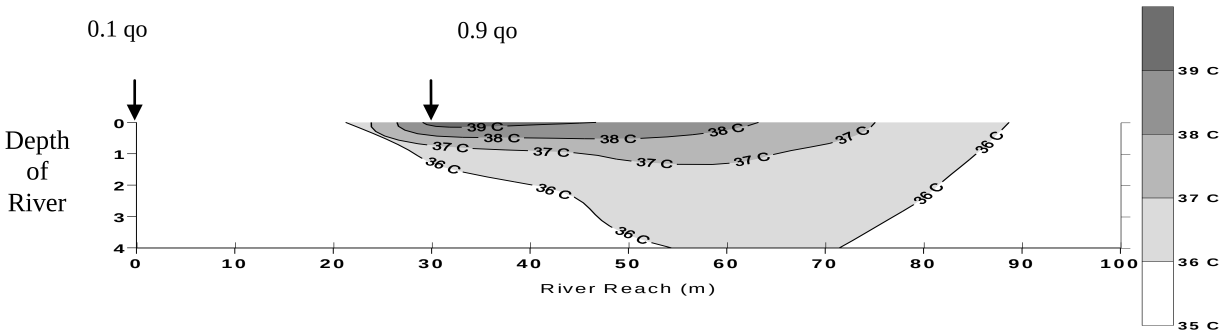


Fig. 30: Temperature Distribution where q1=0.1qo,q2=0.9qo.

CONCLUSIONS

1. The optimum case to reduce the effects of heated water discharge released from various plants can be obtained by the division of the flow of the heated water by two disposal points instead of one, the first one discharges 0.1 from total flow and the second 0.9 from total flow of heated water in which the distance between them is be equal to or exceeds 30 m, this procedure gave reduction in total effected area approximately 77 % with single point.

2. If the discharge of heated water is equal to or less than 20% from total river flow then the maximum spreading of the thermal pollution plume will not exceed 100 m from the outfall location and after this distance the difference between heated and unheated water does not exceed 2 °C.

Nomenclature

Cs : Concentration of saturated dissolved oxygen mg/l
C_1,C_2: Constants
g : Gravitational acceleration m/s^2
K : Turbulence kinetic energy m^2/s^2
L : Distance between two pipes m
P : pressure N/m^2
q^o : Total heated water discharge m^3/s
q1,q2: Flow of first and second points respectively m^3/s
qr : Flow of river m^3/s
T : Temperature ^oC
tmix,tr: Temperature of mixing zone and river ^oC
U : Velocity in x-direction m/s
V : Velocity in y-direction m/s
W : Velocity in z-direction m/s
α : Heat transfer coefficient $W/(m^2.k)$
ρ : Density Kg/m^3
σ : Prandtle number
μ : Viscosity $N.s/m^2$
ε : Dissipation rate of turbulent kinetic energy m^2/s^3

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