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हीरक जयंती २०१८
Diamond Jubilee 2018
एक साथ प्रगति की ओर
Achieving Excellence Together

Dr. Shirishkumar Gedam
Professor

Dated: 26, February, 2020

To,

The Chief Enginerer, GMLR, MCGM
Office of the Chief Engineer (GMLR)
5-B Bhandar, Bhandup Complex Store Building,
Dargah Road, Khindipada,
Mulund(W), Mumbai 400082

Sub: Submission of Consultancy project report on the studies entitled "Groundwater Flow Simulation Studies Between Tulsi and Vihar Reservoirs for Goregaon-Mulund Link Road Tunnel Project"

Ref.: Letter from your office dated 08/02/2019 on the subject matter

Dear Sir,

As per letter from the Chief Engineer, (GMLR), MCGM, Mumbai dated 08/02/2019, a request was received by IIT Bombay to provide opinion on the impact of proposed GMLR tunnel project on the groundwater flow regime , especially the flow between Tulsi and Vihar reservoirs. The job no DRD/Cr/SSG-2/18-19 was approved by Dean R&D IIT Bombay, to carry out the studies and opine based on the findings from the studies.

Please find enclosed herewith a copy of the final report on the Consultancy project report on the studies entitled "Groundwater Flow Simulation Studies Between Tulsi and Vihar Reservoirs for Goregaon-Mulund Link Road Tunnel Project"

With Regards,

(Dr. Shirishkumar Gedam)

बृहन्मुंबई महानगर पालिका
प्रामुख अभियंता (पूल)
16 MAR 2020
क्र. प्र.अभि/ 16642

E.E. (GMLR)
For further n/a
16/3/20
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Consultancy Project Report

(Indian Institute of Technology Bombay)

Submitted to

Chief Enginerer, GMLR, MCGM
Office of the Chief Engineer (GMLR)
5-B Bhandar, Bhandup Complex Store Building,
Dargah Road, Khindipada,
Mulund(W), Mumbai 400082

Groundwater Flow Simulation Studies Between Tulsi and Vihar Reservoirs for Goregaon-Mulund Link Road Tunnel Project

By

Prof. Shirishkumar Gedam, CSRE

and

Prof. T. I. Eldho, Dept of Civil Engg.

February 2020

Certificate

This report, entitled "Groundwater Flow Simulation Studies Between Tulsi and Vihar Reservoirs for Goregaon-Mulund Link Road Tunnel Project" containing (22) pages is prepared for official use of the sponsor of this study, the Chief Engineer, GMLR, MCGM, Office of the Chief Engineer (GMLR),5-B Bhandar, Bhandup Complex Store Building, Dargah Road, Khindipada, Mulund(W), Mumbai 400082. The technical opinions presented in the report are solely based on the inferences from the scientific analysis of the data pertaining to the ground water movements in the study area using 2D finite element models.

(Prof. Shirishkumar Gedam)

Principal Investigator

(Prof. T. I Eldho)

Co- Principal Investigator

बृहन्मुंबई महानगरपालिका
प्रमुख अभियंता (पूल)
16 MAR 2020
क्र. प्र.अभि/ 16642 /पूल

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Groundwater Flow Simulation Studies Between Tulsi and Vihar Reservoirs for Goregaon-Mulund Link Road Tunnel Project

1. Introduction:

As per letter from the Chief Engineer, (GMLR), MCGM, Mumbai dated 08/02/2019, a request was received by IIT Bombay to provide opinion on the impact of proposed GMLR tunnel project on the groundwater flow regime , especially the flow between Tulsi and Vihar reservoirs. The job no DRD/Cr/SSG-2/18-19 was approved by Dean R&D IIT Bombay, to carry out the studies and opine based on the findings from the studies.

2. Study area and data

Three sections are selected at distances 3160m, 3510m and 3860m respectively (See Fig. 1) from the Goregaon portal. The details of the tunnel are provided by MCGM are presented in Table 1.

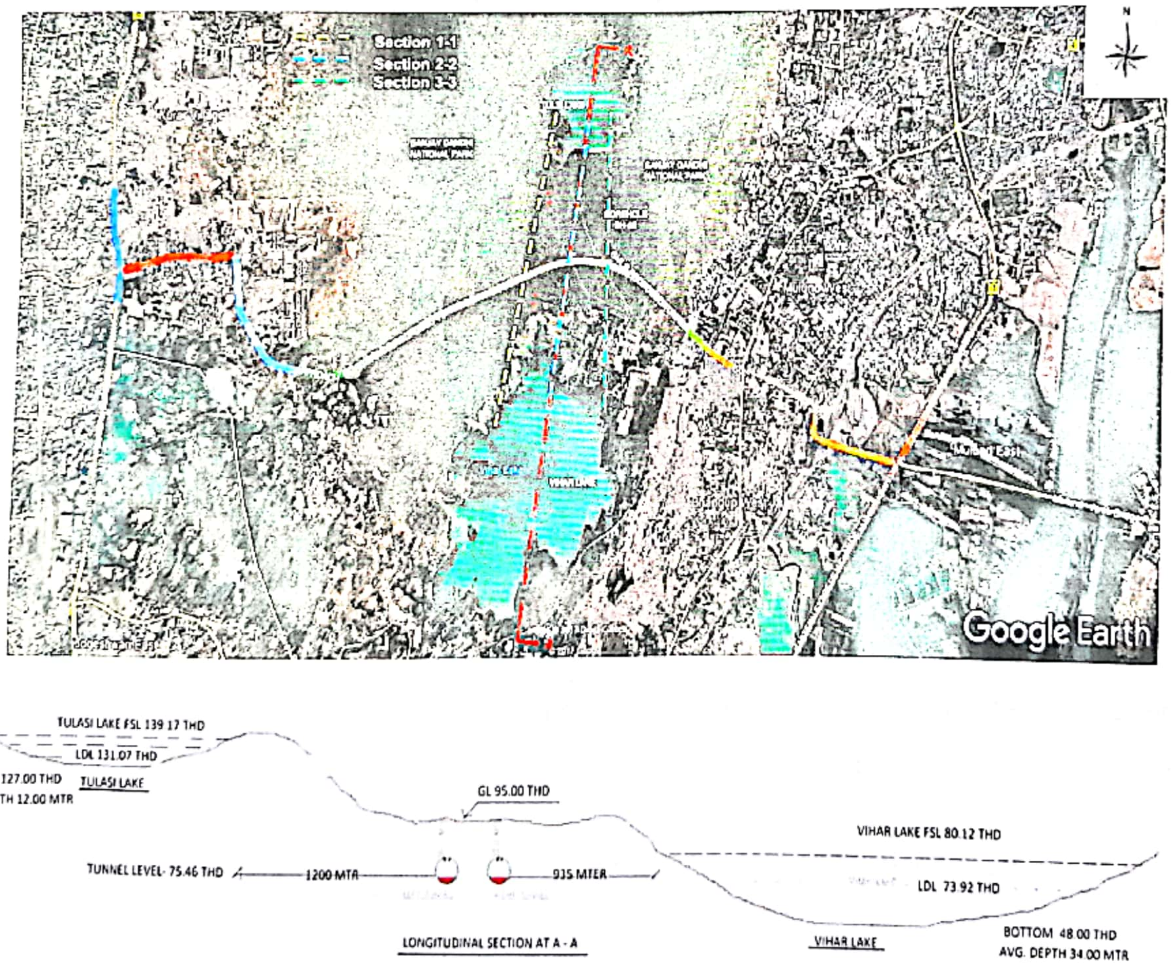

Fig.1. Study area and sections marked

Table 1. Data for the tunnel cross-sections at section 1-1, 2-2 and 3-3

Sr.No.	Location	Chainage	Distance from Goregaon portal	Elevation level of Tunnel(THD)		
				Road Level	Top	Bottom
1	Tunnel Portal at Goregaon side	900	0	75.46	85.46	70.46
	Section 1-1	4060	3160	65.21	75.21	60.21
	Section 2-2	4410	3510	63.46	73.46	58.46
	Section 3-3	4760	3860	61.46	71.46	56.46
2	Tunnel Portal at Mulund side	5600	4700	57.46	67.46	52.46

The cross-section profiles at these sections are extracted using Google earth pro. Tulsi and Vihar lakes are located at the two ends of the three selected sections, as shown in Figure 1.

The models are developed for two flow conditions as the scope of work: 1) when both lakes are at full supply level (FSL) and 2) when both lakes are at lowest drawdown level (LDL). The water level data are provided by MCGM. The water levels corresponding to FSL in Tulsi and Vihar lakes are 139.17m THD and 80.12m THD respectively. Similarly, water levels corresponding to LDL in Tulsi and Vihar lakes are 131.07 THD and 73.92 THD respectively.

The soil data for the site locations are obtained from geophysical seismic refraction test conducted by S. Ghosh & Associates Private Limited (Report no. SAL/SRT/2017-18/01) [1]. The soil data with respect to depth is categorized into 3 layers. The depths of first, second and third layers from the ground level are 0m-2.5m, 2.5m-4.5m and 4.5m-25m respectively. As per the report, average seismic wave velocity for first, second and third layers are 850m/s, 1750m/s and 3600m/s respectively. This increase in average seismic wave velocity with respect to depth indicates a decrease in hydraulic conductivity. The subsoil is characterized primarily by weather surface materials / weathered Basalt as per the report. As no values were given by the clients, based on the report, the hydraulic conductivity of the first, second and third layers are assumed to be 2×10^{-4} m/s, 1×10^{-4} m/s and 4×10^{-5}m/s [2]. The porosity of all three layers is assumed to be 0.11.

3. Methodology

Following assumptions are used in this study.

1) 2D finite element models are considered to understand the effect of tunnels on the groundwater flow.
2) 3-layered model is considered for all cross-sections based on the available subsurface soil data.
3) Standard hydrogeological permeability /hydraulic conductivity values are used in the study are based on available literature as no fixed permeability values are available [2].
4) Three sections are considered in the study to assess the impact of the tunnels.
5) Two levels of the lakes i.e. HFL (Highest Flood level) or, FSL and LDL are considered in the study.

The methodology adopted for the study is presented in Figure 2. The data described in section 1 are used for the development of simulation models using COMSOL Multiphysics software [3] at three sections. While considering a tunnel for analysis, the no-flow boundary condition is applied to the tunnel boundaries. The boundaries adjacent to the lakes are assigned as Dirichlet boundary condition. The analysis is performed in two steps. The analysis with gravity is used to estimate the phreatic line or, the zero pressure line. For estimation of Piezometric pressures, the model is run without considering the gravity effect.

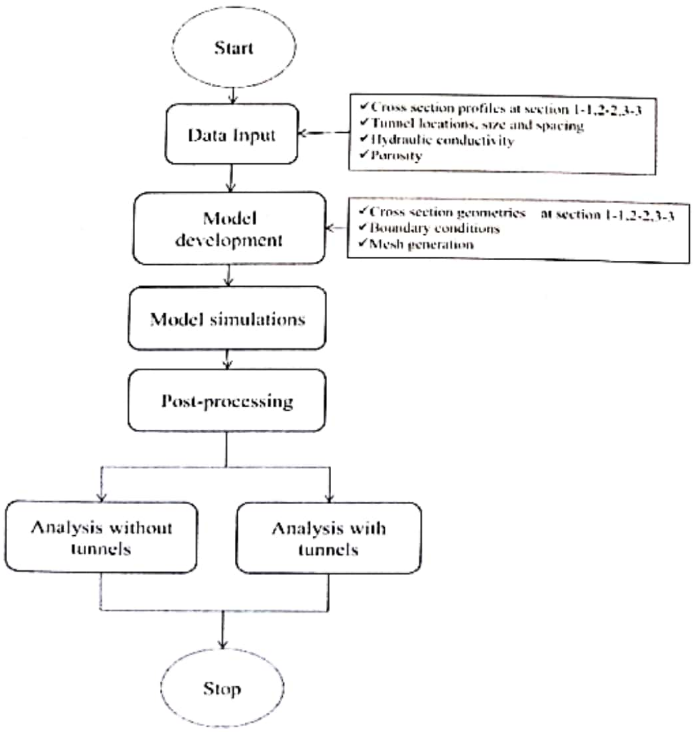

Fig.2 Framework of the study for selected cross-sections

Finally, the results from both analyses are superimposed and post-processed in order to get the pressure and velocity variation in the three sections for 4 cases each.

The cases considered are as follows:

1) When both lakes are at FSL and the effect of tunnels is not considered
2) When both lakes are at FSL and the effect of tunnels is considered
3) When both lakes are at LDL and the effect of tunnels is not considered
4) When both lakes are at LDL and the effect of tunnels is considered

4. Result and Discussion

To study the effect of the tunnels on the water flowing through the subsurface, 13 points around the tunnels for each section are selected as shown in Figure 3, 4, and 5.

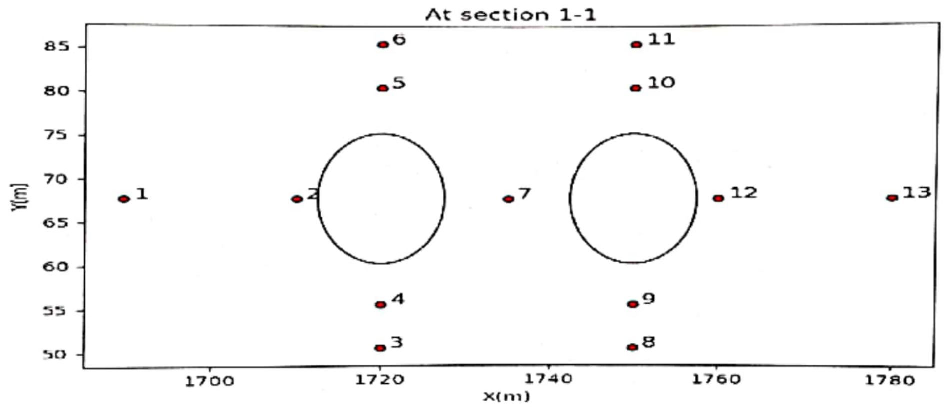

Fig.3 Study points around section 1-1

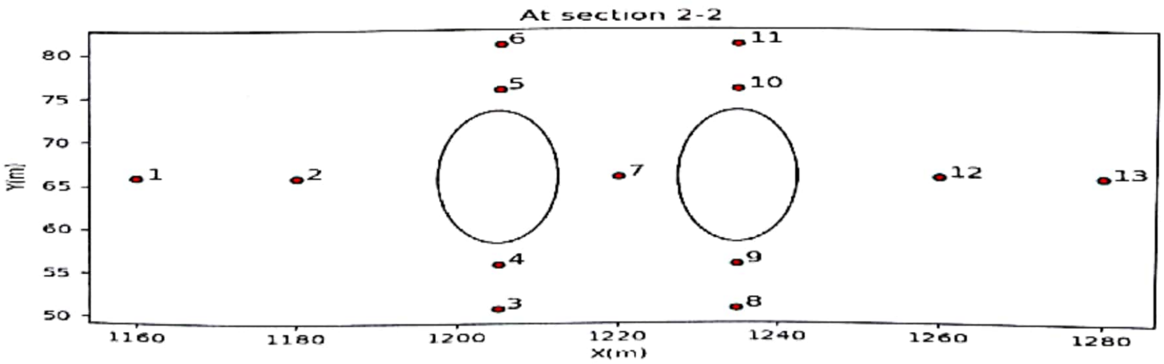

Fig.4 Study points around section 2-2

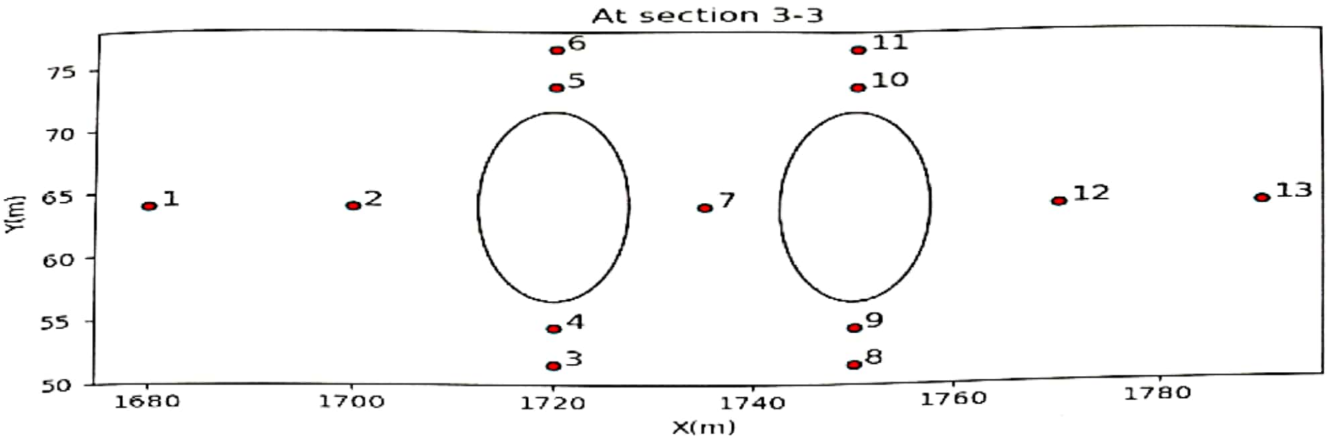

Fig.5 Study points around section 3-3

4.1 Case 1- When both lakes are at FSL condition

Section 1-1:

1. In absence of the tunnels, head value ranges from 104.57m-106.4m for the points considered for the analysis. It consistently decreases in the positive x-direction (see Fig. 6). The velocity at all points is approximately 0.07 m/d.
2. There is a negligible change in the head values when the model is run with considering the tunnel effect (Fig. 7). The range of the percentage difference is -0.14%-0.16% (Table 2). The points 8, 9, 10, 11, 12 and 13 show decrease in heads.
3. However, the percentage change in flow velocity is significant due to the effect of the tunnel. The range of percentage difference is -56.6%-41.9% (Table 2). The highest decrease is observed at point 2 which is located at the upstream of the left tunnel. It is due to the stagnation of flow due to the presence of the tunnel boundary. The effect of stagnation can also be observed at point 1. Due to the same reason, the velocities decrease in downstream regions of both tunnels i.e. points 7, 12 and 13. On the other hand, an increase in velocities is observed at remaining points which are located at the above and below of both tunnels (Fig. 7).

Table 2. Comparison of head and velocity values for Section 1-1

Sl. No.	Spatial coordinates		Without Tunnels		With Tunnels		Percentage Difference	
	x	y	Head(m)	velocity(m/d)	Head(m)	velocity(m/d)	Head Diff (%)	Vel. Diff. (%)
1	1690	67.71	106.40	0.07	106.49	0.06	0.08	-8.6
2	1710	67.71	106.00	0.07	106.16	0.03	0.16	-56.6
3	1720	50.46	105.79	0.07	105.85	0.09	0.06	30.2
4	1720	55.46	105.79	0.07	105.85	0.10	0.06	41.9
5	1720	80.46	105.79	0.07	105.84	0.09	0.04	32.0
6	1720	85.46	105.79	0.07	105.83	0.08	0.04	16.7
7	1735	67.71	105.49	0.07	105.49	0.04	0.01	-43.9
8	1750	50.46	105.18	0.07	105.13	0.09	-0.04	30.1
9	1750	55.46	105.18	0.07	105.13	0.10	-0.04	41.8
10	1750	80.46	105.18	0.07	105.15	0.09	-0.03	31.7
11	1750	85.46	105.18	0.07	105.15	0.08	-0.02	16.5
12	1760	67.71	104.97	0.07	104.82	0.03	-0.14	-56.4
13	1780	67.71	104.57	0.07	104.50	0.06	-0.07	-8.8

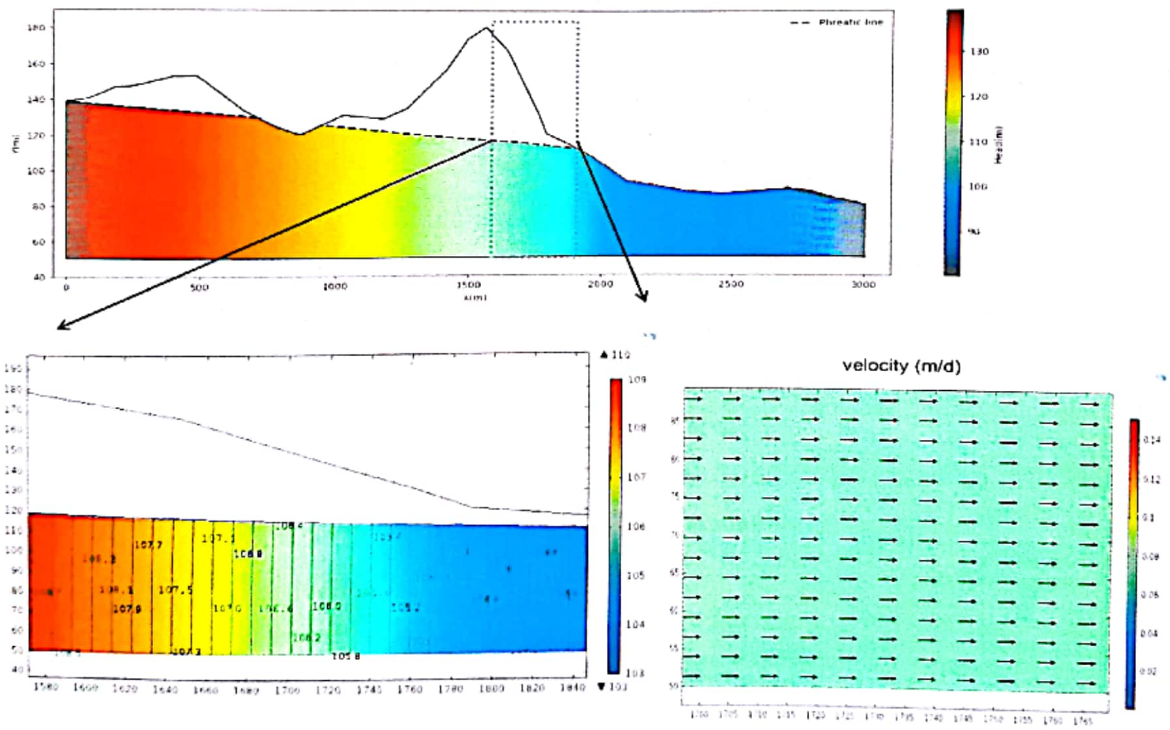

Fig. 6. Variation of head and velocity in section 1-1 (without tunnel) (*The arrows denote velocity direction only and magnitude of velocity is denoted by the colour code in the legend*)

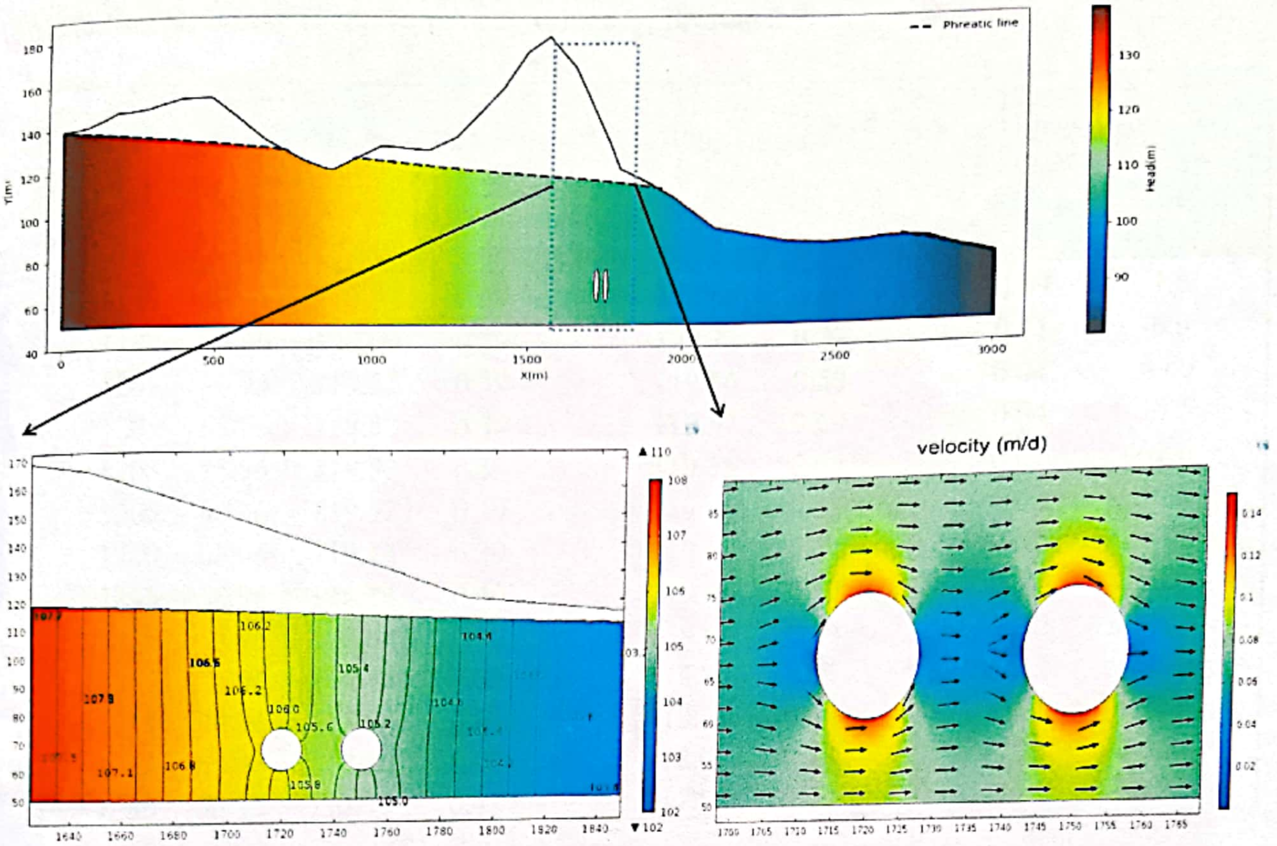

Fig. 7. Variation of head and velocity in section 1-1 (with tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

Section 2-2:

1. In this section, the head value ranges from 117.79m-120.54m for the points considered for the analysis (see Fig. 8 and Table 3) when the tunnel is not considered. The velocity in x-direction ranges from 0.39 m/day to 0.41 m/day. These values are comparatively higher than that of section 1-1 and section 3-3 as the length of section 1-1 is lesser compared to the other two sections which result in higher hydraulic gradient.
2. Similar to Section 1-1, their change in the head values is negligible when the model is run with considering the tunnel effect (Fig. 9). The range of the percentage difference is -0.20-0.11% (Table 3). The points 1, 2, 3, 4, 5 and 6 show an increase in head values while the remaining points show a decrease in head values (Fig. 9).
3. The percentage change in flow velocity is significant due to the effect of the tunnel (See Table 3). The range of percentage difference is -38.5%-75.7%. The points which are present above and below the tunnels show an increase in velocities due to obstruction created by tunnels (See Fig. 8 and 9).

Table 3. Comparison of head and velocity values for Section 2-2

Sl. No.	Spatial coordinates		Without Tunnels		With Tunnels		Percentage Difference	
	x	y	Head(m)	velocity(m/d)	Head(m)	velocity(m/d)	Head Diff (%)	Vel. Diff. (%)
1	1160	65.96	120.54	0.39	120.66	0.39	0.09	-1.6
2	1180	65.96	120.09	0.39	120.22	0.37	0.11	-6.0
3	1205	50.96	119.52	0.39	119.56	0.59	0.04	49.9
4	1205	55.96	119.52	0.39	119.57	0.69	0.04	75.5
5	1205	75.96	119.52	0.39	119.55	0.66	0.02	67.6
6	1205	80.96	119.52	0.39	119.55	0.53	0.02	35.5
7	1220	65.96	119.18	0.39	119.13	0.24	-0.05	-38.5
8	1235	50.96	118.84	0.40	118.68	0.60	-0.13	50.0
9	1235	55.96	118.84	0.40	118.68	0.70	-0.13	75.7
10	1235	75.96	118.84	0.39	118.70	0.66	-0.12	68.3
11	1235	80.96	118.84	0.40	118.71	0.54	-0.11	35.5
12	1260	65.96	118.26	0.40	118.02	0.38	-0.20	-5.8
13	1280	65.96	117.79	0.41	117.56	0.40	-0.19	-1.5

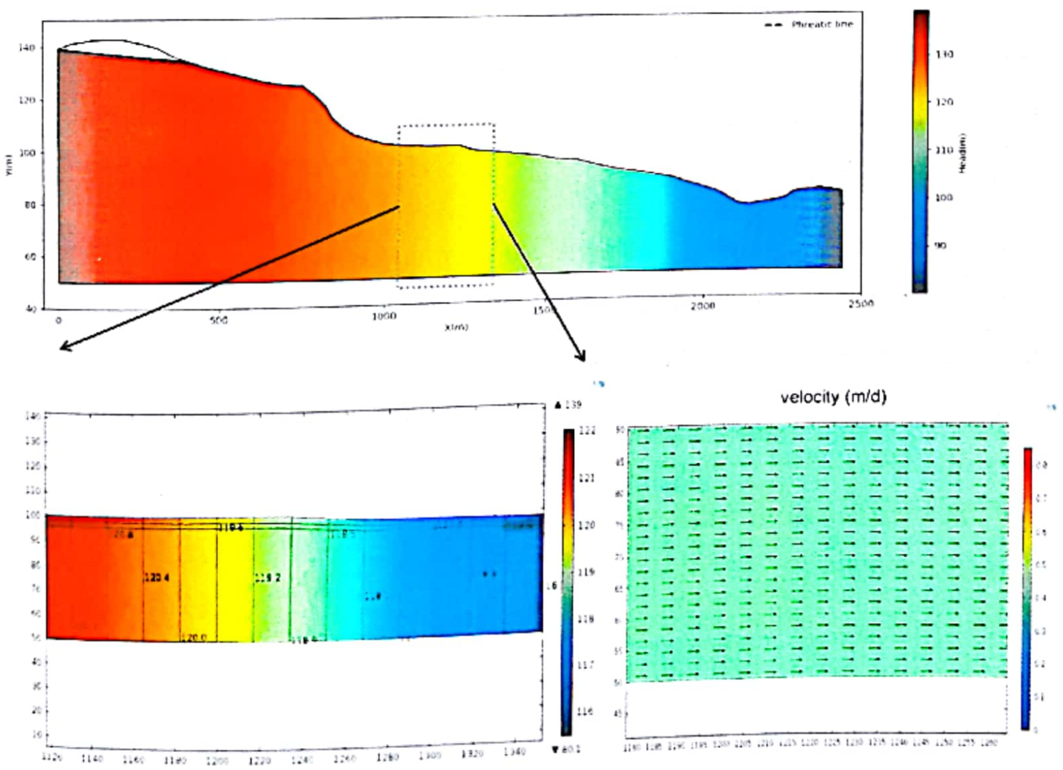

Fig. 8. Variation of head and velocity in section 2-2 (without tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

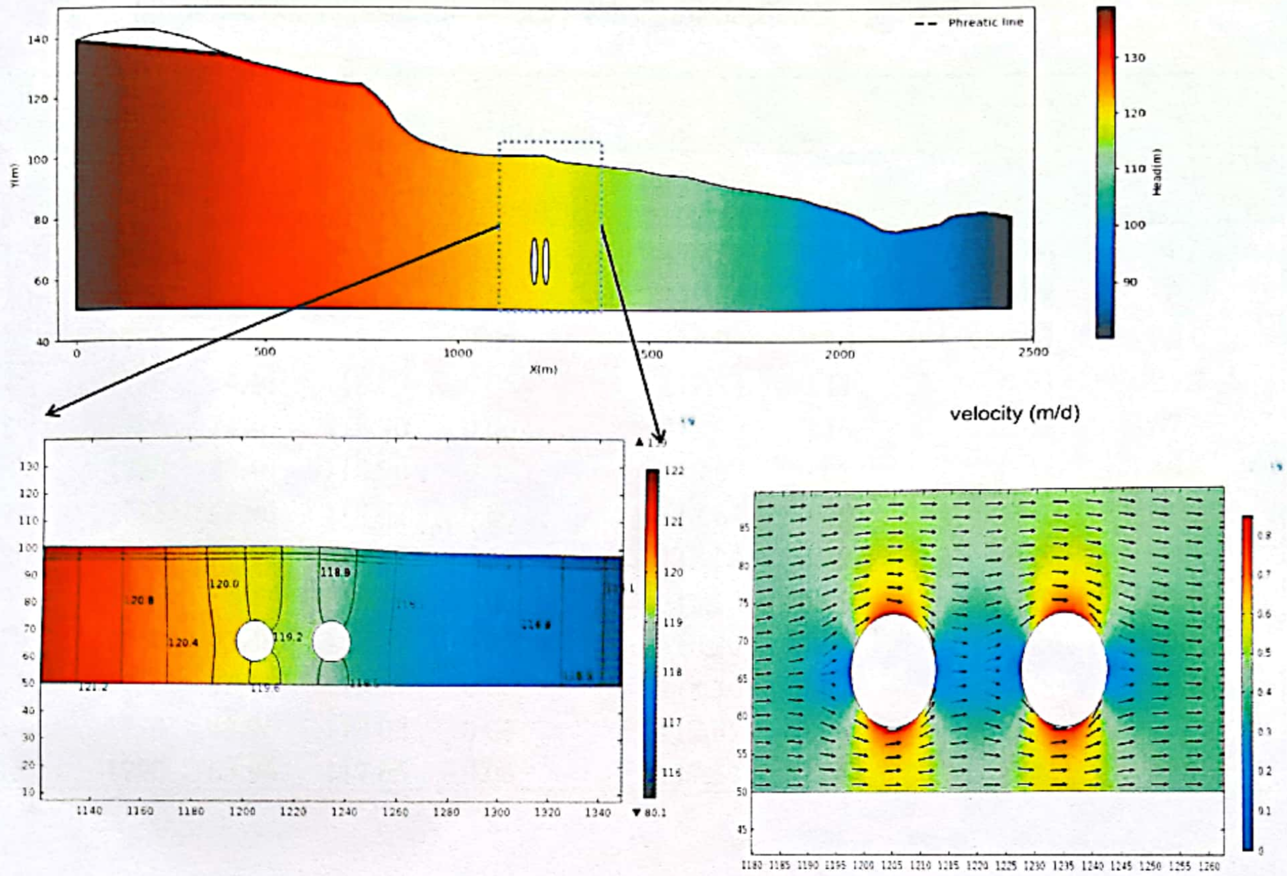

Fig. 9. Variation of head and velocity in section 2-2 (with tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

Section 3-3:

1. The head values at the points vary between 117.66m-119.58m when tunnels are not present (Fig. 10). The change in the head due to the introduction of tunnels varies between -0.11%-0.08% which can be considered to be negligible. Due to the presence of tunnel, the values of head increase for points 1, 2, 3, 4, 5 and 6 while for remaining points it decreases (Table 4).
2. Further, it observed that the percentage change in velocity due to the presence of channel is between -41.2%-81.6% (Table 4). The high value of an increase in velocity is observed at points 4 and 9 which are present at the bottom of two tunnels respectively. On the other hand, the velocity values at points present in between the tunnels, downstream, upstream of tunnels show a decrease in velocity which can be attributed to obstruction of flow due to tunnel (See Fig. 10 and 11).

Table 4. Comparison of head and velocity values for Section 3-3

Sl. No.	Spatial coordinates		Without Tunnels		With Tunnels		Percentage Difference	
	x	y	Head(m)	velocity(m/d)	Head(m)	velocity(m/d)	Head Diff (%)	Vel. Diff. (%)
1	1680	63.96	119.58	0.06	119.65	0.06	0.06	-4.2
2	1700	63.96	119.24	0.06	119.34	0.05	0.08	-13.6
3	1720	51.46	118.89	0.06	118.93	0.10	0.03	60.0
4	1720	54.46	118.89	0.06	118.93	0.11	0.03	81.3
5	1720	73.46	118.90	0.06	118.92	0.10	0.02	67.3
6	1720	76.46	118.90	0.06	118.92	0.08	0.02	40.6
7	1735	63.96	118.63	0.06	118.61	0.04	-0.02	-41.2
8	1750	51.46	118.37	0.06	118.28	0.10	-0.08	60.1
9	1750	54.46	118.37	0.06	118.28	0.11	-0.08	81.6
10	1750	73.46	118.37	0.06	118.30	0.10	-0.06	67.4
11	1750	76.46	118.37	0.06	118.30	0.09	-0.06	40.8
12	1770	63.96	118.02	0.06	117.87	0.05	-0.13	-13.2
13	1790	63.96	117.66	0.06	117.54	0.06	-0.11	-3.9

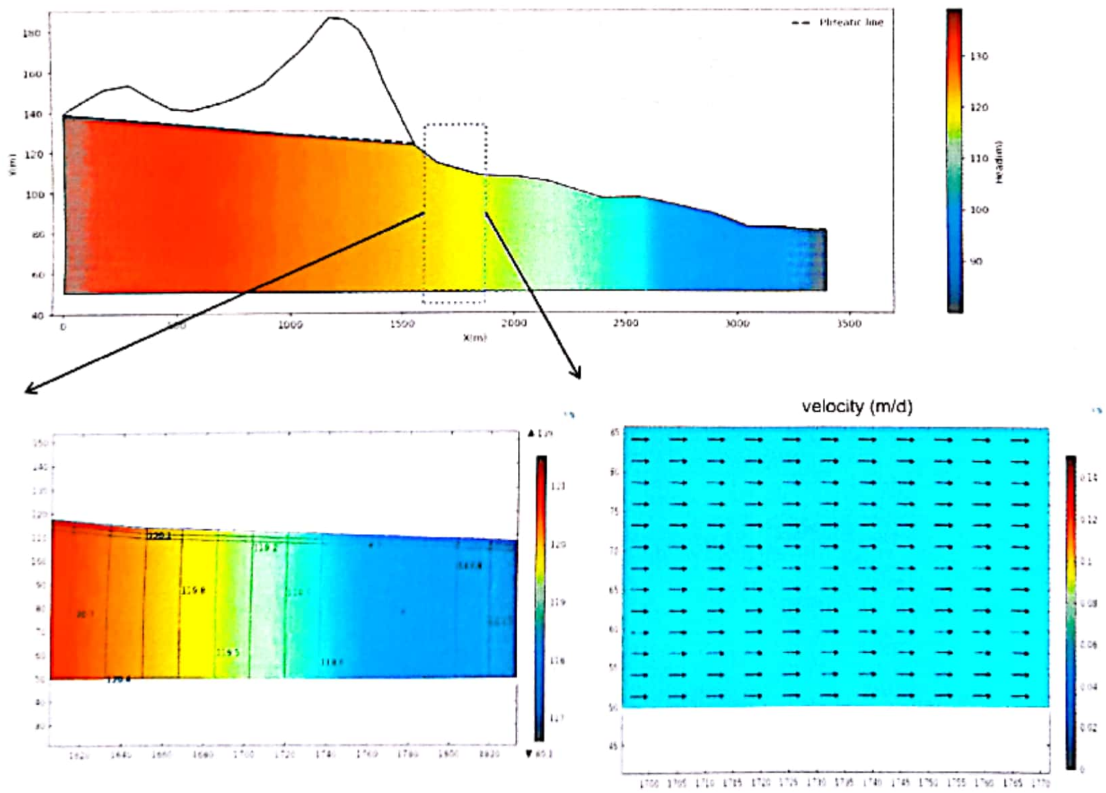

Fig. 10. Variation of head and velocity in section 3-3 (without tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

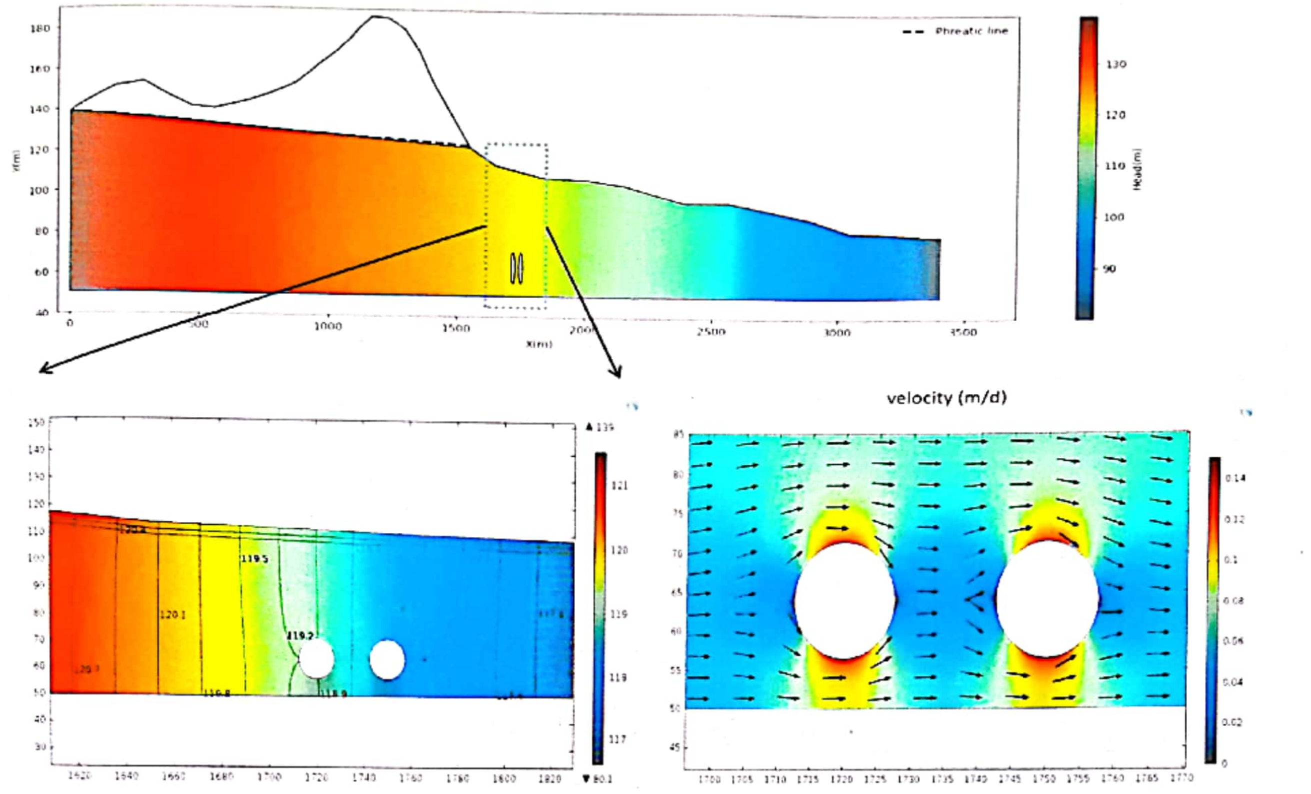

Fig. 11. Variation of head and velocity in section 3-3 (with tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

4.2 Case 2- When both lakes are at LDL condition

Section 1-1:

1. The head value ranges from 99.39m-100.67m for the points considered for the analysis in the absence of the tunnels (See Table 5). The change in the head values is negligible when the model is run with considering the tunnel effect (Figure 12 and 13). The range of the percentage difference is -0.11%-0.12%.
2. The velocity in the x-direction is 0.05m/day at all selected points. Due to the effect of the tunnel, change in velocity is observed which ranges between -56.6%-41.9% (Figure 12 and 13). The highest decreases are observed at points 2, 7 and 12 which are located just upstream of the left tunnel, between the tunnels and downstream of right tunnel respectively (Table 5). It is due to the stagnation of flow due to the presence of the tunnel boundary (See Fig. 12 and 13). On the other hand, velocities at the points above and below the tunnel increase due to obstruction created by the tunnels (Table 5).

Table 5. Comparison of head and velocity values for Section 1-1

Sl. No.	Spatial coordinates		Without Tunnels		With Tunnels		Percentage Difference	
	x	y	Head(m)	velocity(m/d)	Head(m)	velocity(m/d)	Head Diff (%)	Vel. Diff. (%)
1	1690	67.71	100.67	0.05	100.73	0.04	0.06	-8.6
2	1710	67.71	100.39	0.05	100.51	0.02	0.12	-56.6
3	1720	50.46	100.25	0.05	100.29	0.06	0.04	30.2
4	1720	55.46	100.25	0.05	100.29	0.07	0.04	41.9
5	1720	80.46	100.25	0.05	100.28	0.07	0.03	32.0
6	1720	85.46	100.25	0.05	100.28	0.06	0.03	16.7
7	1735	67.71	100.03	0.05	100.04	0.03	0.01	-43.9
8	1750	50.46	99.82	0.05	99.79	0.06	-0.03	30.1
9	1750	55.46	99.82	0.05	99.79	0.07	-0.03	41.8
10	1750	80.46	99.82	0.05	99.80	0.07	-0.02	31.7
11	1750	85.46	99.82	0.05	99.80	0.06	-0.02	16.5
12	1760	67.71	99.68	0.05	99.57	0.02	-0.11	-56.4
13	1780	67.71	99.39	0.05	99.34	0.04	-0.05	-8.8

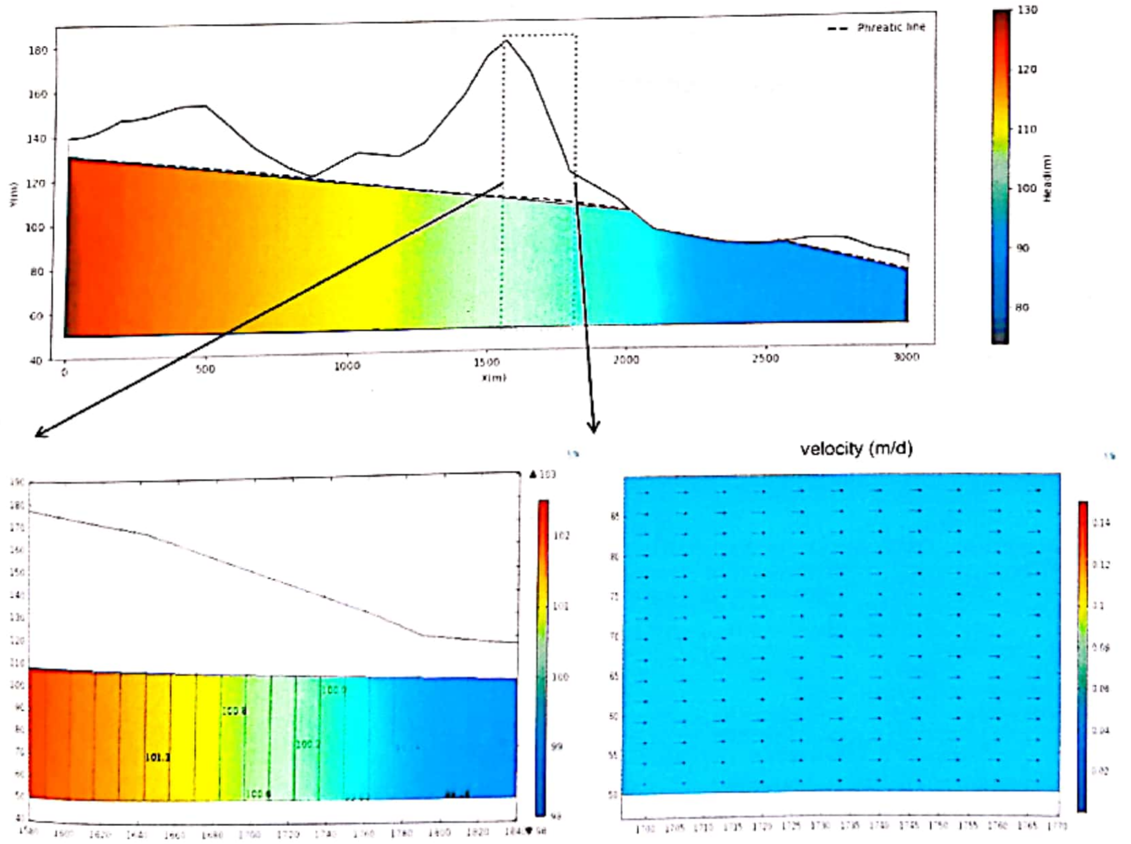

Fig. 12. Variation of head and velocity in section 1-1 (without tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

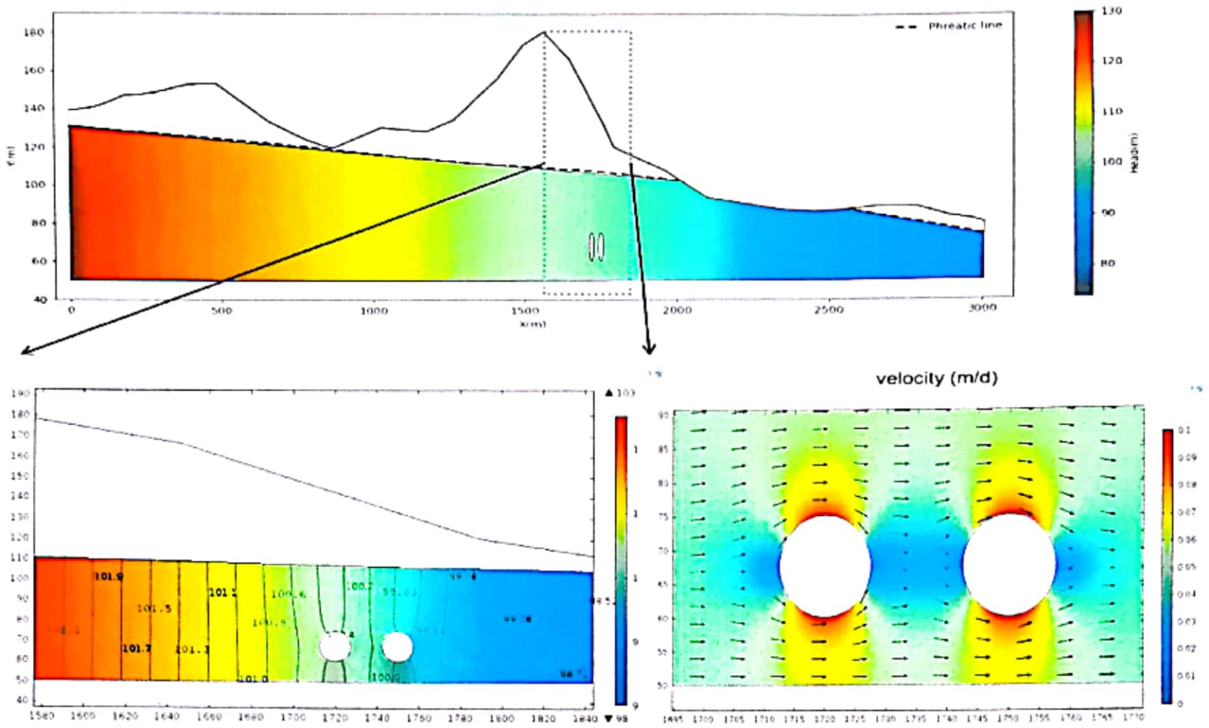

Fig. 13. Variation of head and velocity in section 1-1 (with tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

Section 2-2:

1. The head values at the points vary between 110.4m-113.06m when tunnels are not present (See Table 6). The change in the head due to the introduction of tunnels varies between -0.21%-0.11% (See Fig. 14 and 15).
2. Further, it observed that the percentage change in velocity due to the presence of channel is between -38.5%-75.7%. The high value of an increase in velocity is observed at points 4 and 9 which are present at the bottom of two tunnels respectively. On the other hand, the velocity values at points present in between the tunnels, downstream, upstream of tunnels show a decrease in velocity which can be attributed to obstruction of flow due to tunnel (See Fig. 14 and 15).

Table 6. Comparison of head and velocity values for Section 2-2

Sl. No.	Spatial coordinates		Without Tunnels		With Tunnels		Percentage Difference	
	x	y	Head(m)	velocity(m/d)	Head(m)	velocity(m/d)	Head Diff (%)	Vel. Diff. (%)
1	1160	65.96	113.06	0.38	113.17	0.37	0.10	-1.6
2	1180	65.96	112.62	0.38	112.75	0.36	0.11	-6.0
3	1205	50.96	112.08	0.38	112.12	0.57	0.04	49.9
4	1205	55.96	112.08	0.38	112.12	0.67	0.04	75.5
5	1205	75.96	112.08	0.38	112.10	0.64	0.02	67.6
6	1205	80.96	112.08	0.38	112.10	0.51	0.02	35.5
7	1220	65.96	111.75	0.38	111.69	0.23	-0.05	-38.5
8	1235	50.96	111.41	0.38	111.26	0.58	-0.14	50.0
9	1235	55.96	111.41	0.38	111.26	0.67	-0.14	75.7
10	1235	75.96	111.42	0.38	111.28	0.64	-0.12	67.9
11	1235	80.96	111.42	0.38	111.29	0.52	-0.12	35.9
12	1260	65.96	110.85	0.39	110.62	0.37	-0.21	-5.8
13	1280	65.96	110.40	0.39	110.18	0.39	-0.20	-1.5

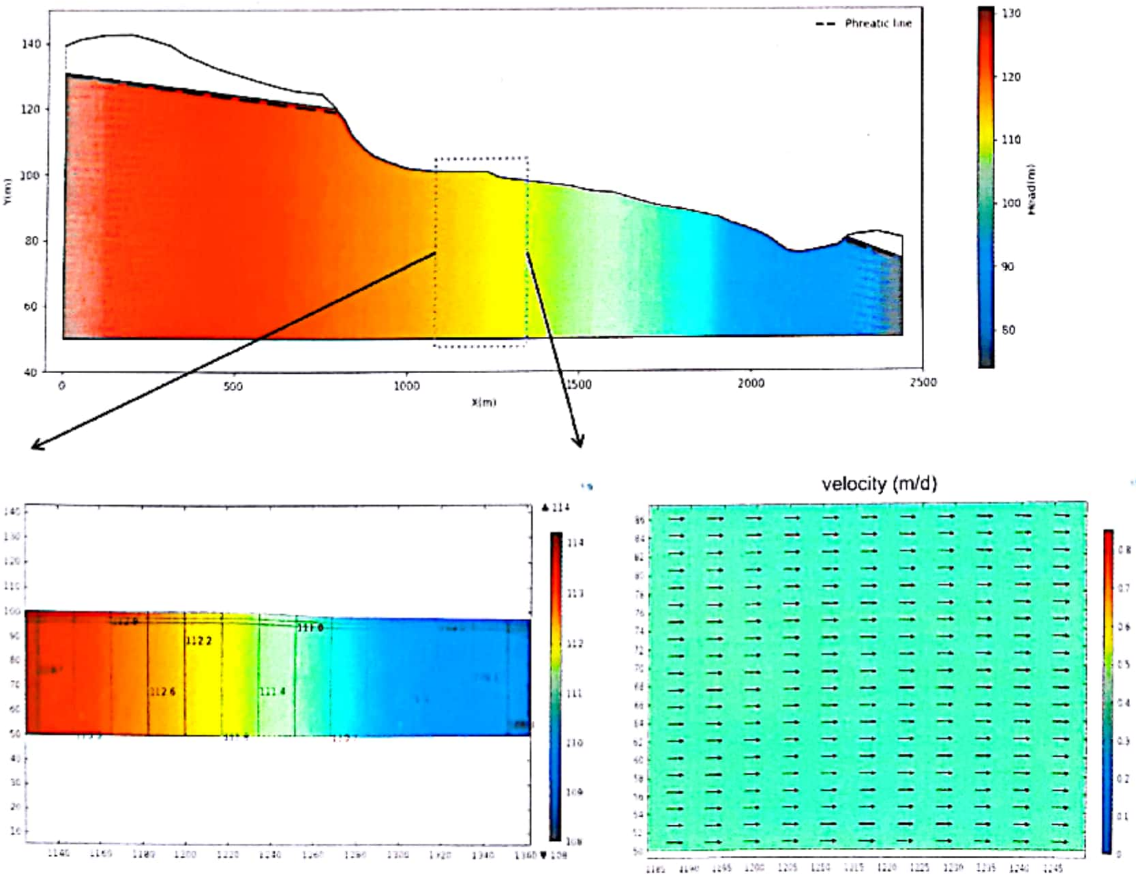

Fig. 14. Variation of head and velocity in section 2-2 (without tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

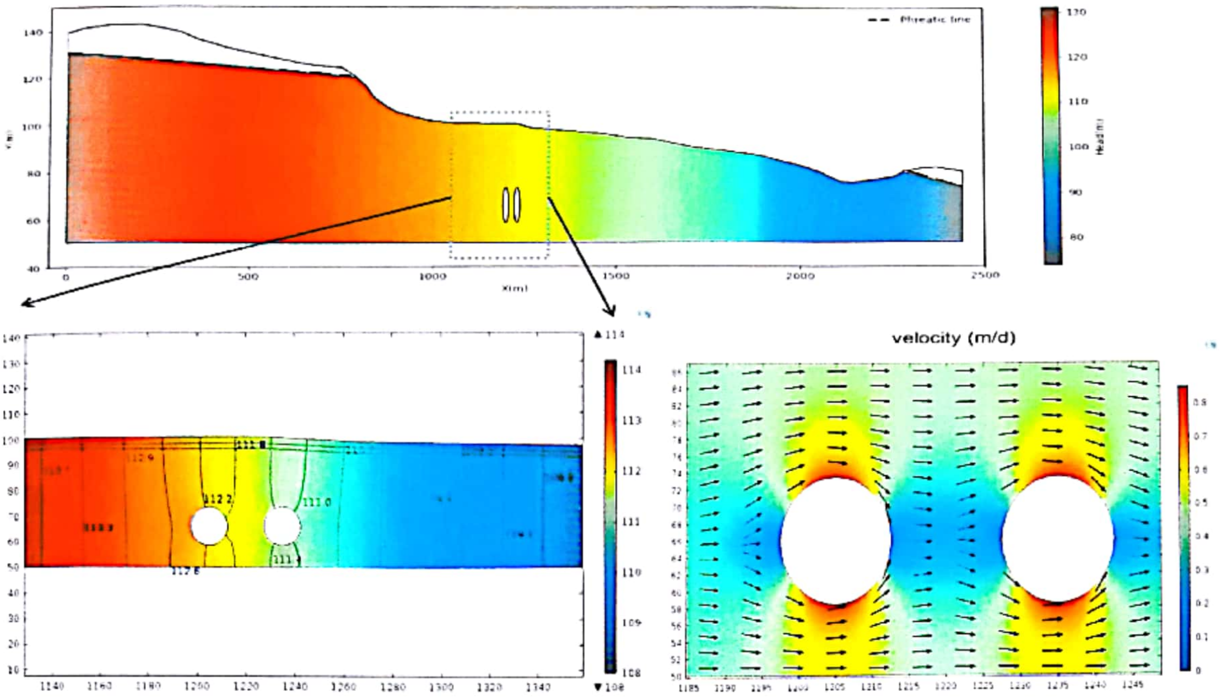

Fig. 15. Variation of head and velocity in section 2-2 (with tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

Section 3-3:

1. The head values at the points vary between 110.3m-112.15m when tunnels are not present. The change in the head due to the introduction of tunnels varies between -0.13%-0.08% which can be considered to be negligible (Fig. 16). Due to the presence of tunnel, the values of head increase for points 1, 2, 3, 4, 5 and 6 while for remaining points it decreases (Table 7).
2. Further, it observed that the percentage change in velocity due to the presence of channel is between -41.2%-81.6% (See Fig. 16 and 17). The high value of an increase in velocity is observed at points 4 and 9 which are present at the bottom of two tunnels respectively. On the other hand, the velocity values at points present in between the tunnels, downstream, upstream of tunnels show a decrease in velocity which can be attributed to obstruction of flow due to tunnel (Table 7).

Table 7. Comparison of head and velocity values for Section 3-3

Sl. No.	Spatial coordinates		Without Tunnels		With Tunnels		Percentage Difference	
	x	y	Head (m)	velocity(m/d)	Head (m)	velocity(m/d)	Head Diff (%)	Vel. Diff. (%)
1	1680	63.96	112.15	0.06	112.22	0.05	0.06	-4.2
2	1700	63.96	111.82	0.06	111.91	0.05	0.08	-13.6
3	1720	51.46	111.49	0.06	111.53	0.09	0.04	60.0
4	1720	54.46	111.49	0.06	111.53	0.10	0.04	81.3
5	1720	73.46	111.49	0.06	111.51	0.10	0.02	67.3
6	1720	76.46	111.49	0.06	111.51	0.08	0.02	40.6
7	1735	63.96	111.24	0.06	111.21	0.03	-0.02	-41.2
8	1750	51.46	110.98	0.06	110.89	0.09	-0.08	60.1
9	1750	54.46	110.98	0.06	110.89	0.11	-0.08	81.6
10	1750	73.46	110.98	0.06	110.91	0.10	-0.06	67.4
11	1750	76.46	110.98	0.06	110.91	0.08	-0.06	40.8
12	1770	63.96	110.64	0.06	110.50	0.05	-0.13	-13.2
13	1790	63.96	110.30	0.06	110.18	0.06	-0.11	-3.9

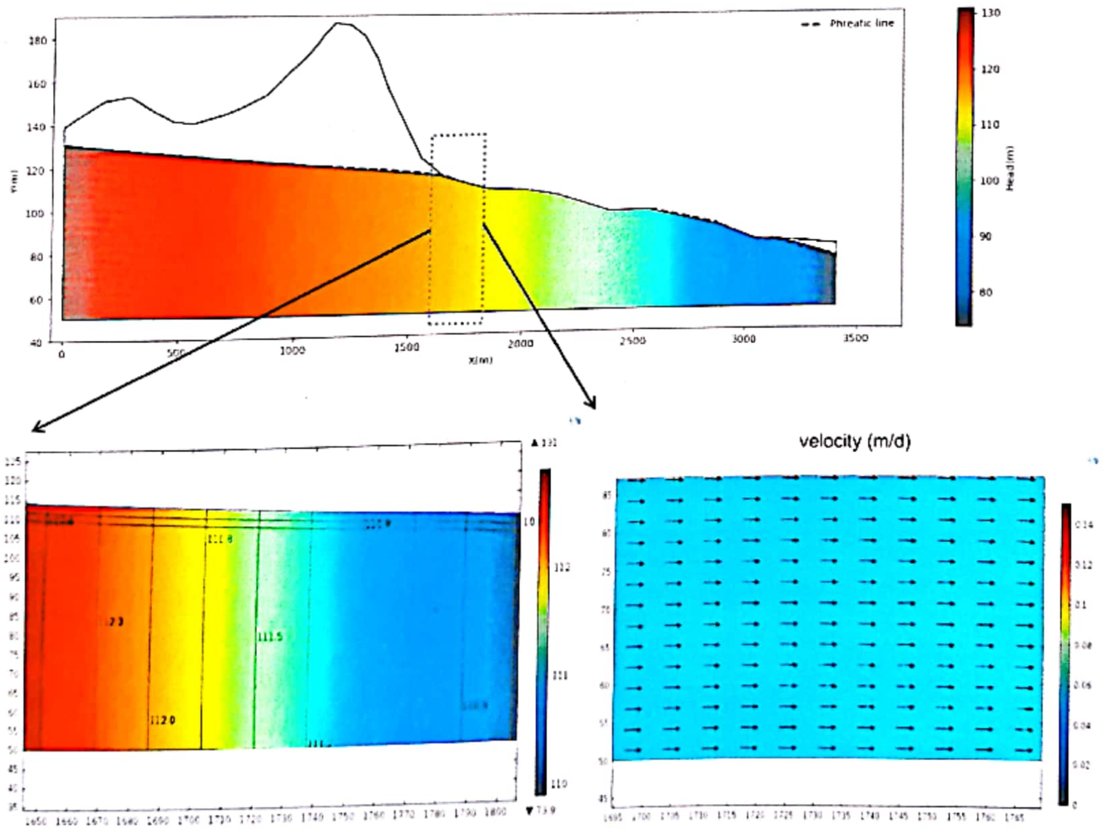

Fig. 16. Variation of head and velocity in section 3-3 (without tunnel) *(The arrows denote velocity direction only and magnitude of velocity is denoted by the colour code in the legend)*

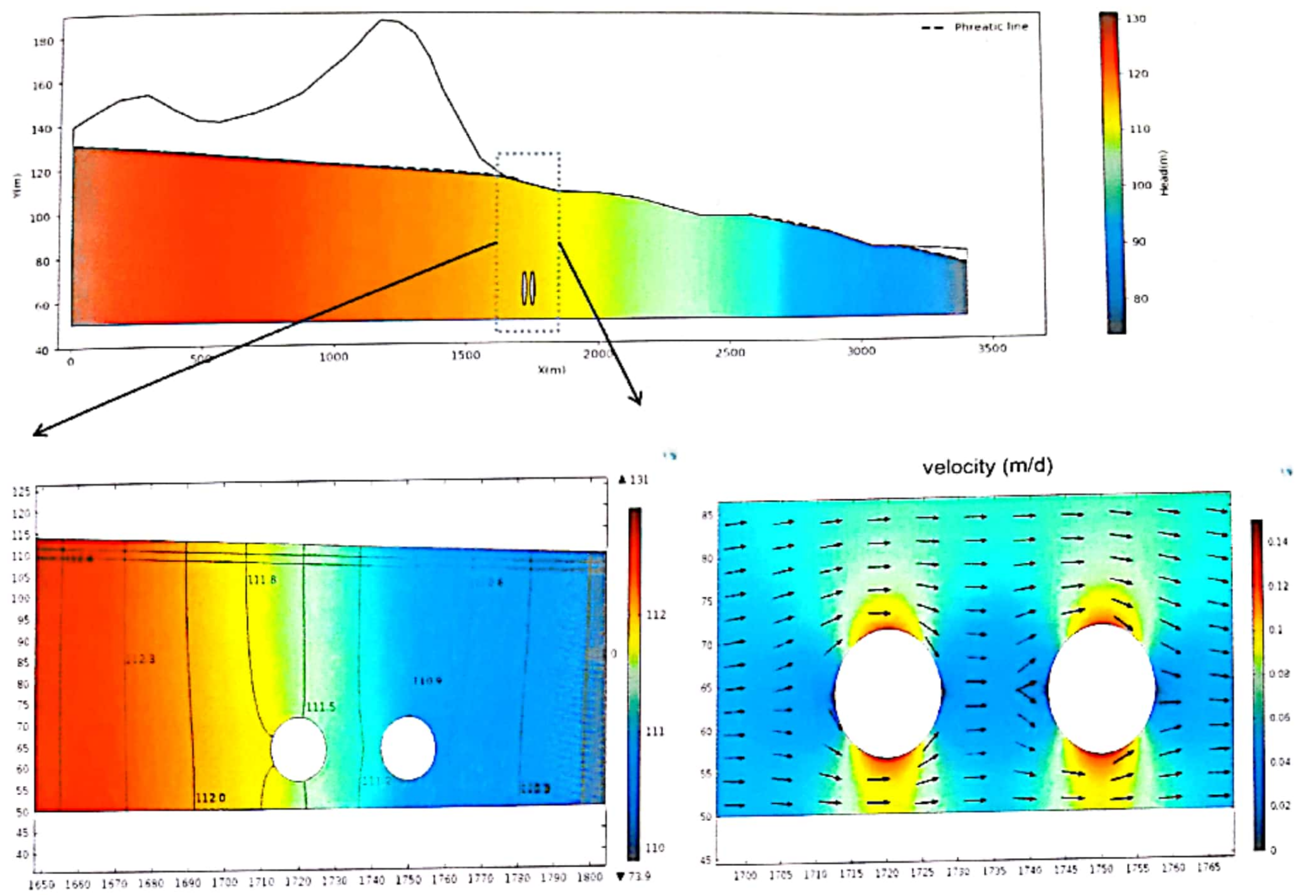

Fig. 17. Variation of head and velocity in section 3-3 (with tunnel) (The arrows denote velocity direction and the magnitude of velocity is denoted by the colour code in the legend)

5. Conclusions and Recommendations

Following conclusions can be drawn from the study.

1. The present study is carried out to understand the effects of the tunnels on the groundwater flow regime.
2. Two-dimensional finite element method (FEM) based models are developed in COMSOL are used in the study.
3. Different cases of 3 sections for two lake levels i.e. HFL/FSL and LDL are considered to understand the subsurface flow regime.
4. The change in head values at the point around the proposed tunnel locations, due to the introduction tunnels, is negligible i.e. $\leq \pm 0.21\%$. Most of the increase in head values are observed in the upstream to the left tunnel increase due to the introduction of the tunnel while head values downstream to the left tunnel decreases. It is due to the displacement of water

due to the presence of the tunnel. However, the diameter of the tunnels are too small to affect the head and flow pattern significantly.

5. As the tunnel boundaries are considered to be impervious/no-flow boundary, a moderate change in velocity is observed at the points around the tunnels. The change in velocity is maximum for the points located very near to the tunnels. This change decreases with increase in distance from the tunnel.
6. The points where a decrease in velocity is observed are located along the x-axis (horizontal axis) in the upstream of the left tunnel, downstream of the right tunnel and between the tunnels. On the other hand, velocities at points along the centre lines of the tunnels and y-axis show a small increase in magnitude.
7. Overall the effects of tunnels on the groundwater flow regime are negligible, as the size of the tunnels compared to the overall depth is insignificant.

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