Prediction of Natural Oil Seepage For Kuwait Water's and Arabian Gulf

BY

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INTERODUCTION

This report provides a description of the numerical model developed to simulate the movement of the oil over the water column. It considers the thermodynamics and hydrodynamics of the plume. The simulation model considered two phases of an oil plume.

Initially the plume contained momentum (due to initial velocity) and the buoyanc (due to density difference between the plume fluid and ambient fluid). The plume velocity and buoyancy dies rapidly as the plume moves away from the point of origin. The main reason for this is the massive entrainment of the surrounding fluid.

During the initial phase, the plume dynamics must be considered. This is referred to as dynamic phase (this phase will be referred to as Phase 1 from this point onwards in this report). A version of this model was also developed at KISR and was validated as described later.

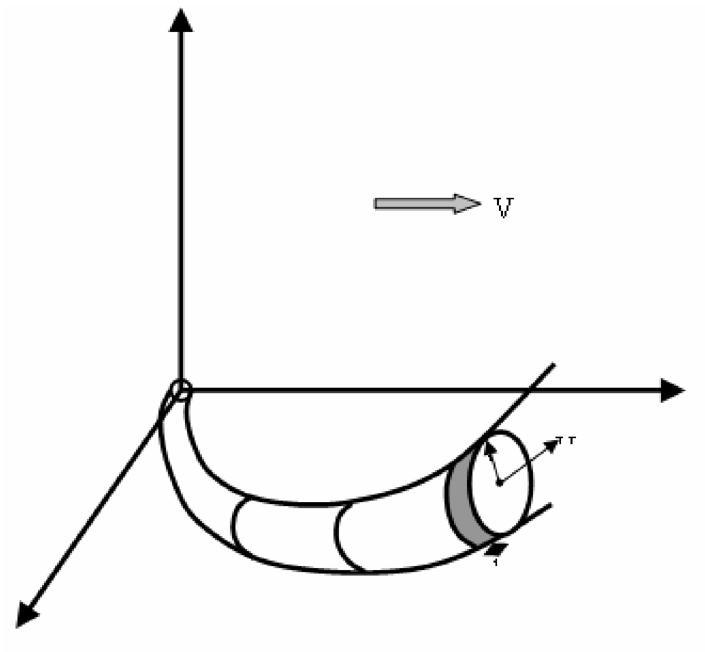
Once the buoyancy and velocity is considerably reduced, the oil is expected to break up into droplets and they move about on their own. This is referred to as passive phase (this phase will be referred to as Phase 2 from this point onwards in this report). Details of these phases and model formulation are given in papers by Yapa and Zheng (1997), Zheng and Yapa (1998), Yapa et al. (1999), Zheng et al. (2003), Chen and Yapa (2003), and Yapa and Chen (2004).

Governing Equations for Simulating the Plume Dynamics (Phase-1)

Many oil spill models were developed to predict the trajectory and fate of surface or near surface oil spills (see ASCE, 1996). The KISR oil spill model represents one of such models (Al-Salem and Lo, 1993). Such models are based on the advection/diffusion equation and are thus valid for simulating oil spills on the water surface. For submerged oil spills or underwater natural seepage, the oil behaves as a submerged buoyant jet requiring other model formulations.

Governing Equations for Simulating Advection Dispersion (Phase-2)

After the dynamic phase (Phase 1), the oil is considered to have reached passive phase (Phase 2). The oil transport in this phase can be simulated by using advection-diffusion equation.



Schematic of the buoyant jet.

Model Validation

Validation Cases were used Version of the Phase-1 KSPoil model by (K. Al-Salem). This section describes the validation for KSPoil model. Five cases taken from Zheng and Yapa (1998) were used to validate the model. These cases represent the movement of buoyant jets in stratified and unstratified flows. The diameter of the jet for all the cases considered is 1.0 m and the density of the ambient water at the bed is 1025 kg/m^3. The density of the buoyant jet at the jet location ρ_o is 950 kg/m^3. The ambient current is in the x-direction (θ_o=0.0). Table 1 provides a input conditions for these cases1.

Case 1: Unstratified Stagnant Ambient

Case 1 represents the flow of a buoyant jet in an unstratified stagnant ambient fluid for calm current condition.

Table 1. Input Conditions For the Studied cases 1

Case	Jet Velocity	Jet Diameter	Jet Density	Jet Angle Horizontal	U	V	Jet Angle x-direc.
1-1	3.52	1	950	0	0.001	0.001	0.0
1-2	5.28	1	950	0	0.001	0.001	0.0
1-3	7.04	1	950	0	0.001	0.001	0.0
1-4	9.68	1	950	0	0.001	0.001	0.0

The jet is directed parallel to the x-axis as provide in Table 1. The experimental data is from Anwar (1987) as given by Zheng and Yapa (1998) compared with model results. Figs 1 and 2 provide **KSPoil** model results for Case 1-1 to 1-4 shows that jet trajectory and the centerline concentration is well predicted. The value of K_c was taken as 0.01 m^2/s. This value was chosen to produce the best results as compared to the measurements. The sensitivity of the model to the value of K_c will be studied later. Figure 3 shows case 1-4 trajectory of buoyant jet from **KSPoil** Model Result.

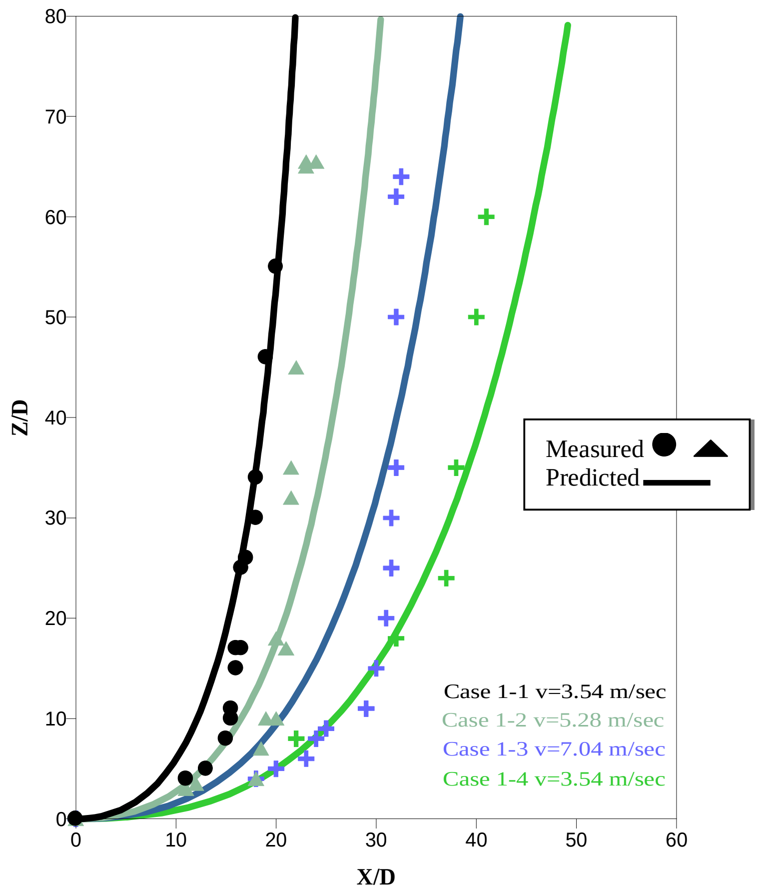


Figure 1. Trajectory of buoyant jet for Case 1

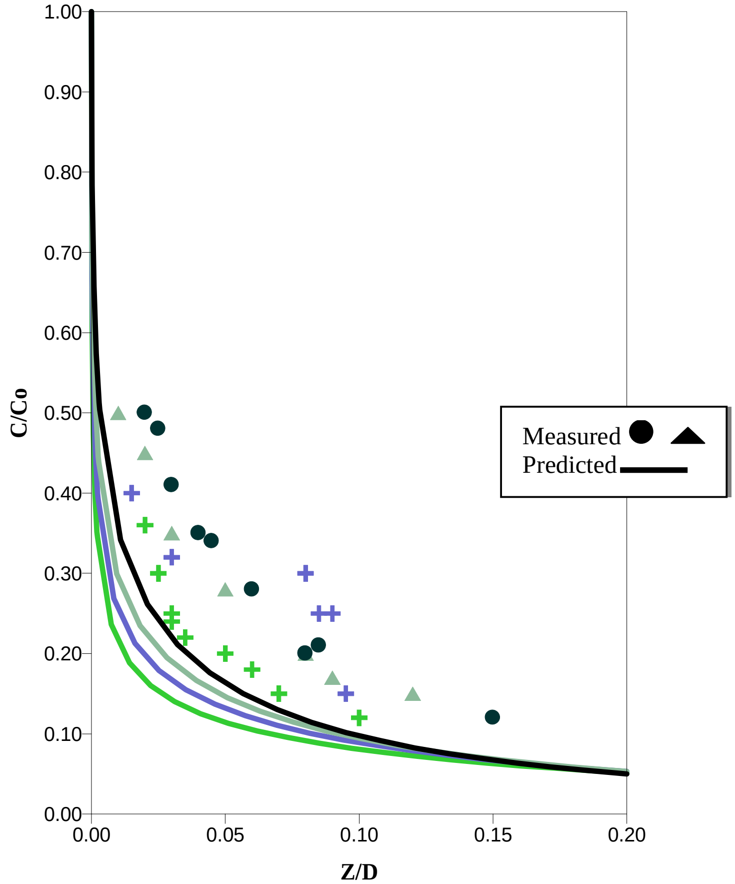


Figure 2. Centreline concentration decay of buoyant jet for Case 1.

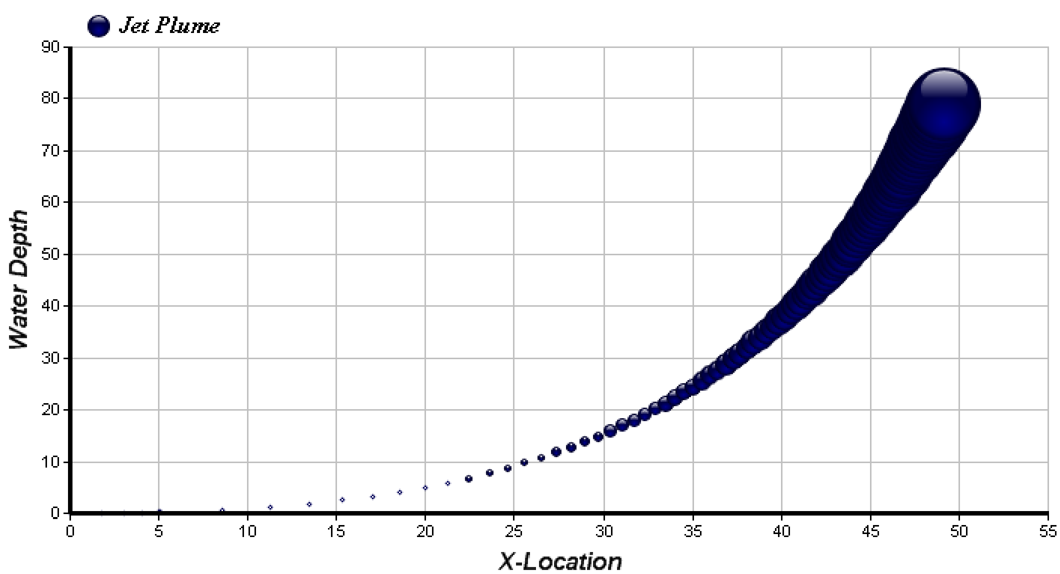


Figure 3. Trajectory of buoyant jet for Case 1-4 from KSPoil Model Result.

Case 2: Stratified Stagnant Ambient

In this case buoyant jets discharged at different angles in a stratified ambient fluid are simulated. The experimental results were given by Gu and Stefan (1988) as provided by Zheng and Yapa (1998). Table 2 provides the input conditions for this case.

The vertical gradient in the density of the ambient fluid ($d\rho_a/dz$ at jet location) is -0.354, -0.7. and -0.663 for cases 2-1, 2-2, and 2-3 respectively. Figure 4 provides the model results for Case 2. The value of K_c was taken as 0.45 m^2/s for Cases 2a, 0.2 m^2/s for Case 2b and 0.021 m^2/s for Case 2c. These values provided good results as shown in Figure 4. Figures 5, 6 and 7 shows trajectory of buoyant jet for Case 2-1 to 3 from KSPoil Model Result.

Table 2. Input Conditions For the Studied cases 2

Case	Jet Velocity	Kc	Jet Diameter	Jet Density	Jet Angle Horizontal	U	V	Jet Angle x-direc
2-1	31.68	0.45	1	950	45	0.001	0.001	0.0
2-2	17.6	0.2	1	950	39	0.001	0.001	0.0
2-3	11.45	0.021	1	950	2.8	0.001	0.001	0.0

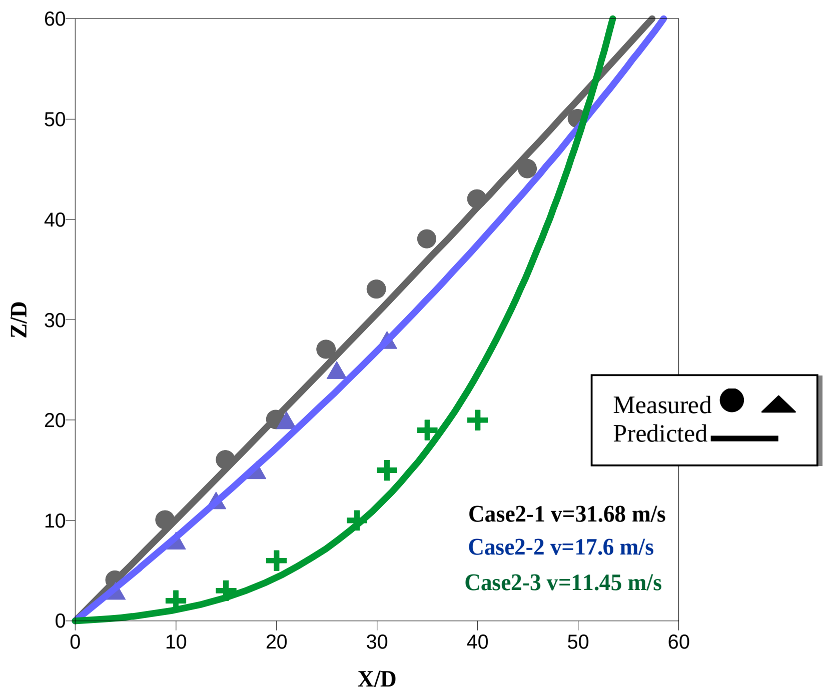


Figure. 4. Trajectory of buoyant jet for Case 2.

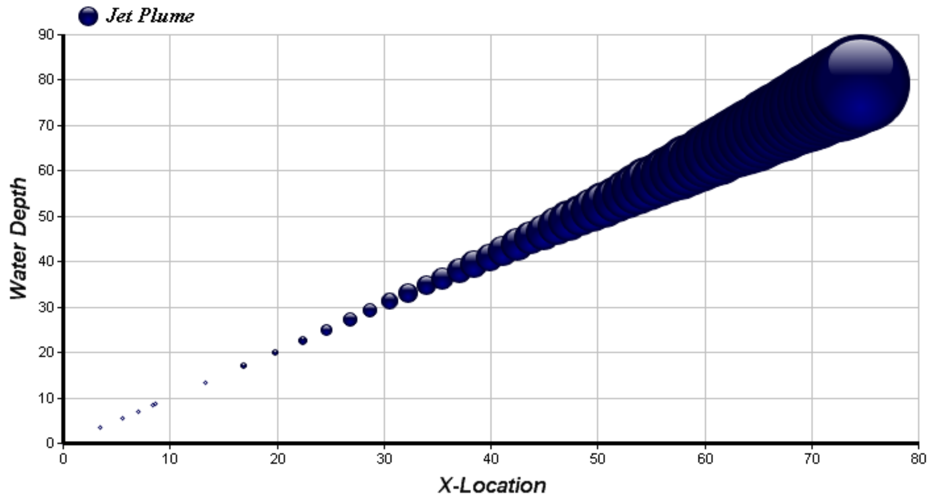


Figure 5. Trajectory of buoyant jet for Case 2-1 from KSPoil Model Result.

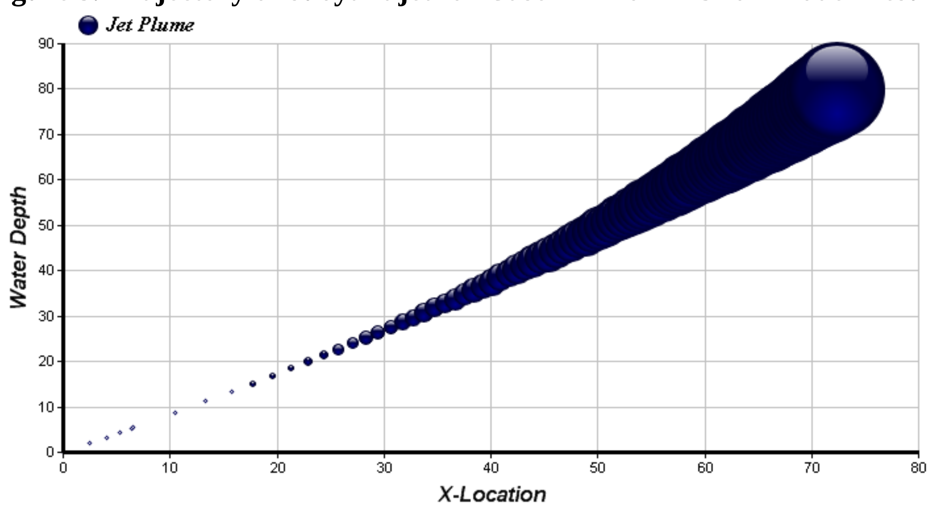


Figure 6. Trajectory of buoyant jet for Case 2-2 from KSPoil Model Result.

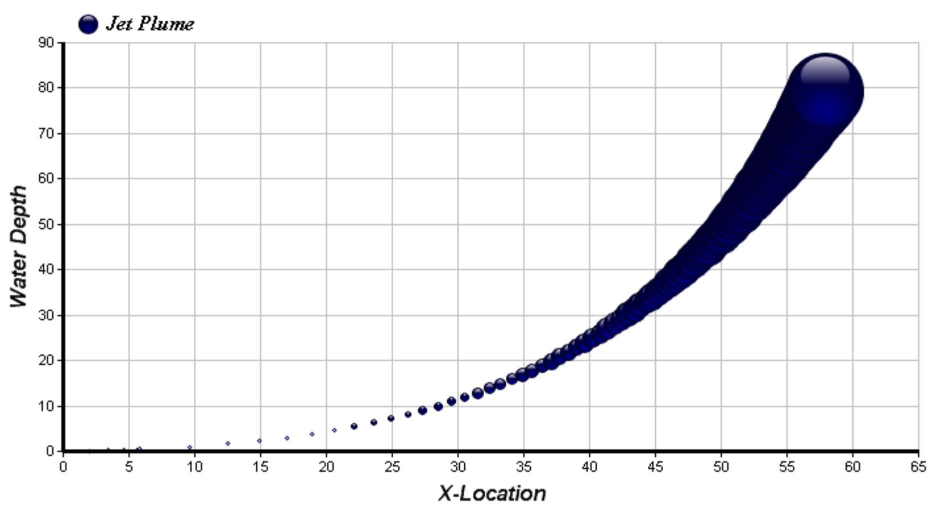


Figure 7. Trajectory of buoyant jet for Case 2-3 from KSPoil Model Result.

Case 3: Unstratified Flowing Ambient (Horizontal Jet)

This case provides a simulation of a buoyant jet discharged horizontally in an unstratified ambient fluid with a flow velocity of 0.476 m/s in the x direction. The jet velocity is 22.0 m/s with the input data as provided in Table 8. The experimental data is from Larsen et al. (1990) as given by as given by Zheng and Yapa (1998).

Figures 8 and 9 provide the model results for this case where the density deficiency is calculated from,

$$Density\ Defficiency = \frac{\rho_a - \rho}{\rho_a - \rho_o}$$

It can be seen that the model provides very good results with the value of K_c taken to be zero. ρa is density of the ambient water at the bed is 1025 kg/m3.ρo is density of the buoyant jet at the jet location ρo is 950 kg/m3. ρ step jet density

Table 3. Input Conditions For the Studied cases 3

Case	Jet Velocity	Kc	Jet Diameter	Jet Density	Jet Angle Horizontal	U	V	Jet Angle x-direc
3-1	22.0	0.0	1	950	0	0.476	0.001	0.0

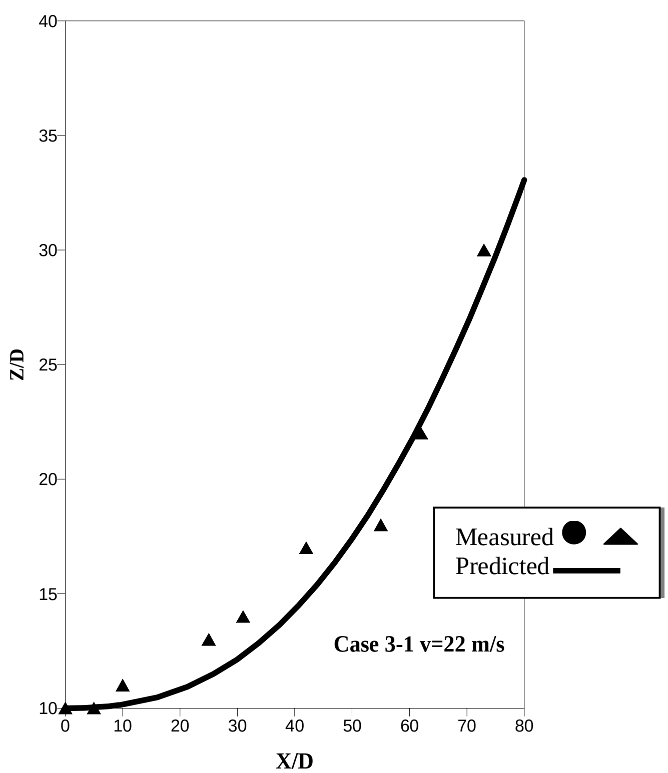


Figure 8. Trajectory of buoyant jet for Case 3

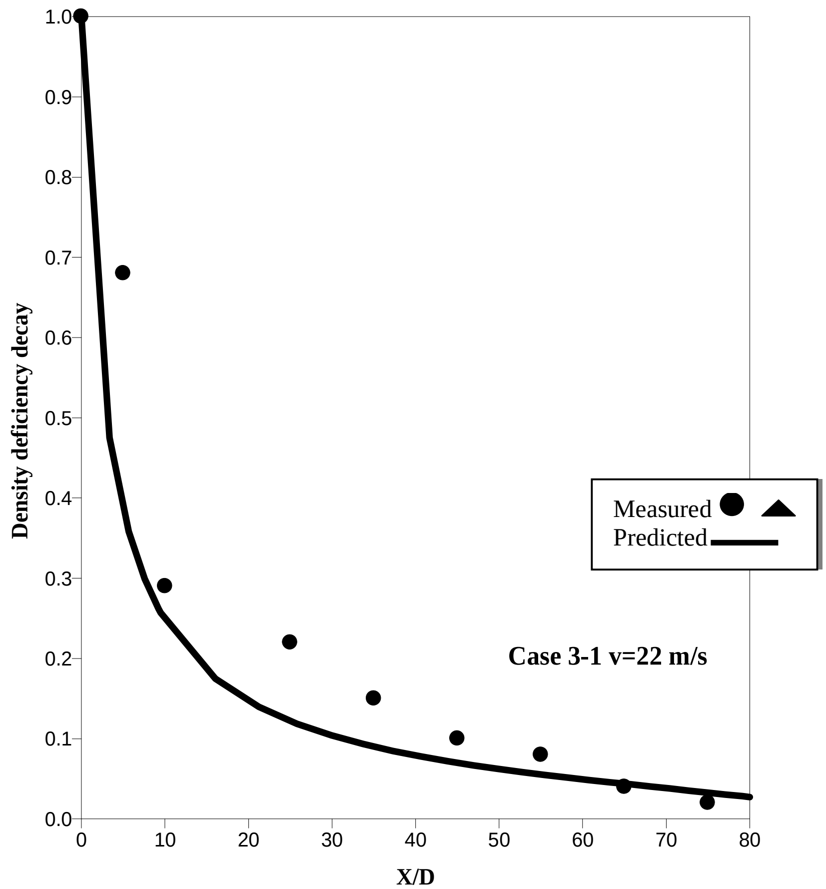


Figure 9. Density deficiency decay for Case 3.

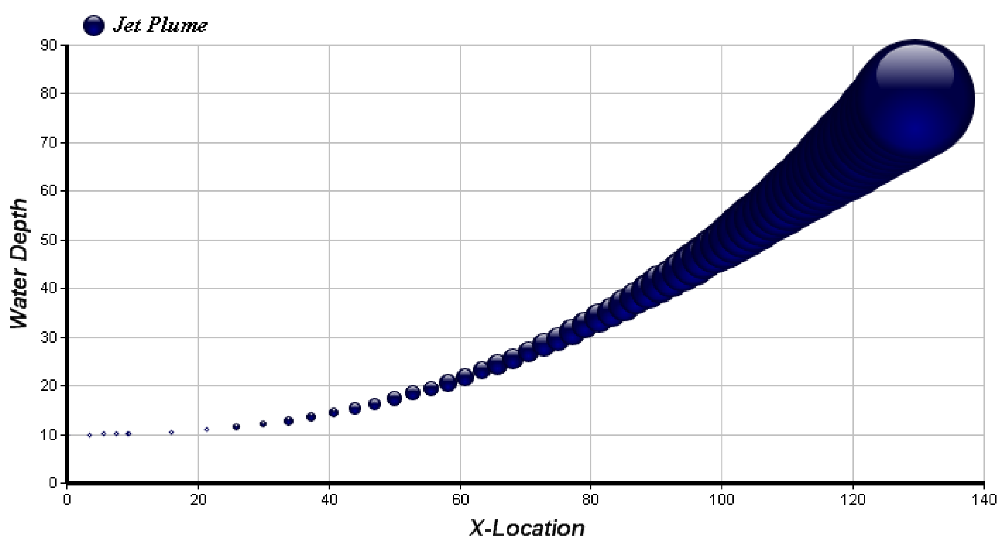


Figure 10. Trajectory of buoyant jet for Case 3-1 from KSPoil Model Result.

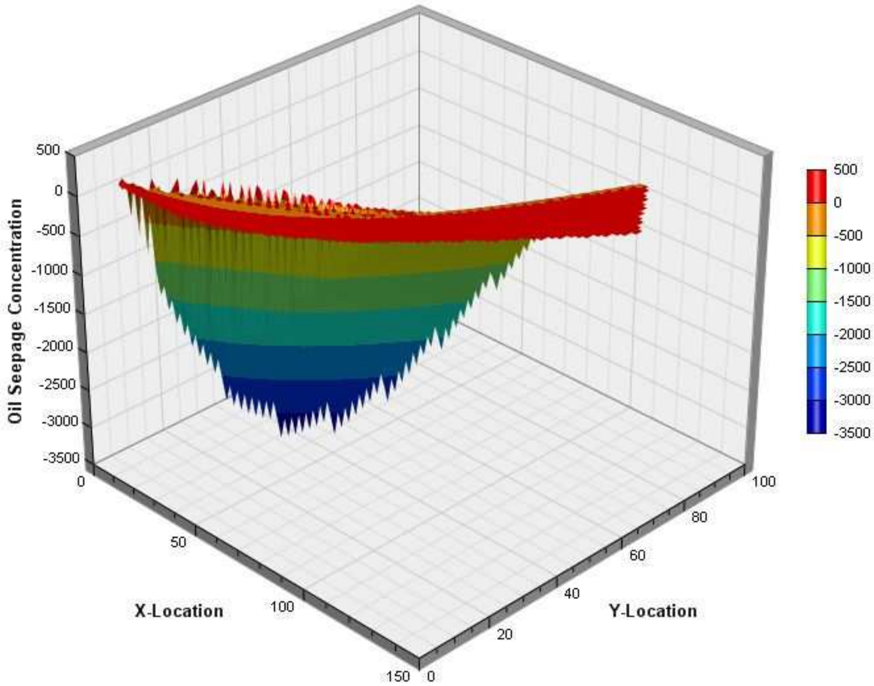


Figure 11. 3D concentration decay of buoyant jet for Case 3 from KSPoil Model Result.

Case 4: Unstratified Flowing Ambient (Vertical Jet)

This case provides a simulation of a buoyant jet discharged vertically as Table 4 in an unstratified ambient fluid with a flow velocity (in the x direction) of 4.4, 2.2, and 1.35 m/s for cases 4a, 4b, and 4c respectively. The velocity of the jet is 17.6 m/s for cases 4a and 4b and 16.3 m/s for case 4c. The experimental data is from Fan (1967) as given by as given by Zheng and Yapa (1998). The value of K_c was taken as 0.0 m^2/s for this case.

Fig 12 and 13 provide the model results for this case. It can be seen that the model predicts the trajectory location very well (Fig. 12). The concentrations are predicted reasonably well as shown in Fig. 13.

Table 4. Input Conditions For the Studied cases 4

Case	Jet Velocity	Kc	Jet Diameter	Jet Density	Jet Angle Horizontal	U	V	Jet Angle x-direc
4-1	17.6	0.0	1	950	90	4.4	0.001	0.0
4-2	17.6	0.0	1	950	90	2.2	0.001	0.0
4-3	16.3	0.0	1	950	90	1.35	0.001	0.0

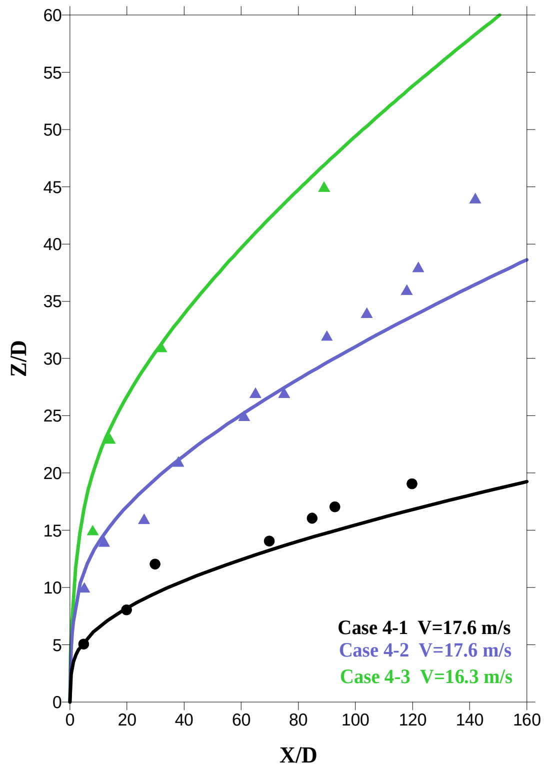


Figure 12. Trajectory of buoyant jet for Case 4

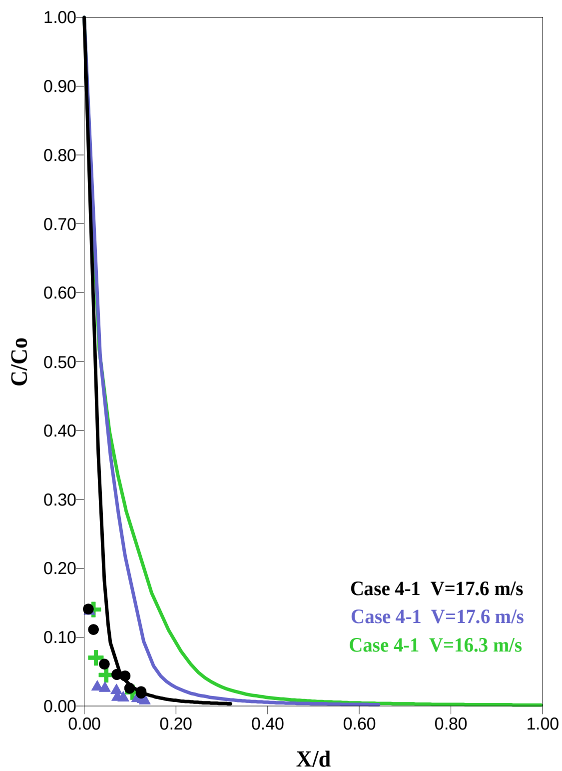


Figure 13. Centerline concentration decay of buoyant jet for Case 4

Application for KSPoil model Simulations

In this section the **KSPoil** model was applied to simulate the movement of oil seepage under different relevant conditions for the area between Quaro and Umm AlMaradem. A water depth of 30 m was assumed that will represent the maximum relevant water depth for Kuwait. The values of K_c, K_T and K_S were taken as 0.001 m^2/s and K_r was taken as 0.0 m^2/s.

The Effect of Ambient Current base on case 5 and case 6.

Case 5 is a total of 2 simulations were conducted to study the importance of the different parameters AND input data listed in Table 5. These cases consists of four simulations with different ambient currents for a jet velocity of 0.50 m/s. Figs. 14 to 19 show the graphical results for the 2 simulations under this case.

Table 5. Input Conditions For the Studied cases 5

Case	Jet Velocity	Kc	Jet Diameter	Jet Density	Jet Angle Horizontal	U	V	Jet Angle x-direc
5-1	0.5	0.001	10 cm	890	90	0.0	0.001	0.0
5-2	0.5	0.001	10 cm	890	90	1.0	0.001	0.0

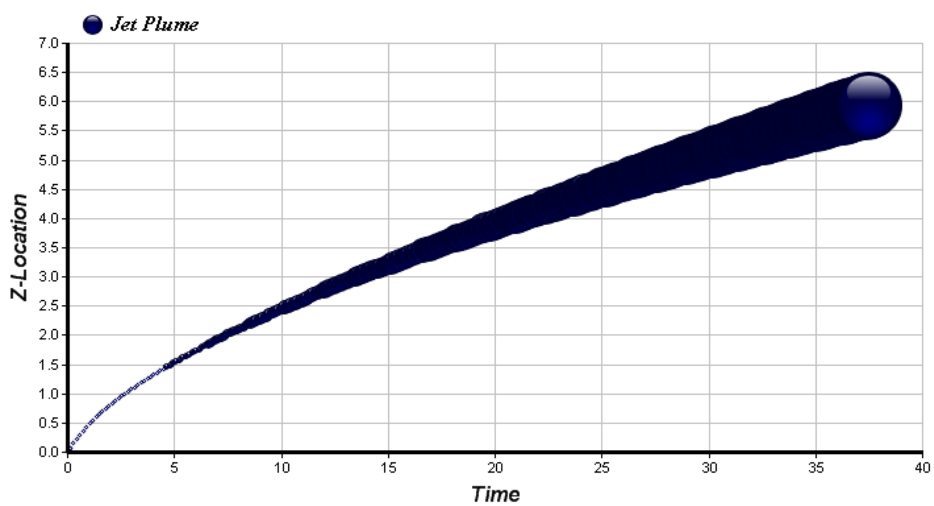


Figure 14. Trajectory of buoyant jet for Case 5-1

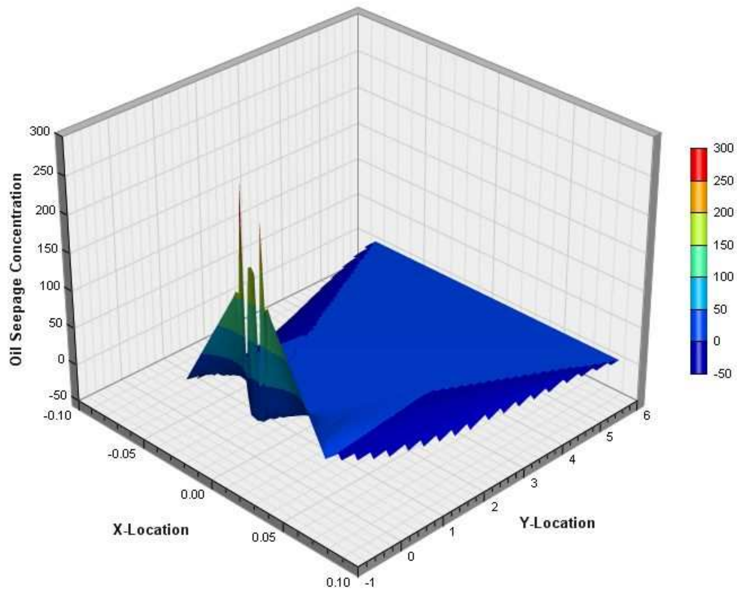


Figure 15. 3D concentration decay of buoyant jet for Case 5-1 from KSPoil Model

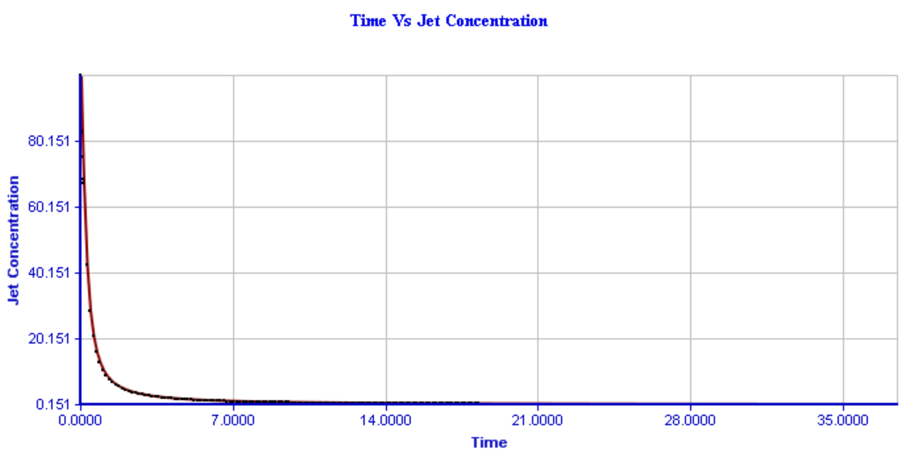


Figure 16. Centerline concentration decay of buoyant jet for Case 5-1

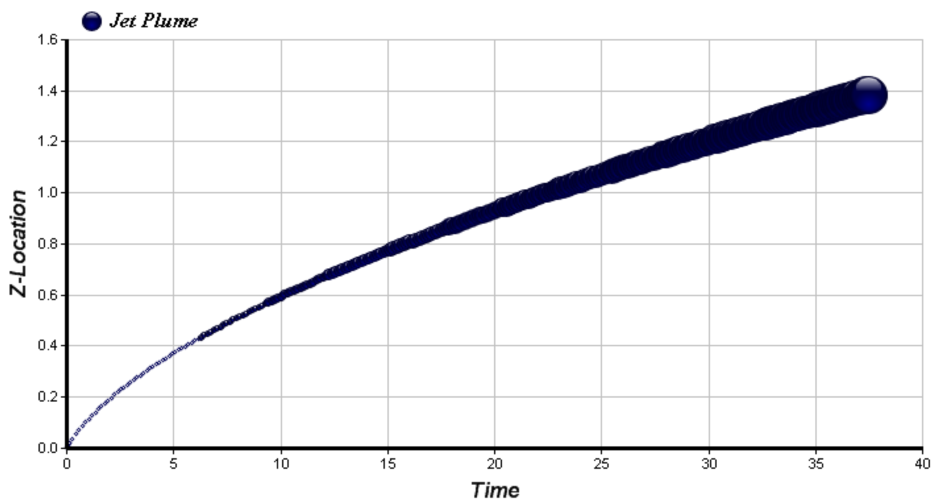


Figure 17. Trajectory of buoyant jet for Case 5-2

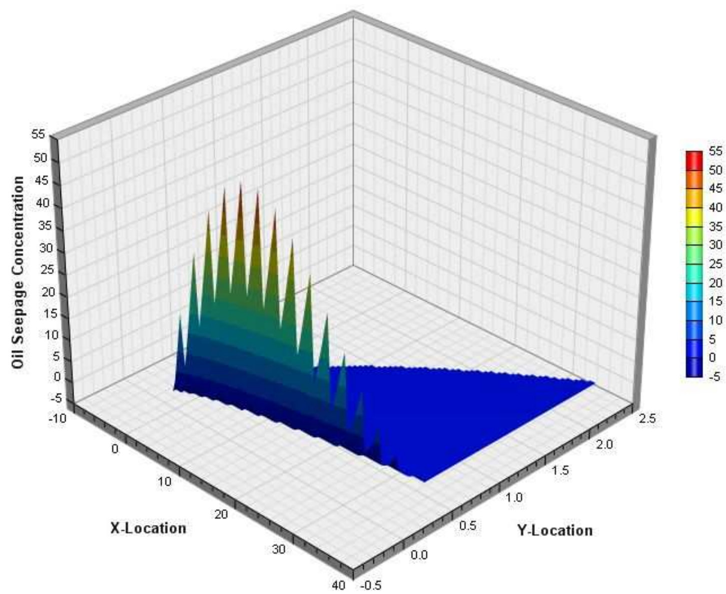


Figure 18. 3D concentration decay of buoyant jet for Case 5-2 from KSPoil Model

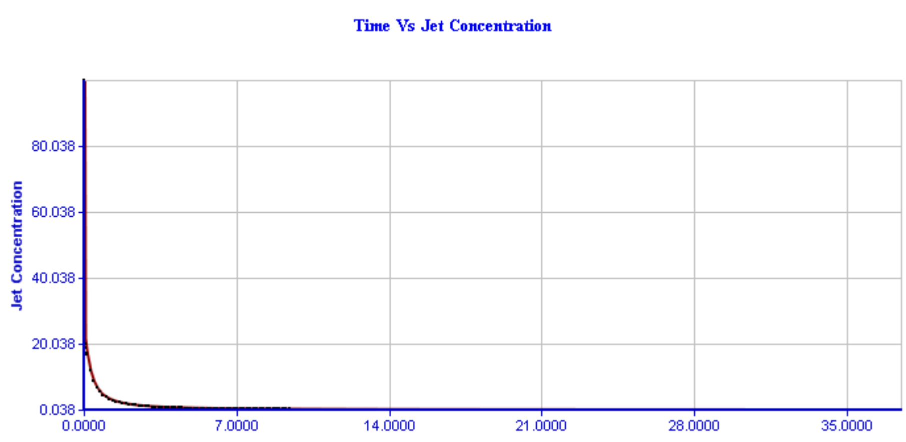


Figure 19. Centerline concentration decay of buoyant jet for Case 5-2

Case 6 is a total of 2 simulations were conducted to study the importance of the different parameters AND input data listed in Table 6.These cases consists of four simulations with different ambient currents for a jet velocity of 8.0 m/s. Figs. 20 to 26 show the graphical results for the 2 simulations under this case.

Table 6. Input Conditions For the Studied cases 6

Case	Jet Velocity	Kc	Jet Diameter	Jet Density	Jet Angle Horizontal	U	V	Jet Angle x-direc
6-1	8.0	0.001	10 cm	890	90	0.0	0.001	0.0
6-2	8.0	0.001	10 cm	890	90	1.0	0.001	0.0

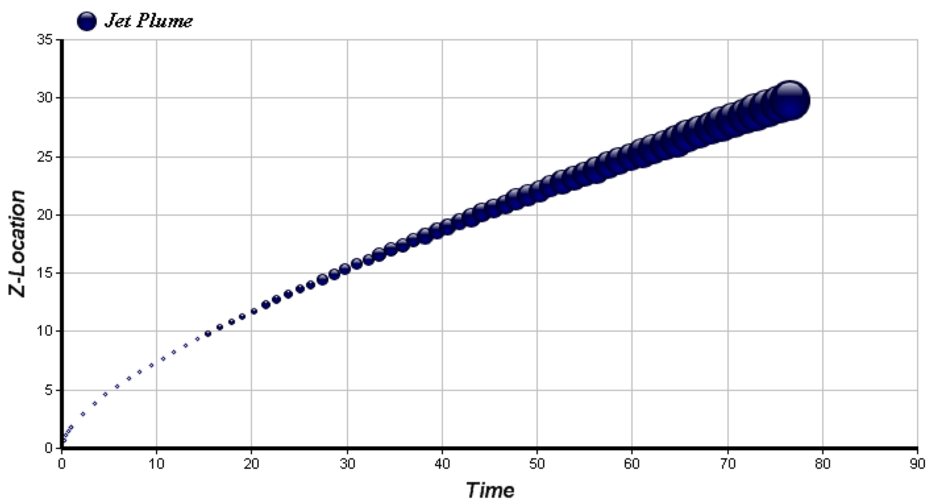


Figure 20. Trajectory of buoyant jet for Case 6-1

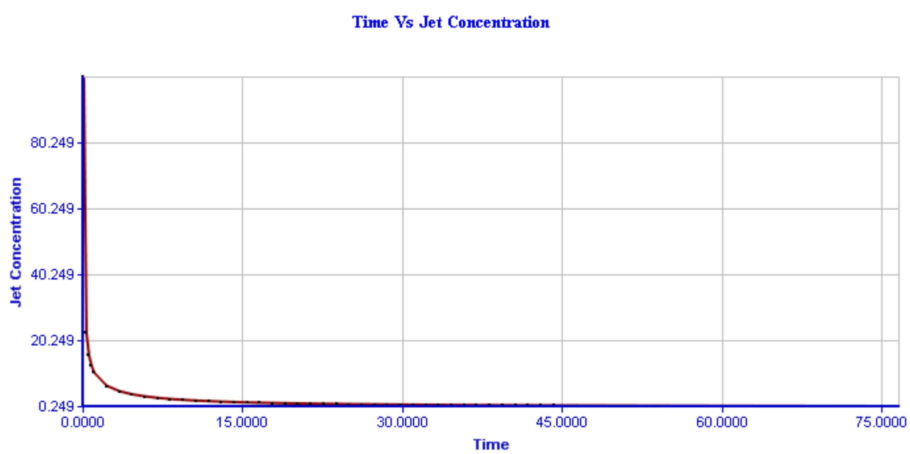


Figure 21. Centerline concentration decay of buoyant jet for Case 6-1

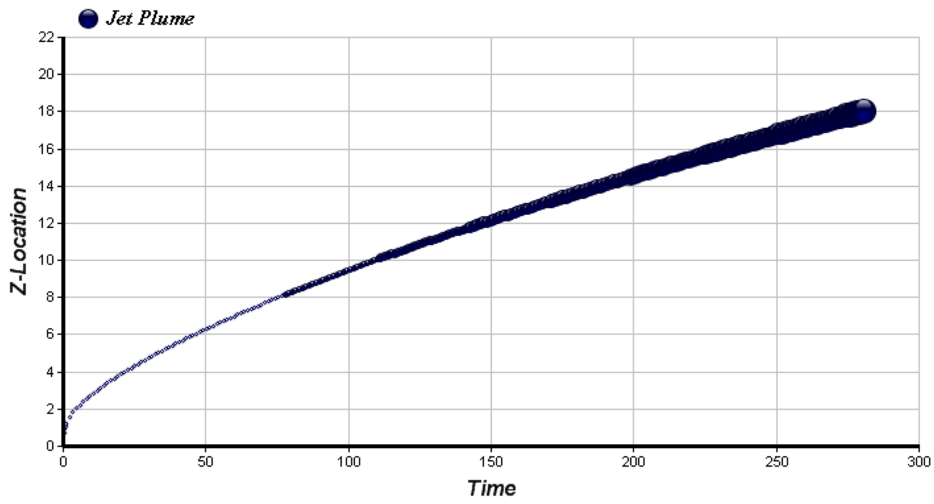


Figure 22. Trajectory of buoyant jet for Case 6-2

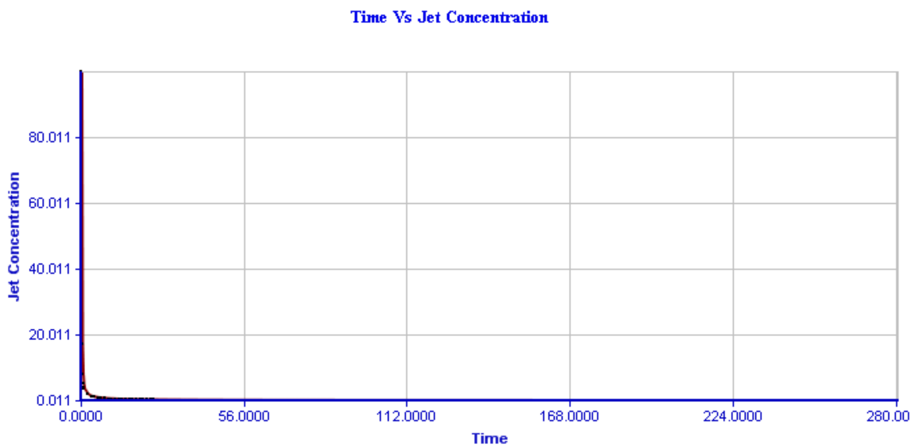


Figure 23. Centerline concentration decay of buoyant jet for Case 6-2

Figure 14 to 23 show that increasing the ambient current reduces the height of rise of Phase-1. The reason for this behavior is that increasing ambient current increases the entrainment. Hence, the plume looses buoyancy faster and bends more.

User Interface for Under waters Oil Seepage Emergency Model for Kuwait Waters and Arabian Gulf

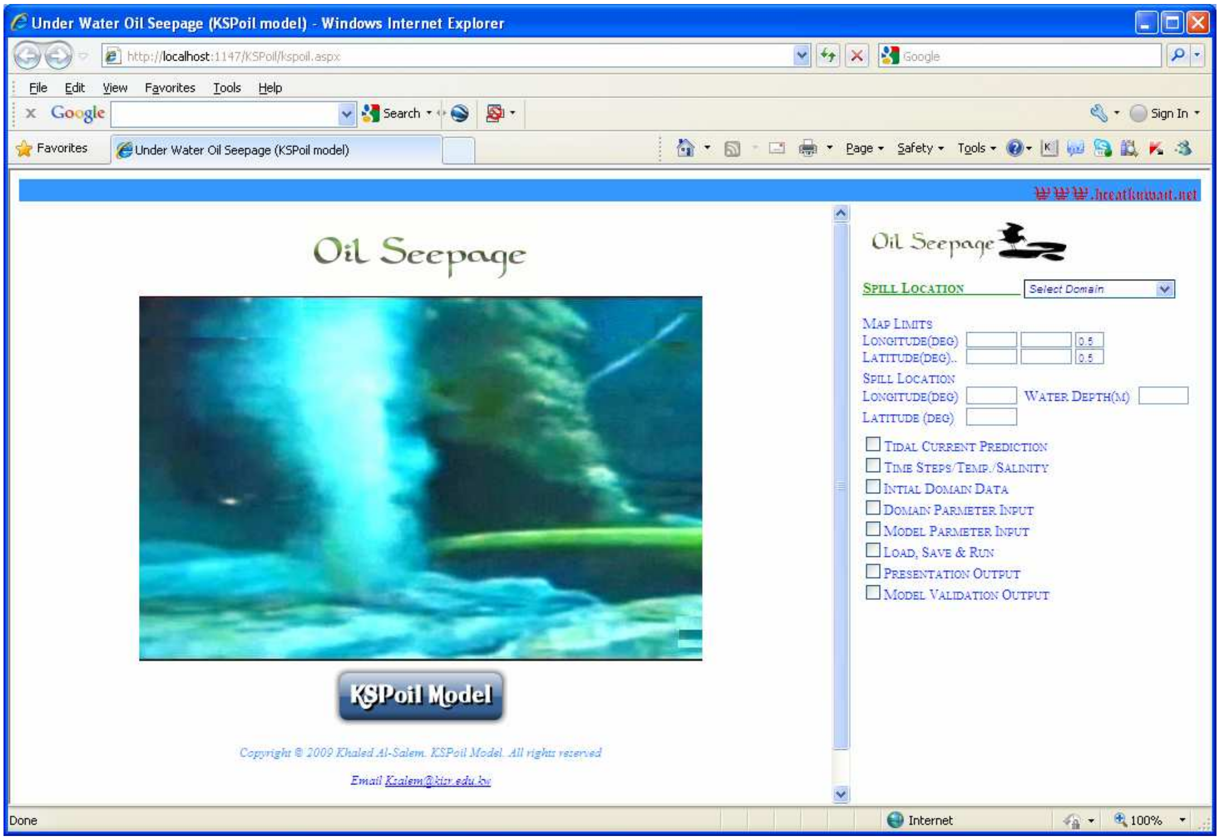


Figure 24. Main page of KSPoil model in Coastal Information System (CIS) website in the internet at address WWW.hceatkuwait.net

Procedure for Stand-Alone Usage of KSPoil model

KSPoil model is an efficient and easy-to-us under water oil spill model. Although more advanced features are anticipated to evolve in the future, this version is sufficiently user-friendly and can provide the base information for Trajectory of buoyant oil seepage jet. In this section of the report, step-by-step instructions are given for use of **KSPoil mode**l. The procedure outlined here to run the model.

Website model adders is WWW.hceatkuwait.net\oilspill\kspoil\kspoil.asp. Figure 24 will display and input option shown as:

Section 1. Locate under water spill location as shown in figure 24.

User have two option of Map as shown in Select Domain as:

Option 1 : Kuwait Water Map

Option 2: Arabian Gulf Map

Map limits will show in Figure 24

User has two options to select the spill coordinates as in Longitude and Latitude

Option 1 select from (**Spill Location drop list**)

Option 2 manual input for spill location in (**longitude / Latitude Box**)

For checking user spill location press on **Check/Save** as shown in Figure 25.

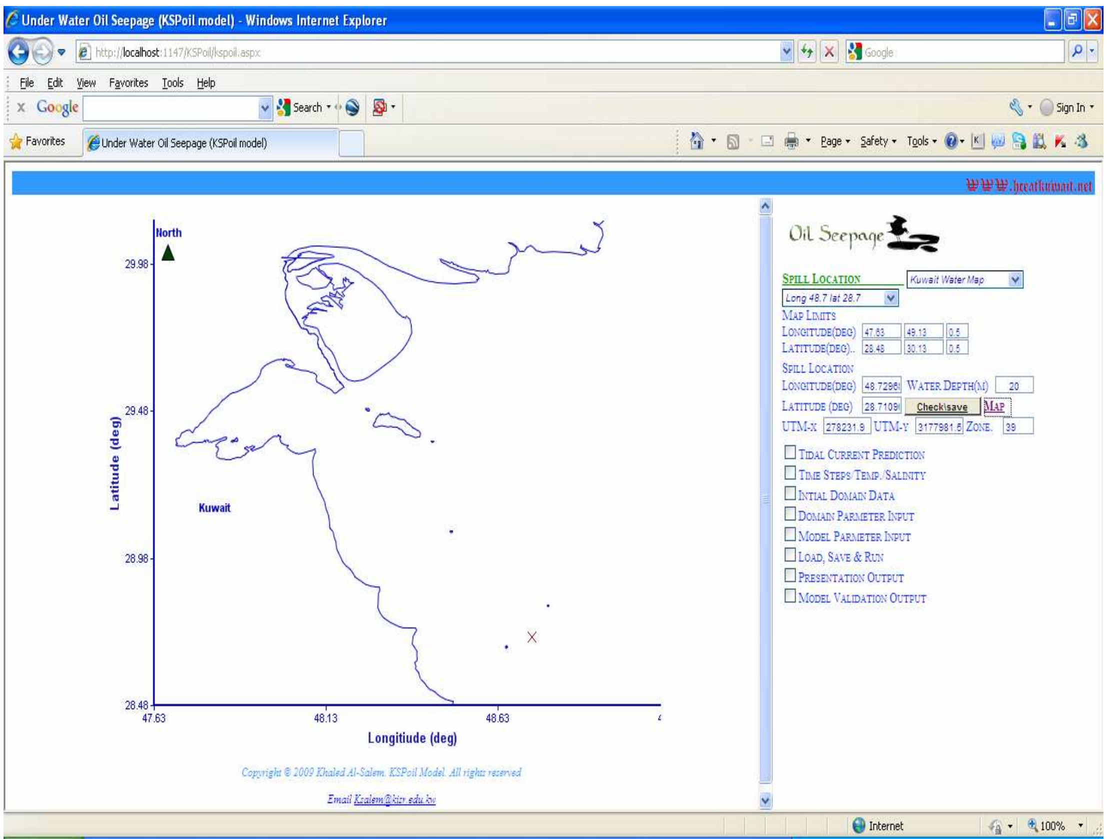


Figure 25. Kuwait Map with Under Water Oil Spill location From KSPoil Model

Figure 25 shows the Location Converted to UTM Scale and The Water Depth (m) and map Zone.

Section 2. Hydrodynamics Calculation for the selected oil spill location.

Check 1. User must select the **Tidal Current Prediction** Check Box. Figure 26 will show the Date and time selection for the oil spill started.

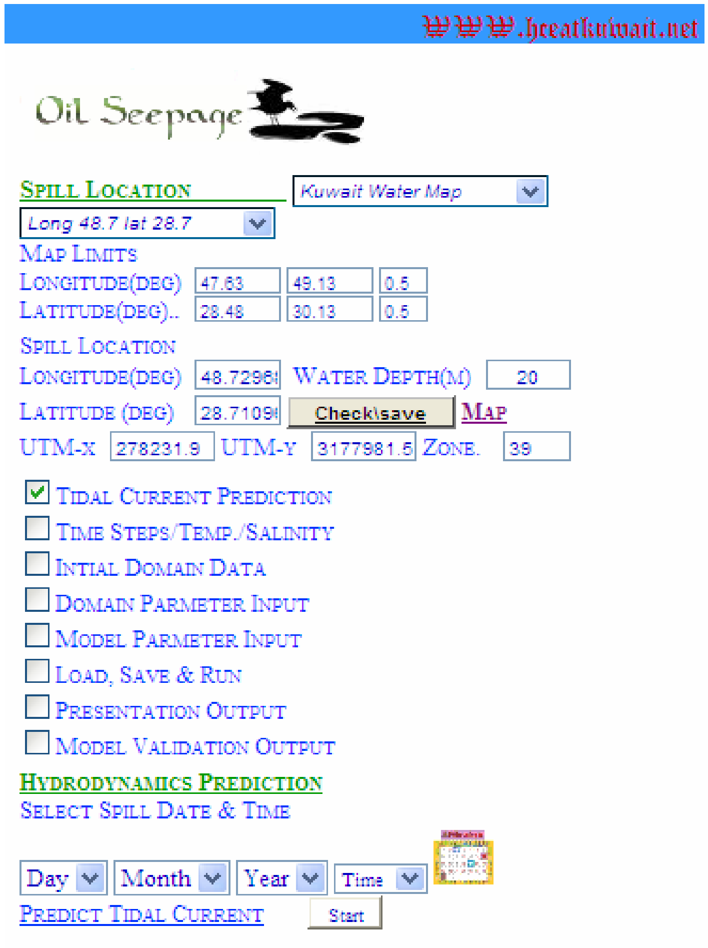


Figure 26. Hydrodynamics Calculation Date and Time Selection.

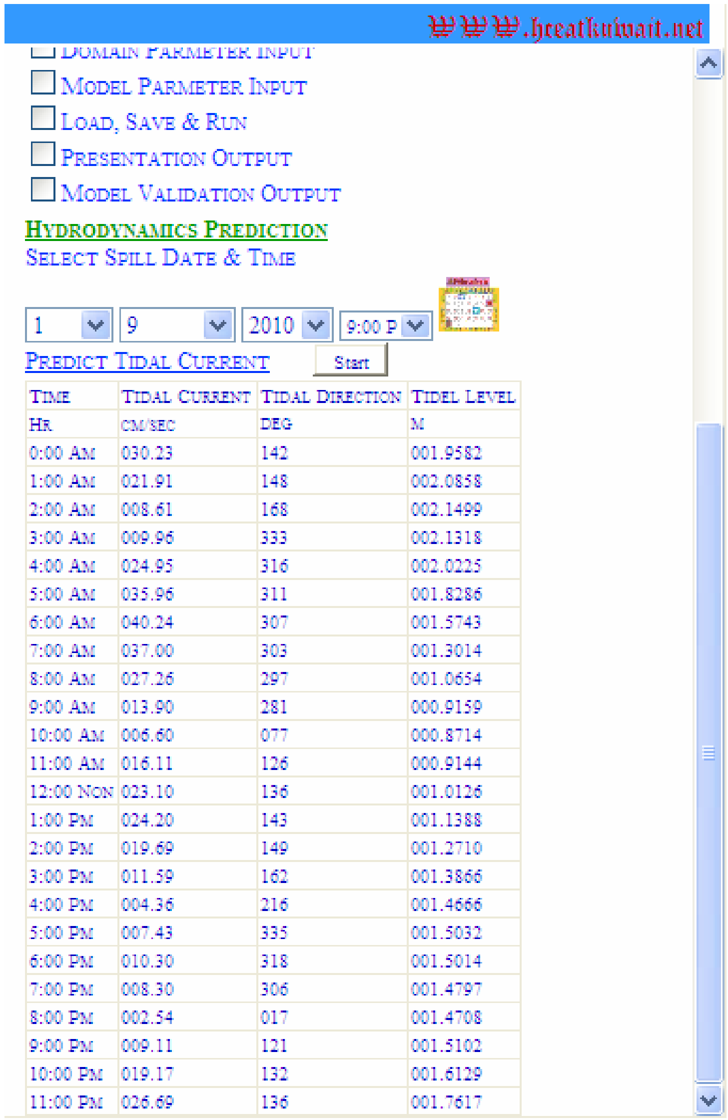
Figure 27 will show the selected date for 24 hours list of the tidal current, direction and Tide level.

Check 2. User must select the **Time step and Temperature and Salinity** check box figure 28 will show as:

1- User must enter time step and total time simulation.

2- 3 Sub check for user to select each as :

Sub Check 1. **Velocity Input Type**. Figure 29 will show for user to how The velocity in Z direction to be calculated as (manual input or logarithmic predict or constant input or Edit input file) based on water depth then user must save data.



Time	Tidal Current	Tidal Direction	Tidel Level
Hr	cm/sec	deg	m
0:00 Am	030.23	142	001.9582
1:00 Am	021.91	148	002.0858
2:00 Am	008.61	168	002.1499
3:00 Am	009.96	333	002.1318
4:00 Am	024.95	316	002.0225
5:00 Am	035.96	311	001.8286
6:00 Am	040.24	307	001.5743
7:00 Am	037.00	303	001.3014
8:00 Am	027.26	297	001.0654
9:00 Am	013.90	281	000.9159
10:00 Am	006.60	077	000.8714
11:00 Am	016.11	126	000.9144
12:00 Non	023.10	136	001.0126
1:00 Pm	024.20	143	001.1388
2:00 Pm	019.69	149	001.2710
3:00 Pm	011.59	162	001.3866
4:00 Pm	004.36	216	001.4666
5:00 Pm	007.43	335	001.5032
6:00 Pm	010.30	318	001.5014
7:00 Pm	008.30	306	001.4797
8:00 Pm	002.54	017	001.4708
9:00 Pm	009.11	121	001.5102
10:00 Pm	019.17	132	001.6129
11:00 Pm	026.69	136	001.7617

Figure 27. 24 hours list of the tidal current, direction and Tide level.

Sub Check 2 Temperature Type Input Figure 30 will show for user to how The Temperature in Z direction to be calculated as (manual input or constant input Or Edit input file) based on water depth then user must save data.

Sub Check 3 Temperature Type Input Figure 31 will show for user to how The Temperature in Z direction to be calculated as (manual input or constant input Or Edit input file) based on water depth then user must save data.

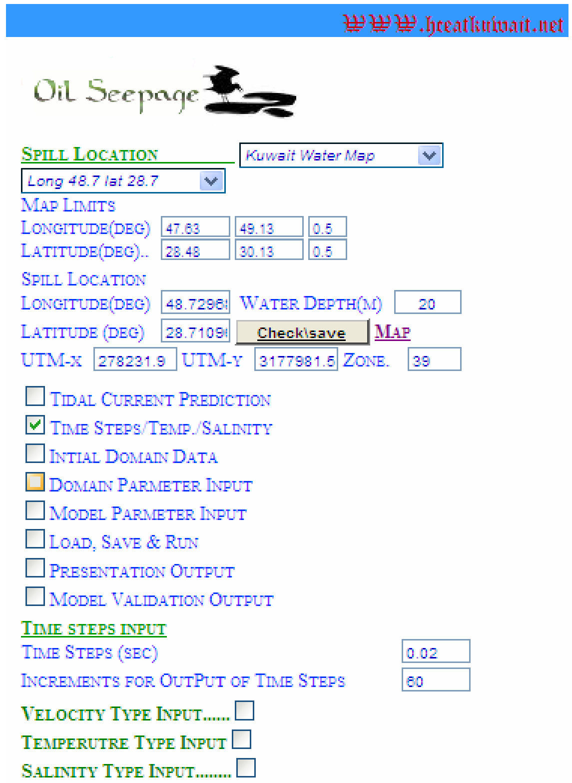


Figure 28. Time step and Temperature and Salinity Checking list.

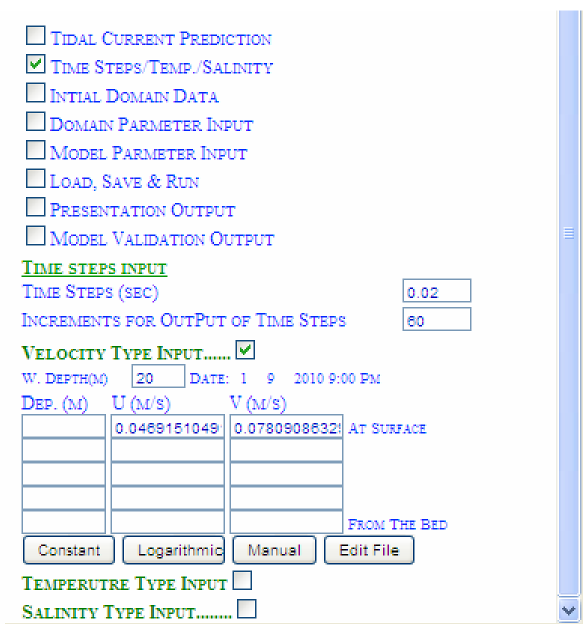


Figure 29. Velocity in Z direction to be calculated as (manual input or logarithmic predictor constant input or Edit input file) based on water depth.

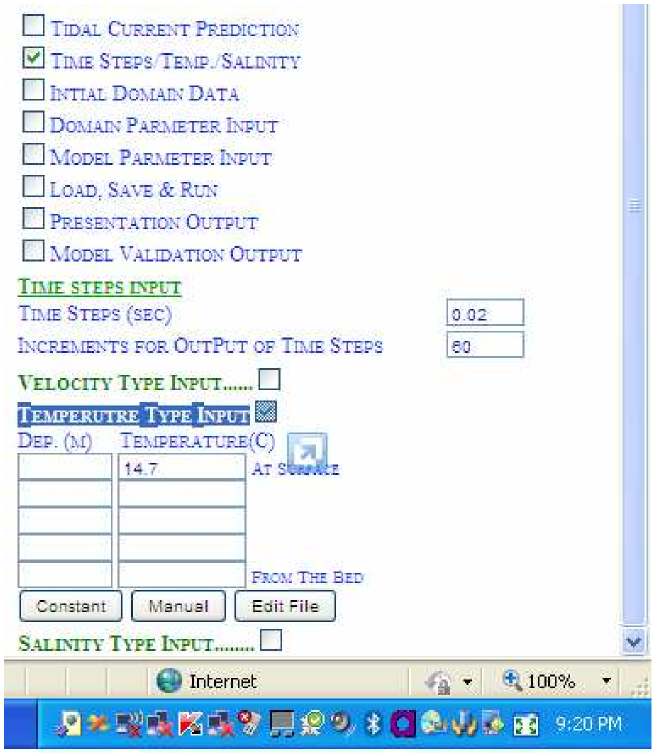


Figure 30. **Temperature Type Input in Z direction to be calculated as (manual input constant input or Edit input file) based on water depth.**

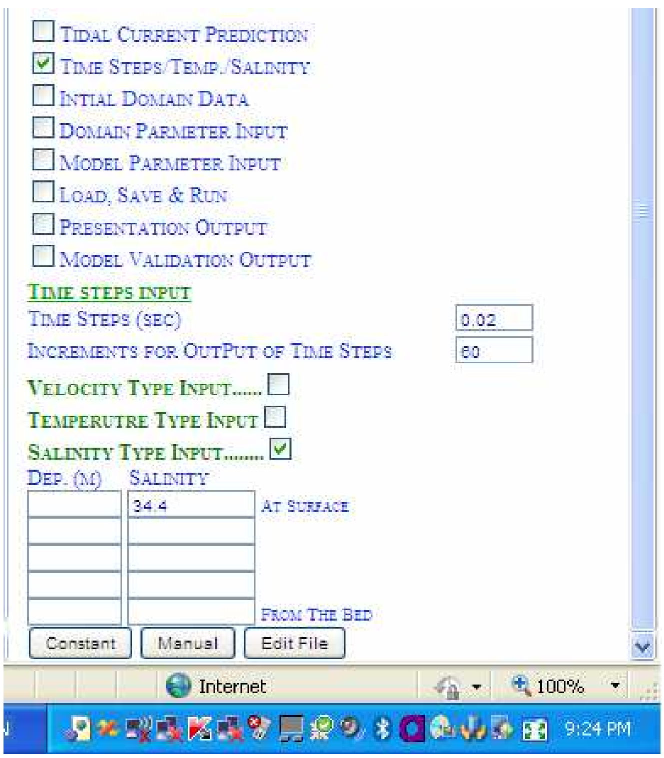


Figure 31. **Salinity Type Input in Z direction to be calculated as (manual input constant input or Edit input file) based on water depth.**

Check 3. User must select the **INITIAL DOMAIN DATA** check box as in figure 32. Figure 32 shows initial domain input data for under water jet oil spill .

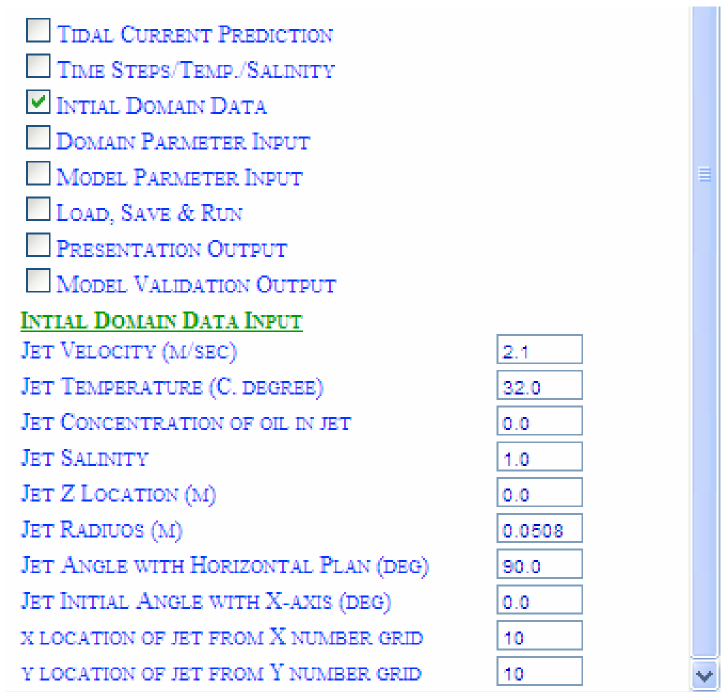


Figure 32. INITIAL DOMAIN DATA check box

Check 4. User must select the **DOMAIN PARAMETER INPUT** check box as in figure 33. Figure 33 shows domain parameters input data for under water jet oil spill .

Check 5. User must select the **MODEL PARAMETER INPUT** check box as in figure 34. Figure 34 shows model parameters input data for under water jet oil spill.

Check 6. User must select the **LOAD , SAVE & RUN** check box.

3 sub check option for user to select as shown in figure 35.

Sub check 1. **Load**

This option is for loading old save Input file

Sub check 2. **Save**

This option is for save the update input or new input data files

Sub check 3. **Run**

This option to start simulation.

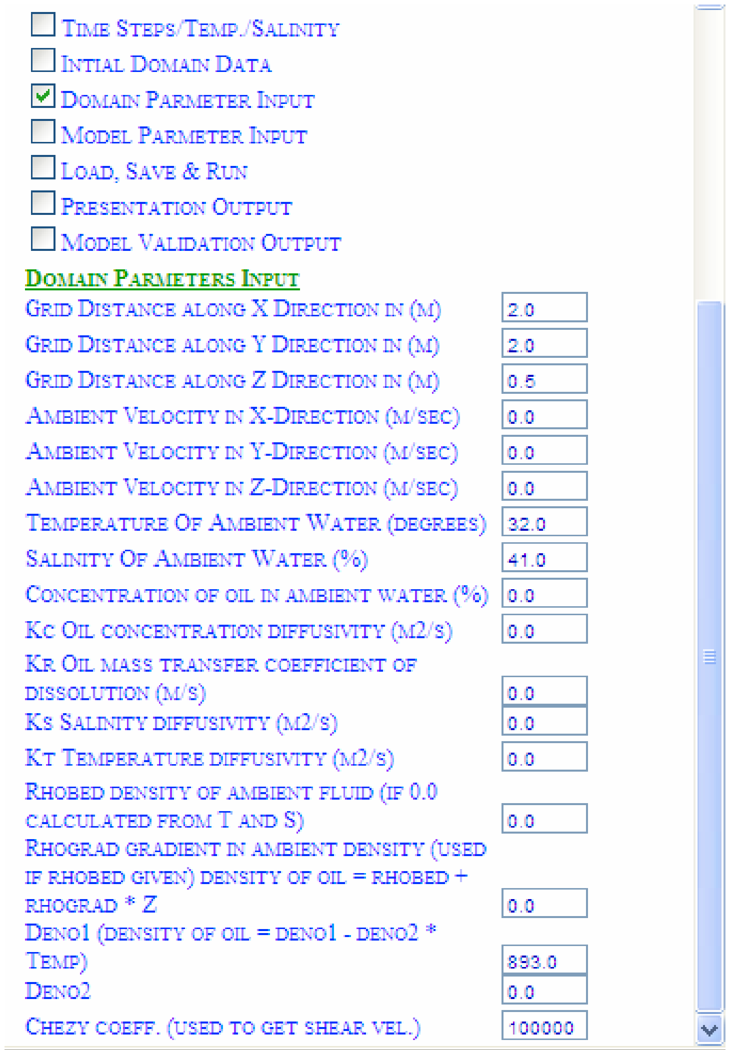


Figure 33. Domain Parameter Input check box

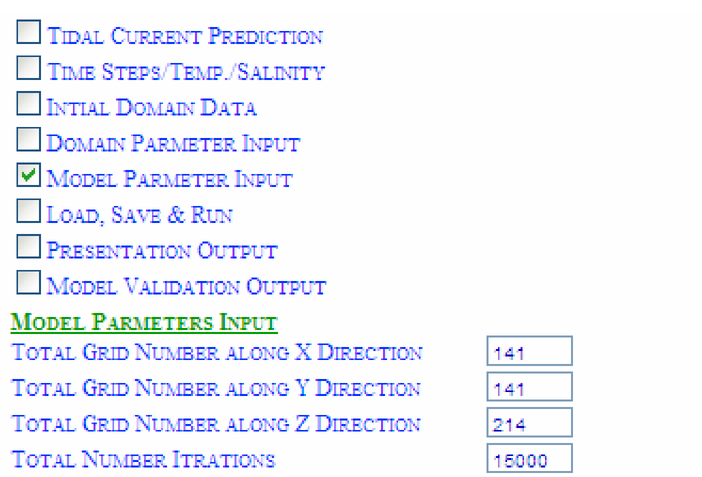


Figure 34. Domain Parameter Input check box

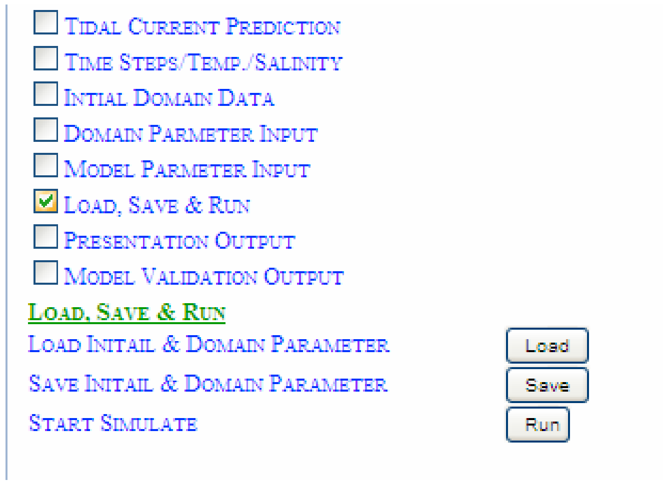


Figure 35. LOAD , SAVE & RUN Check Box

After user select save in figure 35 then start simulation the KSPoil model by press on Run. The time consumed for simulation base on the user internet connection.

Section 3. Output Presentation:

Check 7. User must check on (**Presentation Output**) as shown in figure 35.

Figure 36 will show a number of check list of graphically output presentation.

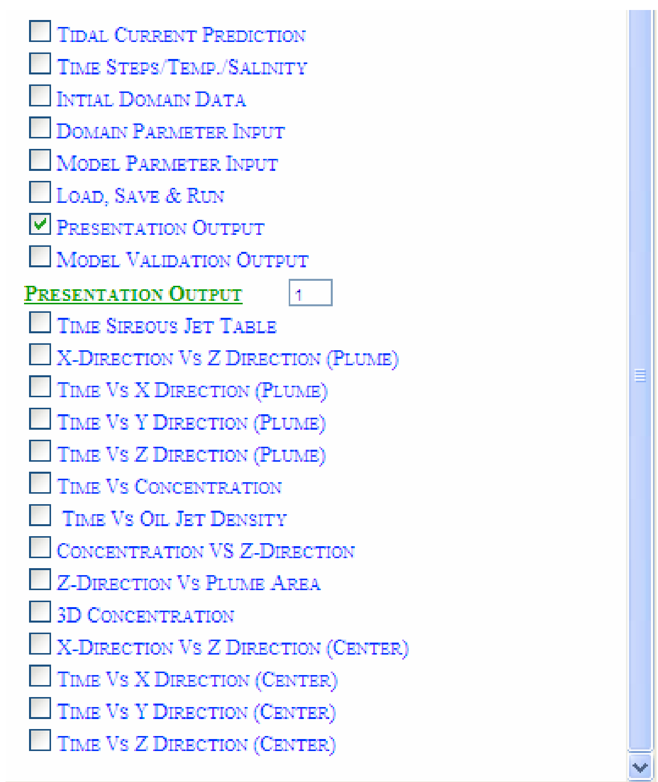


Figure 36. Check Box For Output Presentation

Check 8. User must check on (**Model Validation output**) shown in figure 35. Figure 37 will show a number of check list of graphically output.

- [ ] Tidal Current Prediction
- [ ] Time Steps/Temp./Salinity
- [ ] Intial Domain Data
- [ ] Domain Parmeter Input
- [ ] Model Parmeter Input
- [ ] Load, Save & Run
- [ ] Presentation Output
- [x] Model Validation Output

Validation Output

- [ ] Trajectory of buoyant jet
- [ ] Centerline concentration decay of buoyant jet
- [ ] Density deficiency decay

Figure 37. Check Box For Output Presentation

Figures 38, 39, 40,41,42,43 show sample of **KSPoil model** output Presentation.

KSPoil Model

Oil Spill Location: Longitude(deg)= 48.72968 Latitude(deg)= 28.71096 Water Depth(m)= 20
Date: 1/9/2010 At Time= 9:00 Pm

Time	Radius	X-location of jet	Y-location of jet	Z-location of jet	Jet concentration	Jet Density	Time Incr.	Xloc(UTM)	Yloc(UTM)
0	0.05	0	0	0	100	890	0	294634.4	3208310.3
0.12	0.0756	0	0	0.1885	53.12517	953.55068	0.1885	294634.4	3208310.3
0.24	0.0959	2E-05	3E-05	0.32946	37.37212	974.90793	0.32946	294634.40002	3208310.30003
0.36	0.1132	0.00012	0.00019	0.44791	29.22078	985.95914	0.44791	294634.40012	3208310.30019
0.48	0.1286	0.00026	0.00044	0.5527	24.15092	992.83261	0.5527	294634.40026	3208310.30044
0.5	0.131	0.00029	0.00048	0.56917	23.48292	993.73826	0.56917	294634.40029	3208310.30048
1.1	0.1927	0.00159	0.00264	0.98622	13.0481	1007.88529	0.98623	294634.40159	3208310.30264
1.7	0.2424	0.00375	0.00625	1.32332	9.10175	1013.23557	1.32336	294634.40375	3208310.30625
2.3	0.2858	0.00671	0.01117	1.62048	6.98642	1016.10343	1.62057	294634.40671	3208310.31117
2.9	0.3252	0.01033	0.01719	1.89256	5.65978	1017.90203	1.89274	294634.41033	3208310.31719
3.5	0.3617	0.01464	0.02437	2.14706	4.74833	1019.13774	2.14738	294634.41464	3208310.32437
4.1	0.396	0.01954	0.03252	2.38833	4.08368	1020.03883	2.38883	294634.41954	3208310.33252
4.7	0.4284	0.02506	0.04171	2.61921	3.57766	1020.72487	2.61997	294634.42506	3208310.34171
5.3	0.4593	0.03111	0.05178	2.84164	3.17984	1021.26421	2.84271	294634.43111	3208310.35178
5.9	0.4888	0.03774	0.06282	3.05708	2.85949	1021.69853	3.05853	294634.43774	3208310.36282
6.5	0.5171	0.04488	0.0747	3.26656	2.59553	1022.05639	3.26847	294634.44488	3208310.3747
7.1	0.5443	0.05254	0.08745	3.47095	2.37562	1022.35454	3.4734	294634.45254	3208310.38745
7.7	0.5705	0.06071	0.10105	3.67092	2.18867	1022.60799	3.674	294634.46071	3208310.40105
8.3	0.5958	0.06934	0.11542	3.86698	2.02859	1022.82503	3.87078	294634.46934	3208310.41542
8.9	0.6202	0.07848	0.13063	4.05965	1.88993	1023.01302	4.06426	294634.47848	3208310.43063
9.5	0.6439	0.08807	0.14659	4.24925	1.7683	1023.17792	4.25478	294634.48807	3208310.44659
10.1	0.6666	0.09812	0.16332	4.43614	1.66181	1023.32229	4.44268	294634.49812	3208310.46332
10.7	0.6887	0.10863	0.18081	4.62061	1.567	1023.45083	4.62827	294634.50863	3208310.48081
11.3	0.7106	0.11956	0.19901	4.80284	1.48149	1023.56676	4.81174	294634.51956	3208310.49901
11.9	0.733	0.13095	0.21797	4.98281	1.40241	1023.67397	4.99307	294634.53095	3208310.51797

Figure 38.

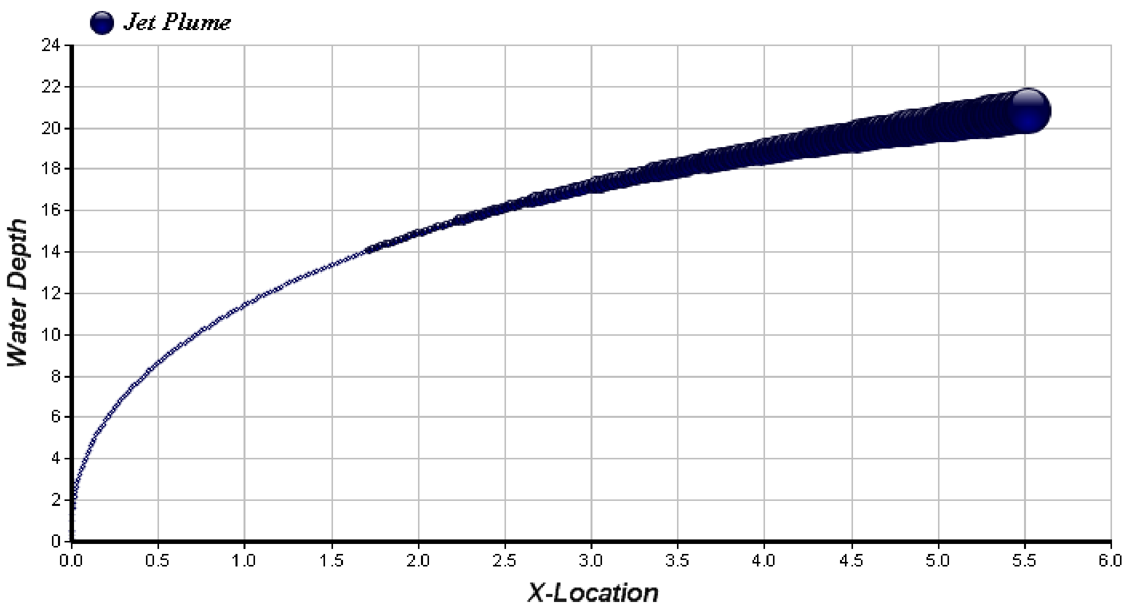


Figure 39.

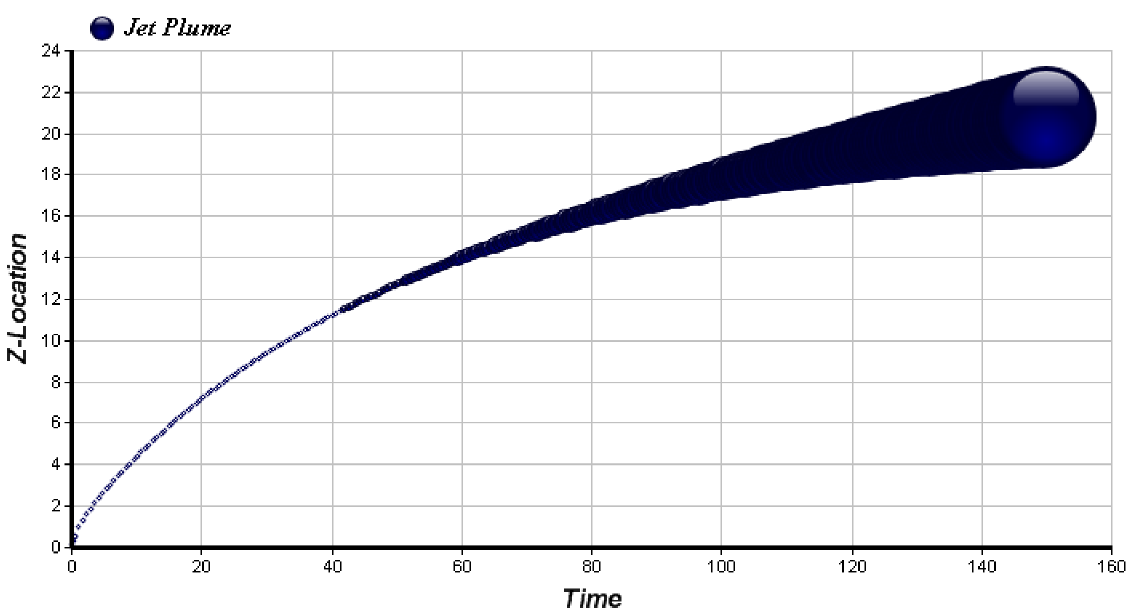


Figure 40.

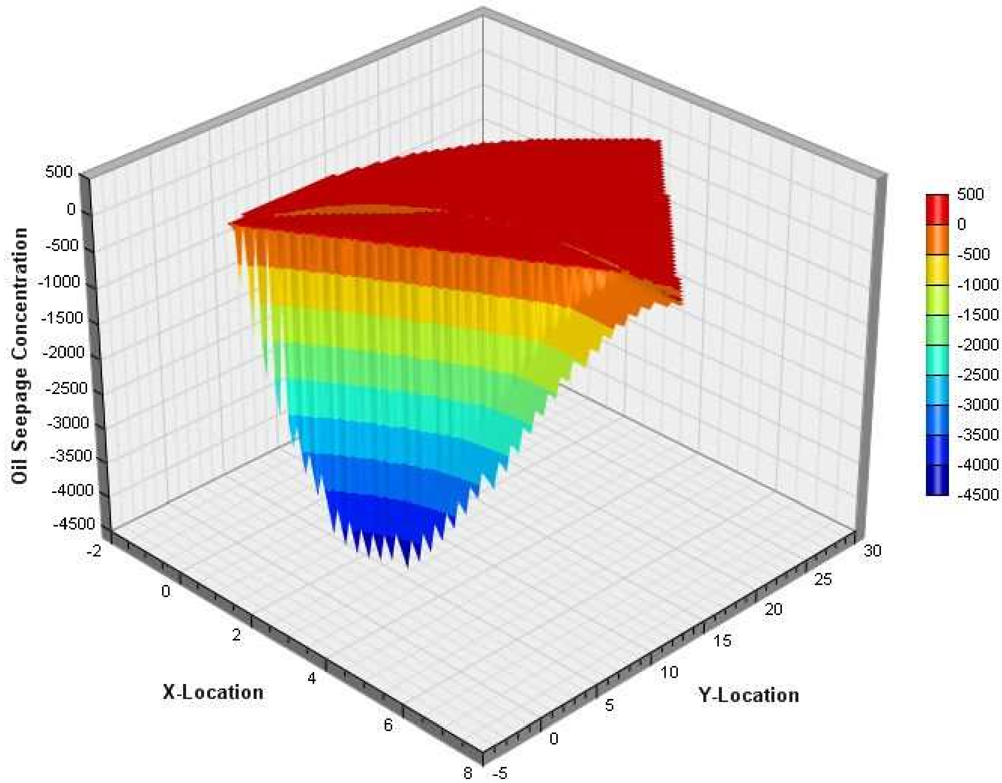


Figure 41.

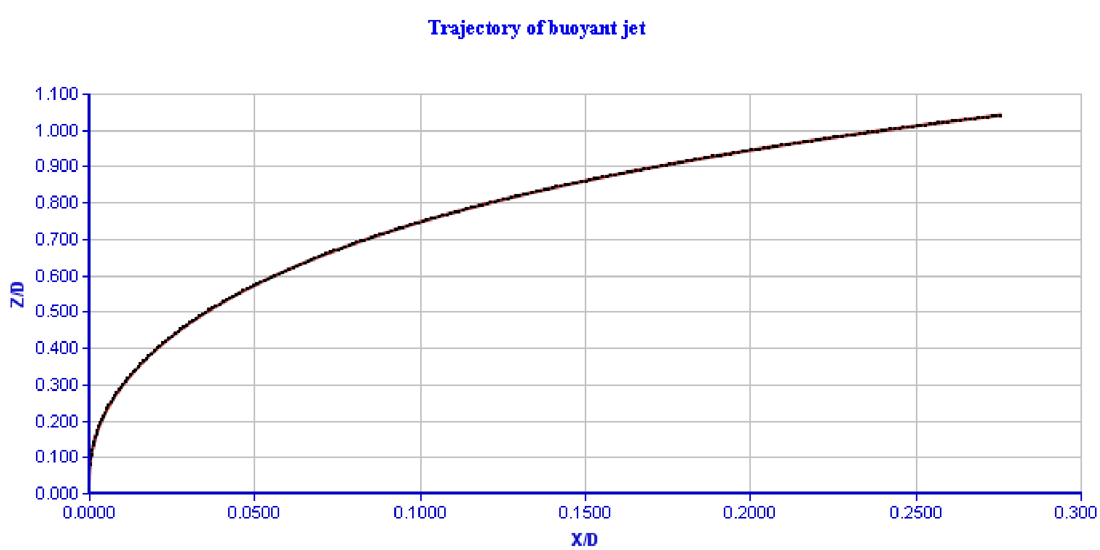
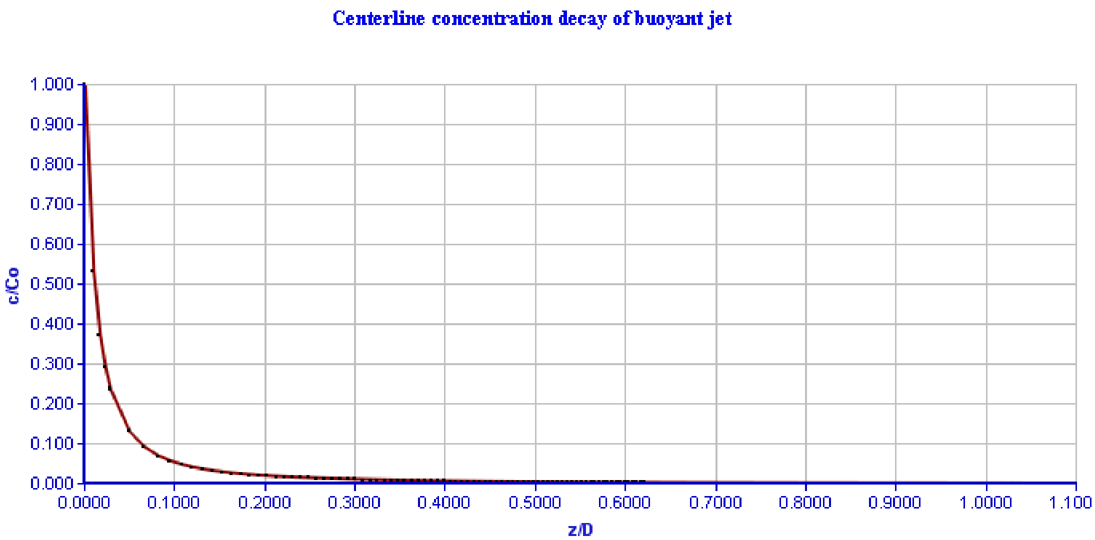


Figure 42.



Centerline concentration decay of buoyant jet
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
c/Co
0.0000
0.1000
0.2000
0.3000
0.4000
0.5000
0.6000
0.7000
0.8000
0.9000
1.0000
1.100
z/D

Figure 43.