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Groundwater Modeling Efforts Presentation

Prepared by
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July 2006

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Presentation by Dr. Chandramouli Viswanathan
Meeting with Dr. Alaudin Kahn, Dr. Lindell Ormsbee, Jim Kipp, Steve Hampson
To Discuss Status of KRCEE Modeling Activities

July 2006

Groundwater Modeling Efforts
Paducah Gaseous Diffusion Plant

Regional Groundwater Flow and Contaminant

Transport Model

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Overview

- 1. Introduction
- 2. Model Description
- 3. UK Modeling Efforts
  - 3.1 Hydraulic Model Re-calibration
  - 3.2 Sensitivity Analyses
    - Physical parameters
    - Hydraulic parameters
    - Contaminant parameters
  - 3.3 Pump-Treat Studies
  - 3.4 Hydraulic Barrier Studies
- 4. Summary and Conclusions
- 5. Future Direction

1. INTRODUCTION

- Need for Groundwater Models
- UK's Groundwater Modeling Efforts
- Importance of Sensitivity Analyses

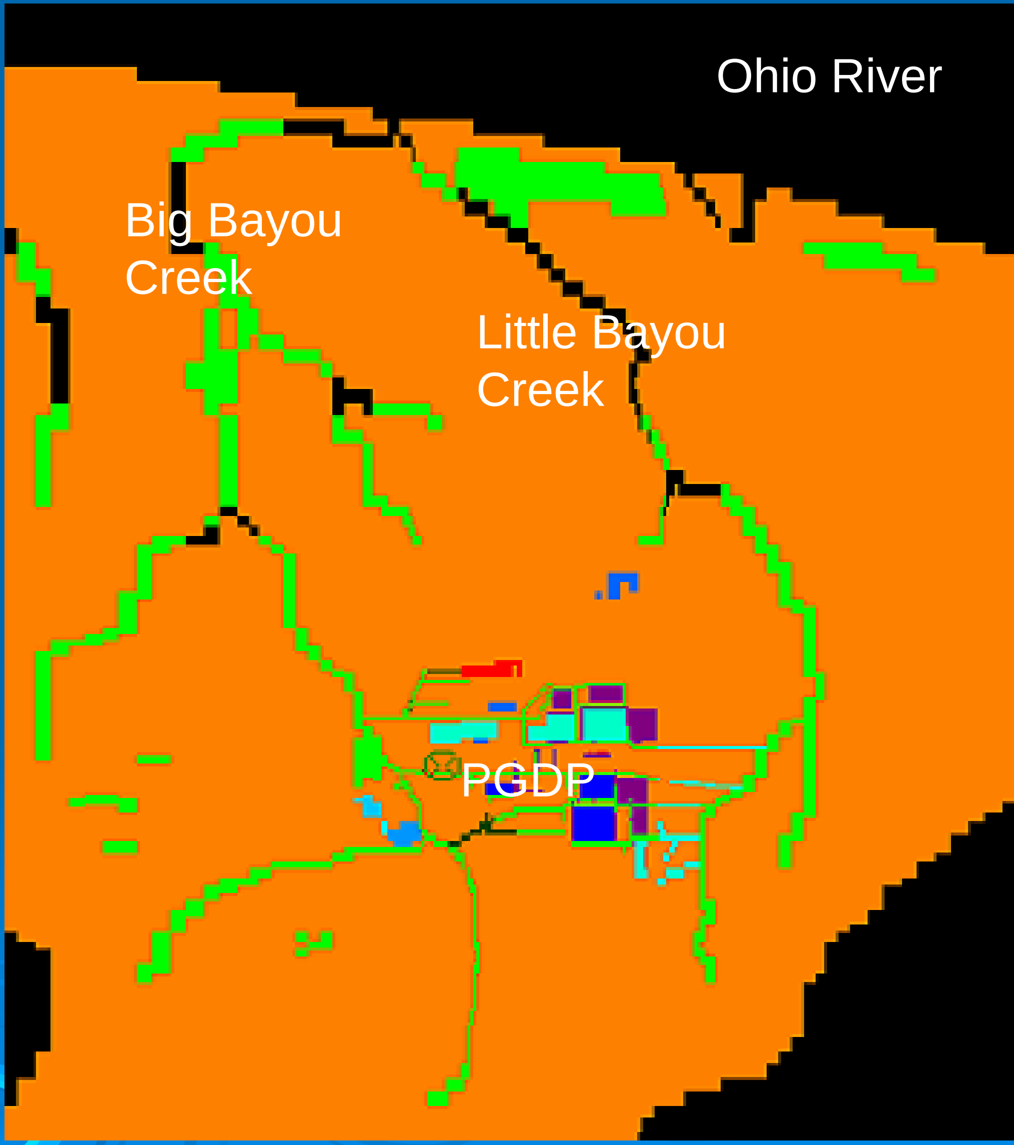
PGDP Regional Groundwater Flow and Contaminant Transport Model

Background

- First developed in 1994
  - Flow model of RGA only using MODFLOW
- Revised in 1996, 1997, 1998, and 2000
- Revisions made in 1998 included addition of transport modeling capabilities
- Latest model uses MODFLOWT for contaminant transport (HydroSolve Inc and GeoTrans Inc)

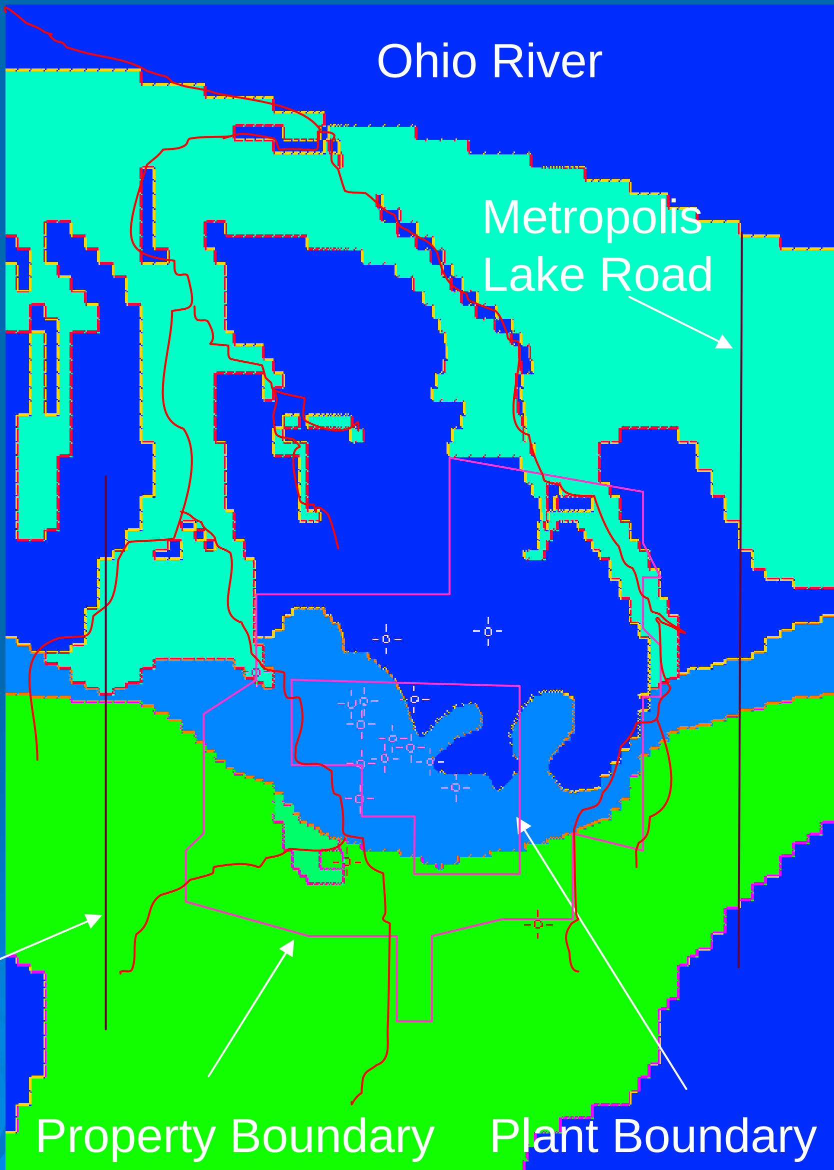
2. Model Description

Overview



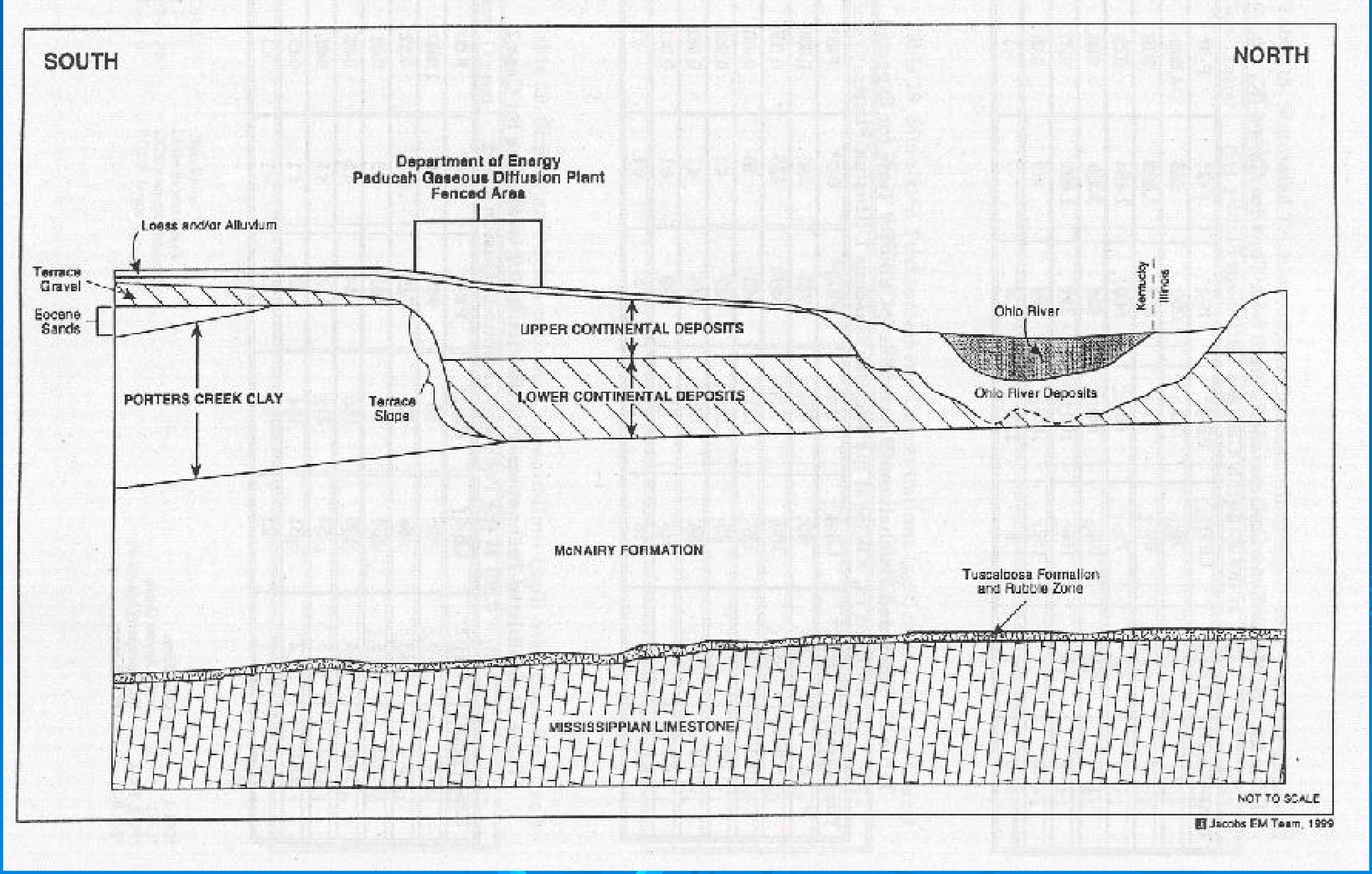
Model Description

- Covers nearly 100 sq. km (38.6 sq. mi)
- Most model boundaries coincide with natural boundaries



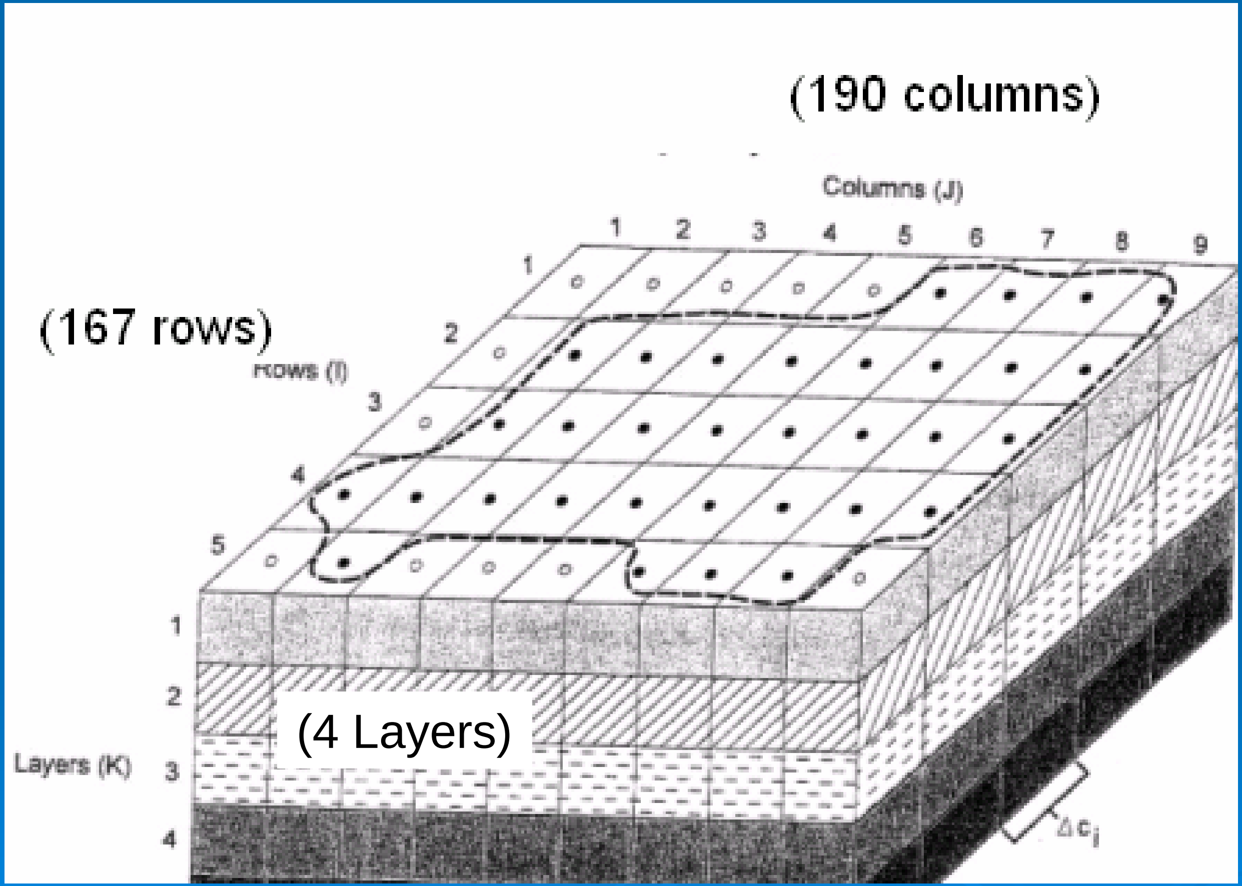
Model Description

Geology of Regional Aquifer



Model Description

Conceptual Model



1st layer represents sands, silts and clays of the upper continental deposits (HU2A)

2nd layer represents lower portion of the Upper continental deposits (HU2B) and in some area near Ohio river it represents alluvial deposits.

3rd layer simulates the permeable sands and gravels of hydrogeologic units HU4 and HU5

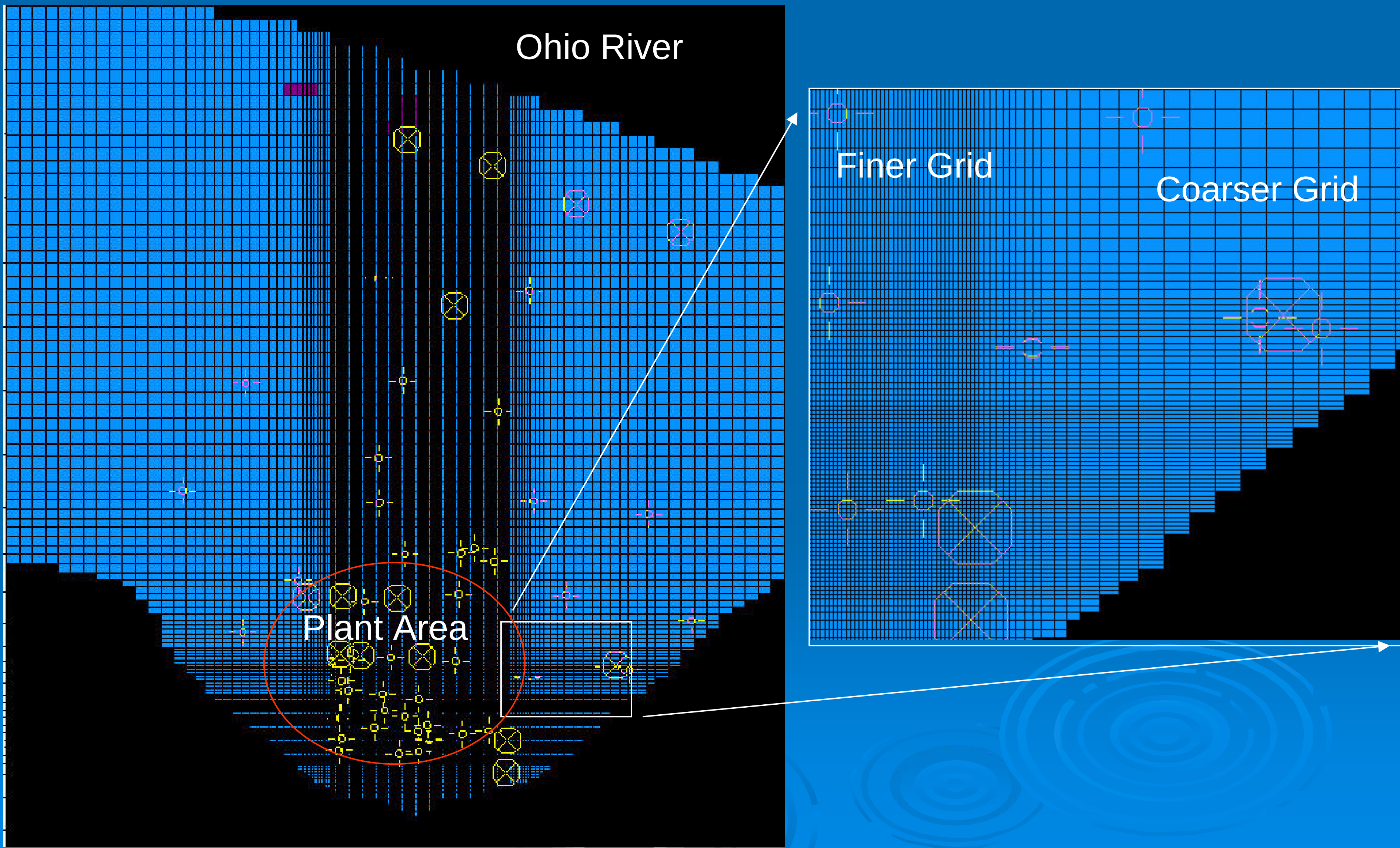
4th layer simulates the McNairy Formation flow system (HU6)

Model Description

- Finite Difference Grid
  - 167 rows (about 36,000ft)
  - 190 columns (about 25,000 ft)
- Variable grid size
  - Smaller spacing in the plant vicinity
  - Column width varies from 45 – 425 ft
  - Row height varies from 50 – 425 ft
- Total number of cells = 126,920
  - 95,215 active cells (75%)
- Two Stress Periods

Model Description

Finite Difference Grid



Model Description
Boundary conditions

- Ohio river in the North: As constant head boundary condition in Layer 3.
- Ohio river stage
  - 300.04 ft in stress period 1
  - 306.86 ft in stress period 2.
- 1122 cells are used for defining this boundary condition in the north.

Model Description

Boundary conditions

- Big Bayou and Little Bayou creeks – river flow boundary conditions
- Storm water and effluent discharges ditches
- 18 different outfalls

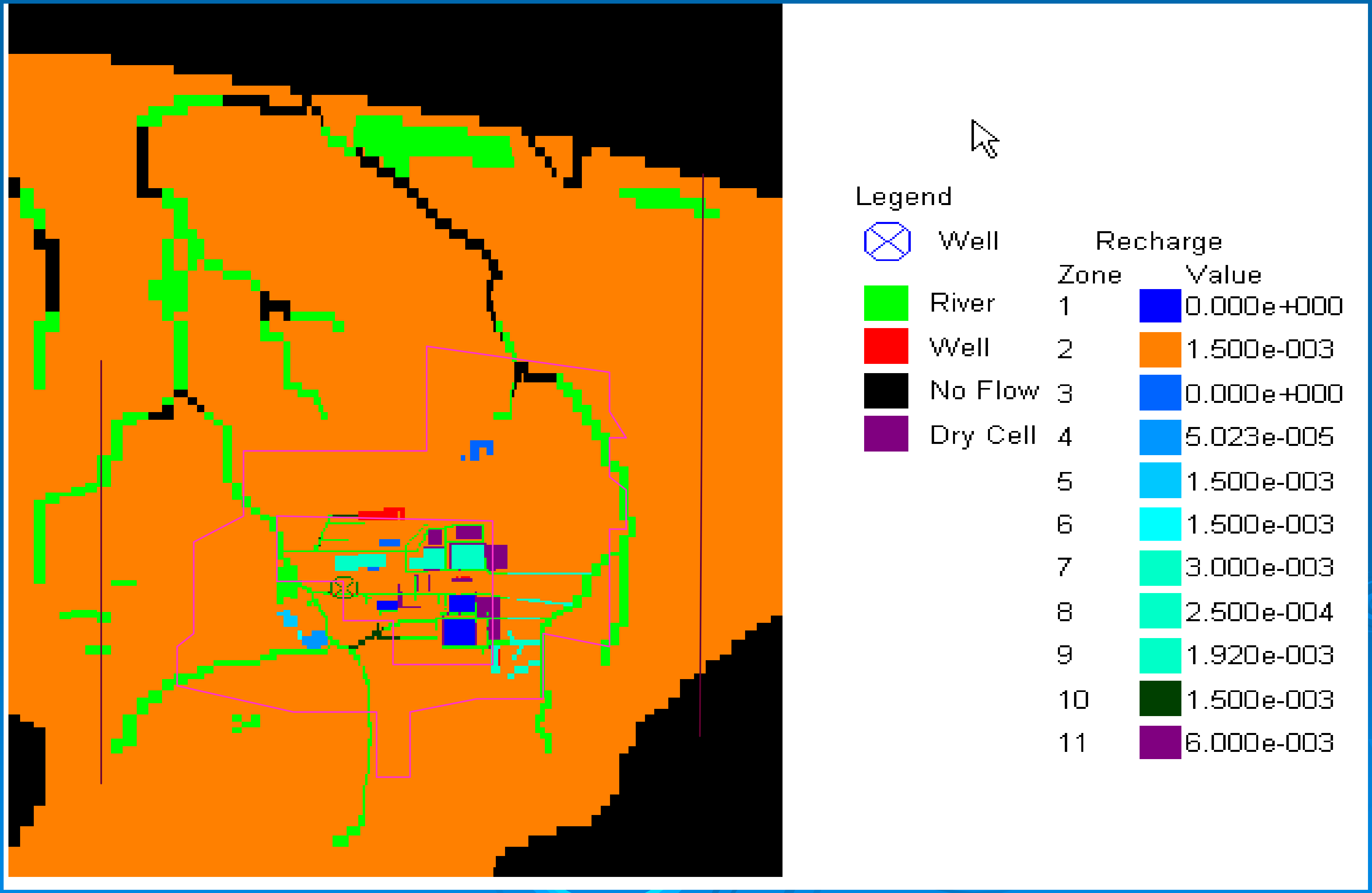
Model Description

Other parameters

- Variable Recharge in layer 1 (top layer)
- Seven different zones
  - General rainfall recharge zone
  - Six other zones in plant area
    - Ditches
    - Lagoons
    - Outfalls
    - Other impervious areas

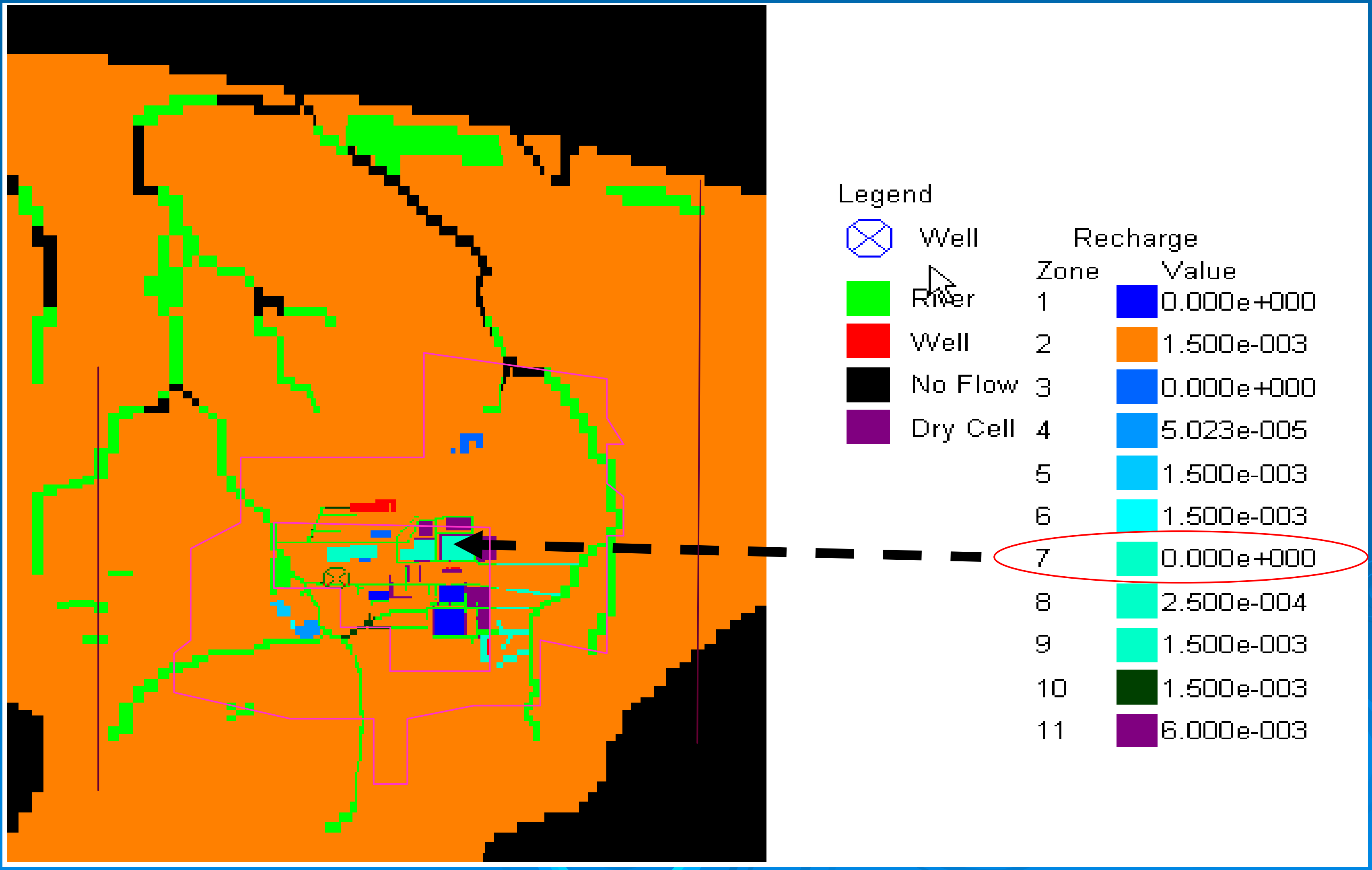
Model Description

Recharge Zones – Stress Period 1 (ft/day)



Model Description

Recharge Zones – Stress Period 2



Model Description

Other Parameters

- Kx = Ky = 0.10 Kz in some layers
- Kx = Ky = *0.01* Kz in some other layers
- Storage coefficient = 0 for all layers
- Porosity = 0.3

Model Description

Transport Parameters

- Soil/water partitioning coefficient (Kd)
  - The Kd value is contaminant and medium specific and indicates constituent’s affinity to bind with the soil
- Bulk Density
- Half life

- For TCE Kd =0.05L/kg, bulk density = 1.9 and half life = 9729.05 days (26.5 years)

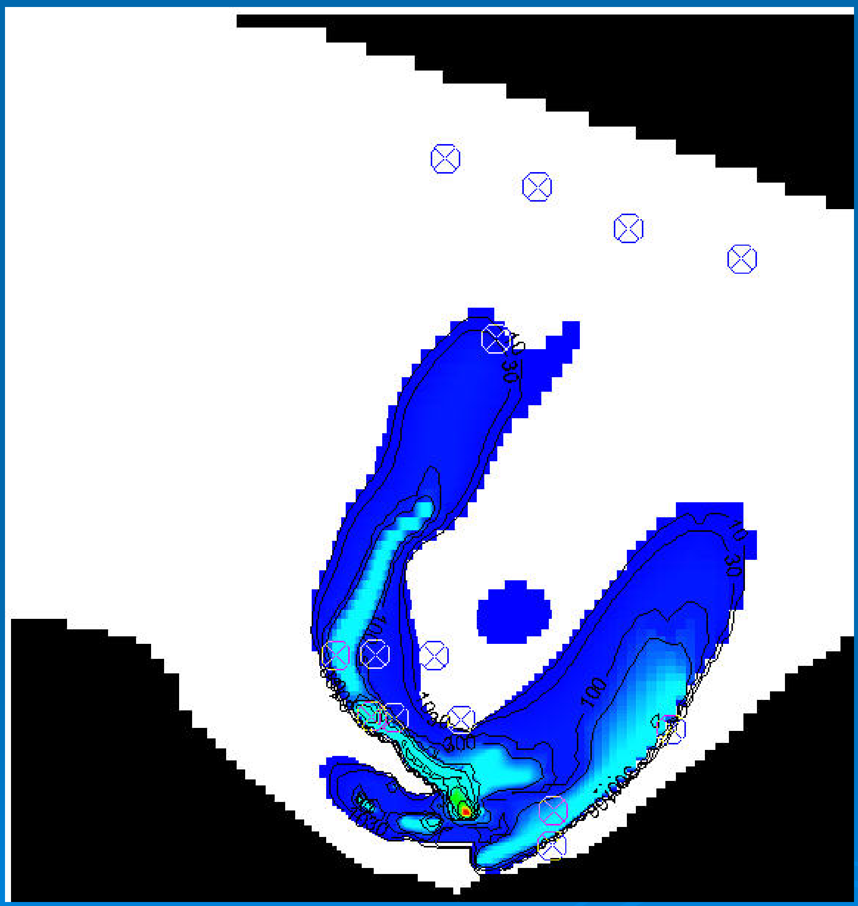
Model Description

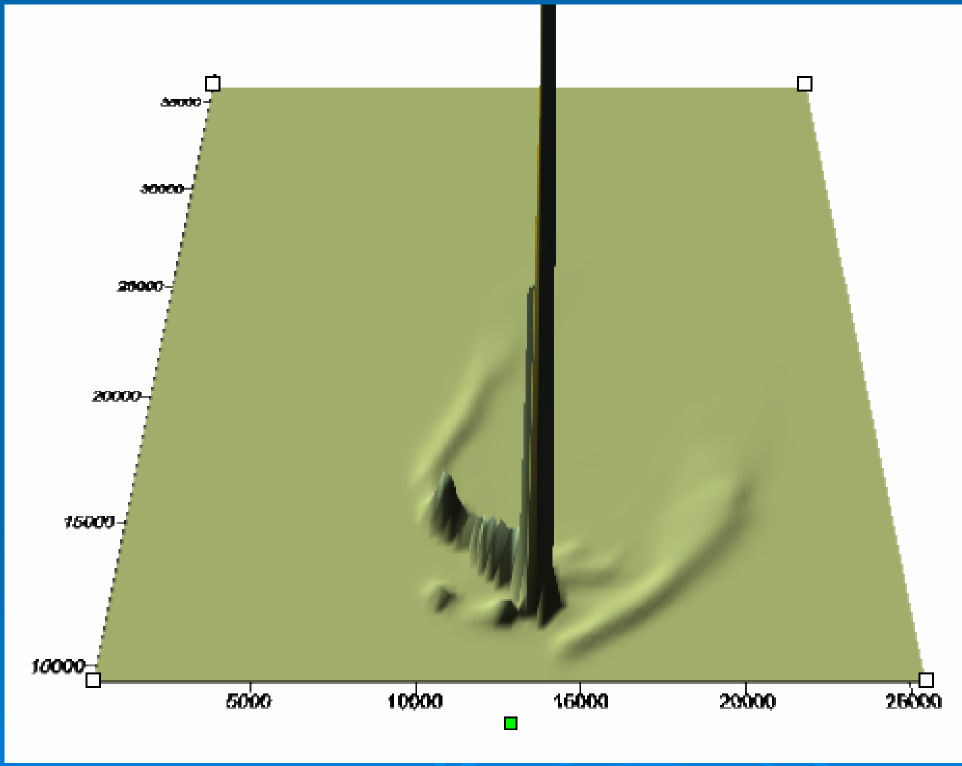
Initial Concentrations

- 1000 zones of initial concentration
- Tc99:
  - For zone 1, Initial Concentration = 0
  - For zones between 2 to 197, Initial Concentration = 15 + Zone# * 5
  - For zones between 198 to 597, Initial Concentration = 1000 + (Zone# - 197) * 10
  - For zones between 598 to 1000, Initial Concentration = 5000 + (Zone# - 597) * 20
  - Maximum concentration at source point is about 10,700.
- TCE:
  - For zones between 1 to 201, Initial Concentration = (Zone# –1)*5
  - For Zone 202, Initial concentration = 2000
  - For zones between 203 to 398, Initial Concentration = (Zone# –203) *500 + 2500
  - For Zones between 399 to 1000, Initial Concen. = (Zone# –399)*1000 + 100000
  - Maximum concentration at source point is about 500,000 (µg/l).

Model Description

Initial TCE Concentration Plumes

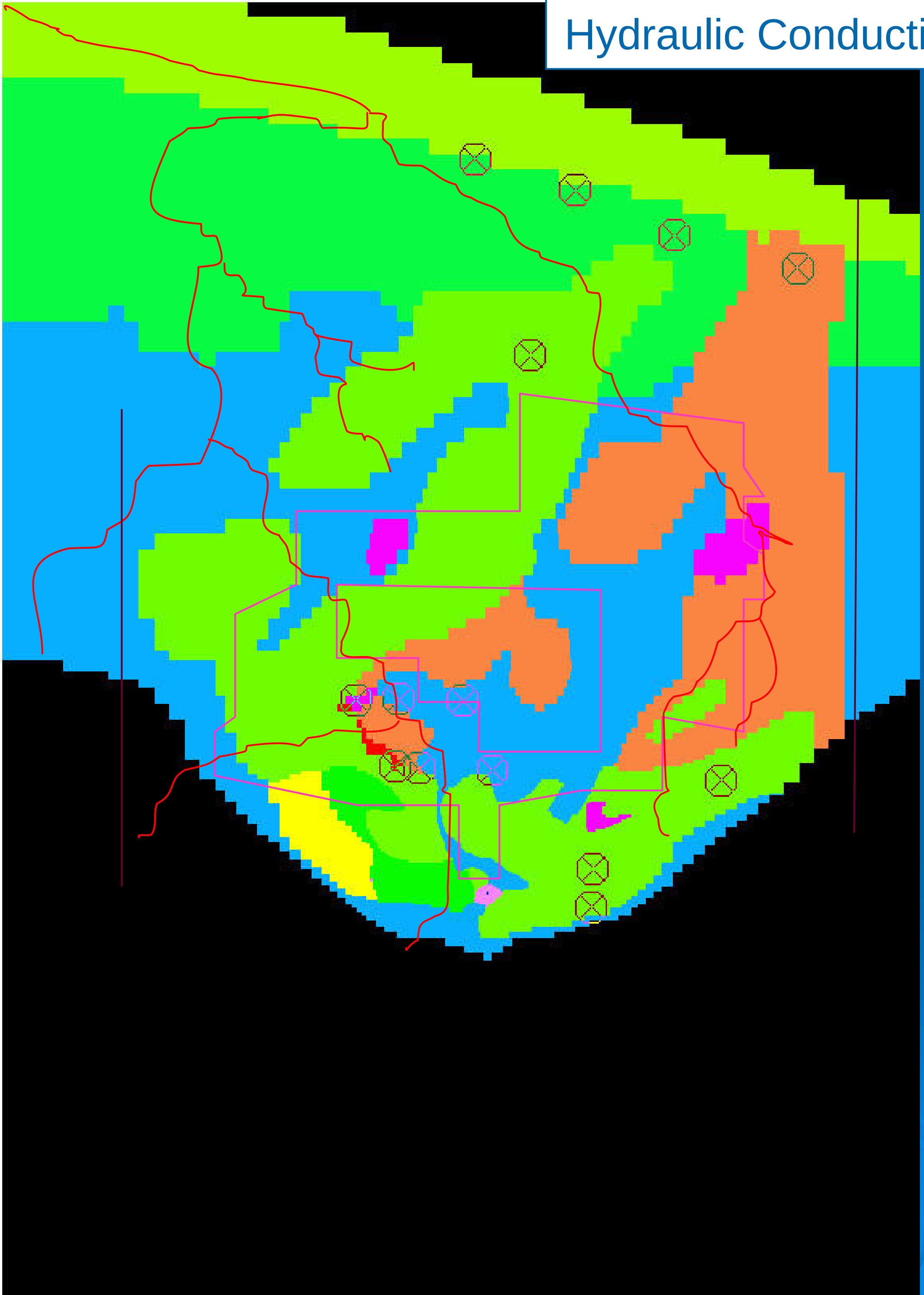




3. Hydraulic Model
3.1 Re-calibration Efforts

- Hydraulic Parameters
  - Hydraulic conductivities were adjusted based on observed heads in more than 100 monitoring wells
  - Majority of the monitoring wells penetrate to RGA – layer 3
  - A few wells go all the way to layer 4.
  - Initial hydraulic conductivities were assigned based on site lithology

Hydraulic Conductivity Zones for Layer 3



	Kx	Ky	Kz	Color
1	1	1	0.01	
2	3.5	3.5	0.035	
3	4.5	4.5	0.45	
4	200	200	20	
5	40	40	0.4	
6	50	50	5	
7	3	3	0.03	
8	12	12	1.2	
9	2	2	0.02	
10	200	200	20	
11	0.8	0.8	0.008	
12	40	40	0.4	
13	75	75	7.5	
14	1500	1500	150	
15	200	200	20	
16	500	500	50	
17	0	0	0	
18	0	0	0	
19	0	0	0	
20	0	0	0	
21	0	0	0	
22	1500	1500	150	
23	1500	1500	150	
24	1500	1500	150	
25	1500	1500	150	
26	0	0	0	
27	200	200	20	
28	0	0	0	
29	0	0	0	
30	0	0	0	
31	0	0	0	
32	0	0	0	
33	0	0	0	
34	0	0	0	
35	0	0	0	

Measured and Computed Heads

Table 3. Summary of Model Residuals for 1998 Refined Model for the Paducah Gaseous Diffusion Plant

Name	X	Y	Layer	Observed	Computed	Residual
MW 007	10788.54	13243.04	2	361.59	362.21	-0.62
MW 043	16115.5	17847.23	3	323.56	322.64	0.92
MW 052	11295.59	13579.74	3	324.19	324.44	-0.25
MW 054	11060.36	13885.99	3	324.17	324.35	-0.18
MW 063	10751.76	14542.56	3	323.98	324.18	-0.20
MW 064	10752.13	14527.54	1	363.21	366.33	-3.12
MW 065	10752.59	14512.42	3	323.97	324.19	-0.22
MW 069	13644.25	11572.96	2	341.74	342.03	-0.29
MW 071	13614.57	11573.14	3	325.04	324.90	0.14
MW 073	12486.97	12913.31	3	324.51	324.66	-0.15
MW 075	12370.09	12805.14	2	364.92	361.56	3.36
MW 103	11735.36	10146.46	3	325.61	325.27	0.34
MW 104	11390.73	9964.42	2	349.8	351.92	-2.12
MW 106	9548.6	14638.23	3	324.36	323.91	0.45
MW 124	19866.65	14373.68	3	324	323.50	0.50
MW 125	12324.69	19786.58	3	321.71	321.54	0.17
MW 126	19868.99	14383.97	3	323.79	323.48	0.31

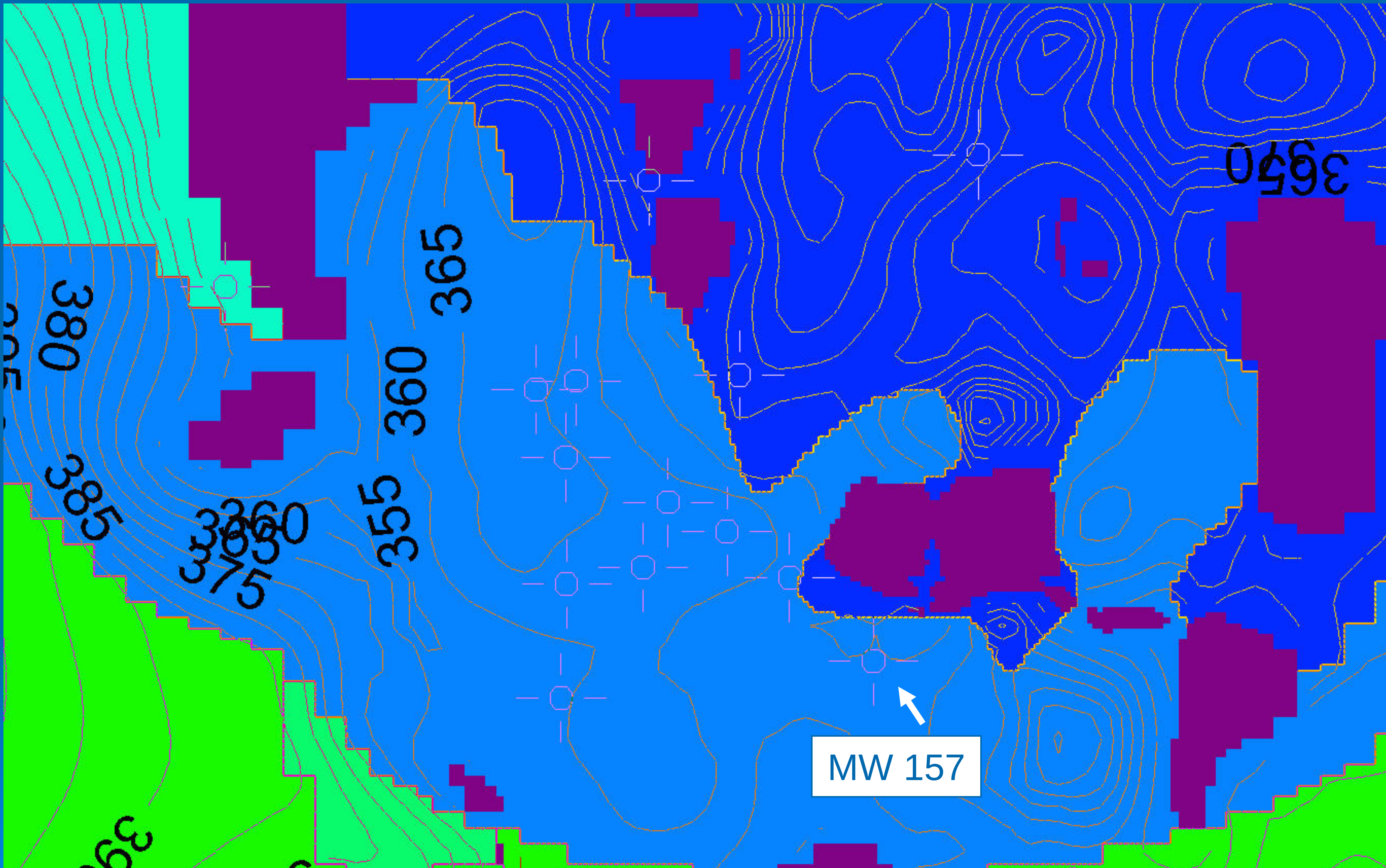
Table 3. Summary of Model Residuals for 1998 Refined Model for the Paducah Gaseous Diffusion Plant (Continued)

Name	X	Y	Layer	Observed	Computed	Residual
MW 127	12323.39	19808.53	1	348.89	347.64	1.25
MW 130	16503.61	7723.28	2	371.9	373.42	-1.52
MW 131	16506.09	7708.36	1	371.98	373.36	-1.38
MW 132	17427.71	19839.65	3	322.8	320.66	2.14
MW 134	9652.5	17216.23	3	322.91	322.97	-0.06
MW 137	16260.75	22798.16	3	319.04	318.86	0.18
MW 142	5825	20177.05	3	322.53	322.07	0.46
MW 143	5831.4	20160.94	2	332.43	332.53	-0.10
MW 144	17217.4	14016.88	3	323.99	324.00	-0.01
MW 147	12318.22	27195.99	3	317.26	317.50	-0.24
MW 149	21227.17	19402.36	3	321.48	320.07	1.41
MW 150	22640.36	15887.1	3	322.93	322.56	0.37
MW 152	17294.86	26783.97	3	313.35	312.44	0.91
MW 154	11769.99	12837.01	1	363.89	363.33	0.56
MW 155	13962.5	11977.9	3	324.94	324.86	0.08
MW 156	13961.8	11943.6	3	324.89	324.86	0.03
MW 157	13961.8	11958.7	1	347.51	355.46	-7.95
MW 158	11030.5	12656.1	3	324.45	324.57	-0.12
MW 159	11050.4	12657.5	3	324.47	324.58	-0.11
MW 160	11041.6	12675.4	1	363.02	362.91	0.11
MW 161	11070.6	11980.6	3	324.5	324.67	-0.17
MW 162	11101.3	11980.5	1	360.27	358.88	1.39
MW 163	15946.5	12246.5	3	324.87	324.70	0.17
MW 164	15953.3	12231.7	2	336.99	335.02	1.97
MW 165	14851.8	14545.6	3	324.61	324.52	0.09
MW 166	14835.2	14540.6	2	341.56	342.12	-0.56
MW 167	13165	12738.6	1	368.33	365.75	2.58
MW 168	13165	12722.5	3	324.31	324.72	0.41
MW 169	12429.5	13455.9	3	324.2	324.62	-0.42
MW 170	12429.9	13471.5	1	362.85	363.20	-0.35
MW 171	12569.1	13175.8	1	365.31	364.68	0.63
MW 172	12009.6	13455.1	1	362.68	363.45	-0.77
MW 173	12697.5	14667.6	3	324.39	324.47	-0.08
MW 174	12680.3	14668.5	1	363.84	363.07	0.77
MW 175	13608.4	12219	3	324.82	324.80	0.02
MW 178	13913.9	12431.1	3	324.82	324.79	0.03
MW 179	15471	18275.2	3	323	322.60	0.40
MW 181	14944.7	16754.6	3	323.5	323.30	0.20
MW 182	14960.1	16754.5	1	355.67	357.08	-1.41
MW 184	10600.6	9650	1	359.09	359.09	0.00
MW 185	11385.6	14600.2	3	324.09	324.28	-0.19
MW 187	11133	14611.7	1	363.45	364.16	-0.71

Table 3. Summary of Model Residuals for 1998 Refined Model for the Paducah Gaseous Diffusion Plant (Continued)

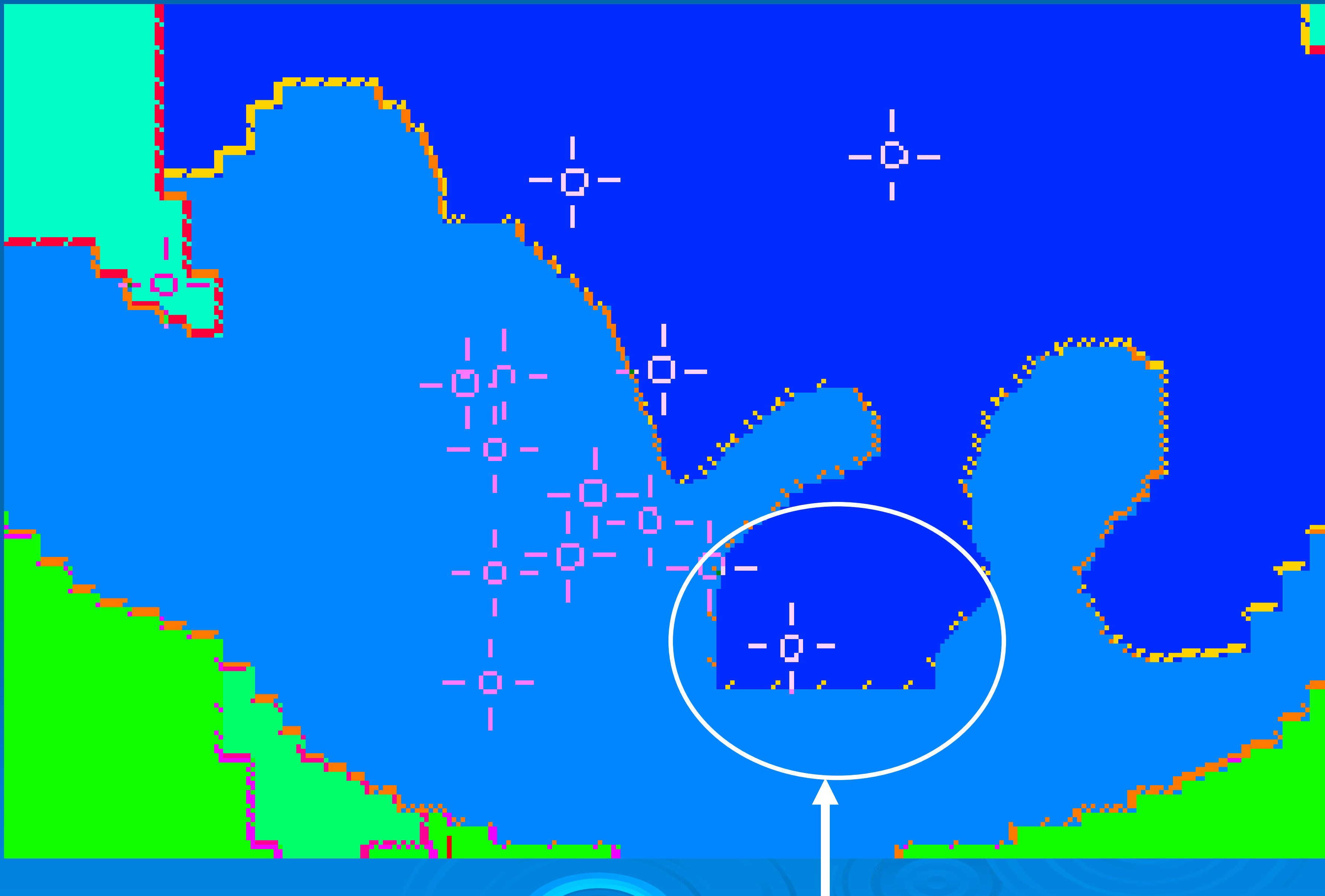
Name	X	Y	Layer	Observed	Computed	Residual
MW 188	10986.7	11590.2	3	324.76	324.72	0.04
MW 189	10989.9	11590	1	354.86	358.39	-3.53
MW 190	11035.9	13885.2	1	366.21	366.70	-0.49
MW 191	20584.9	14247.6	3	323.89	323.28	0.61
MW 193	18503.3	16712.2	3	323.89	323.08	0.81
MW 194	7810	15512.9	3	323.49	323.38	0.11
MW 195	7794.1	15508.4	1	343.93	343.63	0.30
MW 197	11825	16510.4	3	323.14	323.45	-0.31
MW 198	11824.5	16522.1	1	342.99	342.51	0.48
MW 199	7910.9	23737.4	3	321.49	320.11	1.38
MW 200	13163.6	18090.6	3	322.8	322.16	0.64
MW 201	13103.5	23814.7	3	319.87	319.36	0.51
MW 202	12299.5	21260.5	3	321.36	320.90	0.46
MW 203	12972.7	11488.1	3	323.51	324.89	-1.38
MW 205	13627.2	13283.2	3	324.38	324.71	-0.33
MW 206	15063	12142.5	3	324.33	324.79	-0.46
MW 102	11720.18	10144.76	4	325.55	325.39	0.16
MW 121	12309.85	19808.83	4	319.4	321.54	-2.14
MW 122	19863.67	14364.37	4	322.75	323.45	-0.70
MW 140	5808.31	20205.78	4	319.96	322.04	-2.08

Well Location with 7.95m difference



MW 157	13961.8	11958.7	1	347.51	355.46	-7.95

Adjusted Zone Boundary



Note the change in zone color

3.2 Model Sensitivity to various physical, hydraulic and contaminant parameters

Why Sensitivity Studies?

- Gain confidence in model
- Push for detailed water budget analysis
- The findings of the water budget study could significantly impact the current groundwater model
- Model sensitivity studies might help prioritize various tasks identified towards water budget analysis

Sensitivity Studies

- Water Budget Analysis – identify important model parameters
- Pumping at TVA Shawnee Plant
- River stage changes
- Hydraulic conductivity in layer 3
- Plant shut down scenario
  - No outflow to Little Bayou Creek
  - Reduced outflow to Big Bayou Creek

Sensitivity Studies

- Recharge rates
  - Plant recharges (lagoons)
  - Rain recharges
- Leakage along the pipeline
  - Distributed
  - Concentrated
- Effect of Lineal elements
- Recharge from Shawnee Plant Ash Pond
- TCE (Bio)degradation Rates
- Model sensitivity to simultaneous changes in multiple parameters

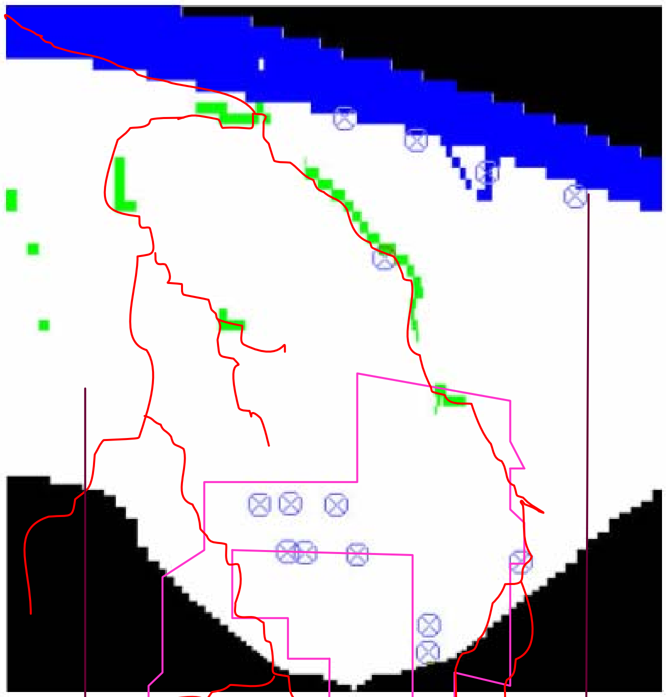
3.2.1 Pumping at TVA Shawnee Plant

Pumping at TVA Shawnee Plant

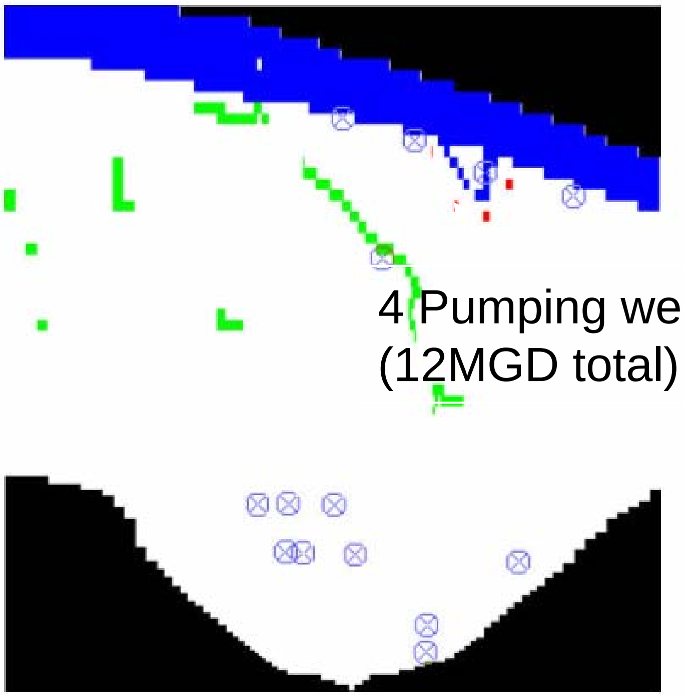
Effect of Shawnee Plant wells

Changes made to this baseline model for sensitivity analysis:

- Four pumping wells were added to the baseline model in layer 3 near Ohio River with a total pumping capacity of 12 Mgd.



Layer 3 of baseline model

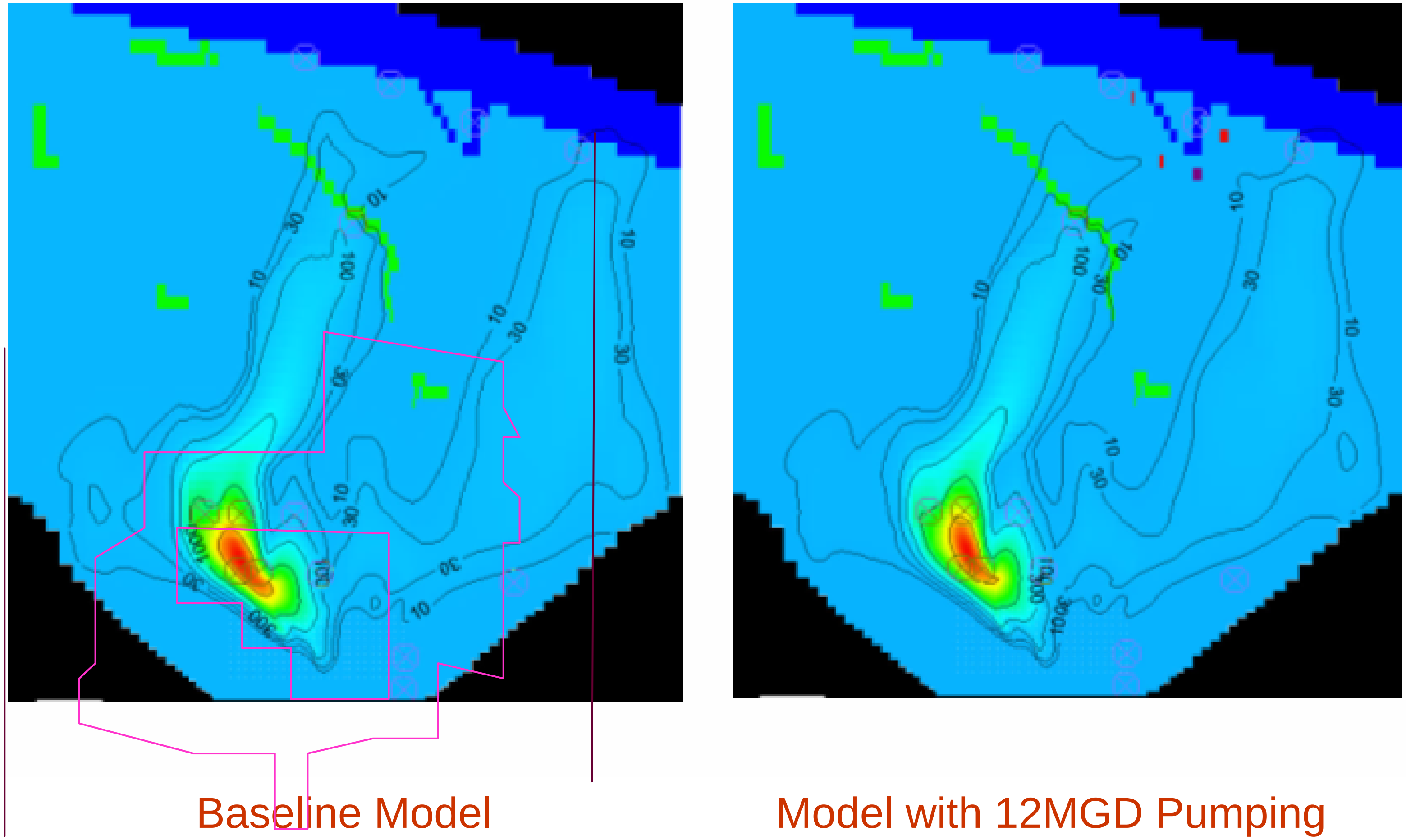


Layer 3 of new model

Pumping at TVA Shawnee Plant

Comparison of results in layer 3 at the end of Stress period 2

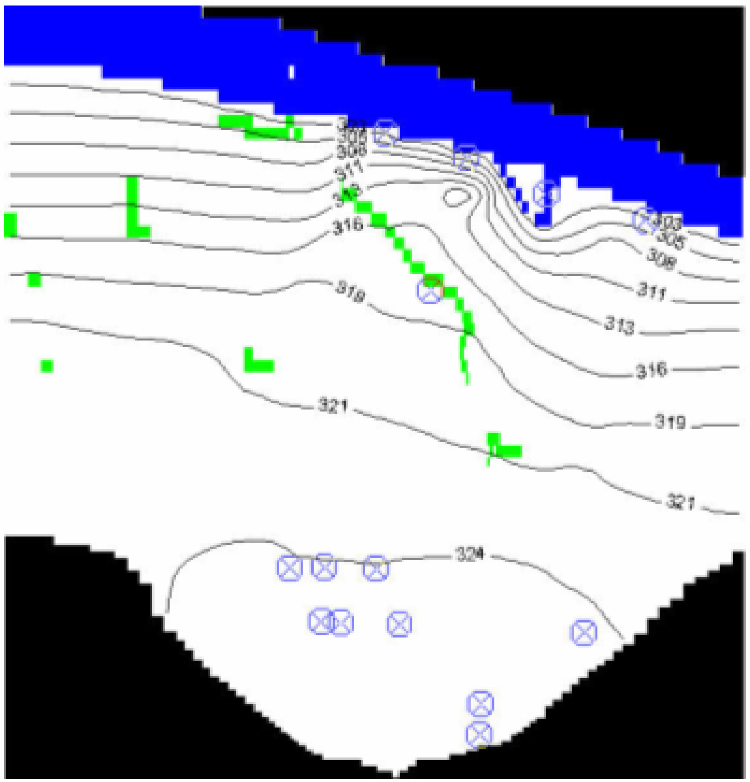
TCE Concentration Contours



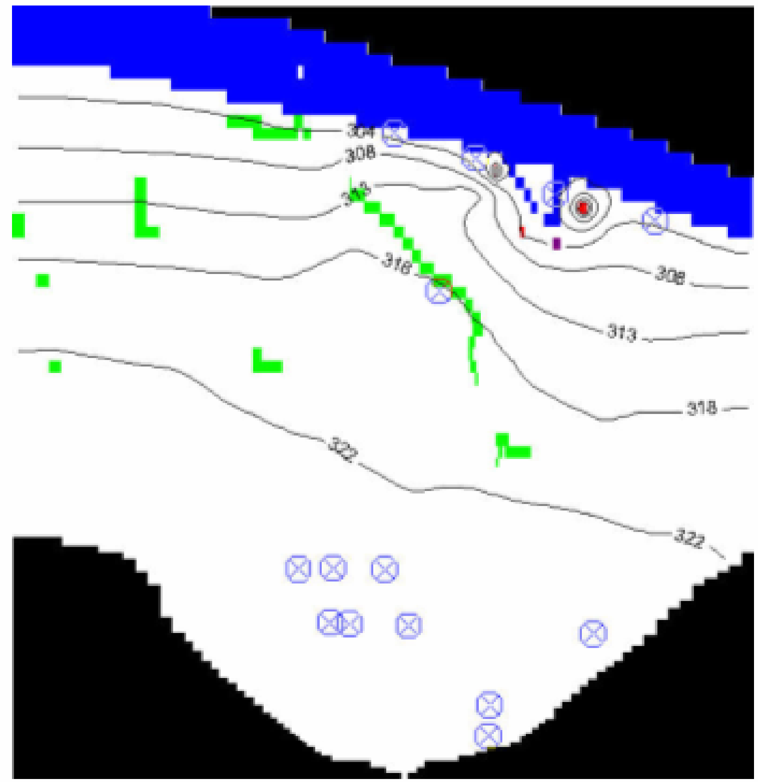
Baseline Model

Model with 12MGD Pumping

Pumping at TVA Shawnee Plant



HGL Contours - Baseline Mode



HGL Contours – with Pumping

Pumping at TVA Shawnee Plant Inferences

- Much of the water is drawn from Ohio River
- Very little influence on layer 3 hydraulic gradeline contours
- Changes in TCE concentration plumes are insignificant
- Model is almost insensitive to changes in pumping at TVA

3.2.2 Changes to River Stage (Olmsted Lock and Dam)

River stage changes

Effect of increase in Ohio River Stage

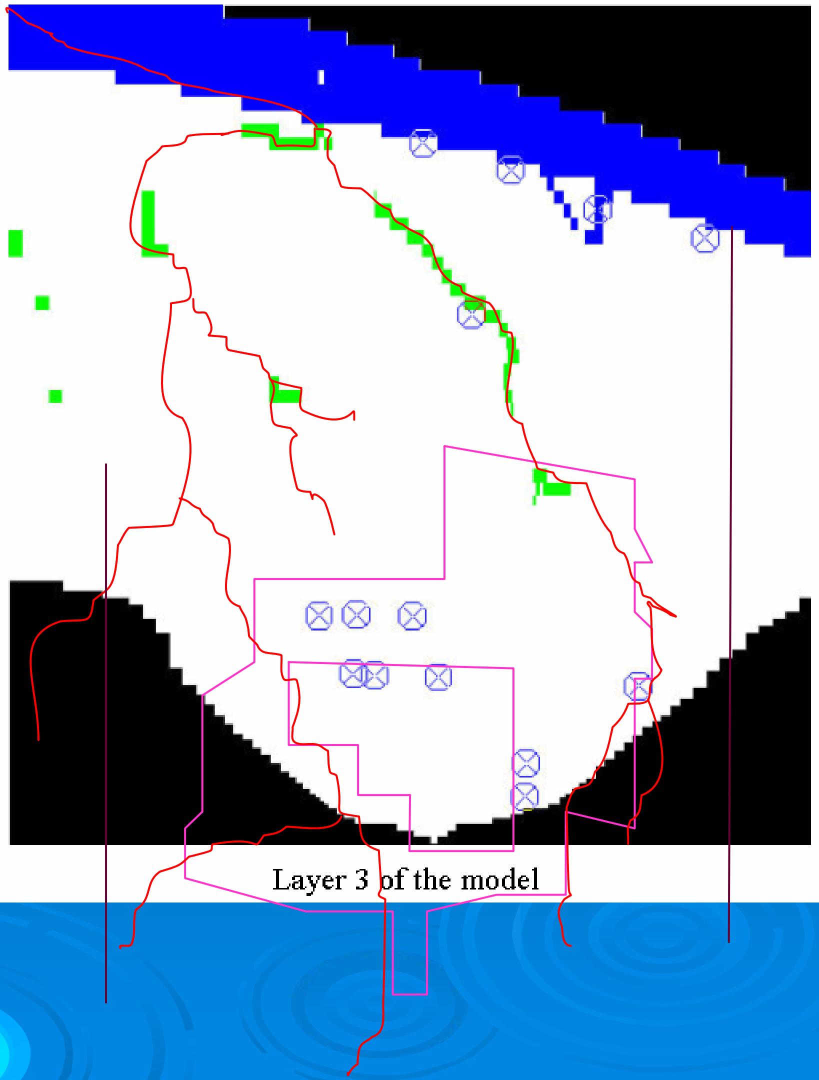
Changes made to this baseline model for sensitivity analysis:

- Head of the Ohio River is changed from 306.84 ft to 300.04 ft in second stress period.
- No visible changes in the model.

River Stage:

Baseline Model Case:
300.04 ft (Stress Period 1)
306.86 ft (Stress Period 2)

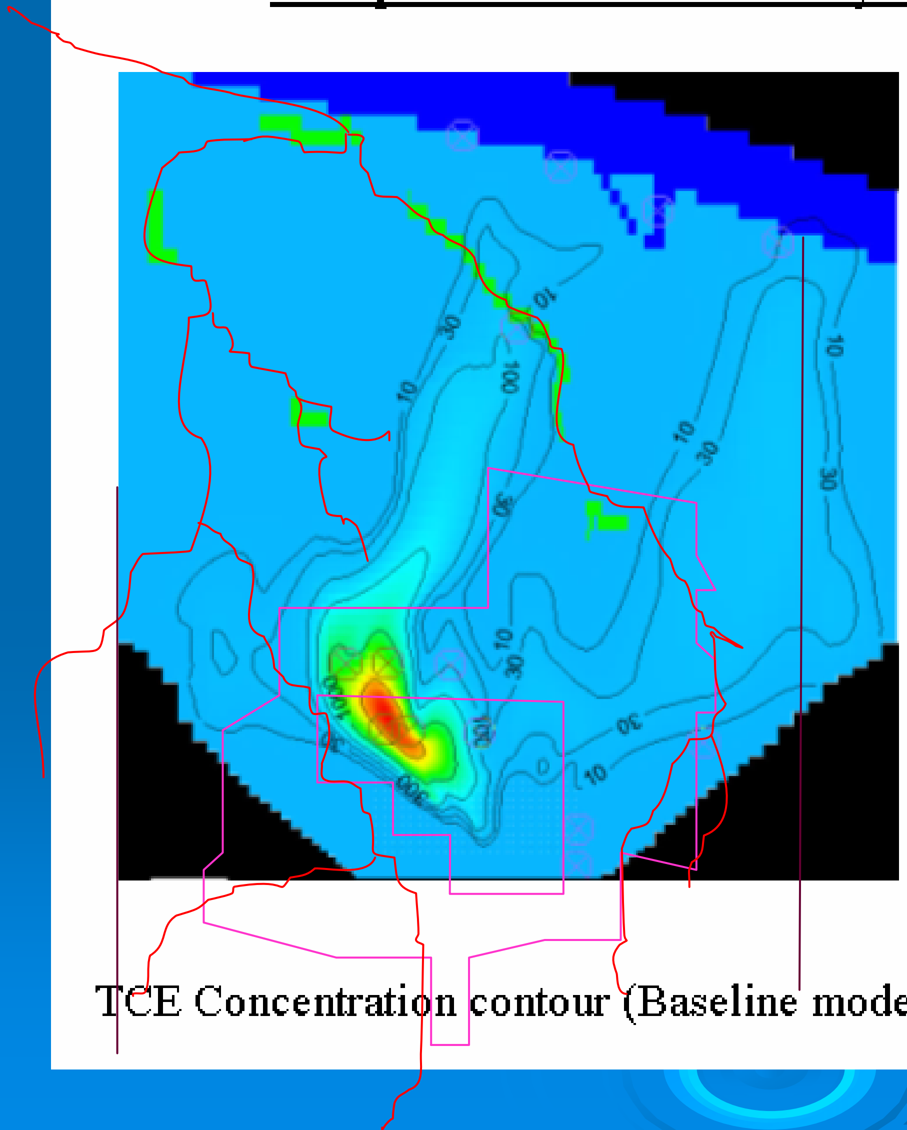
New Model Case:
300.04 ft (Stress Period 1)
300.04 ft (Stress Period 2)



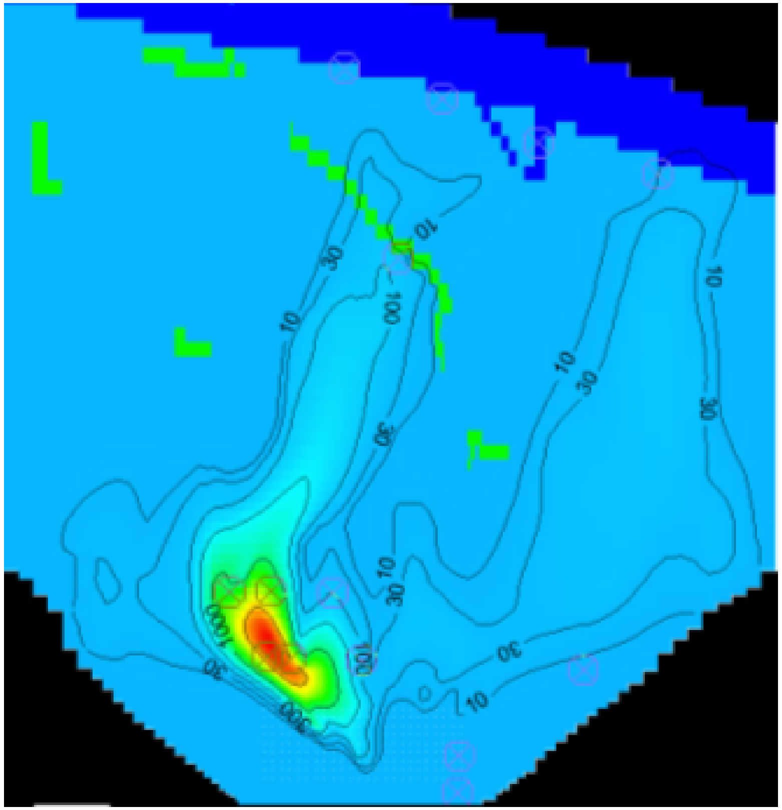
Layer 3 of the model

River stage changes

Comparison of results in layer 3 at the end of Stress period 2



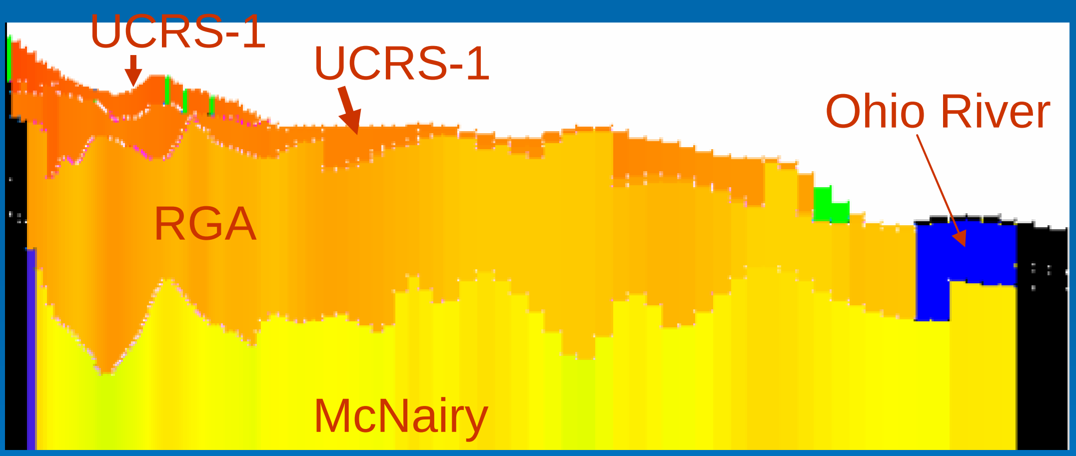
TCE Concentration contour (Baseline model)



TCE Concentration contour (New model)

River stage changes

Cross section



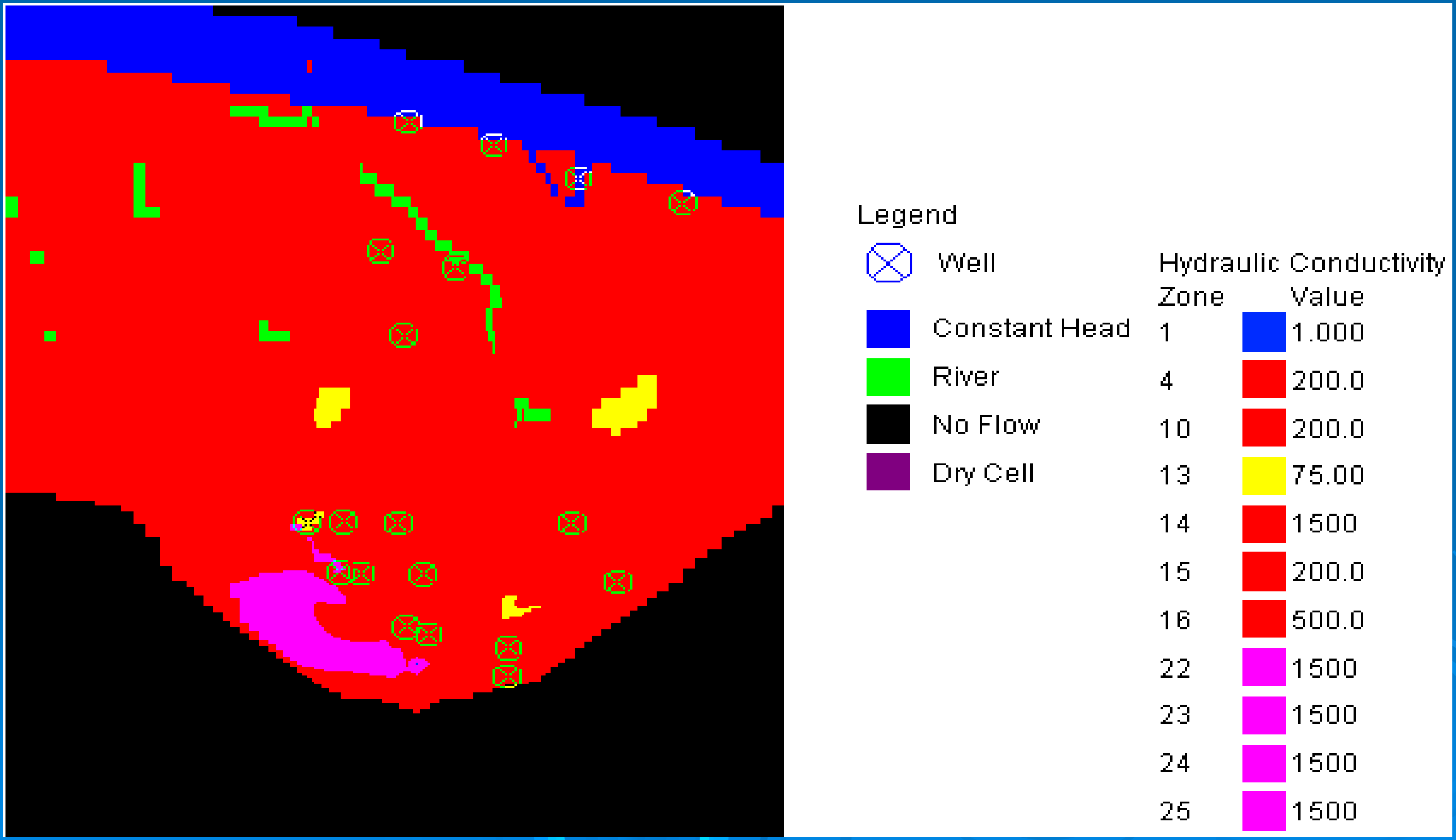
River stage changes Inferences

- Ohio River stage (300-306m) is considerably lower than the average ground elevation (350m)
- Hydraulic conductivity in the top recharge layer is considerably smaller compared to RGA.
- Elevation of RGA at Ohio River is XXX
- 6m change appears to have little or no influence on TCE plume movement
- Model is almost insensitive to changes in Ohio River Stage due to Olmsted Lock and Dam

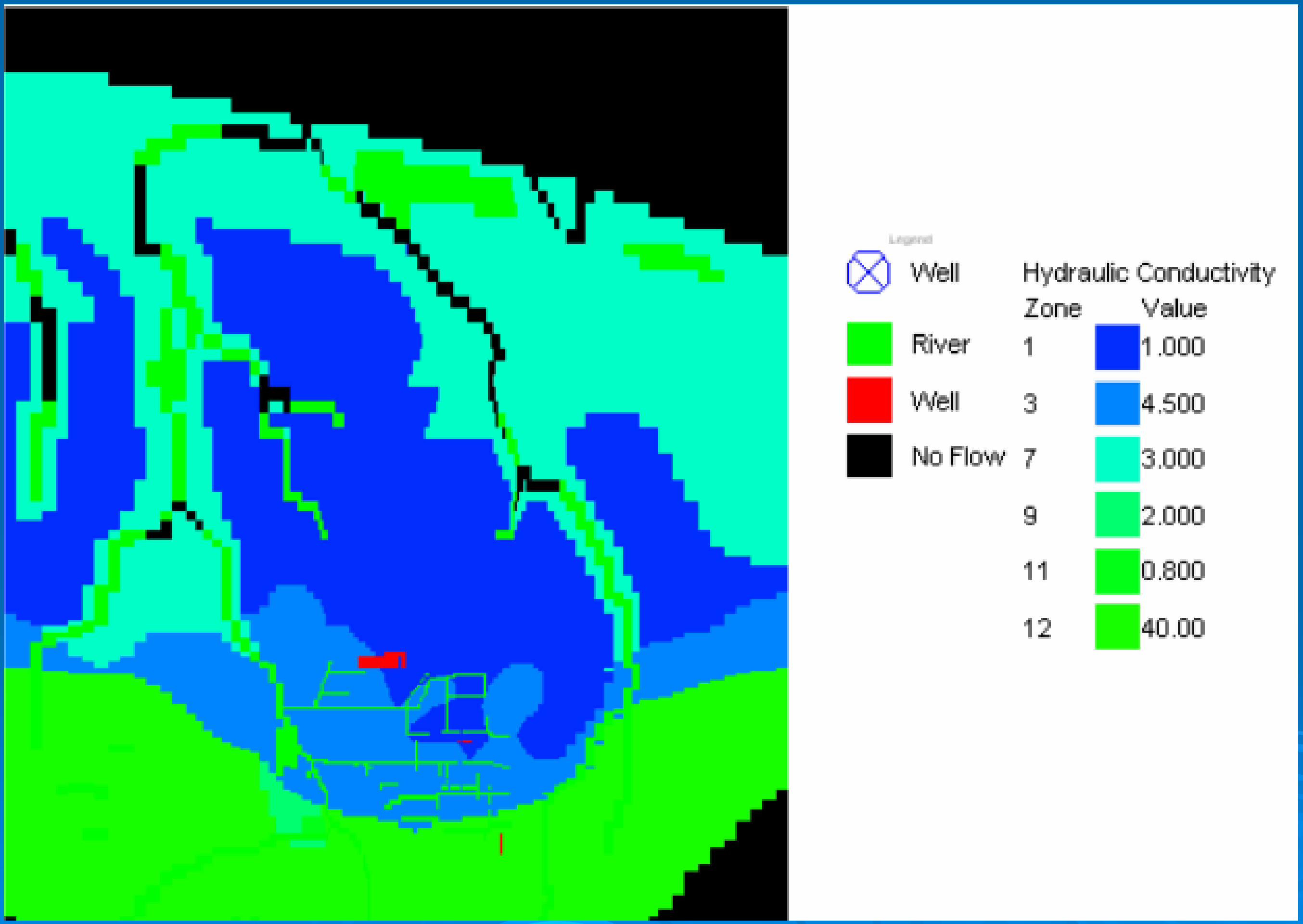
3.2.3 Model Sensitivity to Hydraulic Conductivity in Layer 3

Sensitivity analysis on hydraulic conductivity (K) (RGA Layer - Layer 3)

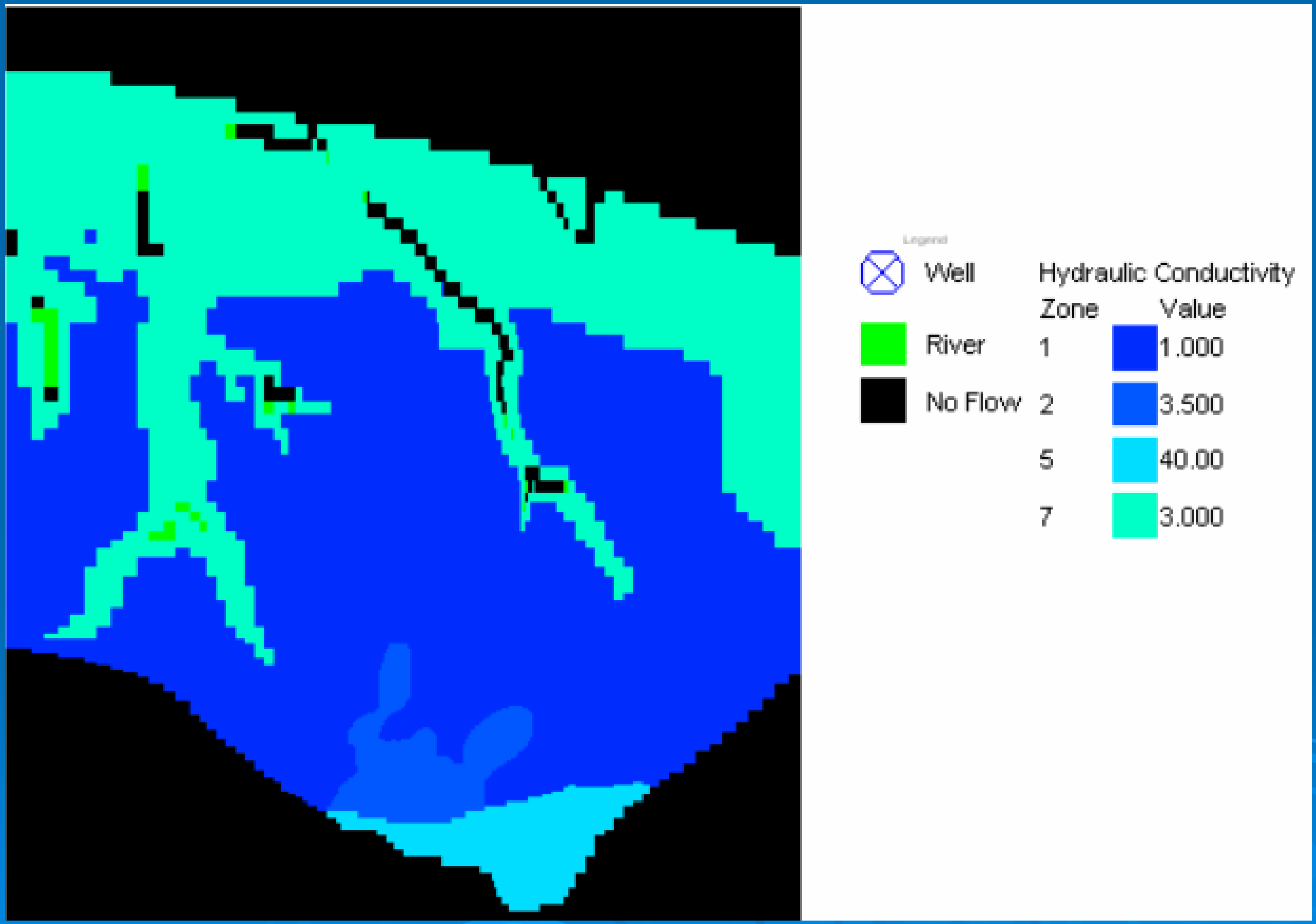
- PGDP model defines the hydraulic conductivity (K) in 21 zones for RGA Layer. In that, 10 zones had K more than or equal to 200 ft/day. These 10 zones cover most of the regional model



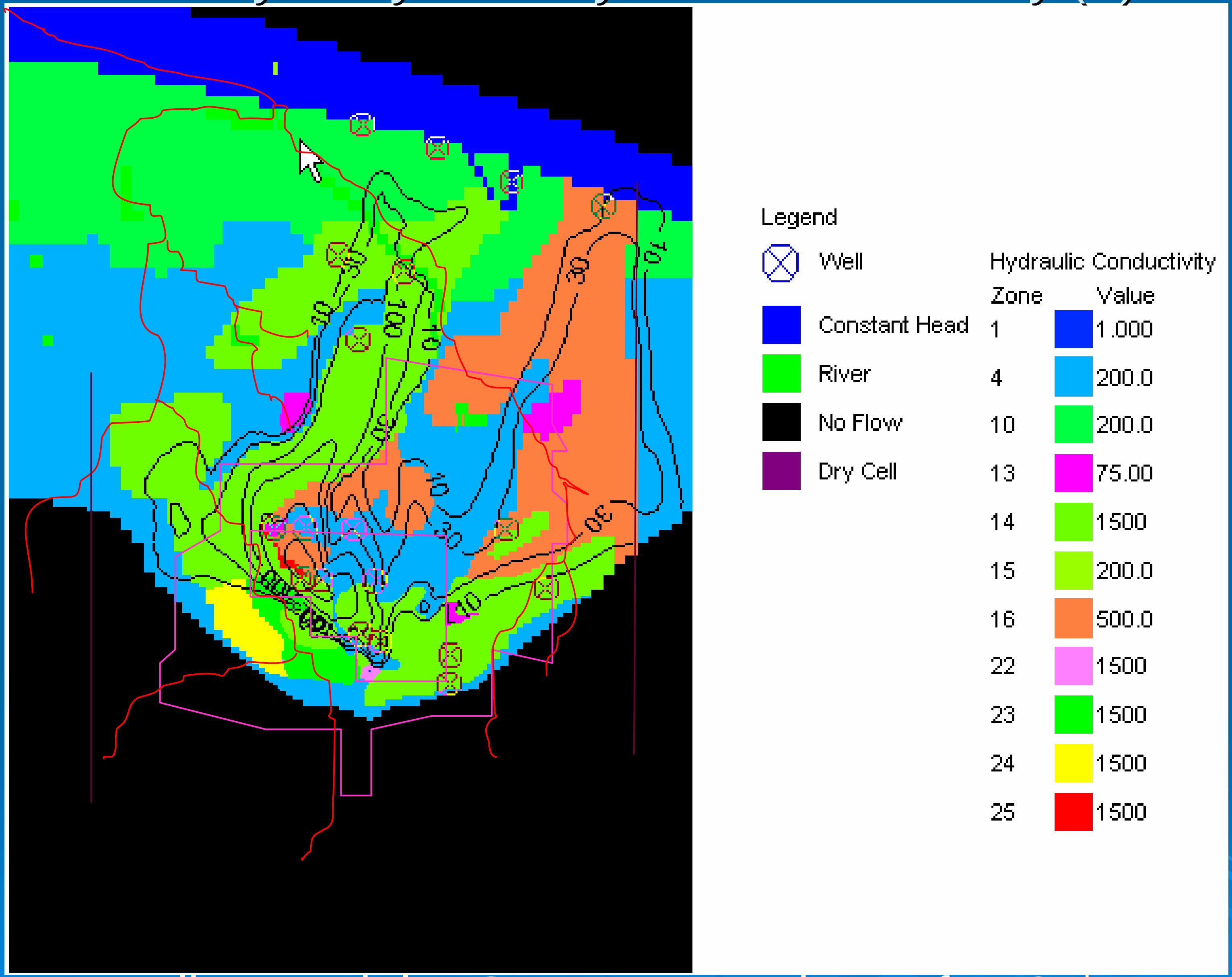
Hydraulic Conductivity Map
Layer 1



Hydraulic Conductivity Map
Layer 2

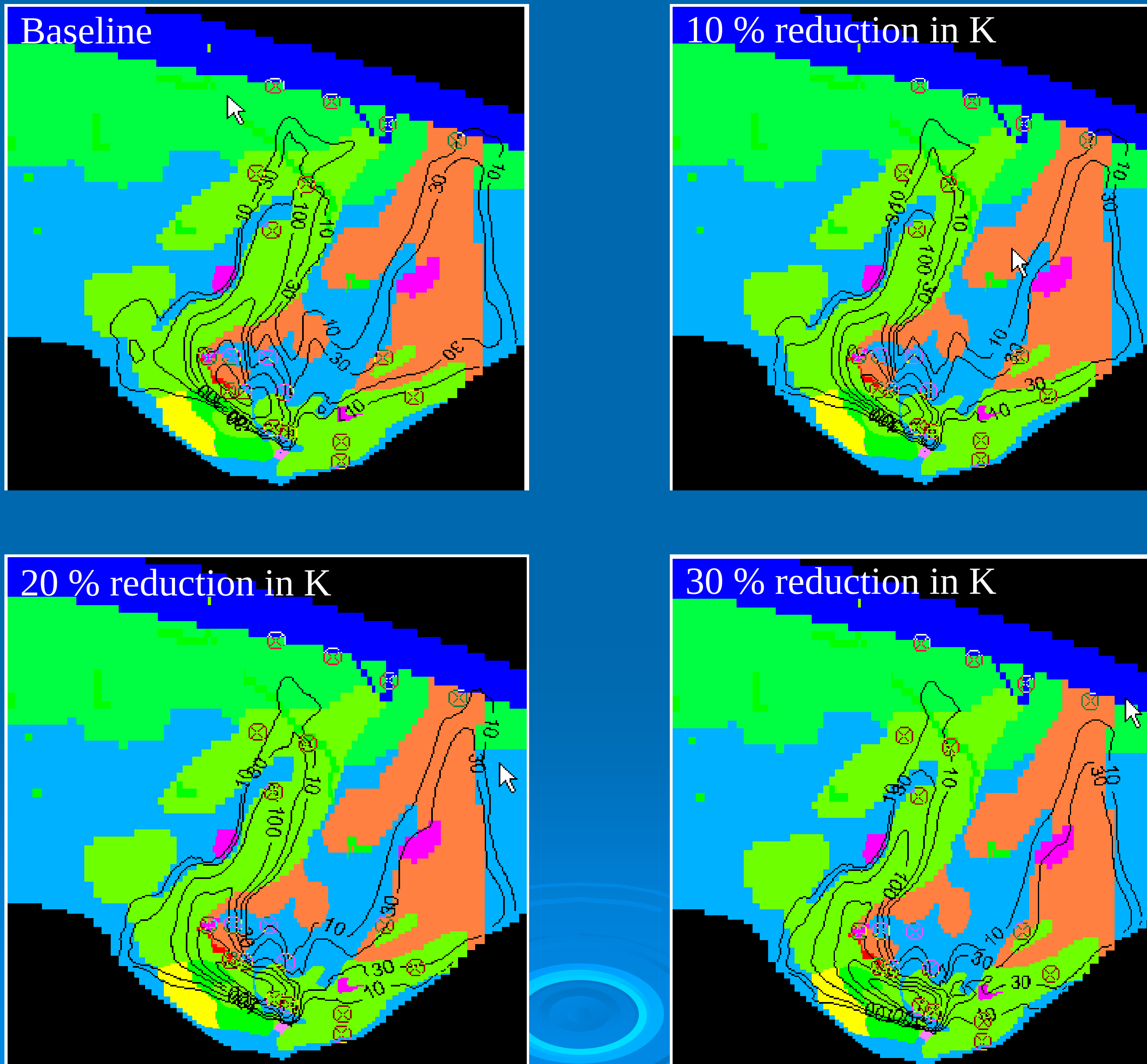


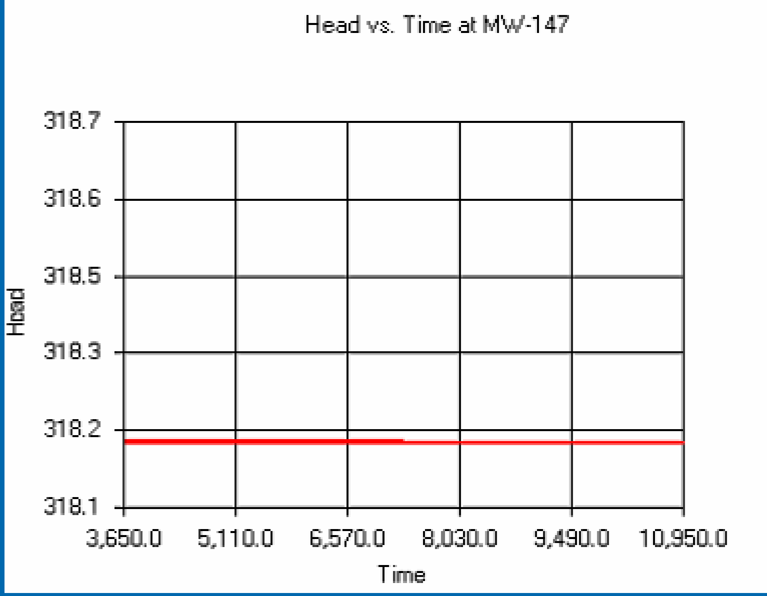
Sensitivity analysis on hydraulic conductivity (K)



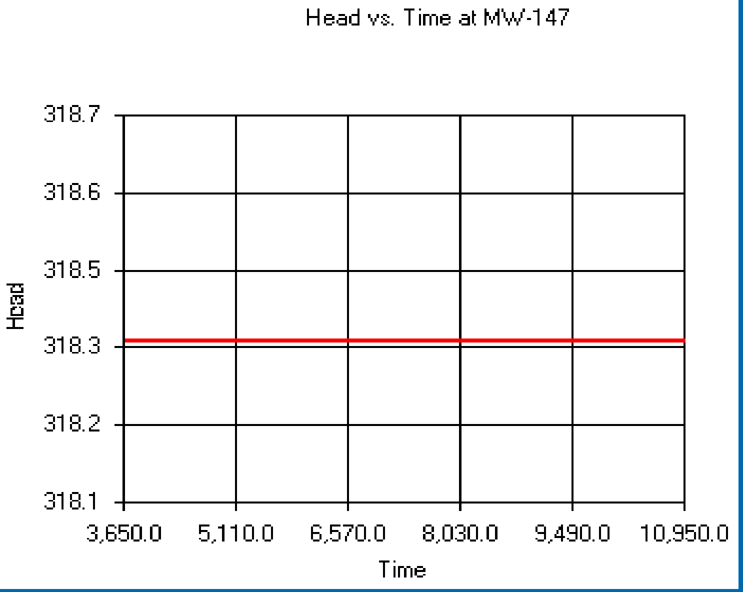
Baseline model TCE concentrations after 2nd stress period (30 Years)– Layer 3

Sensitivity to Changes in Hydraulic Conductivity (K)

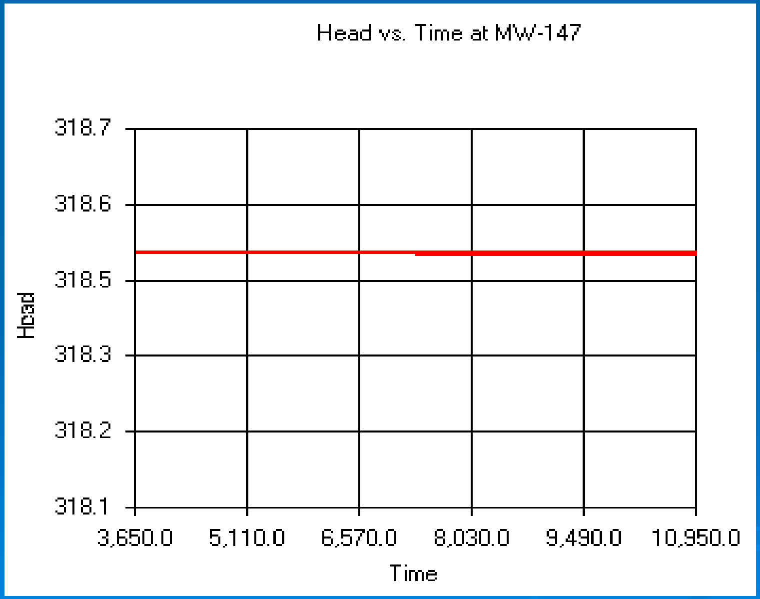




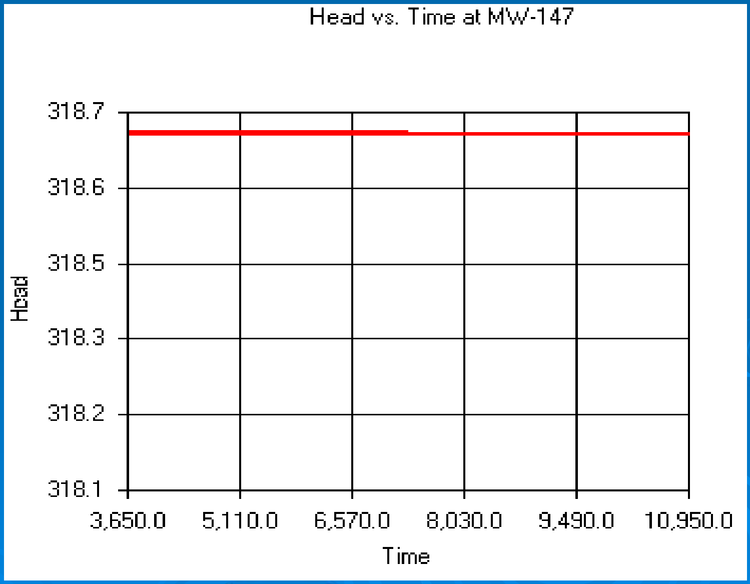
Baseline model (observed : 317.26)



10% reduction in K



20 % reduction in K



30 % reduction in K

Head Variation at Well MW-147 in Different Models

RGA Hydraulic Conductivity Inferences

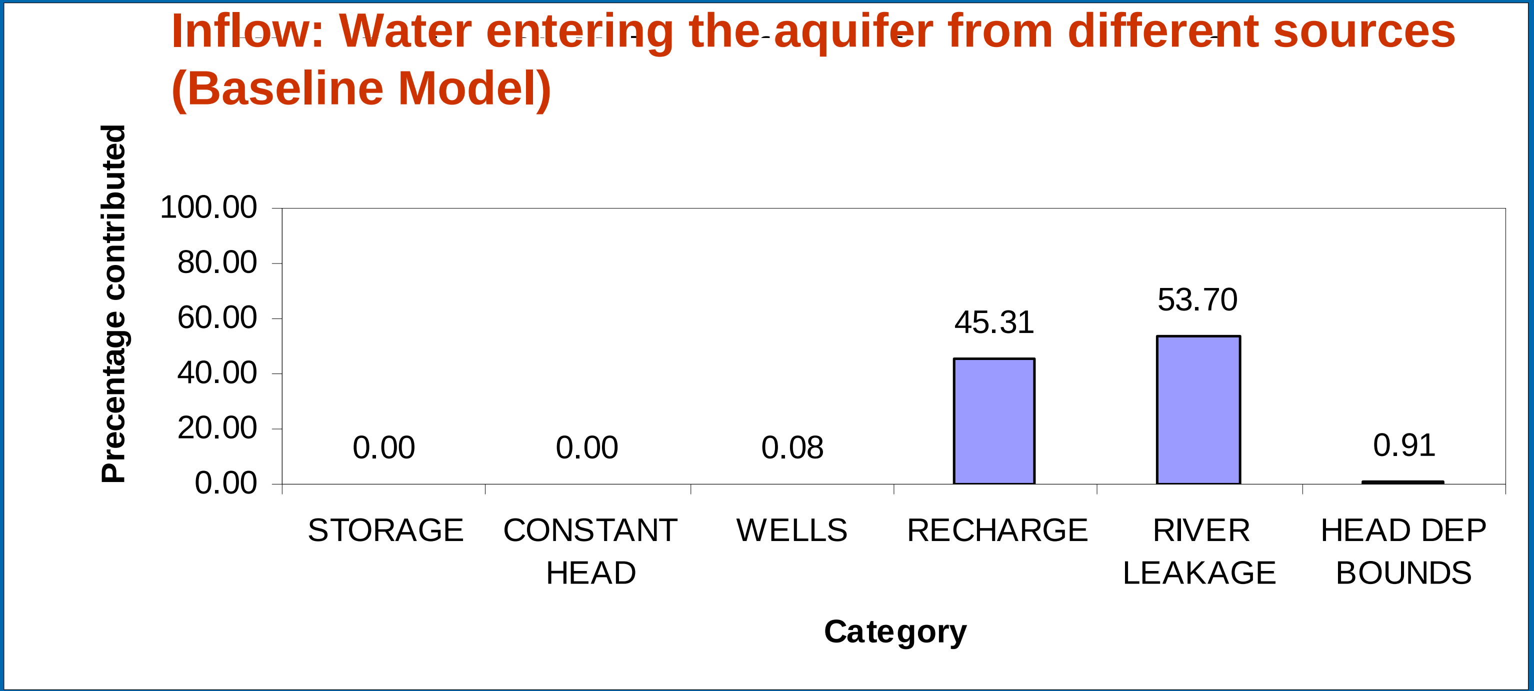
- Significant slowdown in TCE plume movement with reduction in hydraulic conductivities
- No undue influence on water levels
- Model is fairly sensitive to changes in RGA hydraulic conductivities

Observations

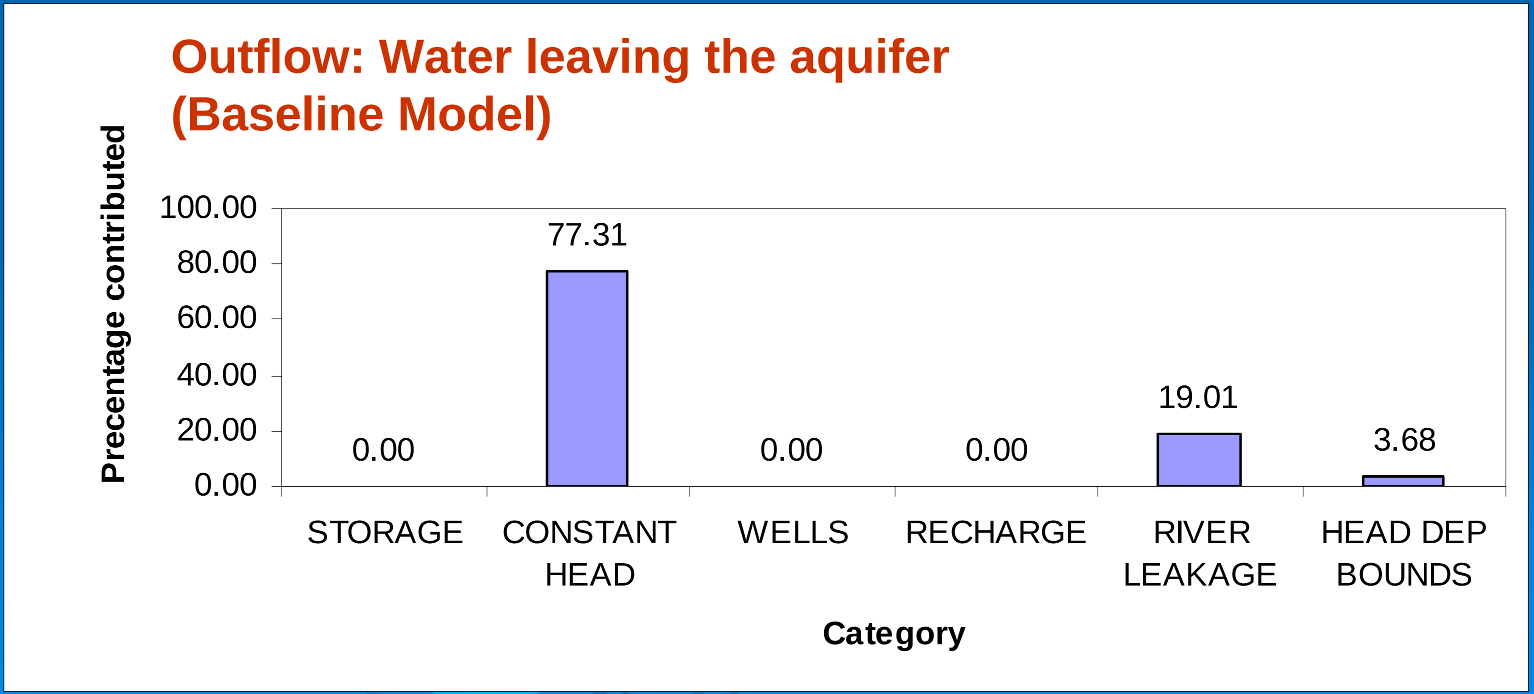
- An analysis performed by monitoring 10 wells in different layers indicated that the calibration suffers more by decreasing K. However, the further fine tuning with more data would be possible.
- More reduction of Hydraulic Conductivity values influences the North West plume movement towards Ohio river. The higher contours did not move like baseline model at the end of the second stress period.
- Based on Water Budget Results of models, Baseline model and model with 30 % reduced K are compared. Percentage outflow through constant head Boundary condition (Ohio river) in 10 years reduces by 7 %.
- Cumulative volume of solute moving out through Ohio river is decreasing with K. On the other hand, volume of solute going out through river leakance increases.

Influence of Hydraulic Conductivity changes on Volumetric Water Balance

Inflow

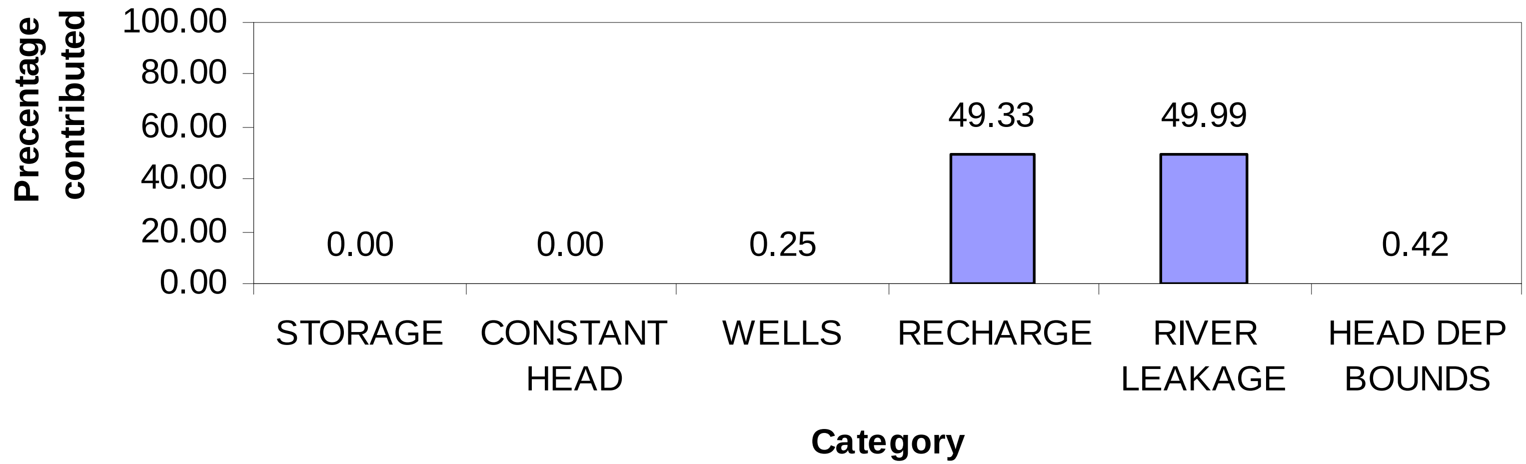


Outflow



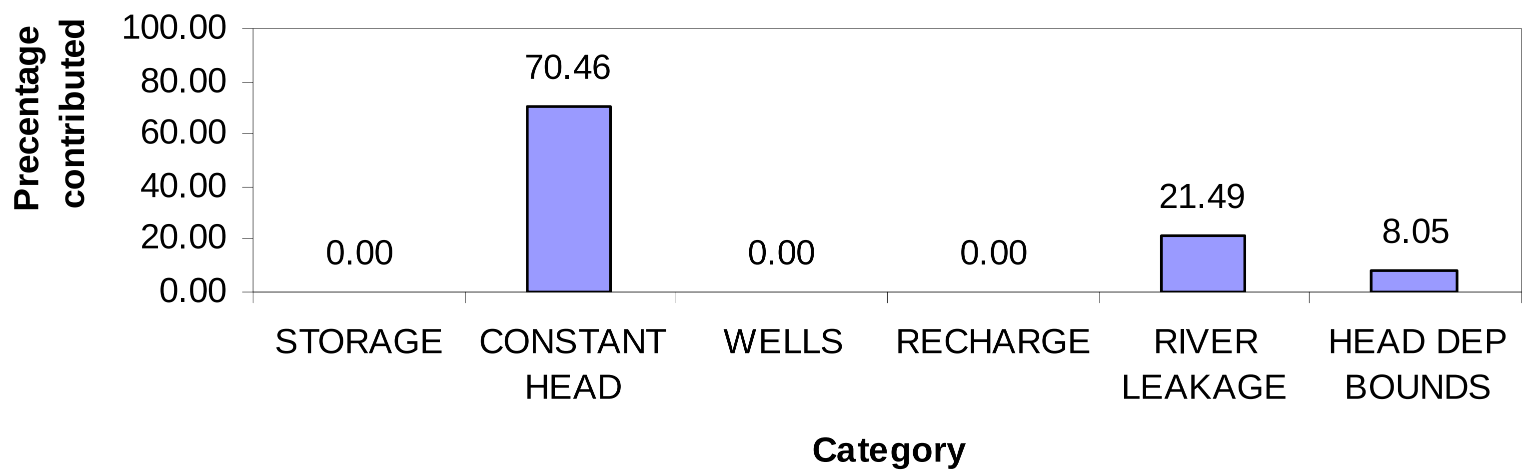
Inflow

Inflow: Water entering the aquifer from different sources (30% reduction in Hydraulic Conductivity)

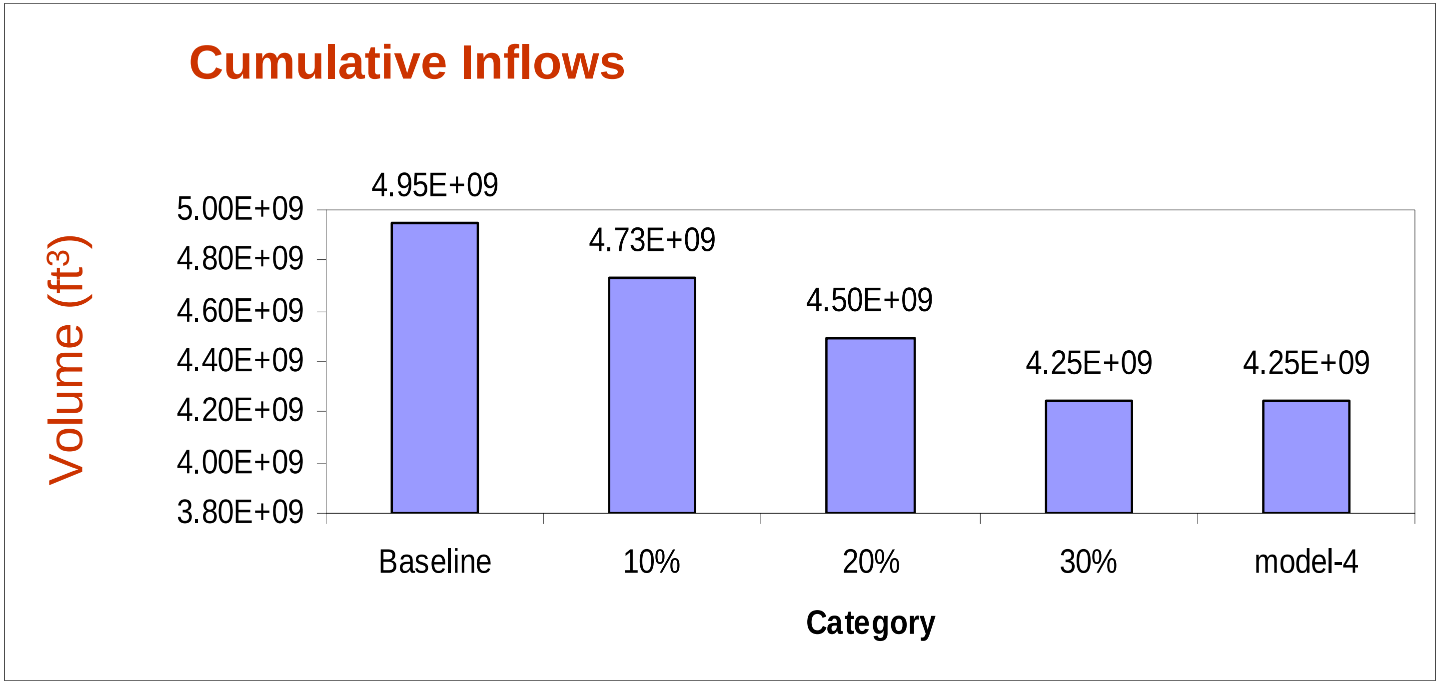


Outflow

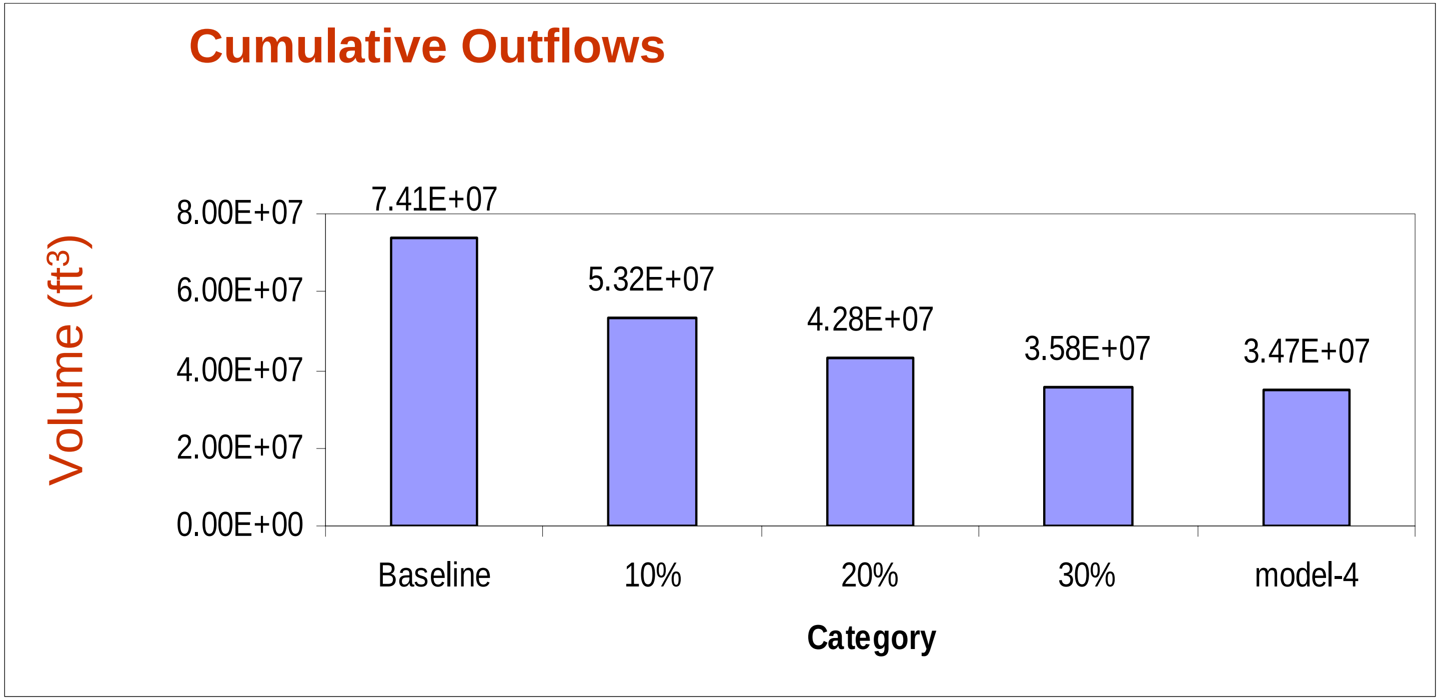
Outflow: Water leaving the aquifer (30% reduction in Hydraulic Conductivity)



Inflow



Outflow



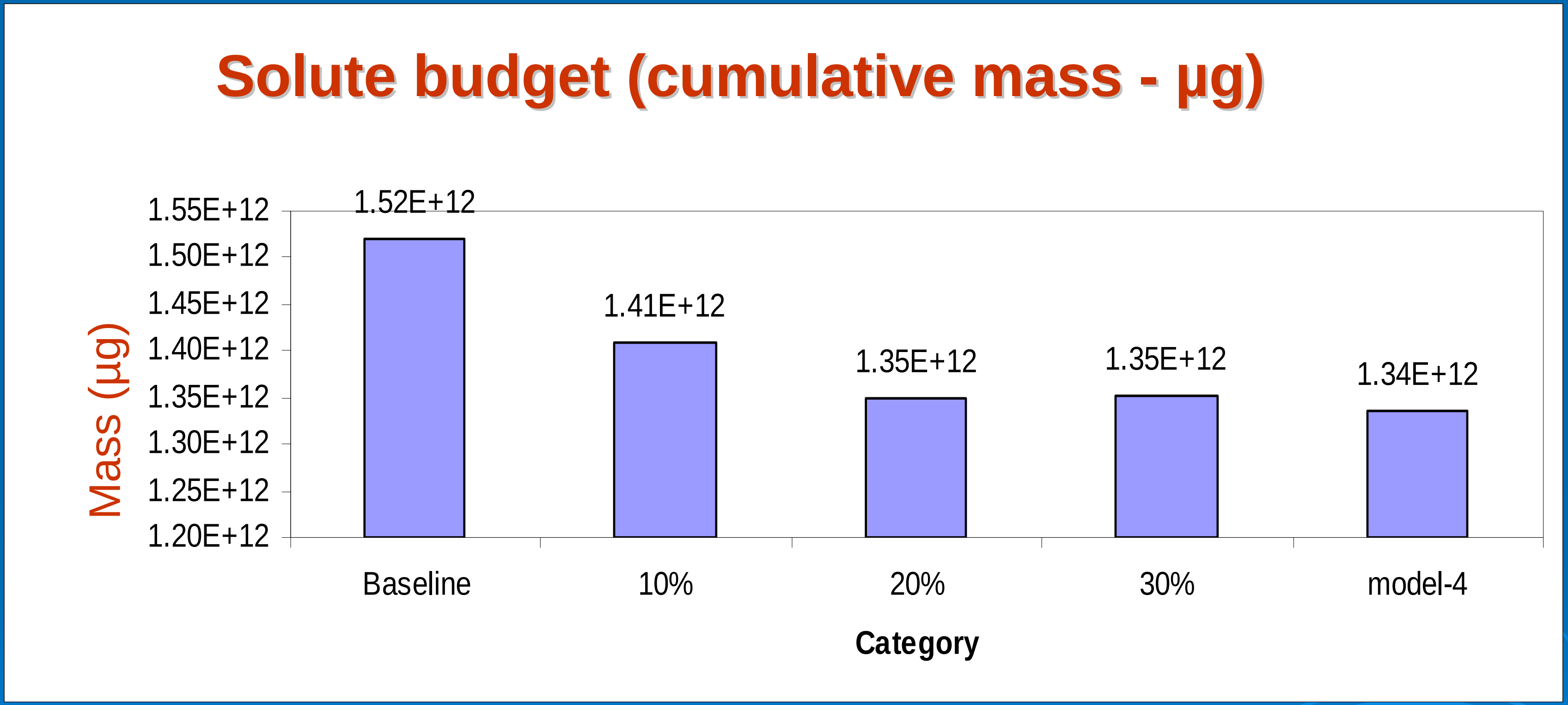
Observations

- For stress period 1 and stress period 2 in the baseline model, % contributions from different categories were same.
- When we compare the % contributions from different categories for Baseline model and model with 30 % reduction in K, % outflow through constant head Boundary condition (Ohio river) reduces by 7 %.
- On the other hand, % outflow through head dependent boundary conditions increases by 4.5 %
- River leakance also increases by 2 %

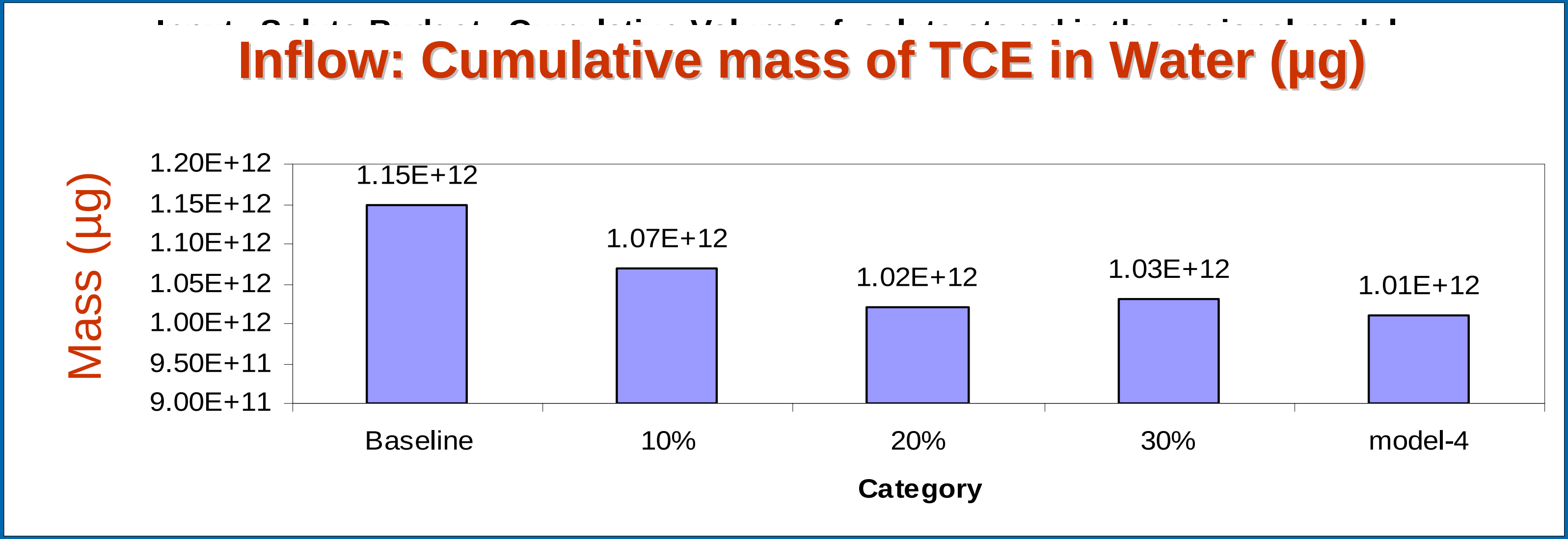
Observations

- Cumulative volume of water into the system through river leakance decreases with decrease in K
- Similar trend is seen for head dependent Boundary conditions
- Cumulative volume of water out of the system through constant head boundary conditions also show a decrease of 15 % (30 % reduction)
- Cumulative volume of water out of the system through river leakance increases by 3 % (30 % reduction). Head dependent boundary conditions also shows such trend (92 % increase)

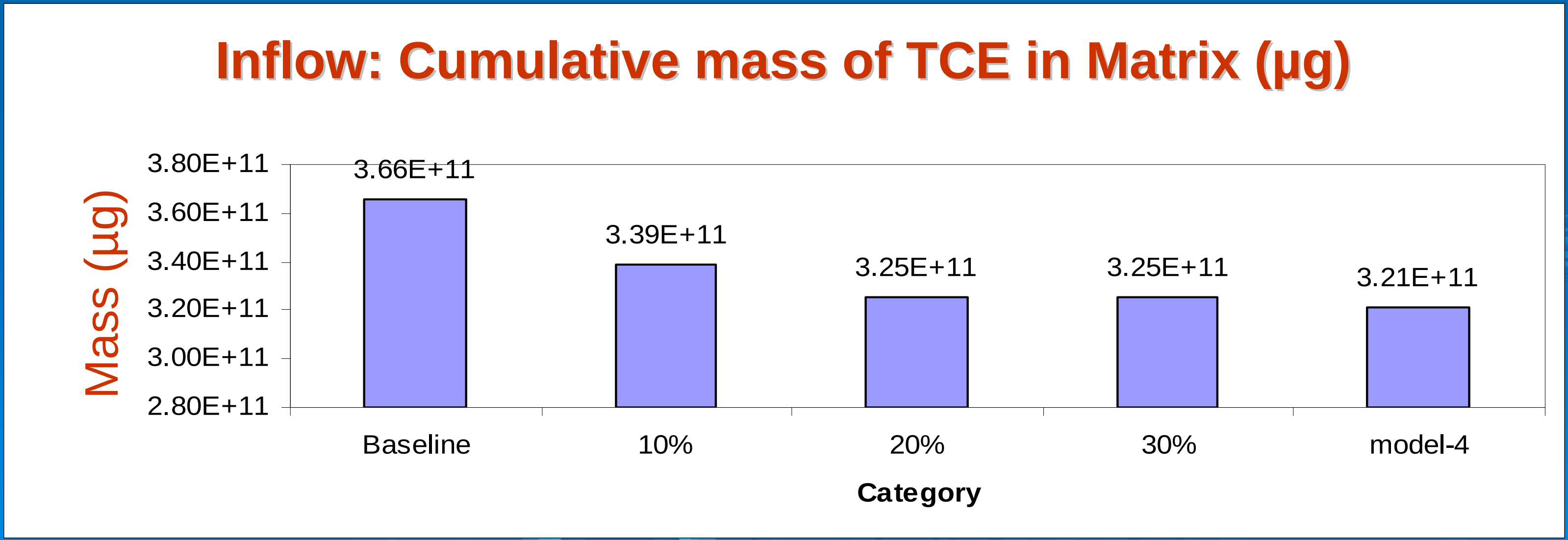
Influence of Hydraulic Conductivity changes on Mass Balance of Solute (TCE) in Stress Period I



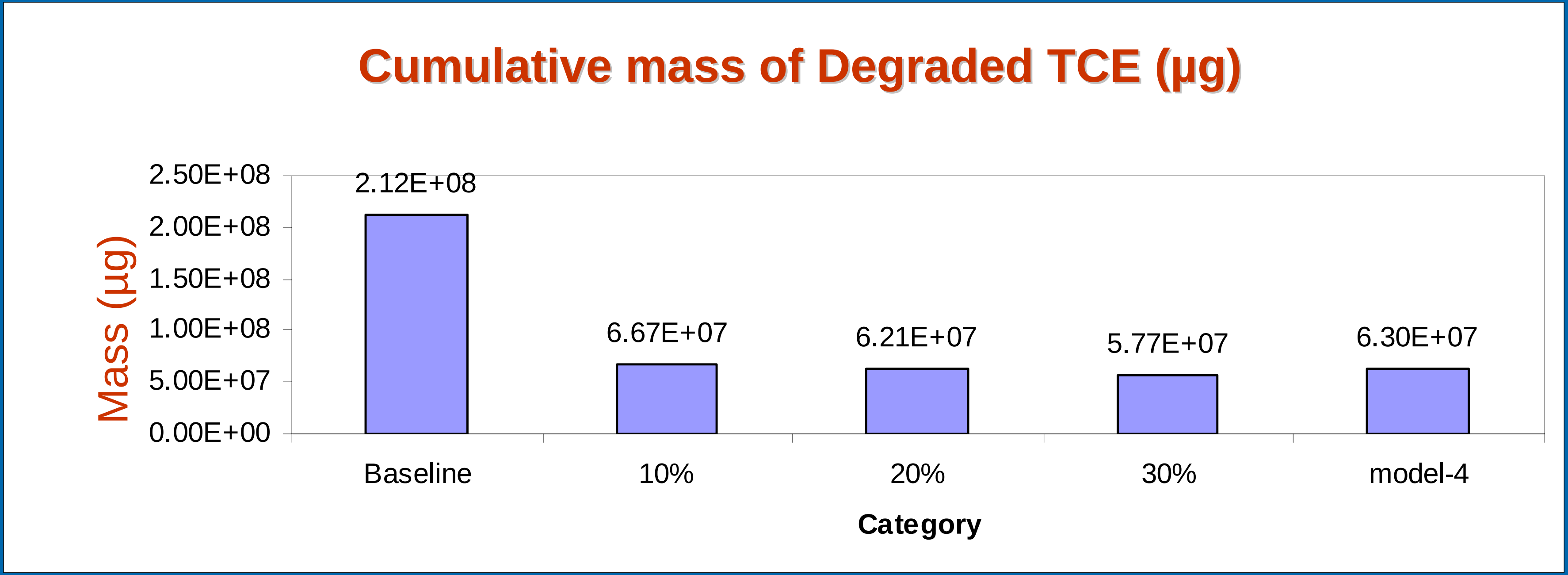
Solute budget (cumulative mass - µg)
Mass (µg)
1.55E+12
1.50E+12
1.45E+12
1.40E+12
1.35E+12
1.30E+12
1.25E+12
1.20E+12
1.52E+12
1.41E+12
1.35E+12
1.35E+12
1.34E+12
Baseline
10%
20%
30%
model-4
Category



Inflow: Cumulative mass of TCE in Water (µg)
Mass (µg)
1.20E+12
1.15E+12
1.10E+12
1.05E+12
1.00E+12
9.50E+11
9.00E+11
1.15E+12
1.07E+12
1.02E+12
1.03E+12
1.01E+12
Baseline
10%
20%
30%
model-4
Category



Inflow: Cumulative mass of TCE in Matrix (µg)
Mass (µg)
3.80E+11
3.60E+11
3.40E+11
3.20E+11
3.00E+11
2.80E+11
3.66E+11
3.39E+11
3.25E+11
3.25E+11
3.21E+11
Baseline
10%
20%
30%
model-4
Category


Cumulative mass of Degraded TCE (µg)
Mass (µg)
2.50E+08
2.00E+08
1.50E+08
1.00E+08
5.00E+07
0.00E+00
2.12E+08
6.67E+07
6.21E+07
5.77E+07
6.30E+07
Baseline
10%
20%
30%
model-4
Category

Inferences from Solute Budget

- Total cumulative volume of solute in the system decreases with the reduction in K
- Cumulative volume of solute in water and in matrix decreases with the reduction in K
- Cumulative volume of solute decayed also decreases.
- Cumulative volume of solute moving out through Ohio river is decreasing with K. On the other hand, volume of solute going out through river leakance increases.

3.2.4 Plant Shutdown Scenario

Water Depth Changes in Big Bayou and Little Bayou Creeks

Plant Shutdown Scenario

- Changes the inflows to Bayou Creeks
- Little Bayou gets affected most
- Big Bayou and Little Bayou Creeks were modeled as “River Boundaries” in baseline model
- Uniform depth of 2.5ft for all river cells
- Influence of complete drying of both creeks
- Reduced inflows

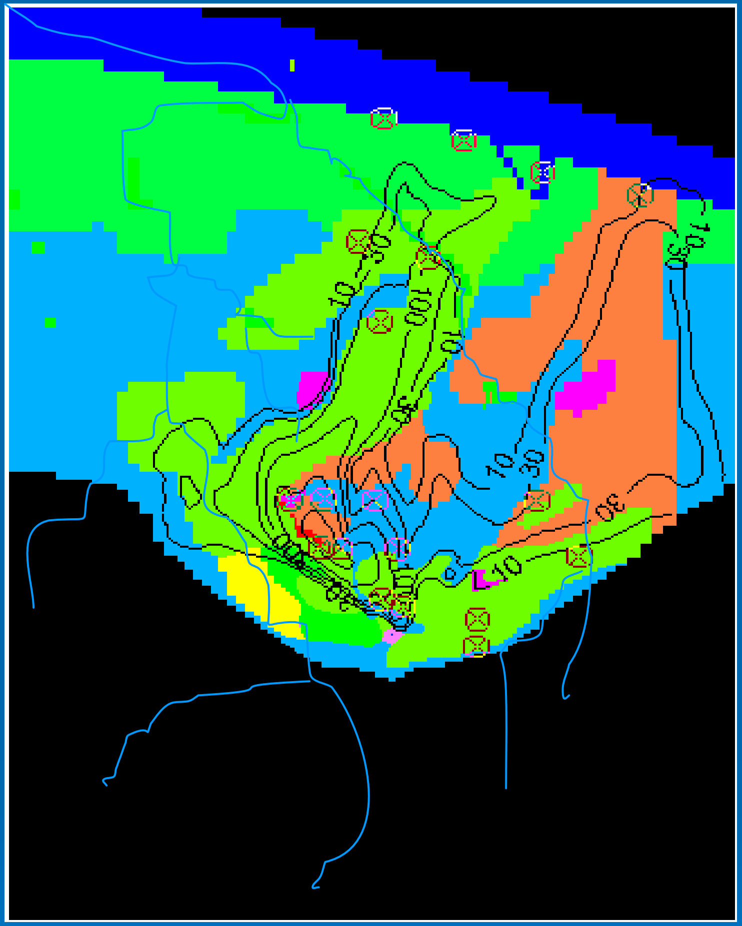
Model Runs with different water depths in Big Bayou and Little Bayou Creeks
(CRSV = Creek and River Stage Variation)

- Model **CRSV** 1 :
  - ✓ reduce BBC stage to 1.25 ft (50 % reduction) and
  - ✓ maintain LBC stage at 2.5 ft as per baseline model.
- Model **CRSV** 2 :
  - ✓ maintain BBC stage to 2.5 ft as per baseline model and
  - ✓ reduce LBC stage to 1.25 ft (50 % reduction).

Plant Shutdown Scenario

- Model **CRSV** 3 :
  - ✓ reduce BBC stage to 1.25 ft and
  - ✓ reduce LBC stage to 0.5 ft.
- Model **CRSV** 4 :
  - ✓ reduce BBC stage to 0.5 ft and
  - ✓ reduce LBC stage to 0.5 ft.
- All other parameters are maintained as per the baseline model.

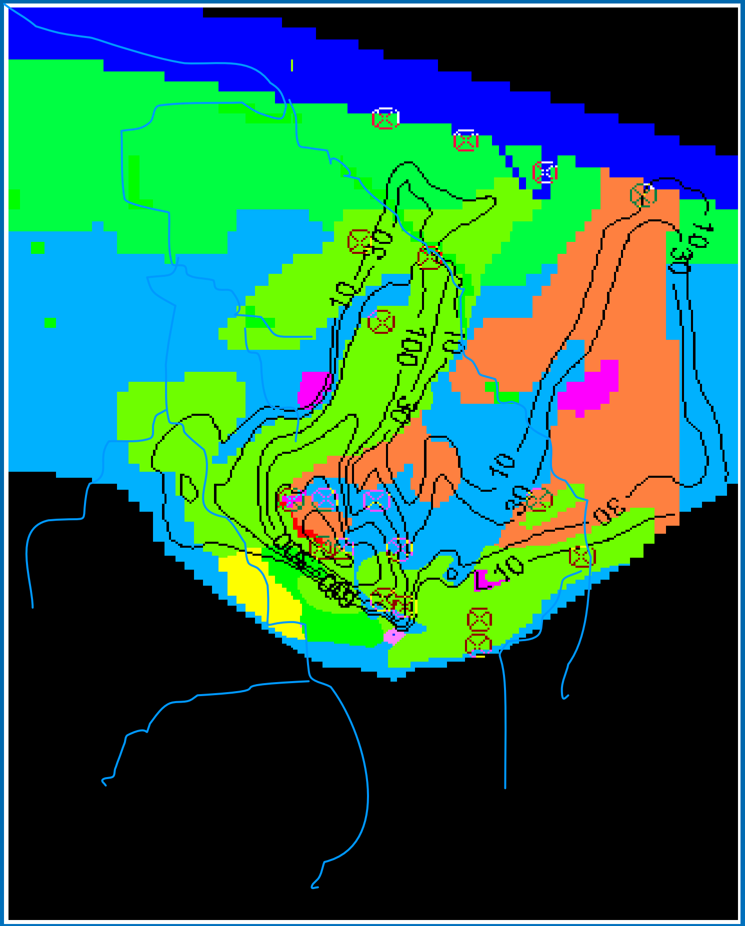
TCE Contours at the end of Stress Period 2 (30 Years)



Baseline model

Big Bayou creek – 2.50 ft stage

Little Bayou creek – 2.50 ft stage



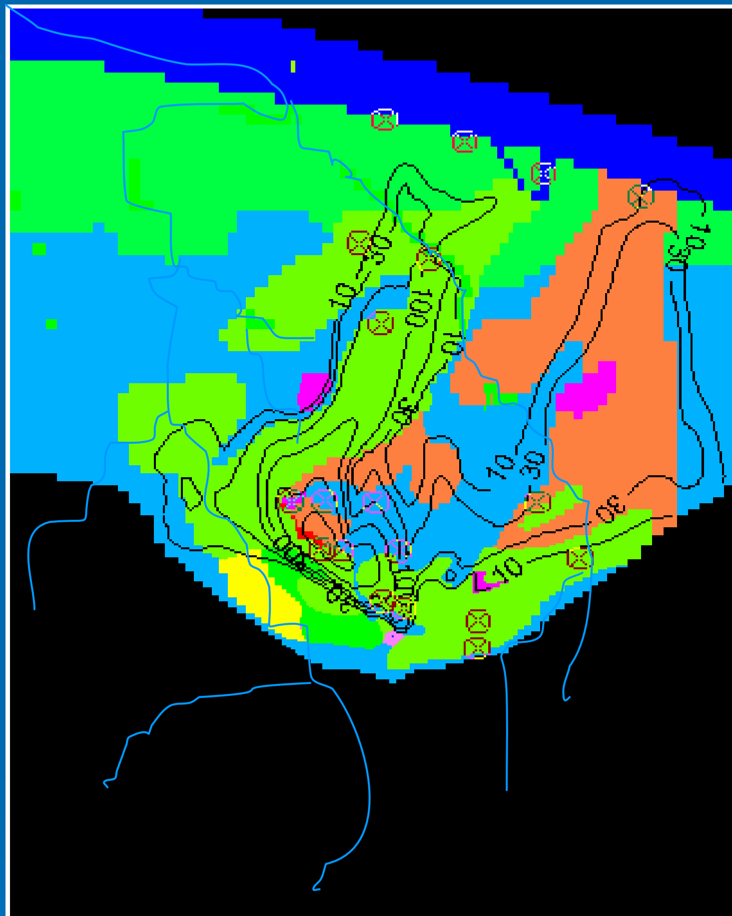
Model CRSV 1

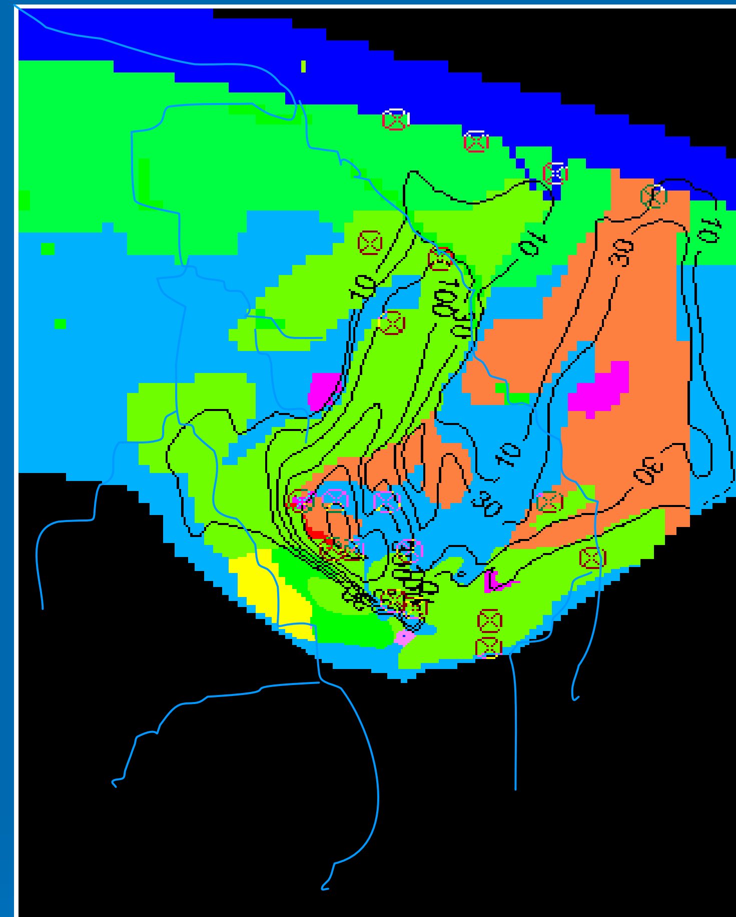
With a change in stream BC in

Big Bayou creek – 1.25 ft stage

Little Bayou creek – 2.50 ft stage

TCE Contours at the end of Stress Period 2 (30 Years)





Baseline model

Big Bayou creek – 2.50 ft stage

Little Bayou creek – 2.50 ft stage

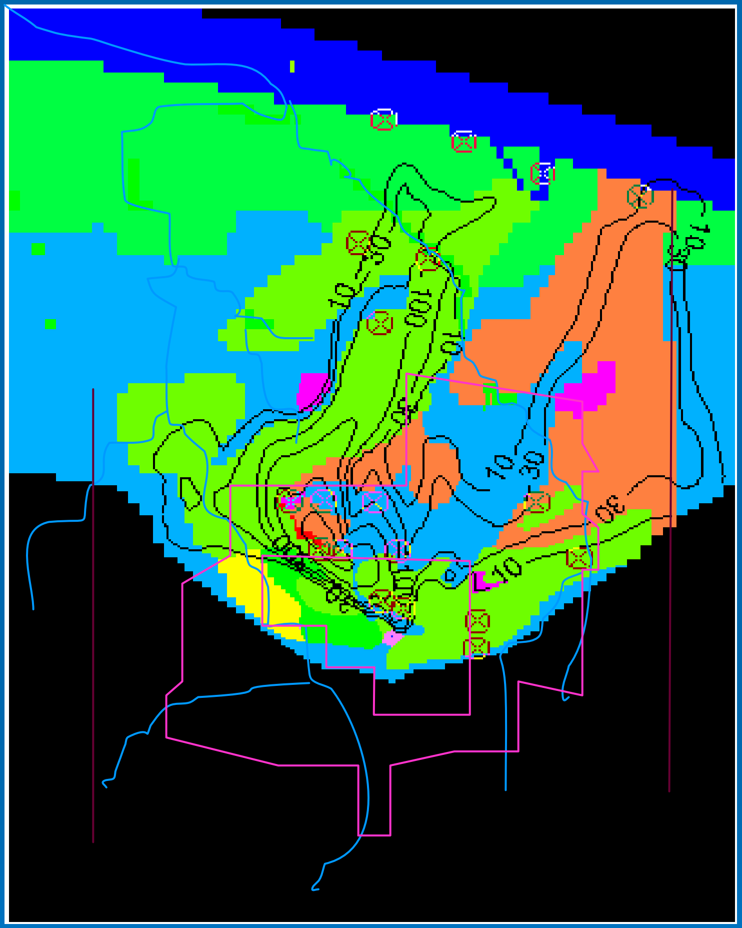
Model CRSV 2

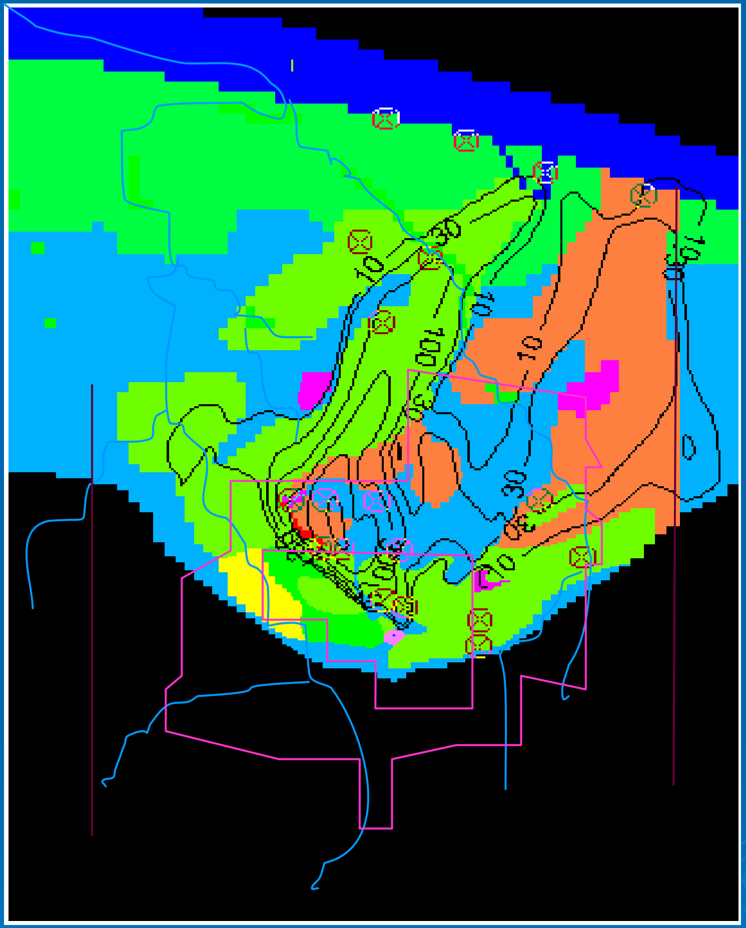
With a change in stream BC in

Big Bayou creek – 2.50 ft stage

Little Bayou creek – 0.50 ft stage

TCE Contours at the end of Stress Period 2 (30 Years)

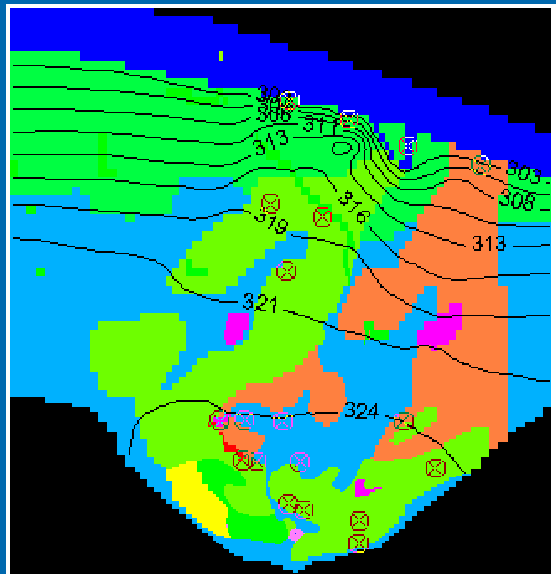




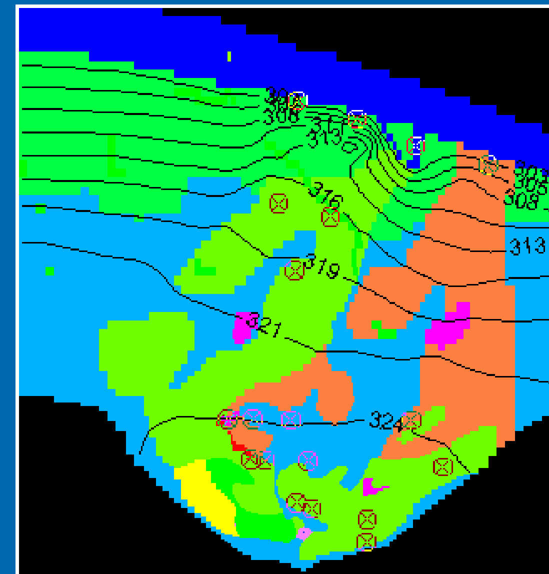
Baseline model
Big Bayou creek – 2.50 ft stage
Little Bayou creek – 2.50 ft stage

Model CRSV 3
With a change in stream BC in
Big Bayou creek – 1.25 ft stage
Little Bayou creek – 0.50 ft stage

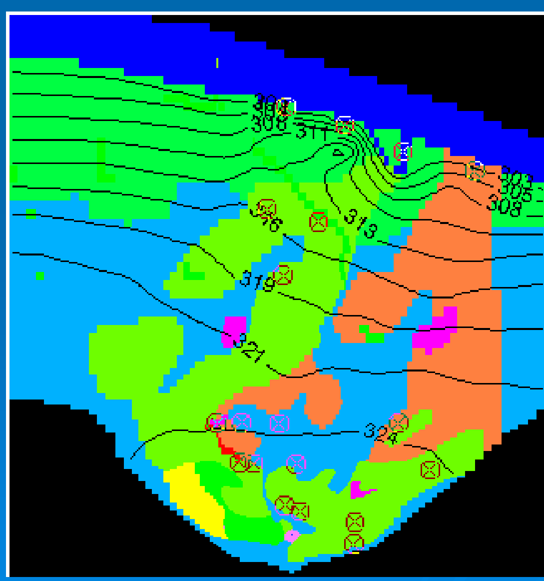
Comparing Hydraulic Gradient Contours



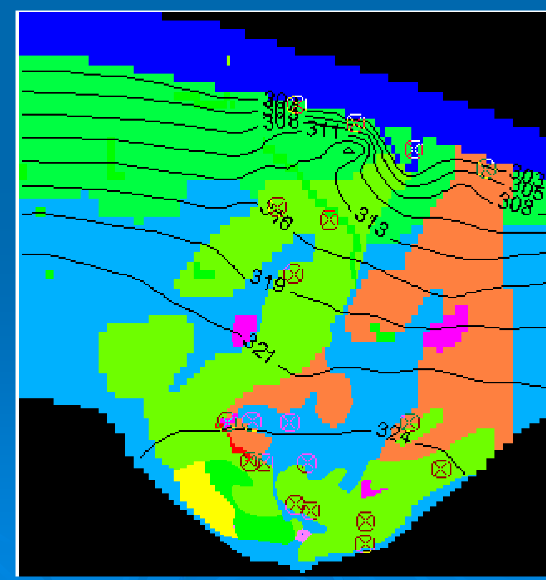
Baseline model



CRSV 2



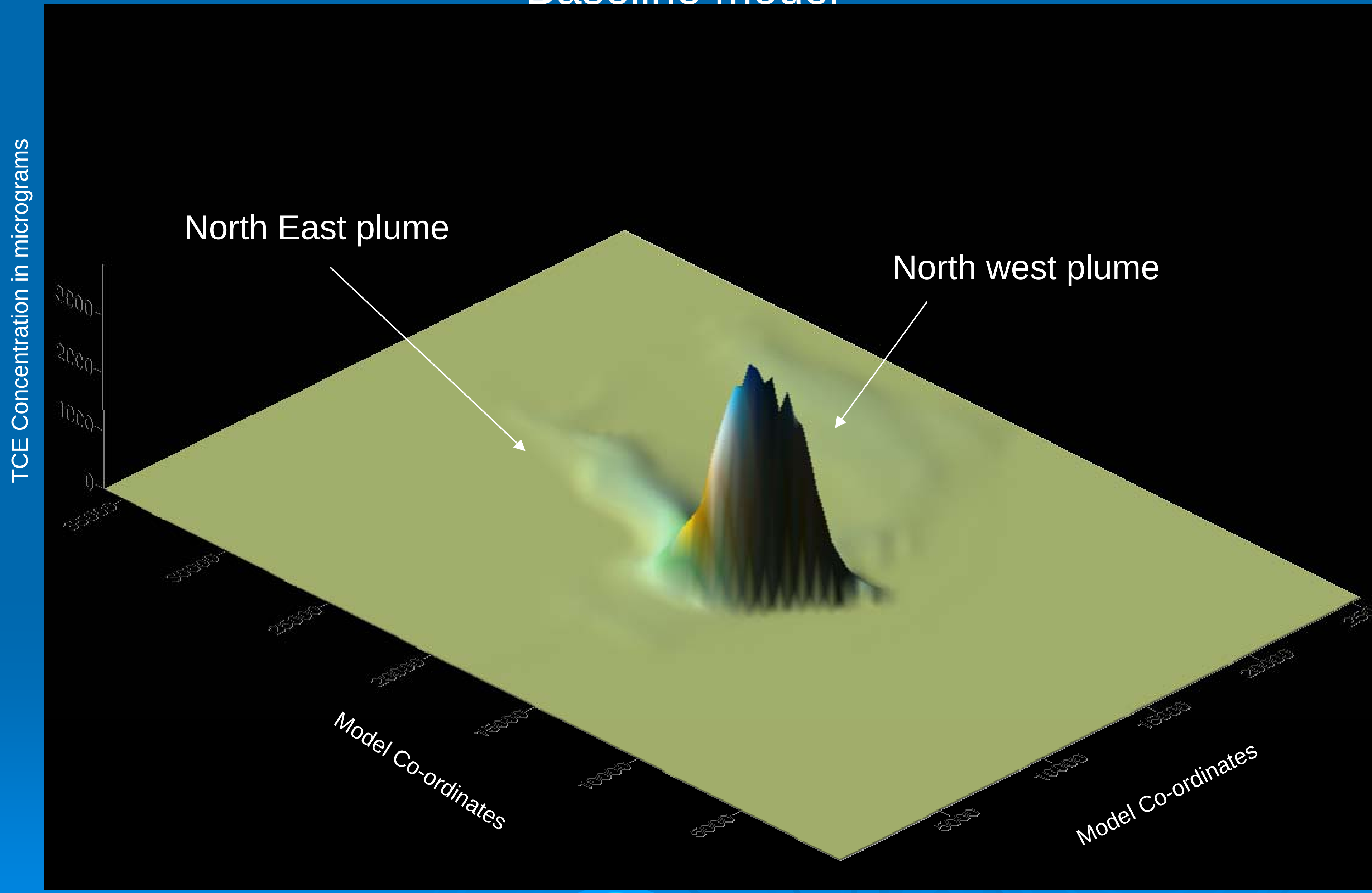
CRSV 3



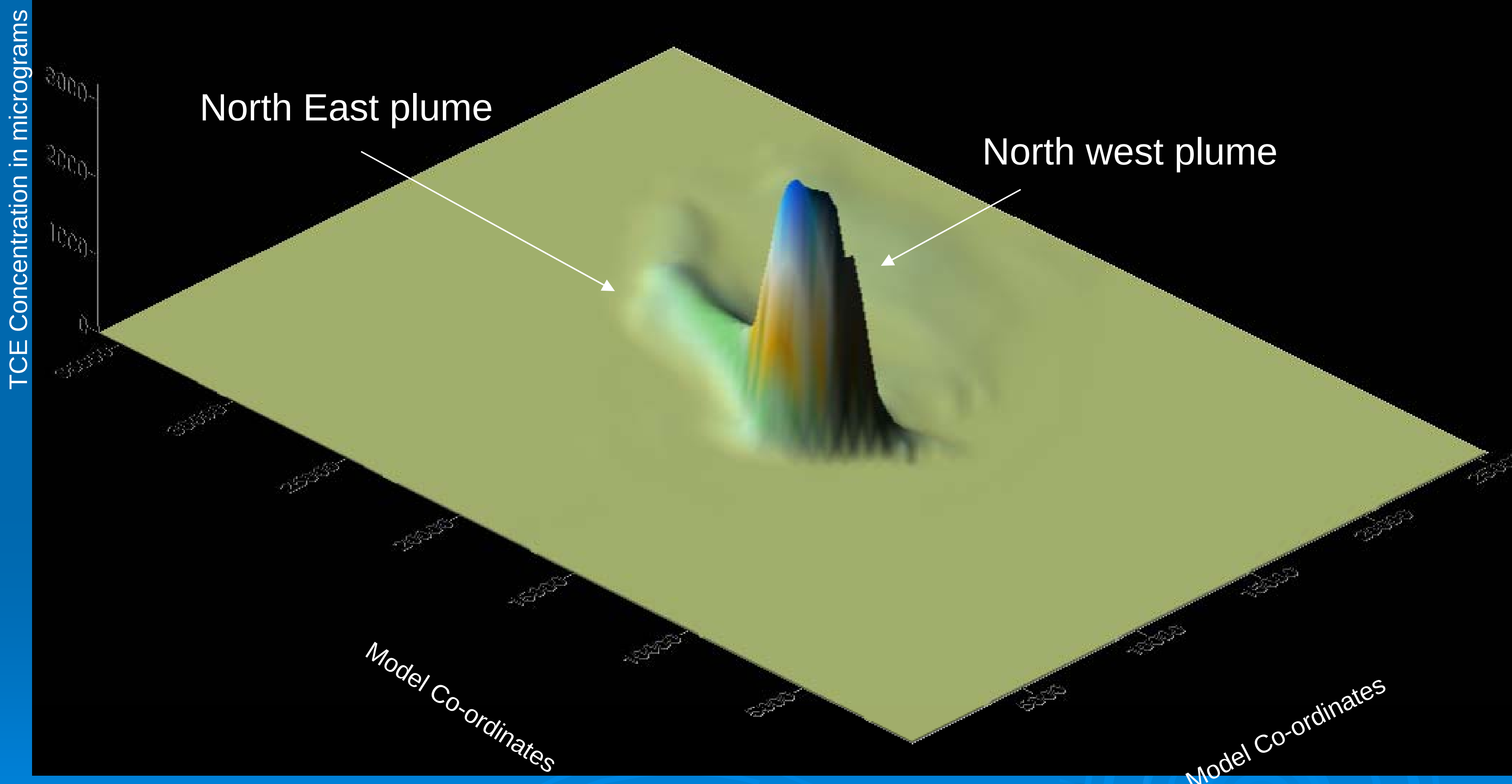
CRSV 4

Comparing Baseline and CSV4 Models using 3D Plots

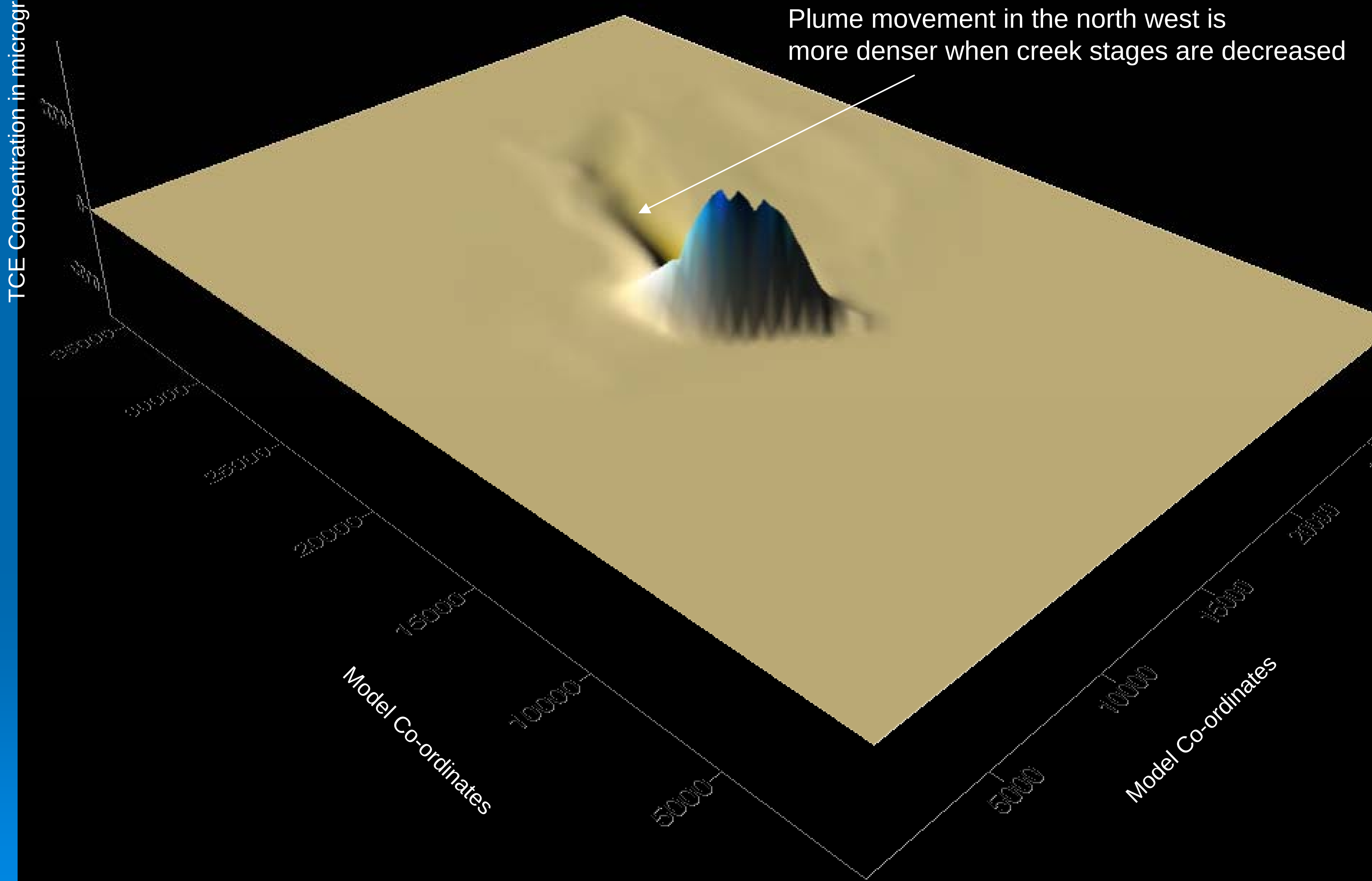
Baseline model

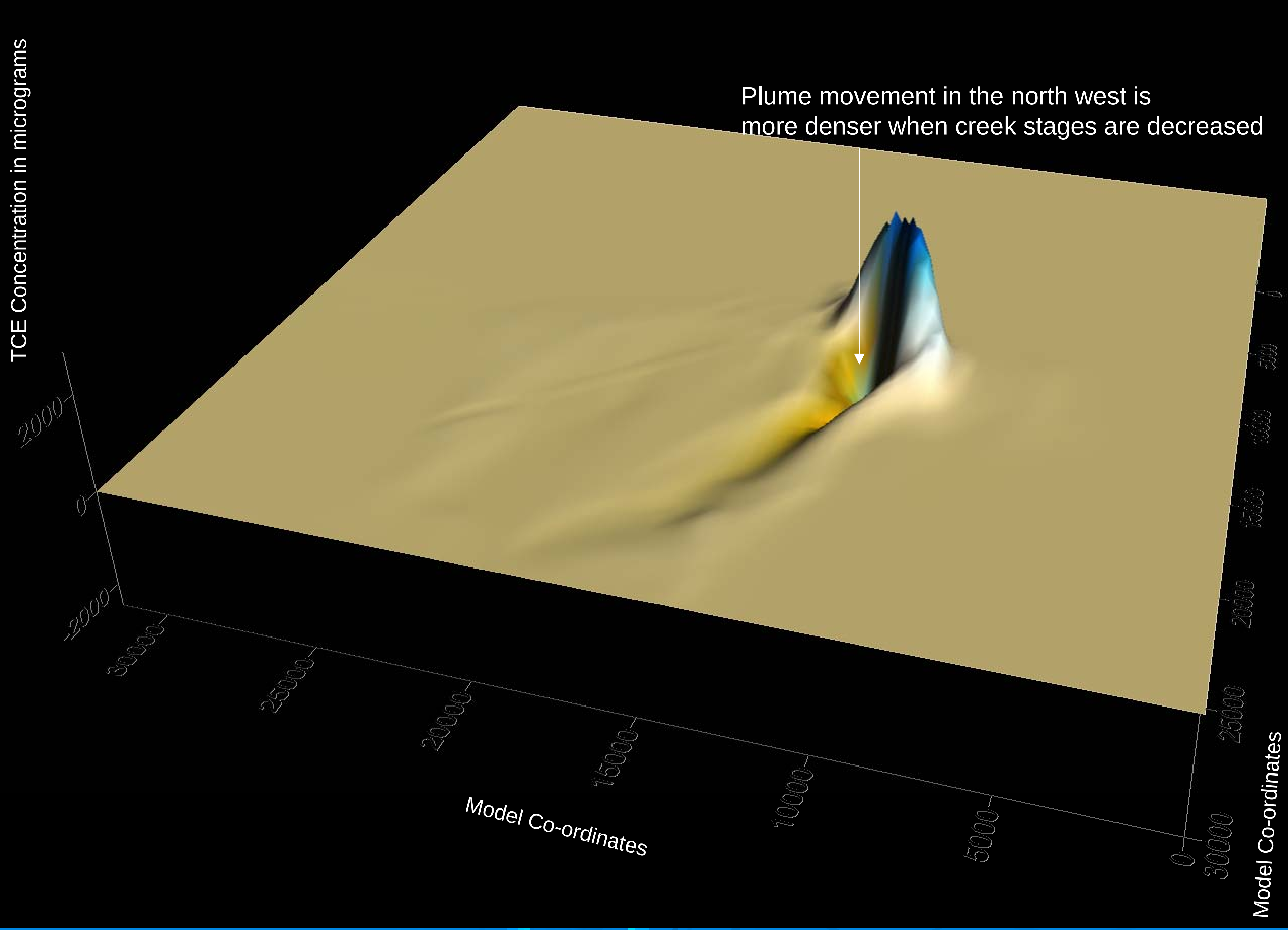


CRSV 4 model


TCE Concentration in micrograms
North East plume
North west plume
Model Co-ordinates
Model Co-ordinates

Delta difference between Baseline and CRSV 4





Plume movement in the north west is
more denser when creek stages are decreased
TCE Concentration in micrograms
2000
0
-2000
30000
25000
20000
15000
10000
5000
0
Model Co-ordinates
30000
25000
20000
Model Co-ordinates

Inferences

- Changes to Little Bayou Creek (LBC) have more influence on the model than changes to Bib Bayou Creek (BBC)
  - Hydraulic Conductivities underneath LBC are much higher than Hydraulic Conductivities underneath BBC
- Reduction of depth in LBC influences volumetric water balance considerably.
- Plant Shut Down Scenario Will have a significant Influence on TCE Plume movement

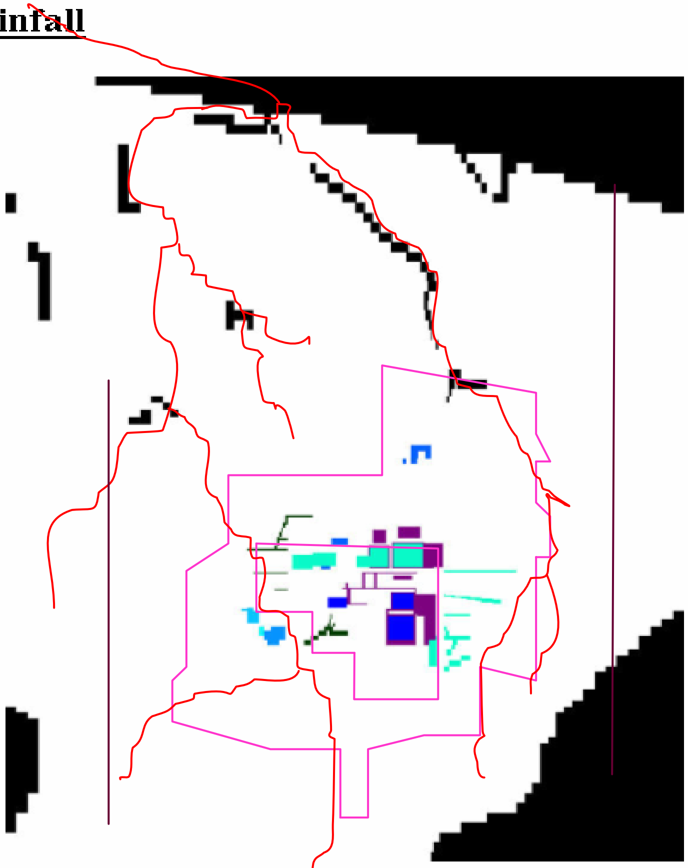
3.2.5 Influence of Changes to Recharge Rates

Recharge rates – Rainfall

Effect of changes in rainfall

Changes made to this baseline model for sensitivity analysis:

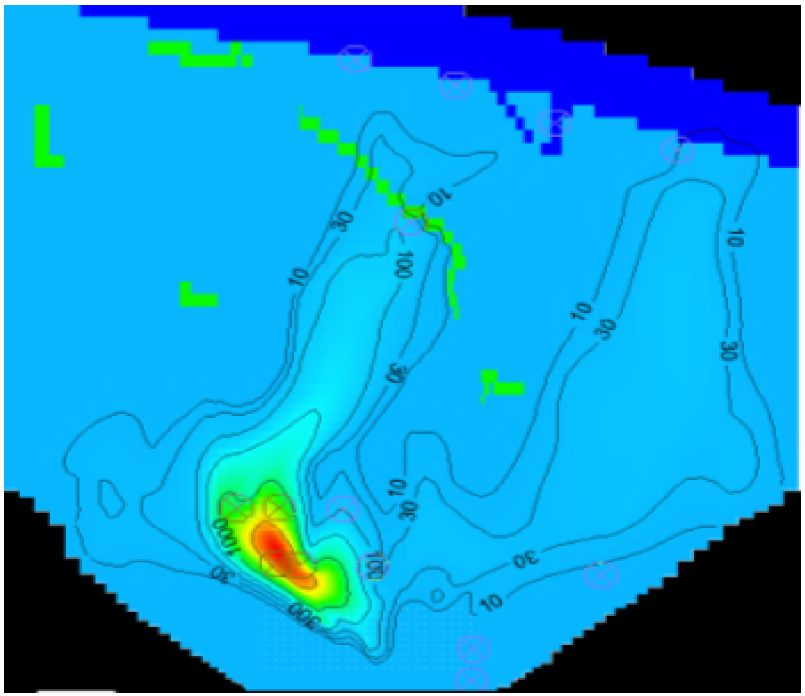
- Rainfall recharge was increased by 25%



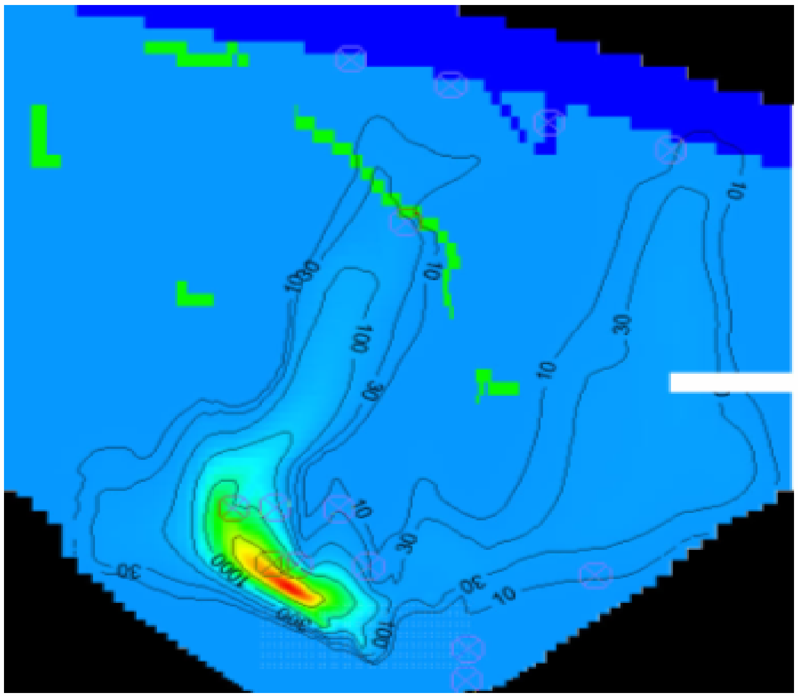
Layer 1 of the model

Recharge rates – Rainfall

Comparison of results in layer 3 at the end of Stress period 2

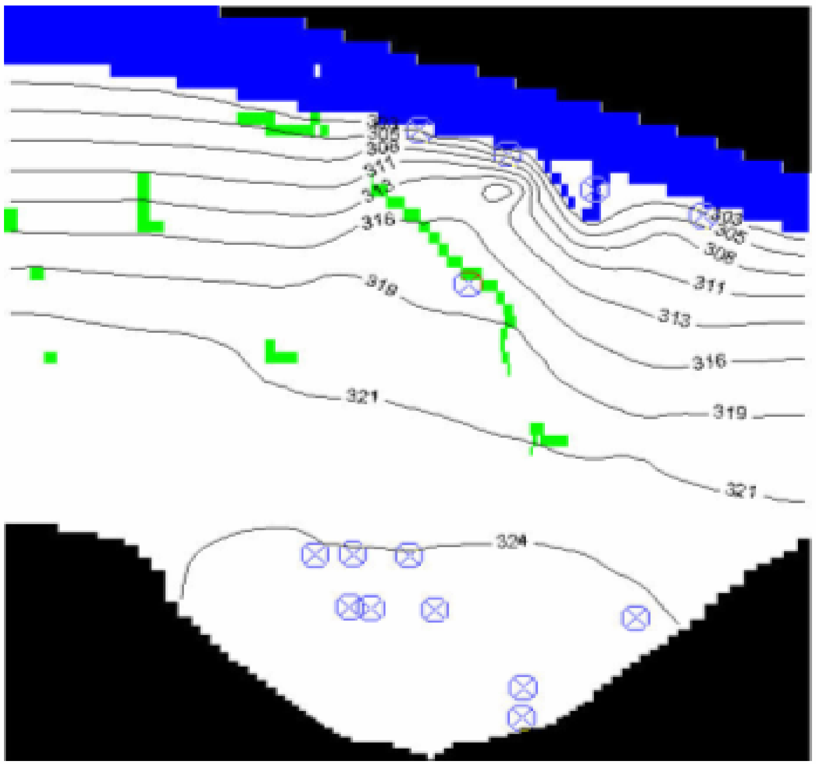


TCE Concentration contour (Baseline model)

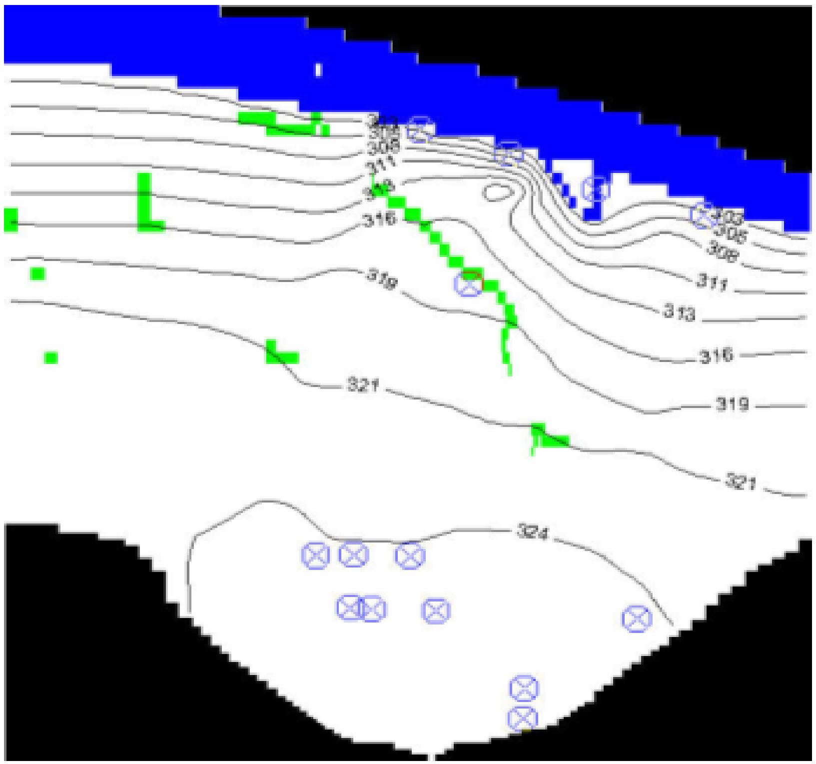


TCE Concentration contour (New model)

Recharge rates – Rainfall



HGL Contours (Baseline model)



HGL Contours (Present model)

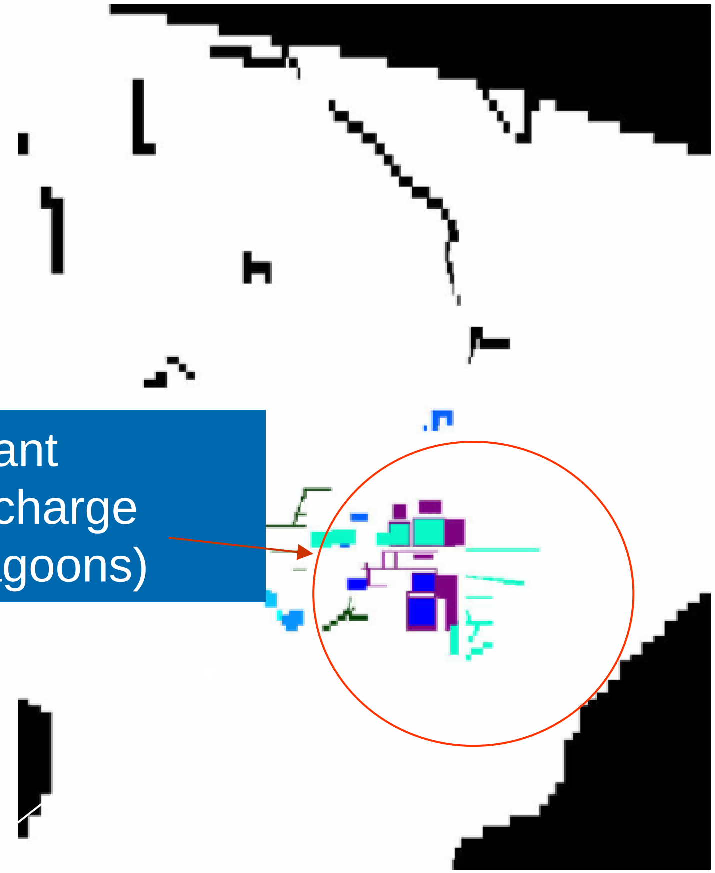
Recharge rates – Rainfall

Changes made to this baseline model for sensitivity analysis:

- Rainfall recharge was decreased by 25%

Rainfall recharge (rest of the cells)

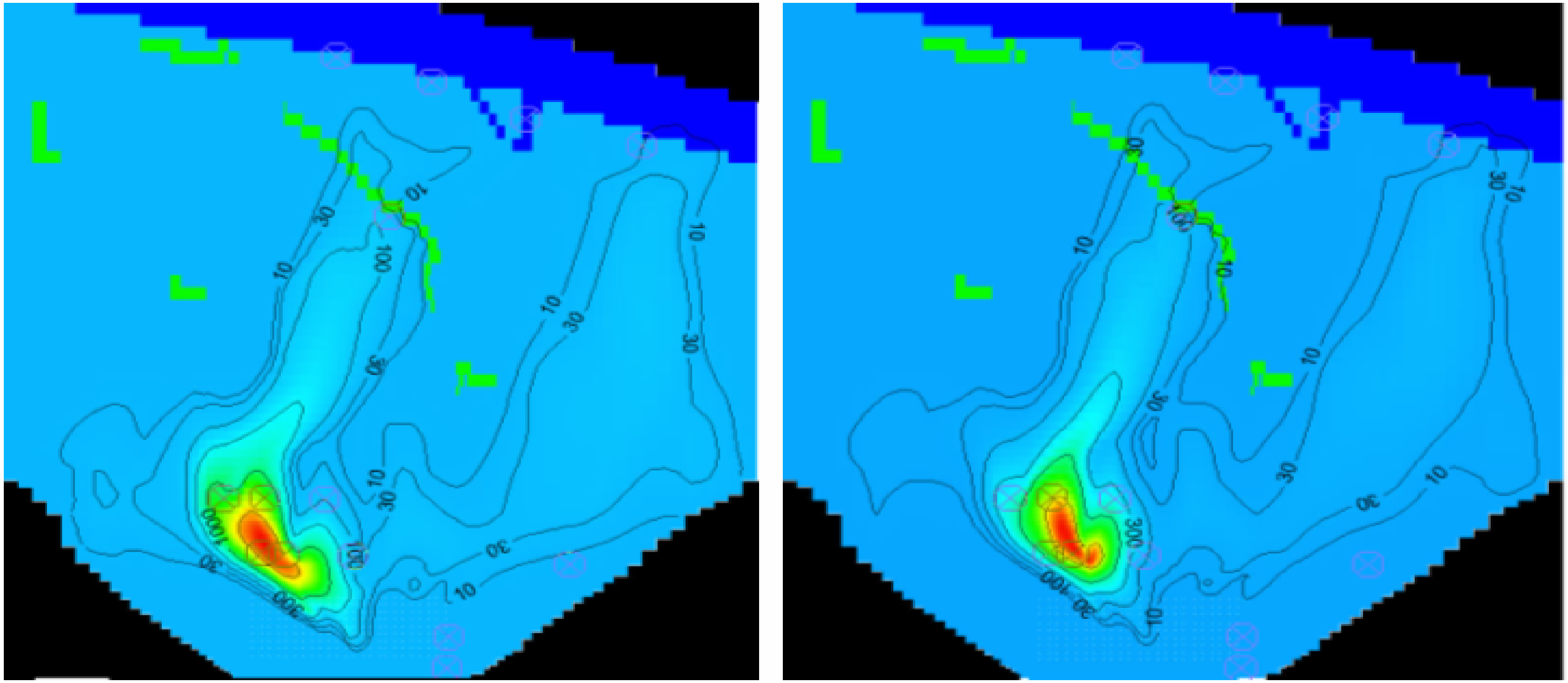
Plant recharge (lagoons)



Layer 1 of the model

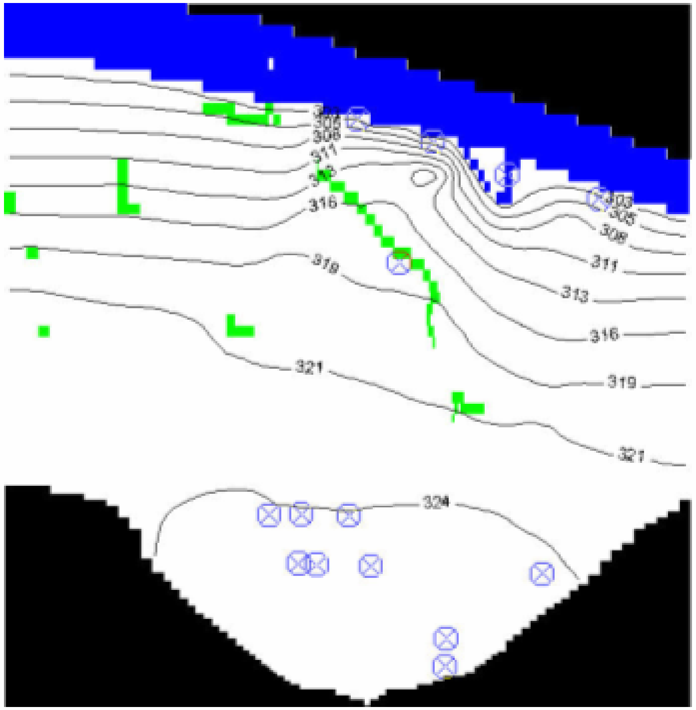
Recharge rates – Rainfall

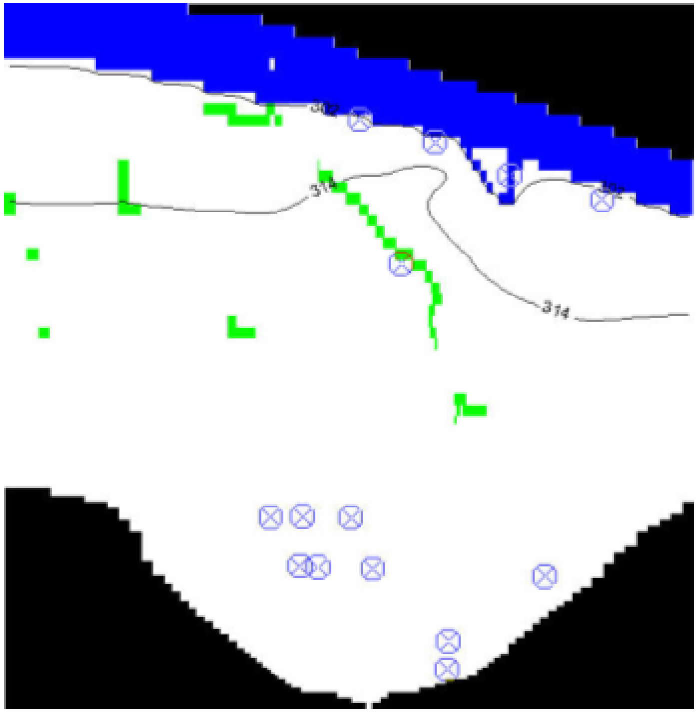
Comparison of results in layer 3 at the end of Stress period 2



TCE Concentration contour (Baseline model) TCE Concentration contour (New model)

Recharge rates – Rainfall



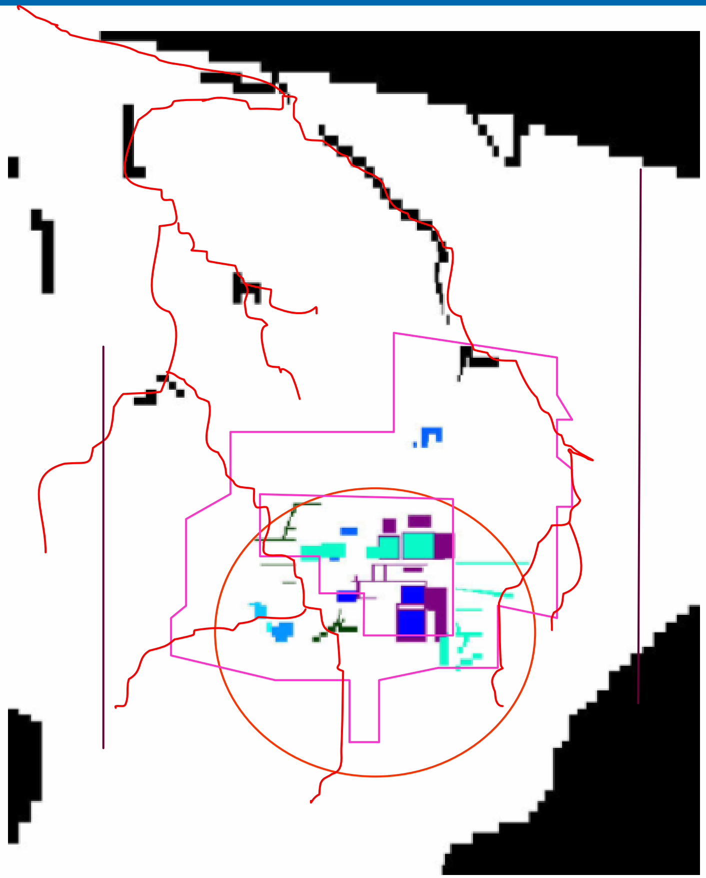


HGL Contours (Baseline model)　　HGL Contours (Present model)

Recharge rates – Plant (lagoons)

Changes made to this baseline model for sensitivity analysis:

- Plant recharge was increased by 25%

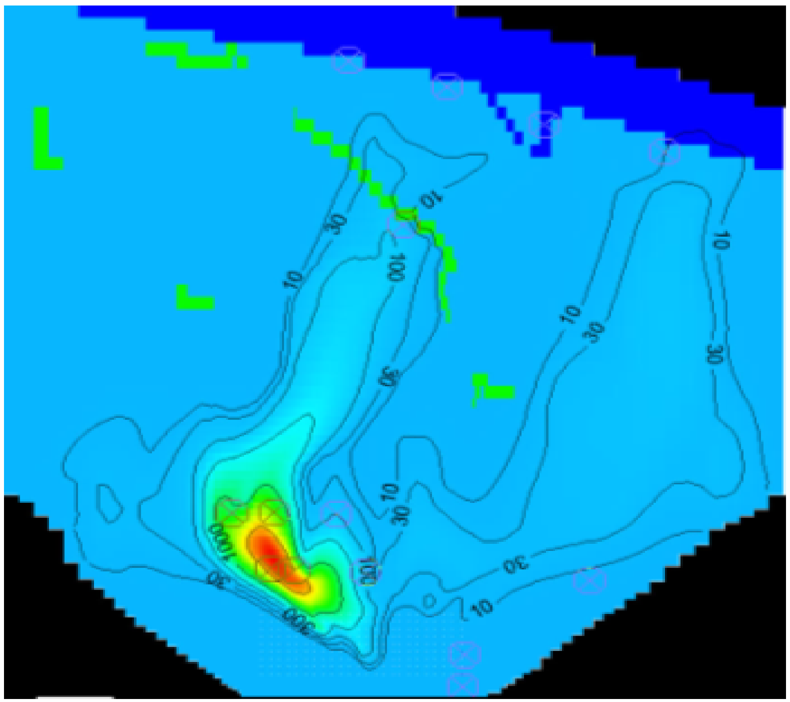


Layer 1 of the model

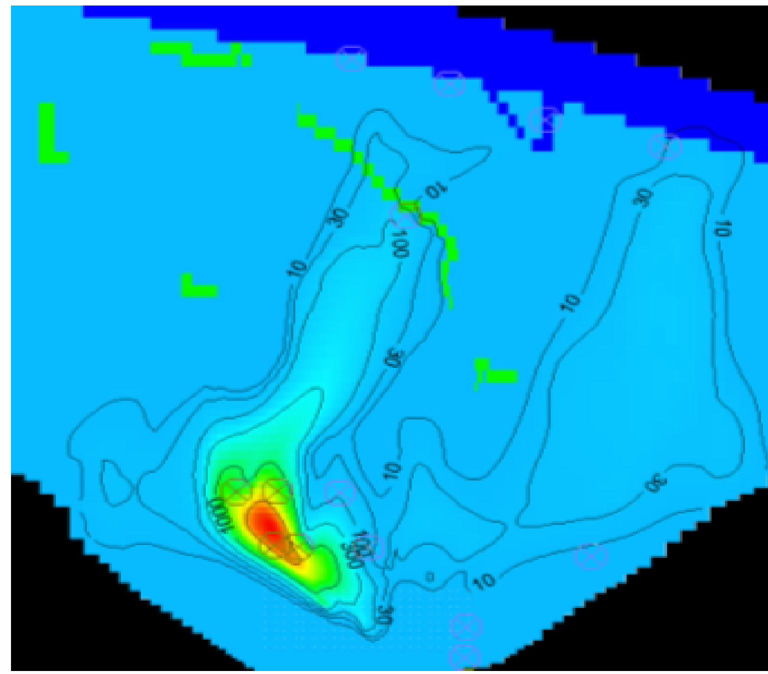
Recharge rates – Plant

25% increase in plant recharge

Comparison of TCE concentrations at the end of Stress Period 2 (30years)

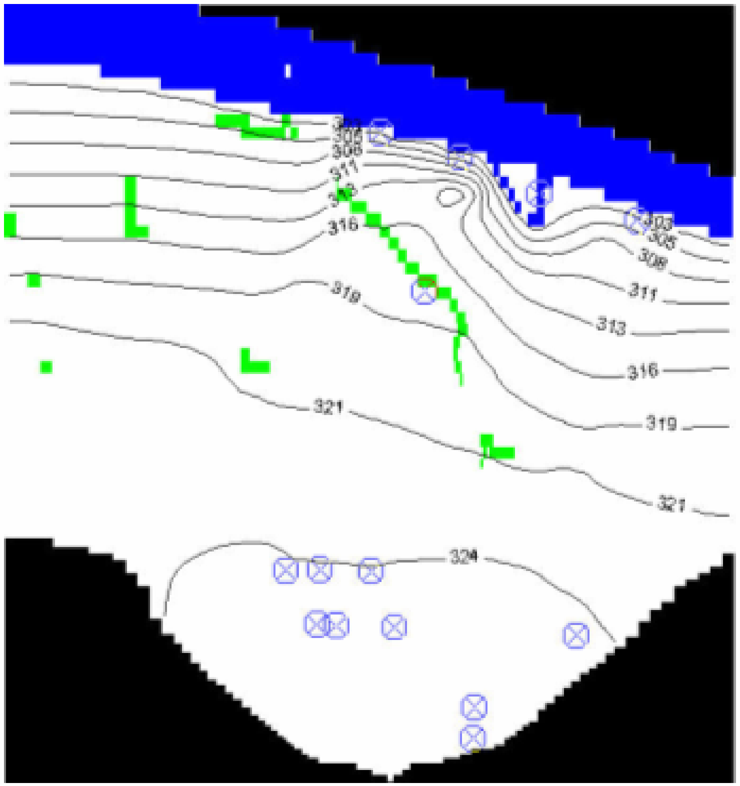


TCE Concentration contour (Baseline model)

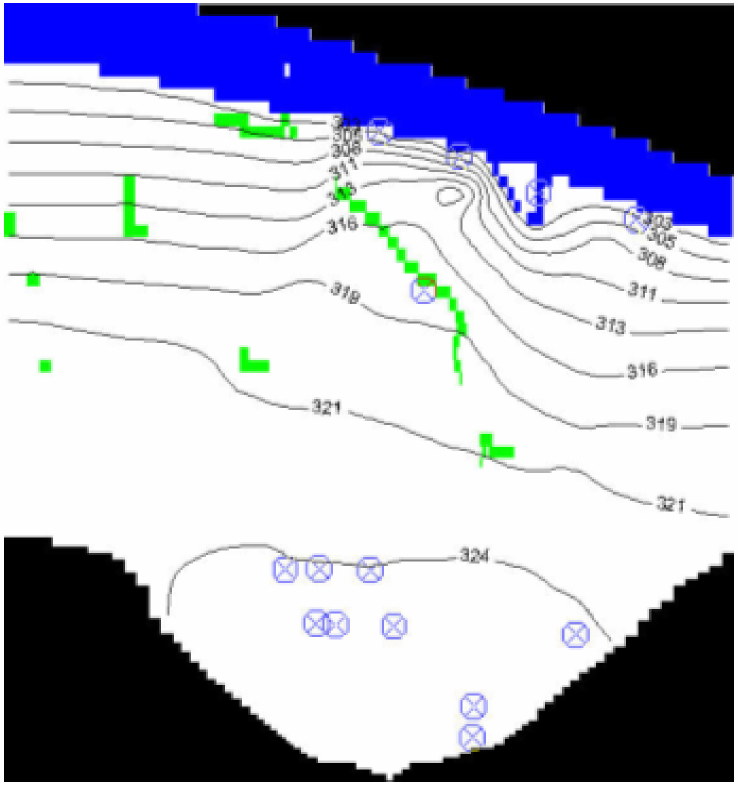


TCE Concentration contour (New model)

Recharge rates – Plant



HGL Contours (Baseline model)

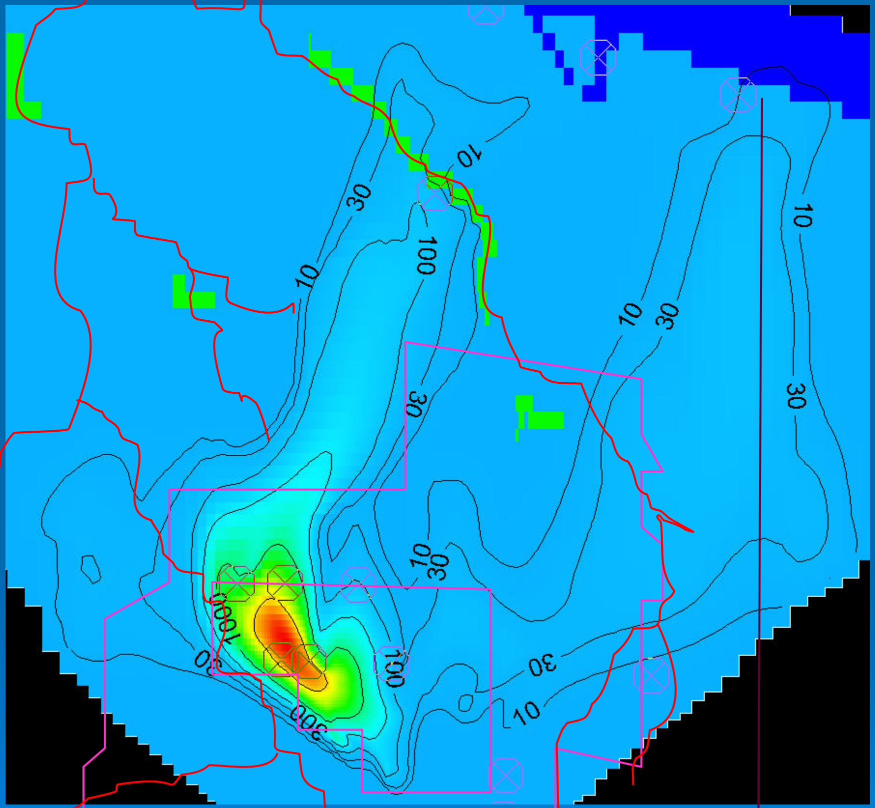


HGL Contours (Present model)

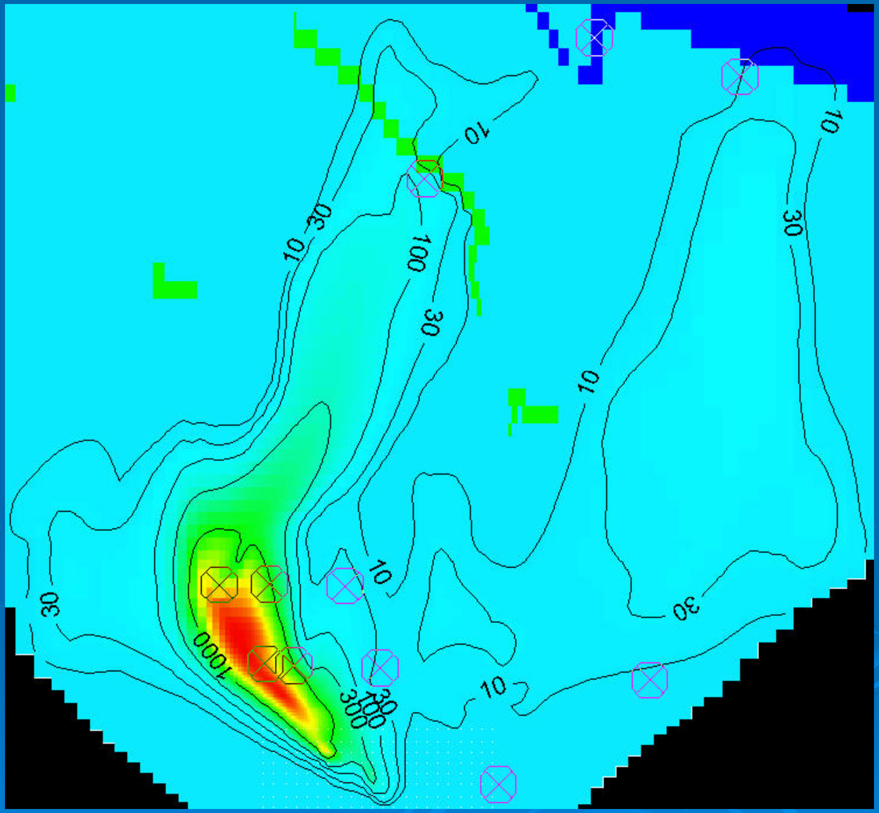
Recharge rates – Plant

100% increase in plant recharge

Comparison of TCE concentrations at the end of Stress Period 2 (30years)



Baseline Model



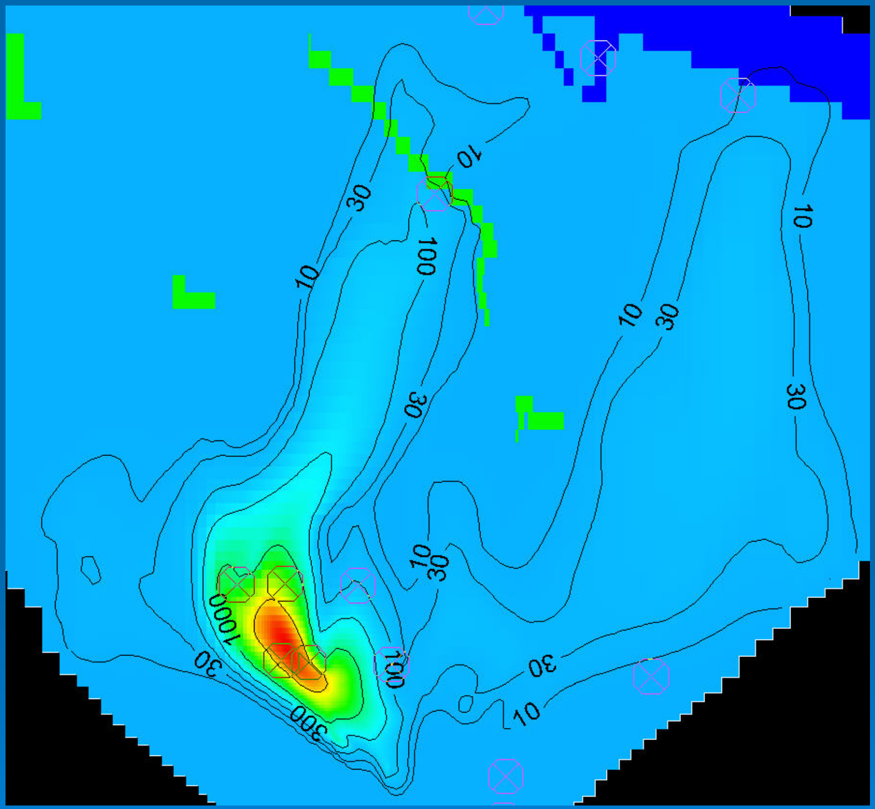
New Model

100% increase in plant recharge

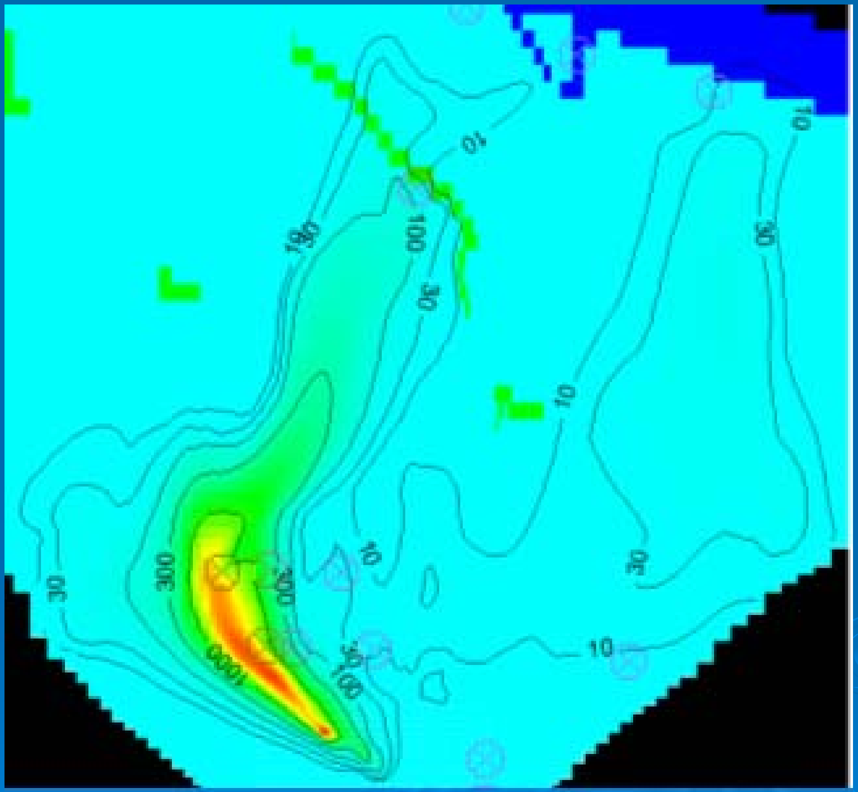
Recharge rates – Plant

200% increase in plant recharge

Comparison of TCE concentrations at the end of Stress Period 2 (30years)



Baseline Model



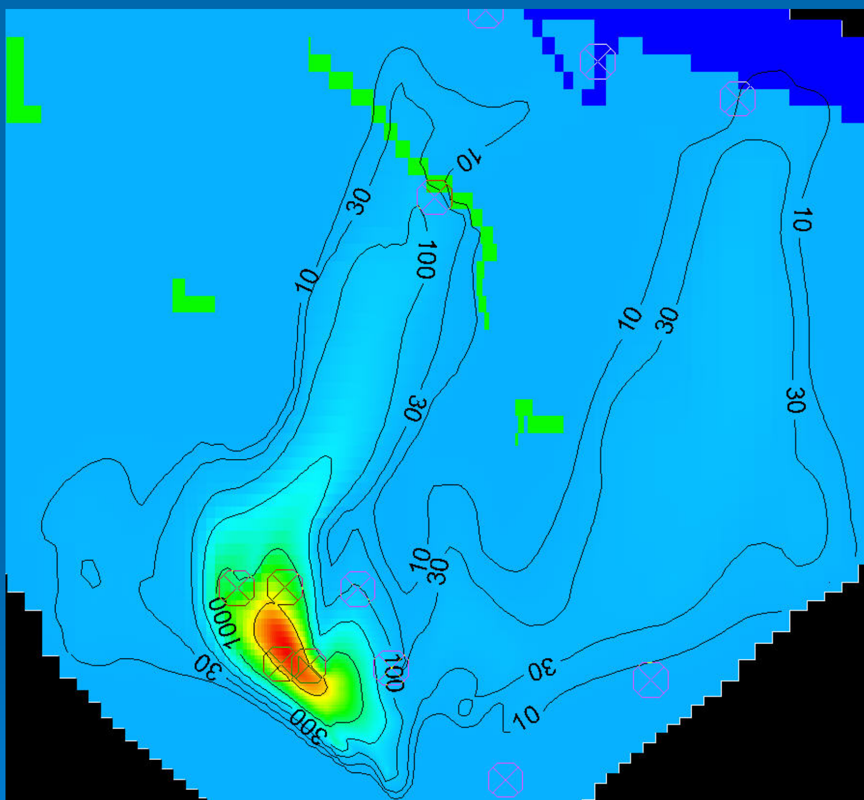
New Model

200% increase in plant recharge

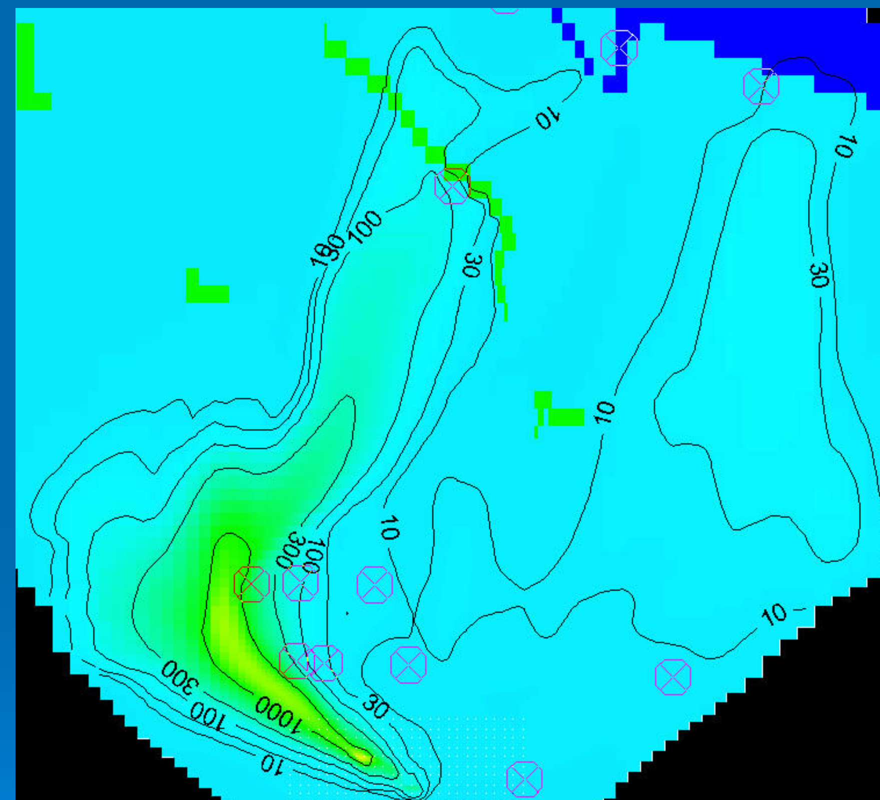
Recharge rates – Plant

400% increase in plant recharge

Comparison of TCE concentrations at the end of Stress Period 2 (30years)



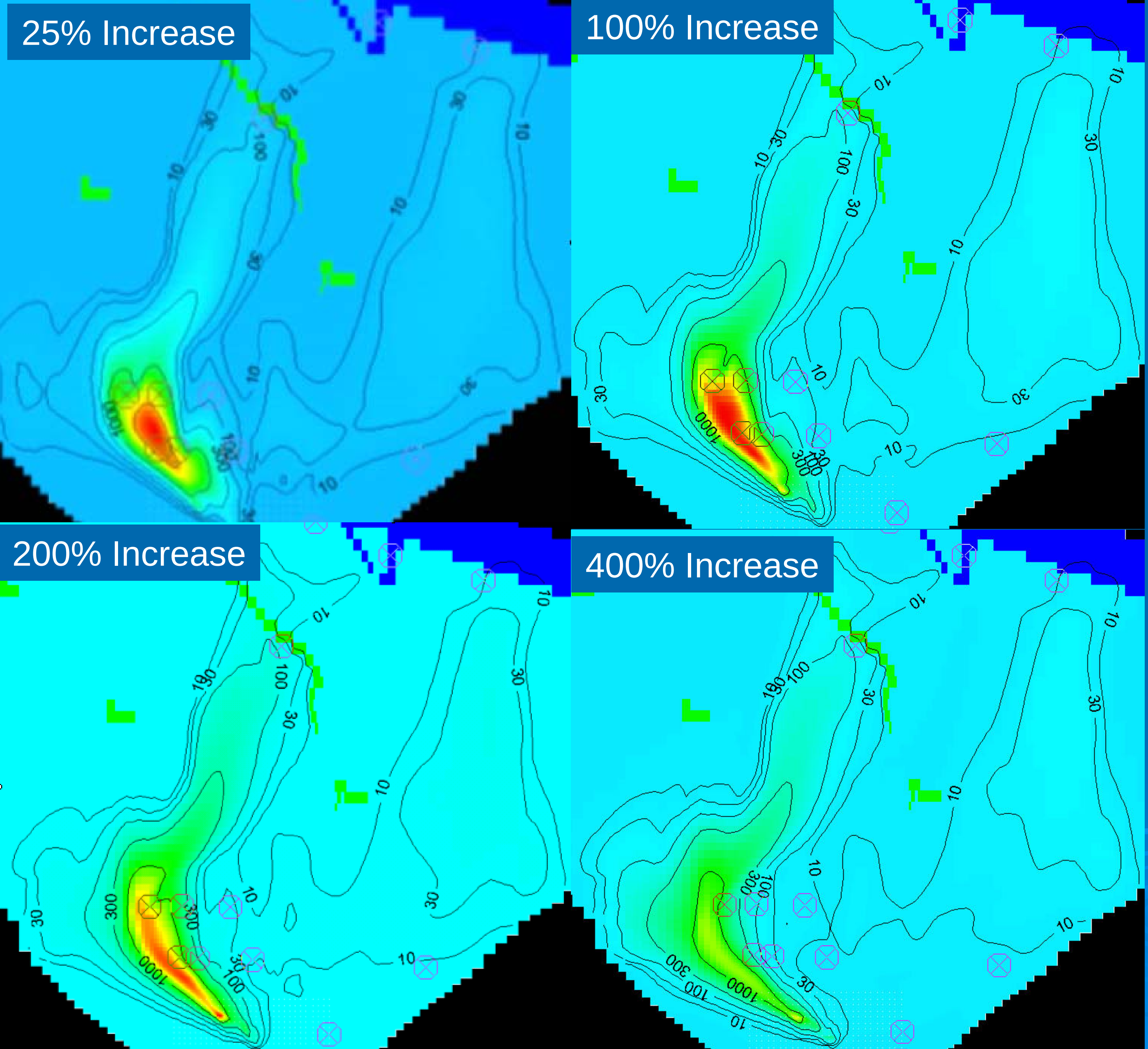
Baseline Model



New Model

400% increase in plant recharge

Effect of Plant Recharge



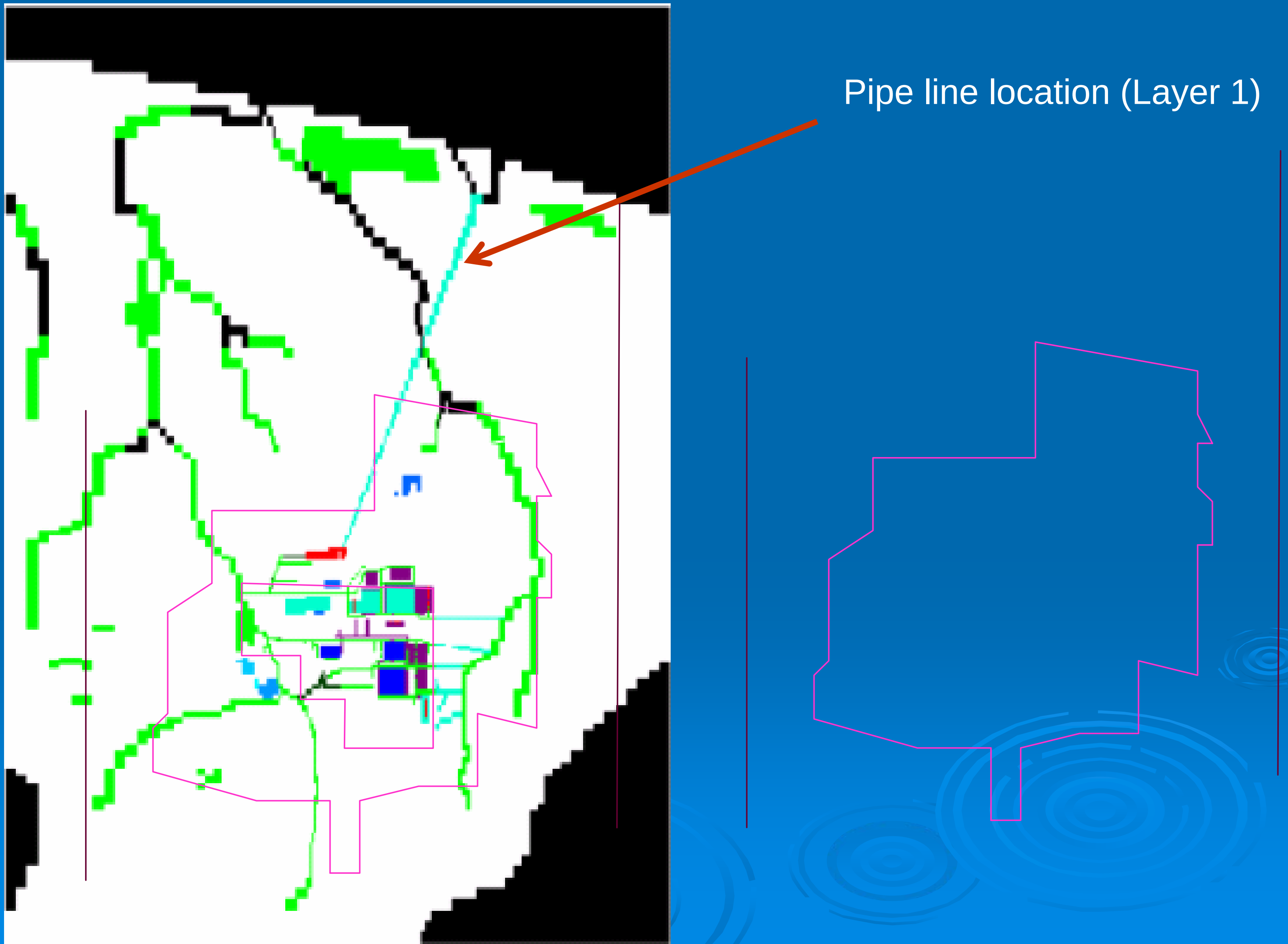
Inferences

- Model is almost insensitive to changes to rainfall and other plant recharges

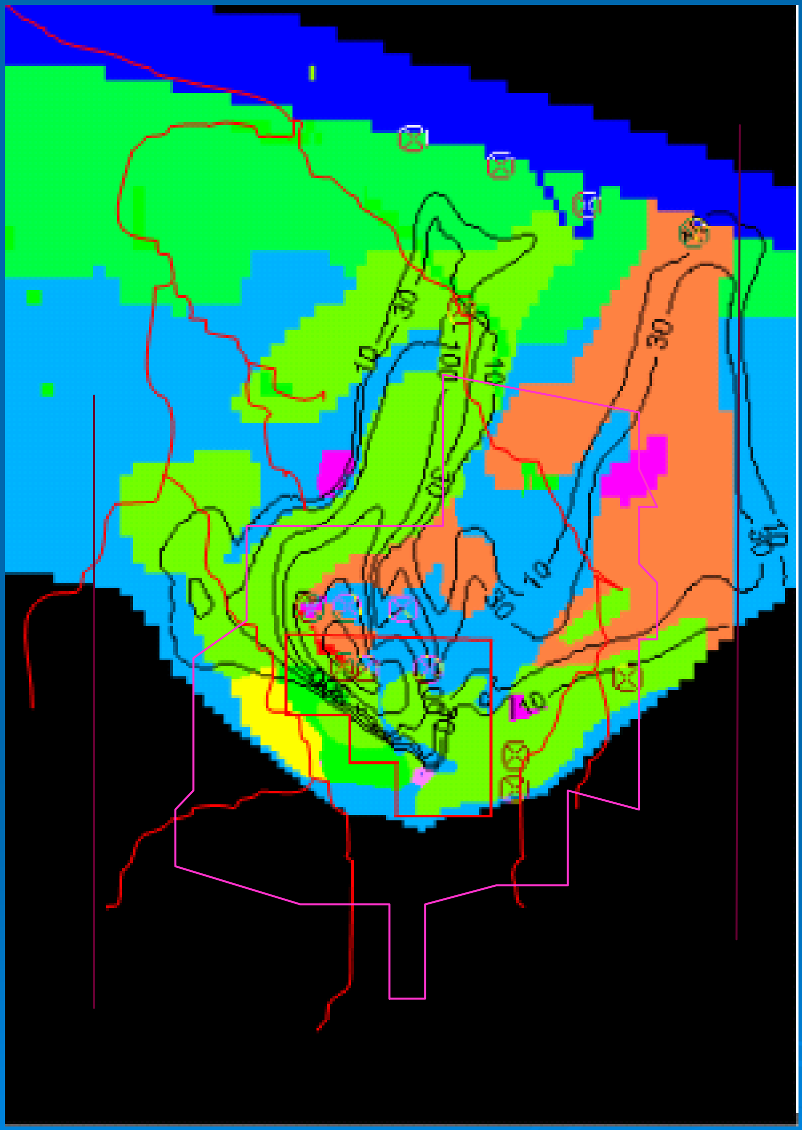
3.2.6 Effect of Leakage Along Pipeline Carrying Water to PGDP

Effect of Leakage Along Pipeline Carrying Water to PGDP

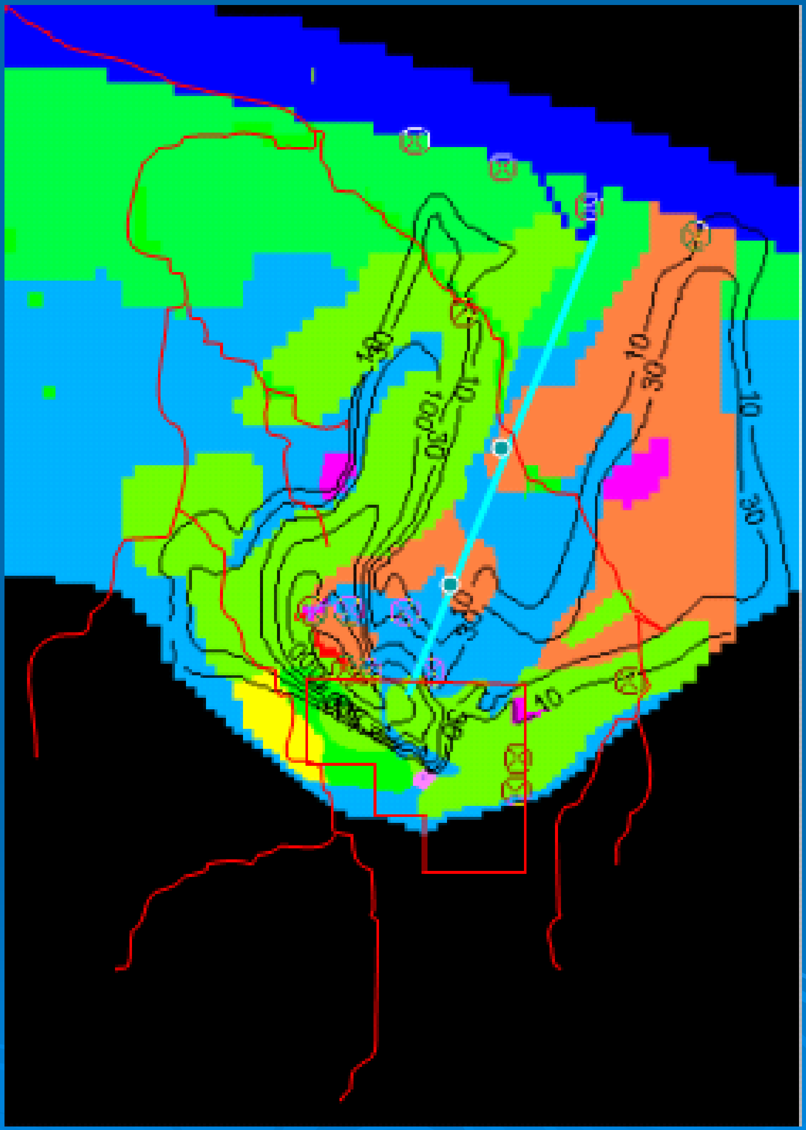
- Two 3 foot diameter pipelines from Ohio River (near Shawnee Plant) to PGDP
- Total flowrate = 11.4 MGD
- Uniform Leakage along the pipeline
- Isolated (Point) Leakage



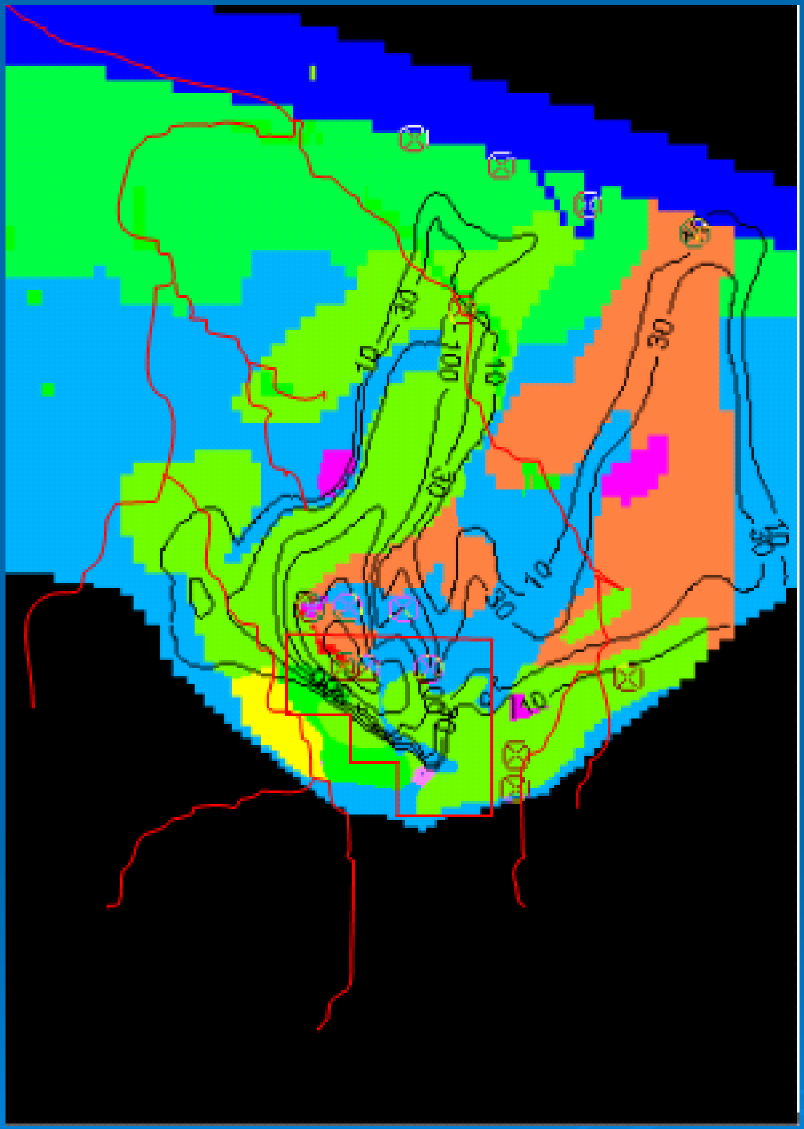
Pipe line location (Layer 1)



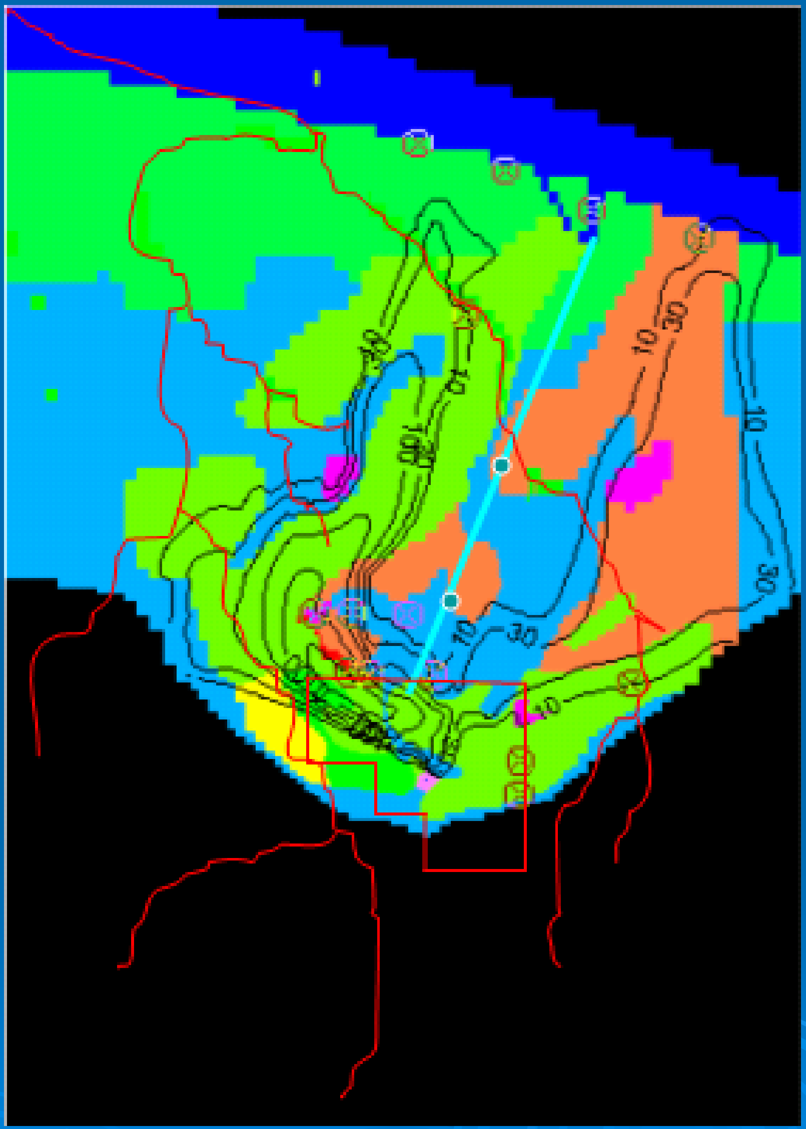
Baseline model



With 10 % uniform leak throughout the pipe line

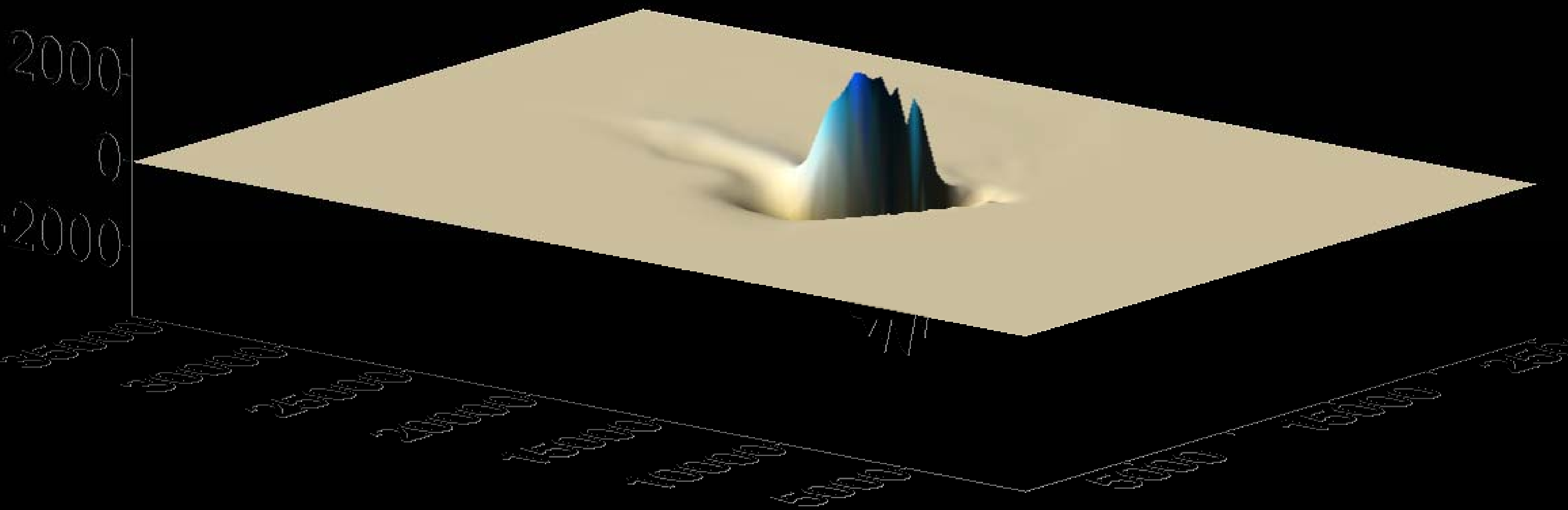


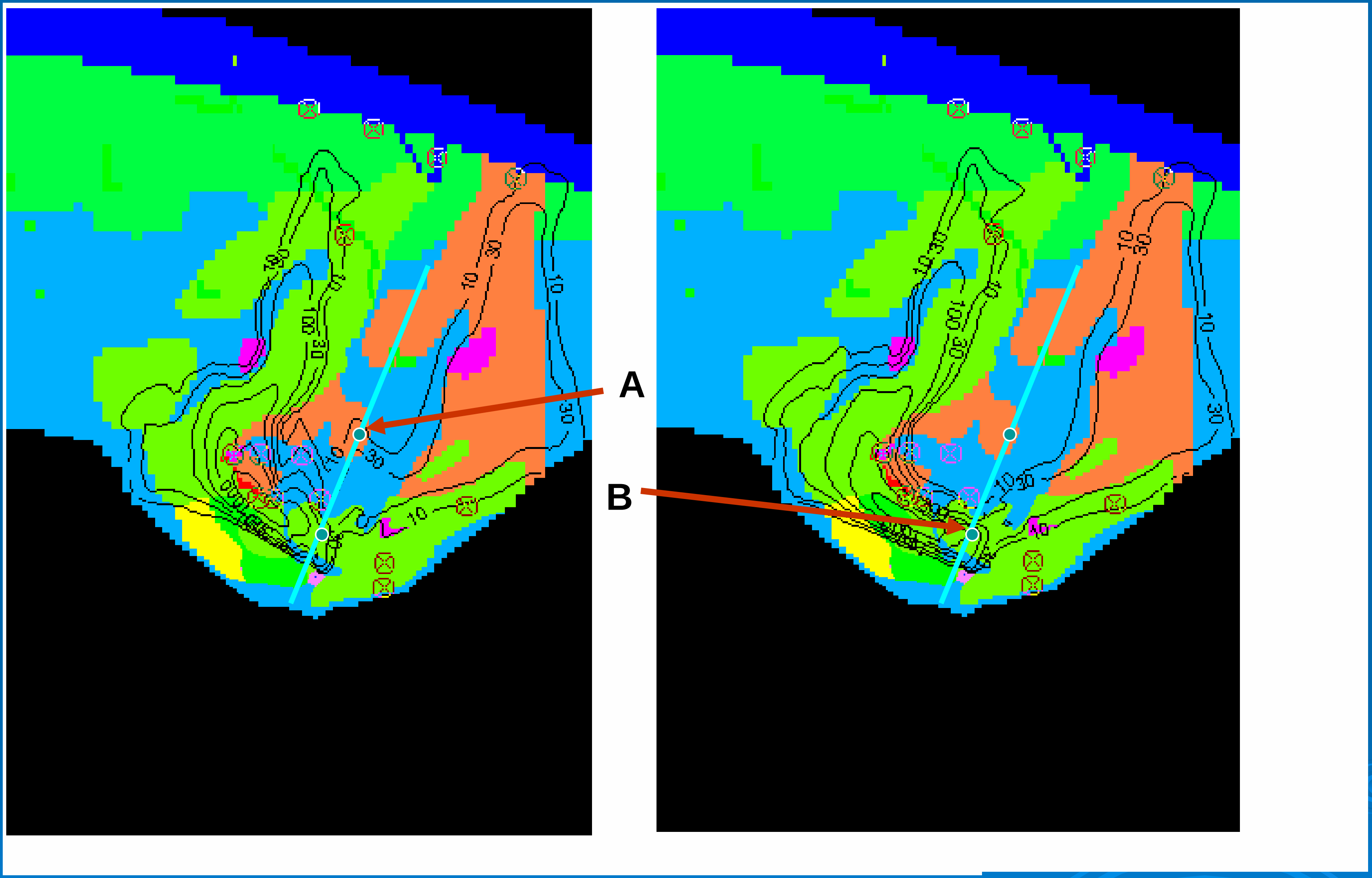
Baseline model



With 20 % uniform leak throughout the pipe line

Delta Difference between Baseline model and 20 % leakage uniform throughout the pipeline





With (10 % loss of total volume) at Point A in the pipe line

With (10 % loss of total volume) at Point B in the pipe line

Inferences

- 10% leakage (uniformly distributed along the pipeline) appears to have very little influence on TCE plume
- 20% uniform leakage appears to have noticeable influence

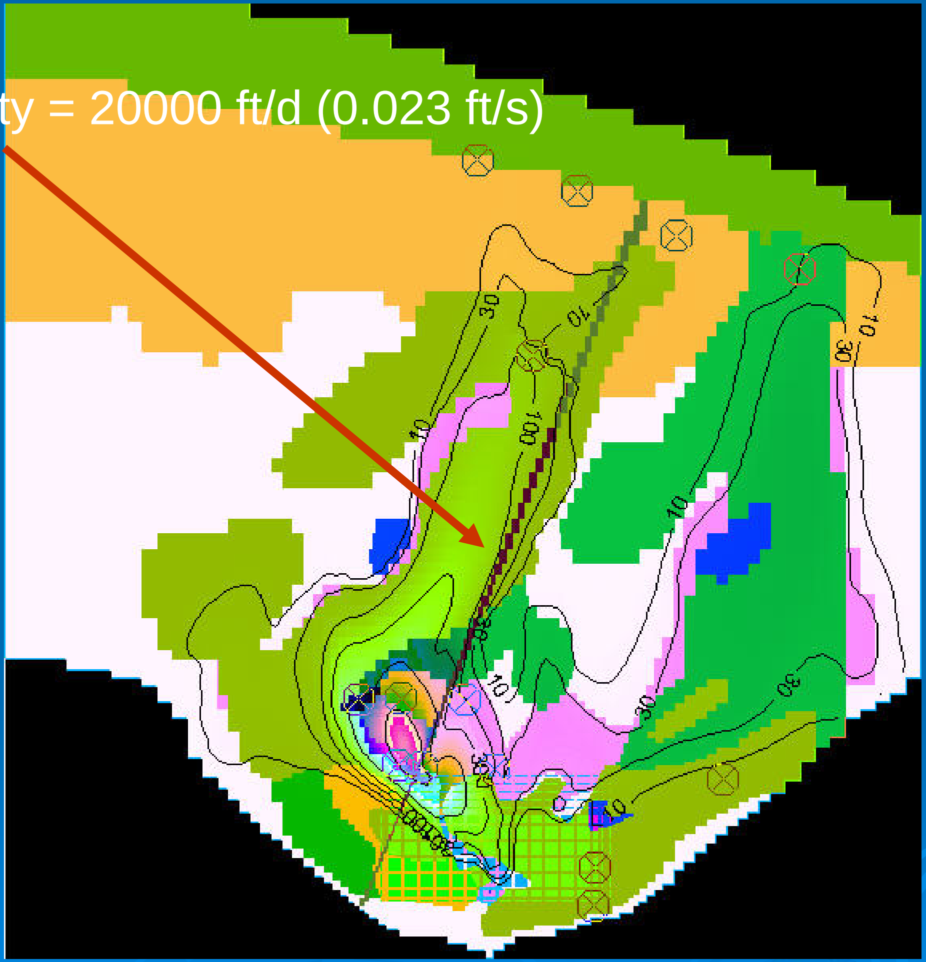
- 10% Point leakage appears to have a noticeable localized influence.

- Since 10% point leakage as well as 20% distributed leakage are very high values to go unnoticed, the model may be considered relatively insensitive to leakages along the pipeline.

3.2.6 Effect of Lineal Elements (Fracture Zones)

Effect of Lineal Element

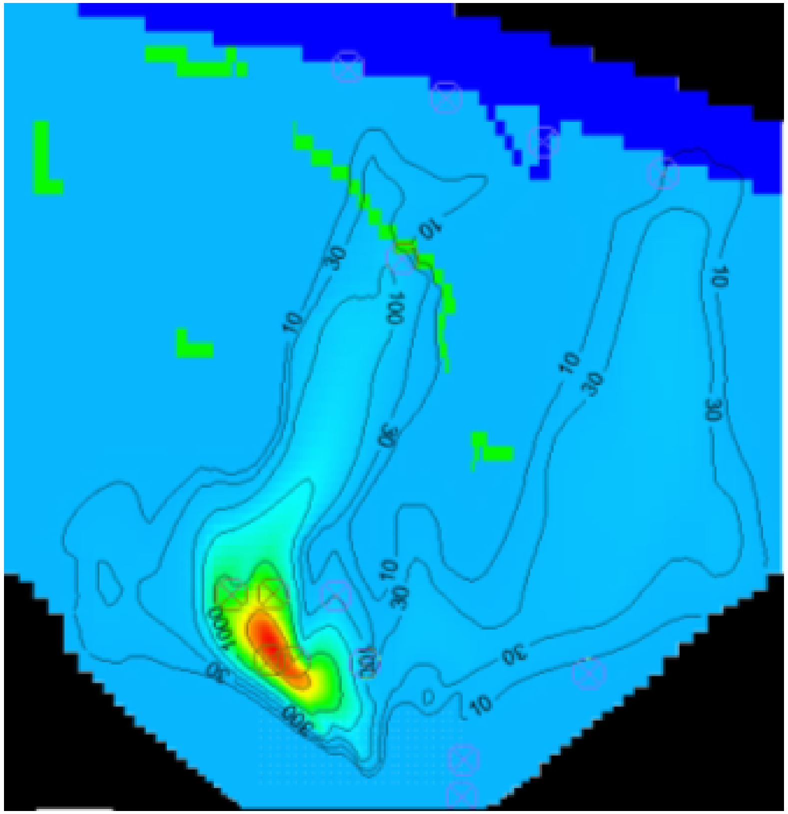
Hydraulic Conductivity = 20000 ft/d (0.023 ft/s)



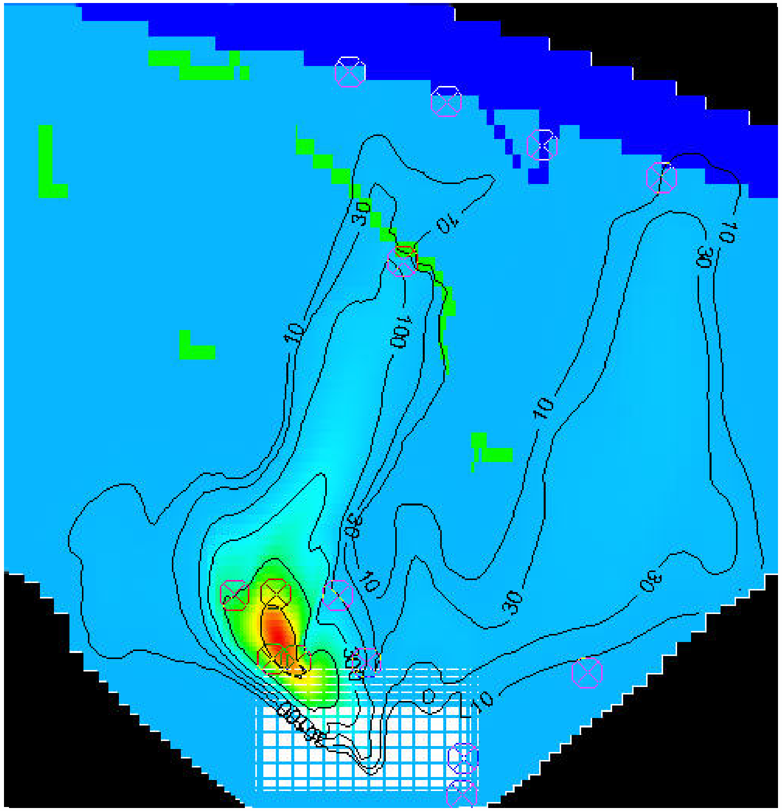
- Model 1 : With Lineal Element
  (K = 2000 ft/day)
- Model 2 : With Lineal Element
  (K = 20000 ft/day)

Effect of Lineal Element

<u>Comparison of results in layer 3 at the end of Stress period 2</u>

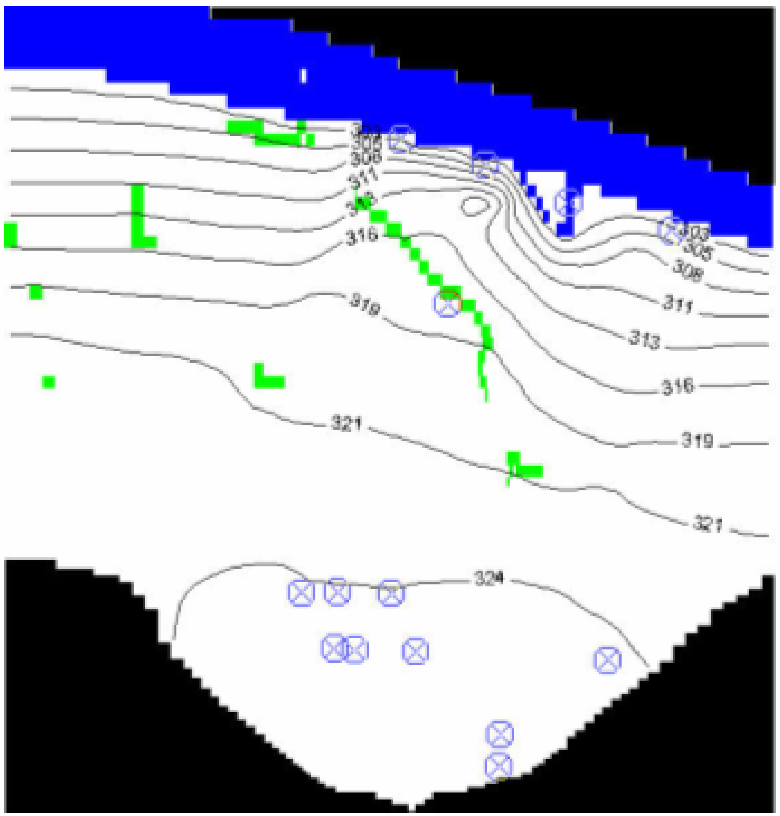


Baseline Model

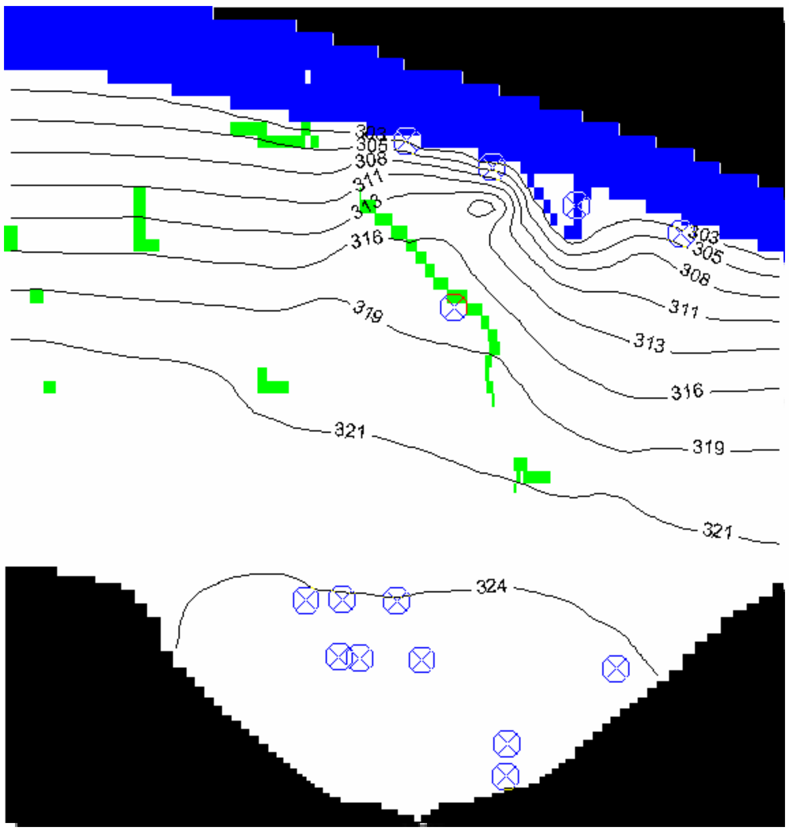


Model 1 with Lineal Element having K = 2000 ft/day

Effect of Lineal Element



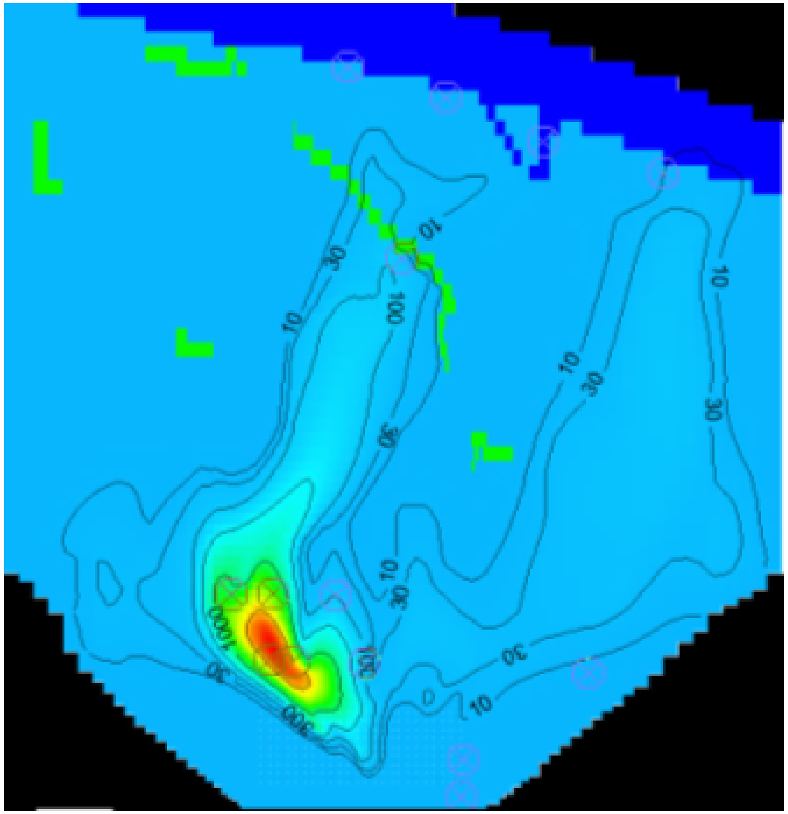
Baseline Model



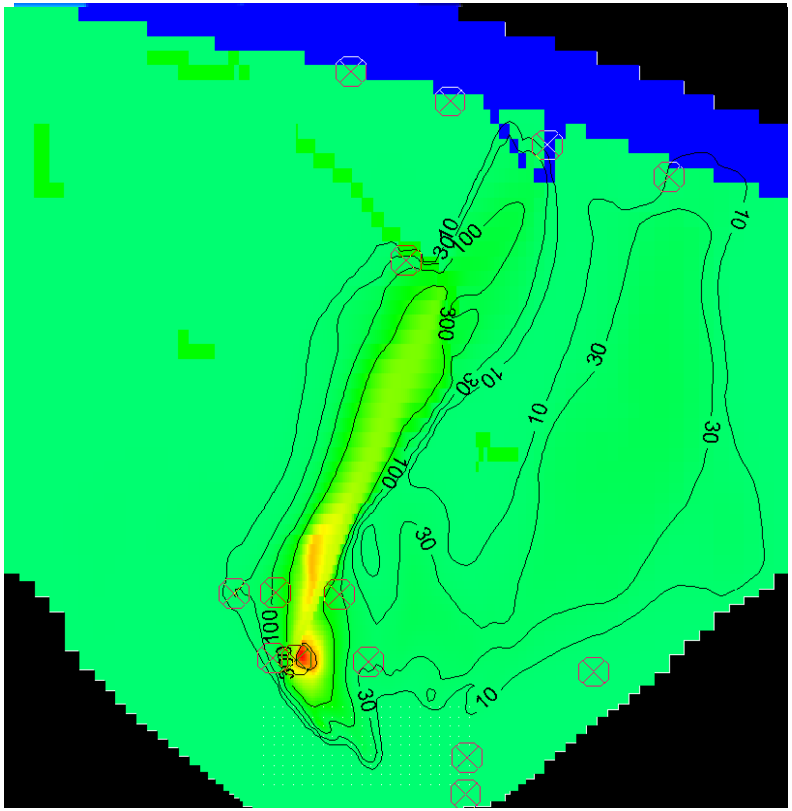
Model 1 with Lineal Element having K = 2000 ft/day

Effect of Lineal Element

Comparison of results in layer 3 at the end of Stress period 2

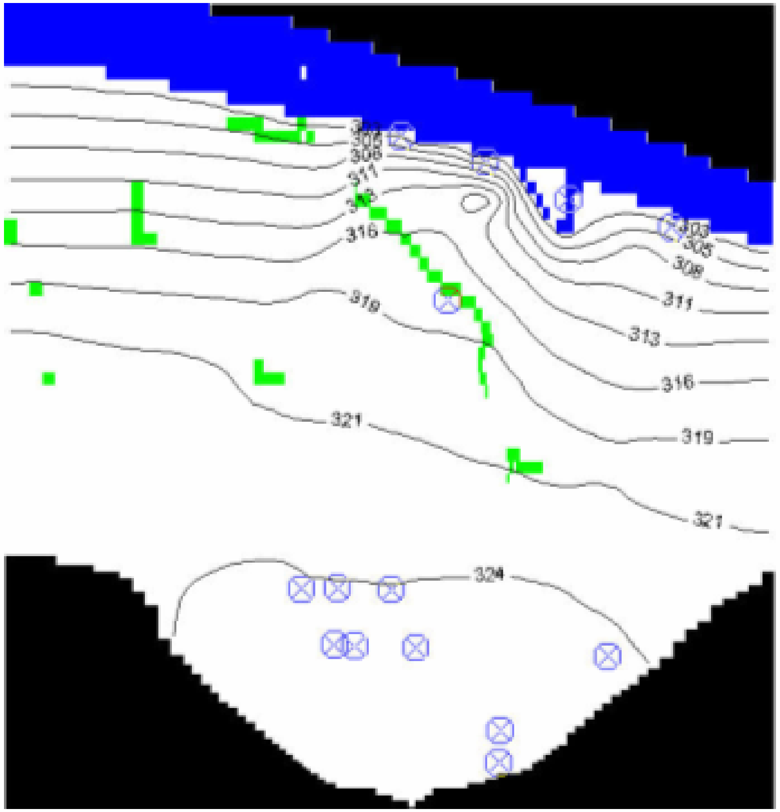


Baseline Model

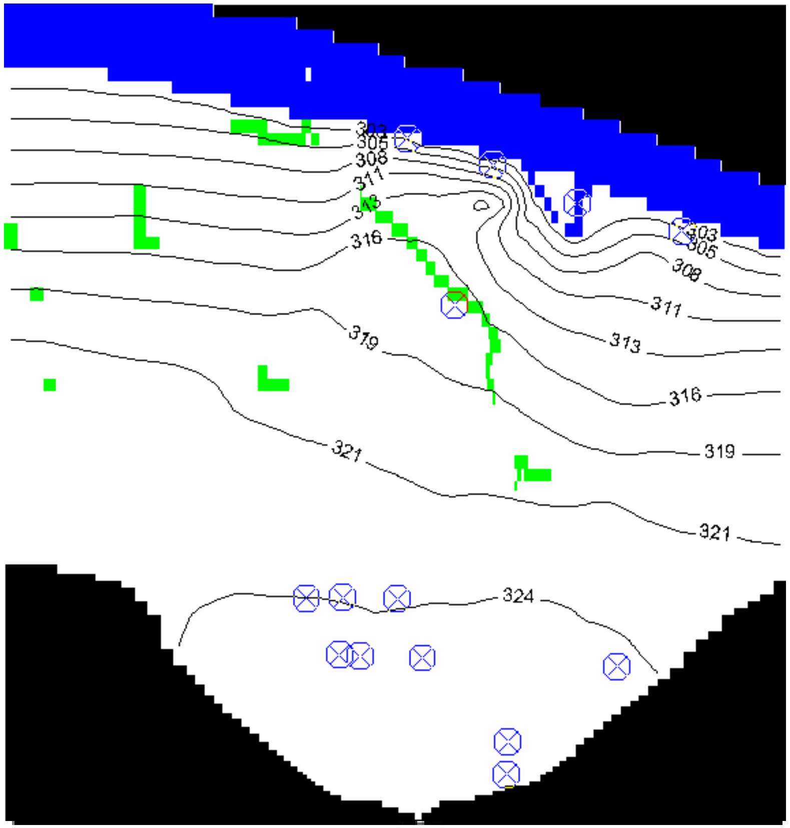


Model 2 with Lineal Element having K = 20000 ft/day

Effect of Lineal Element



Baseline Model



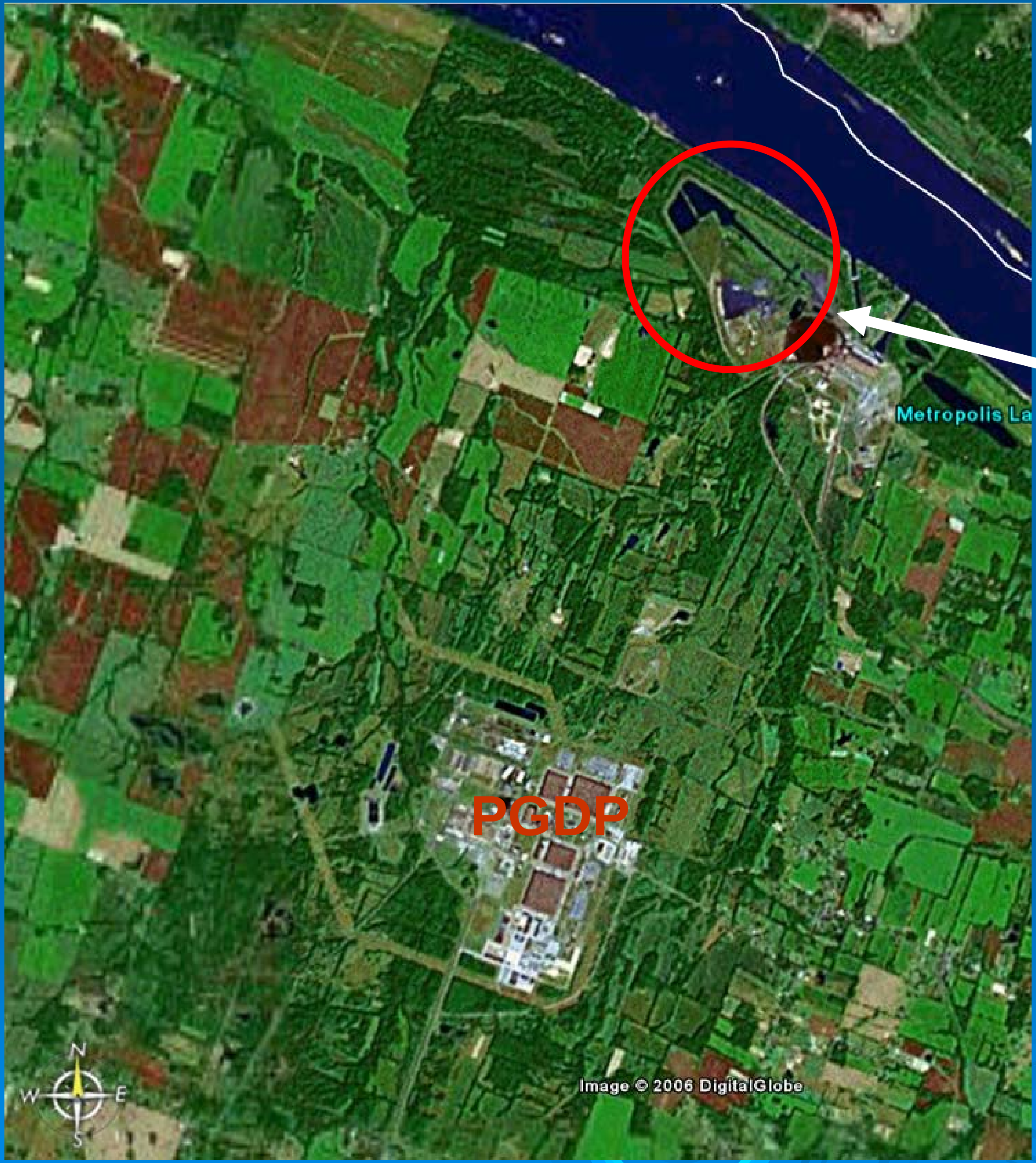
Model 2 with Lineal Element having K = 20000 ft/day

Inferences

- A 2000 ft/day Hydraulic Conductivity for the lineal element appears to have practically no influence on the TCE plume.
- A 20000 ft/day Hydraulic Conductivity appears to completely alter the shape of TCE plume.

- Model is almost insensitive to lineal elements if the hydraulic conductivity of the lineal elements is limited to a reasonable value

3.2.7 Recharge from Shawnee Plant Ash Pond

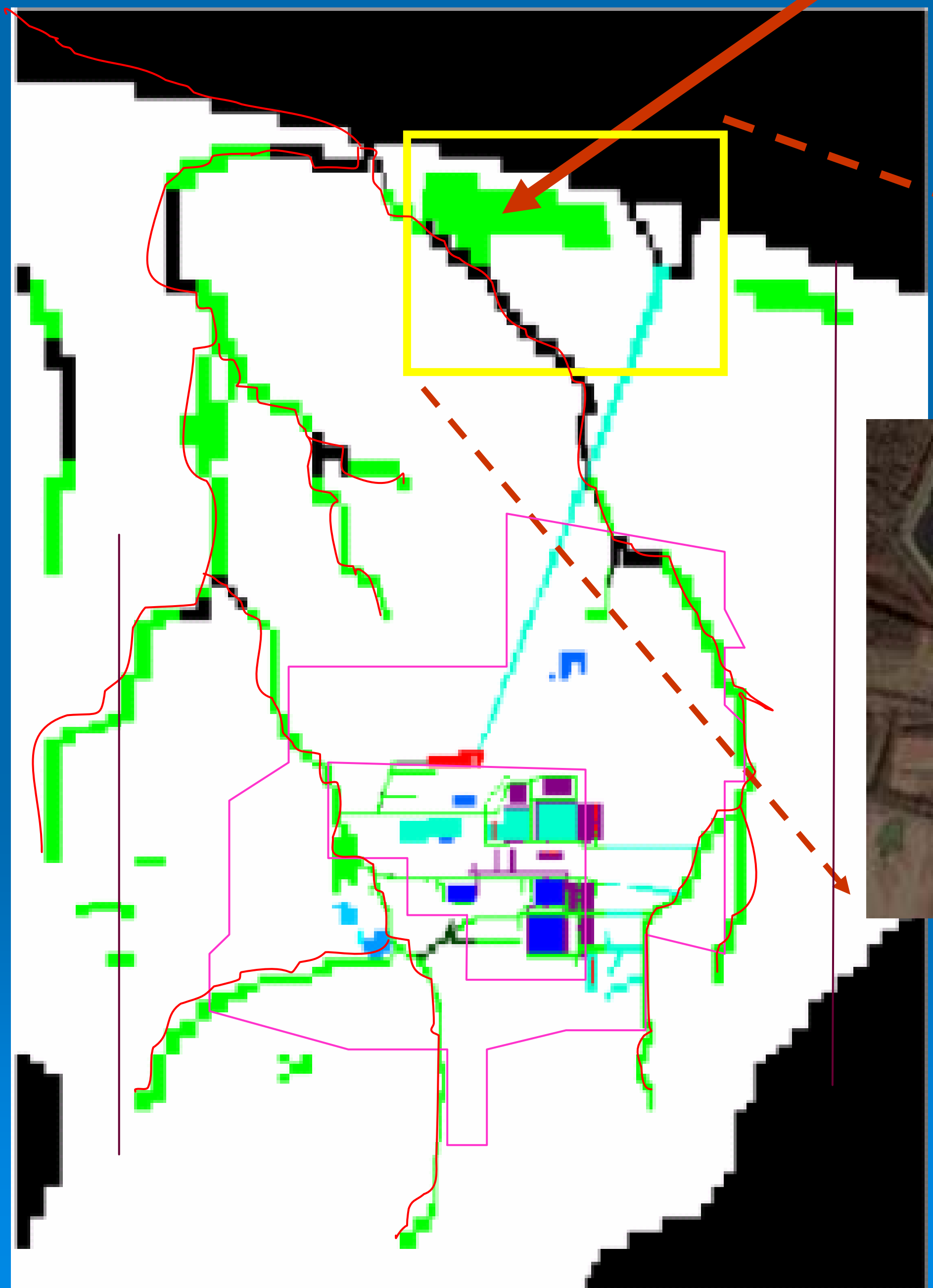


Ash pond at Shawnee plant

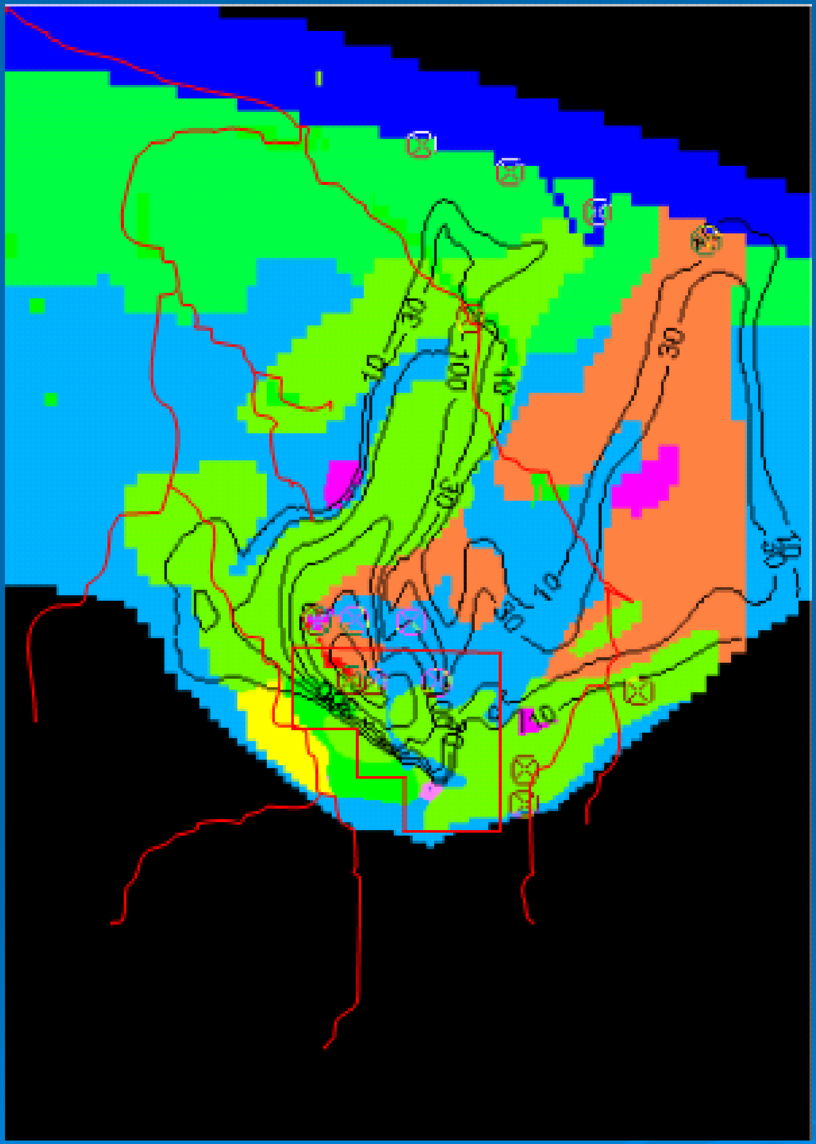
Ash pond at Shawnee plant

- In the PGDP baseline model, the entire Shawnee plant area was handled as river boundary condition.
- Using this boundary condition, the whole Shawnee plant area is treated as a Lagoon with 10 ft water depth.
- The elevation of Shawnee plant area was estimated to be 336' msl in the model.
- The hydraulic conductivity for the area in the baseline model was kept at 2125 ft/day.
- Conducted model sensitivity runs to document influence of lagoon on model flow system
  1. varying the water depth to 20 ft and
  2. by eliminating the lagoon, the influences were documented.
- When the water depth is increased to 20 ft, there is no influence in TCE contours.
- When the lagoon is removed completely, the north west plume is significantly affected and reaches Ohio river due to non availability of higher head. (Stress period 2)

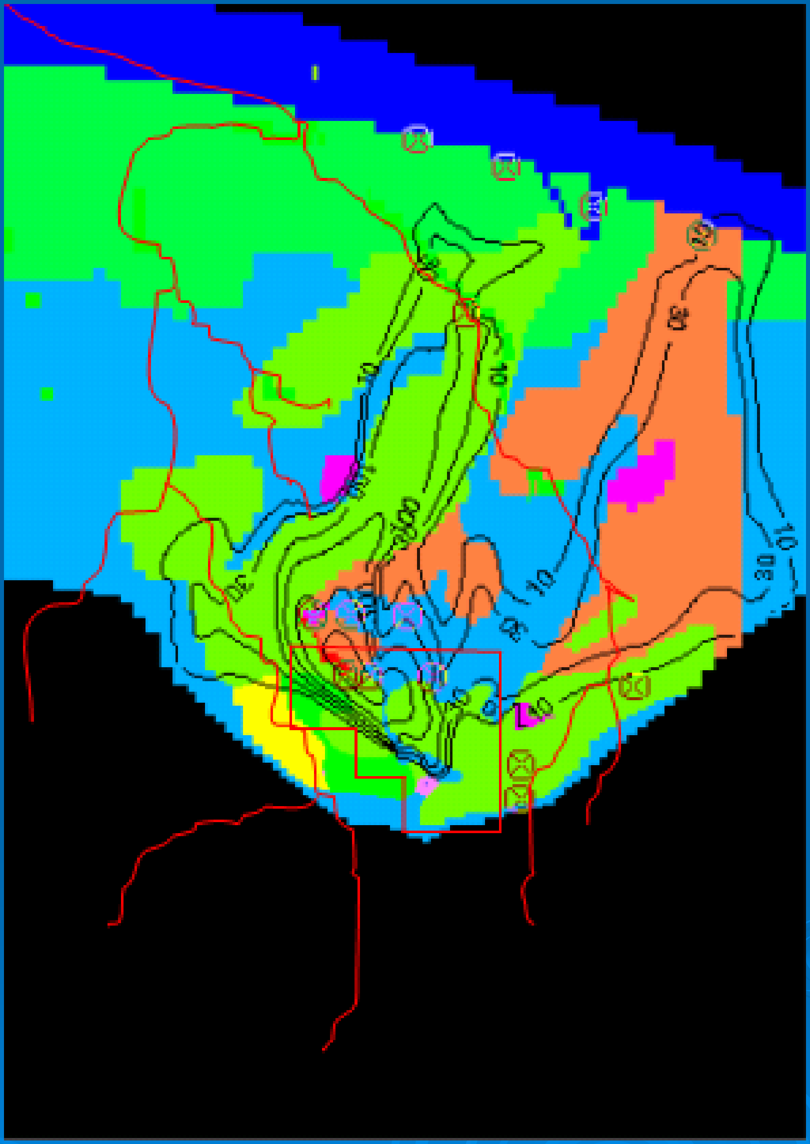
Ash pond at Shawnee plant



TCE Concentration Contours after 2nd Stress Period

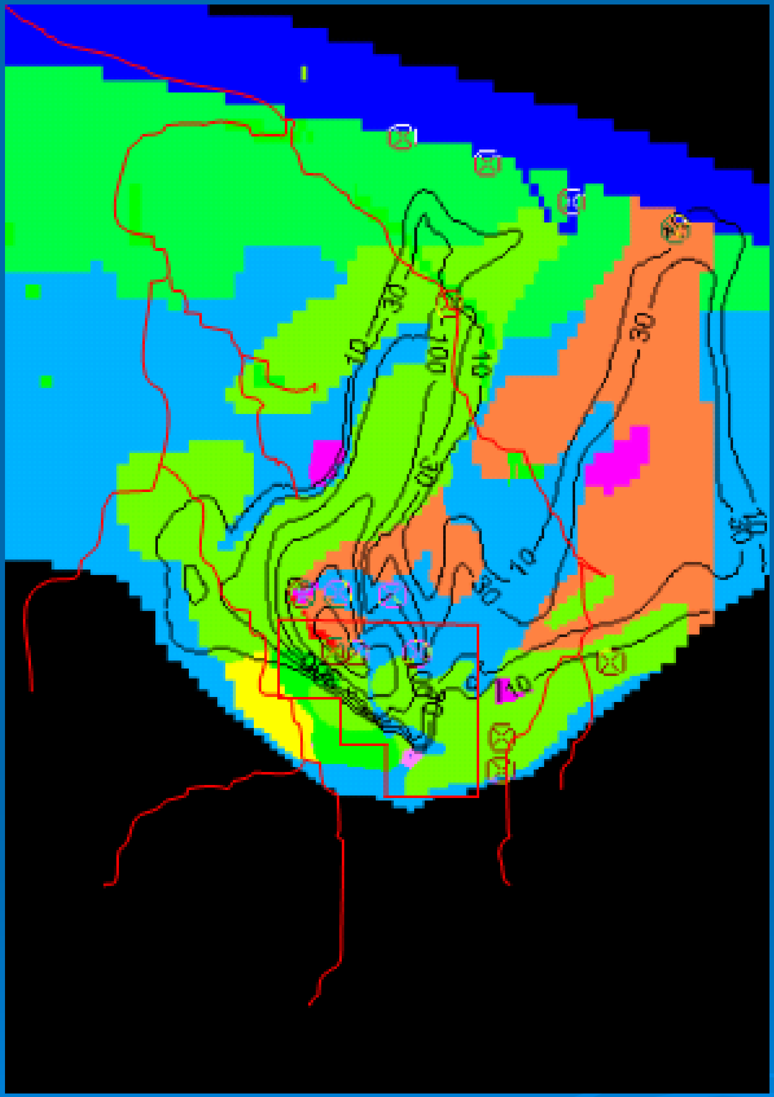


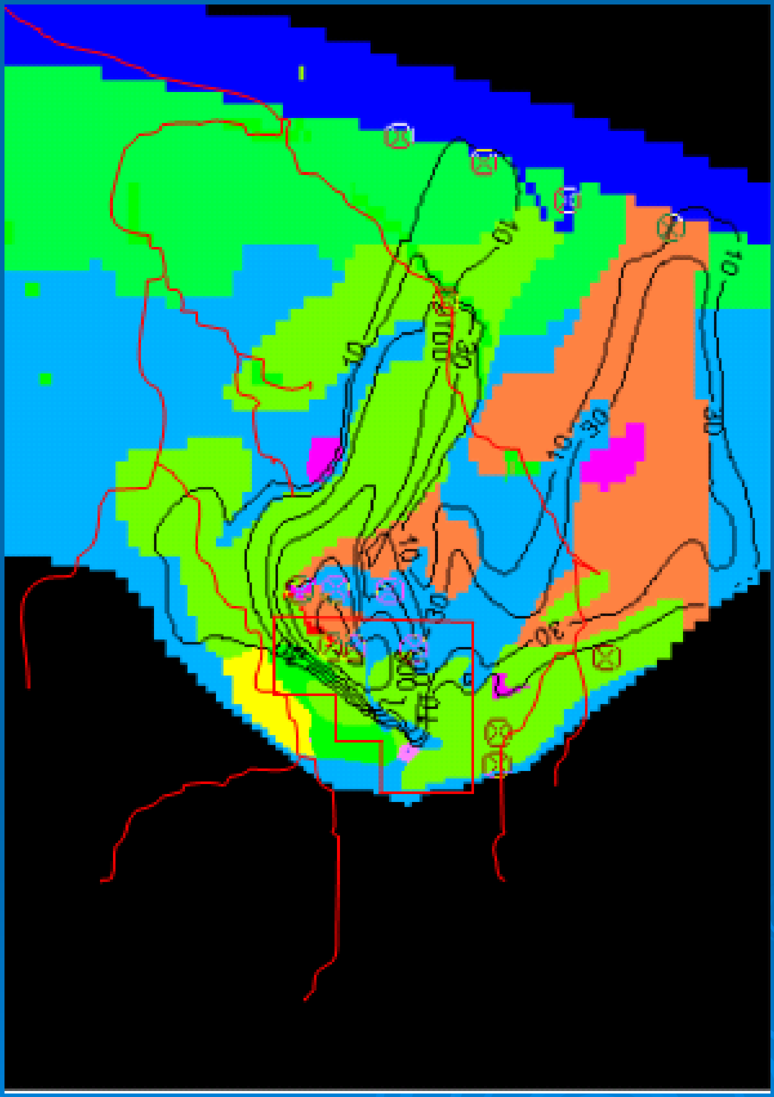
Baseline Model



Increasing the Lagoon depth to 20 ft

TCE Concentration Contours after 2nd Stress Period

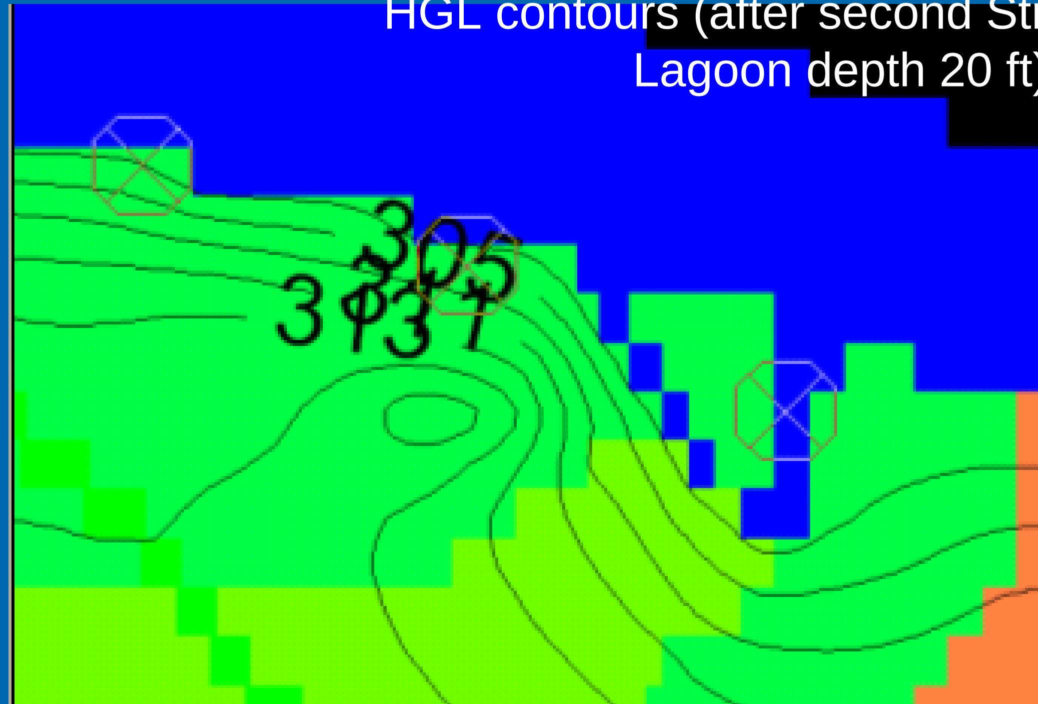




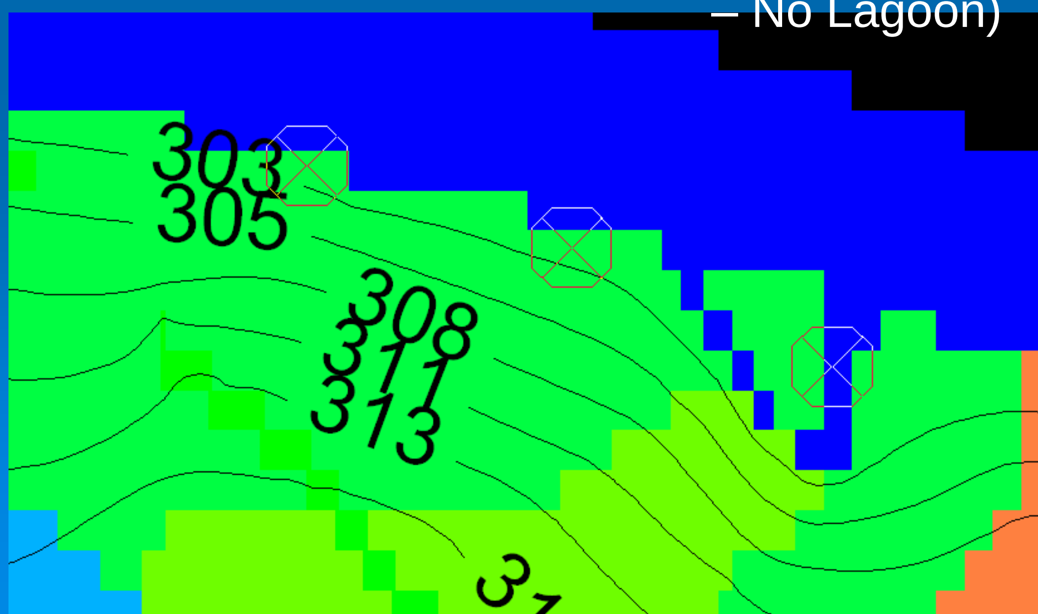
Baseline Model

Without the Lagoon

HGL contours (after second Stress period - Lagoon depth 20 ft)



HGL contours (after second Stress Period – No Lagoon)



Inferences

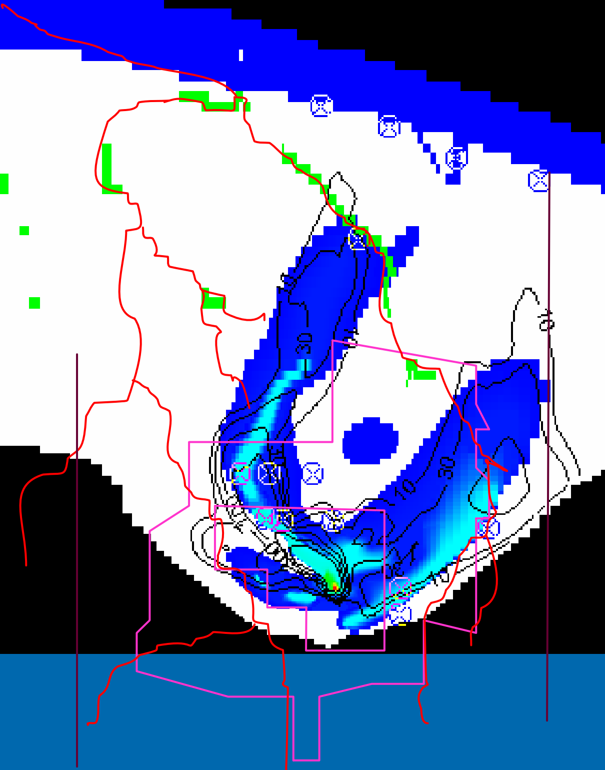
- Increasing water levels in ash pond by 20ft appears to have no influence on TCE plume
- Complete removal of ash pond appears to significantly impact the north west plume

- Model is somewhat sensitive to ash pond levels

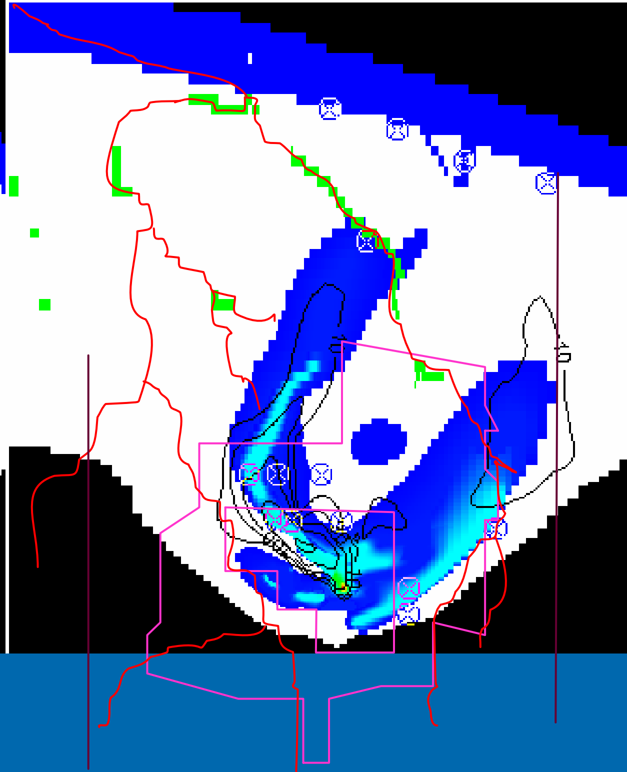
3.2.8 Effect of Biodegradation – defined using Half Life Period in the model

Effect of Biodegradation Half Life Period

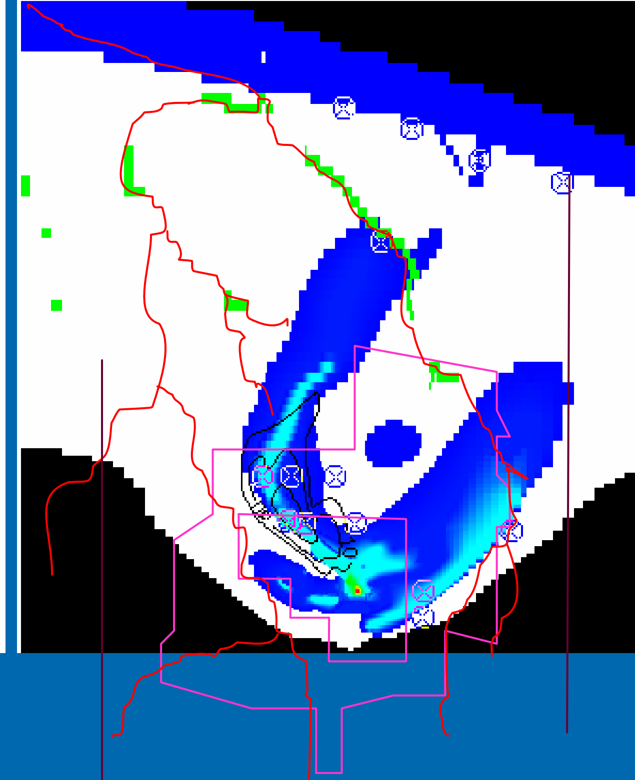
- Biodegradation of TCE in the PGDP Regional Ground water model is handled using Half Life Period.(26.65 years : 9729.04 days)
- Trials were made with 5 years, 10 years,15 years, with varying half Life period in two zones and with varying half Life period in Four zones. Varying half life period in different zones are experimented to simulate lesser biodegradation near DNAPL sources.
- Far-field TCE concentrations do no agree with calibrated model/field measurements under “no half-life” scenario.



At the end of 10 years

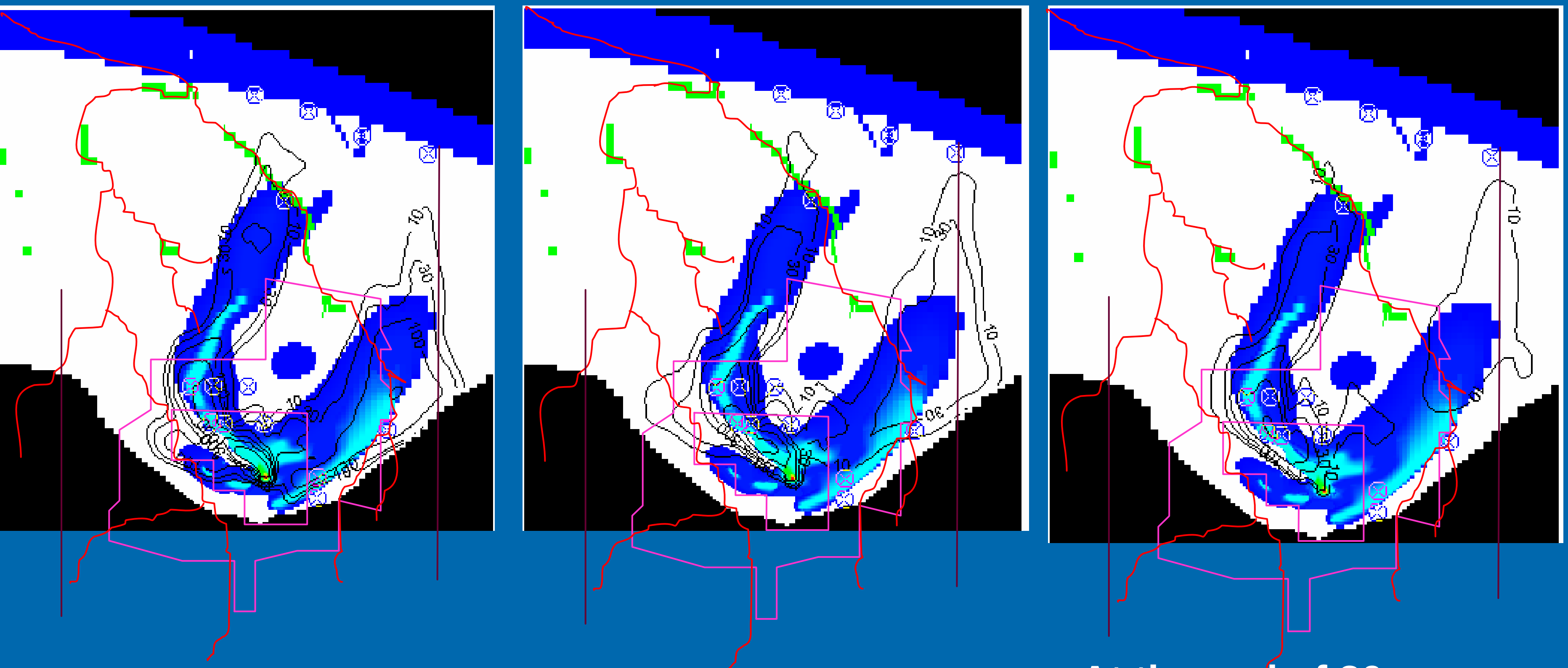


At the end of 20 years



At the end of 30 years

Runs with 5 years Half Life

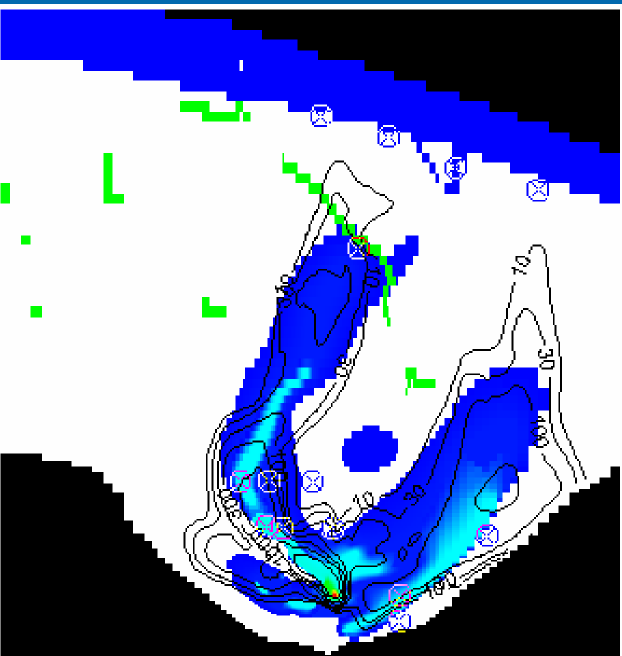


At the end of 10 years

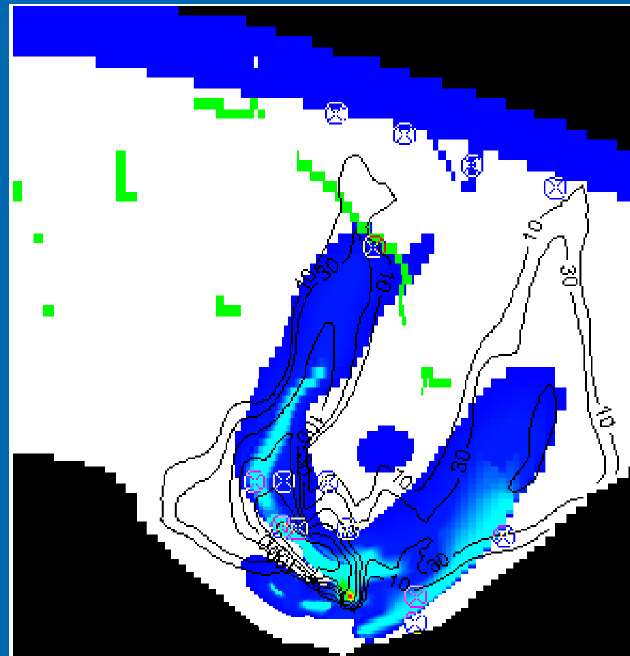
At the end of 20 years

At the end of 30 years

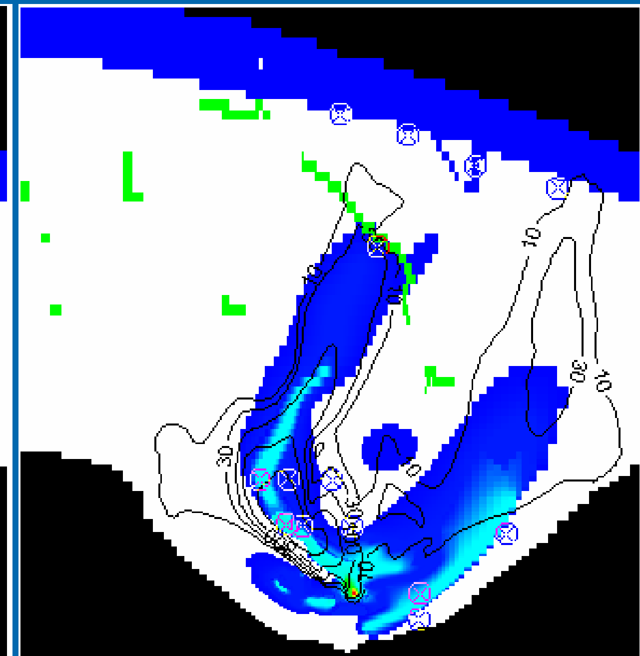
Runs with 10 years Half Life



At the end of 10 years

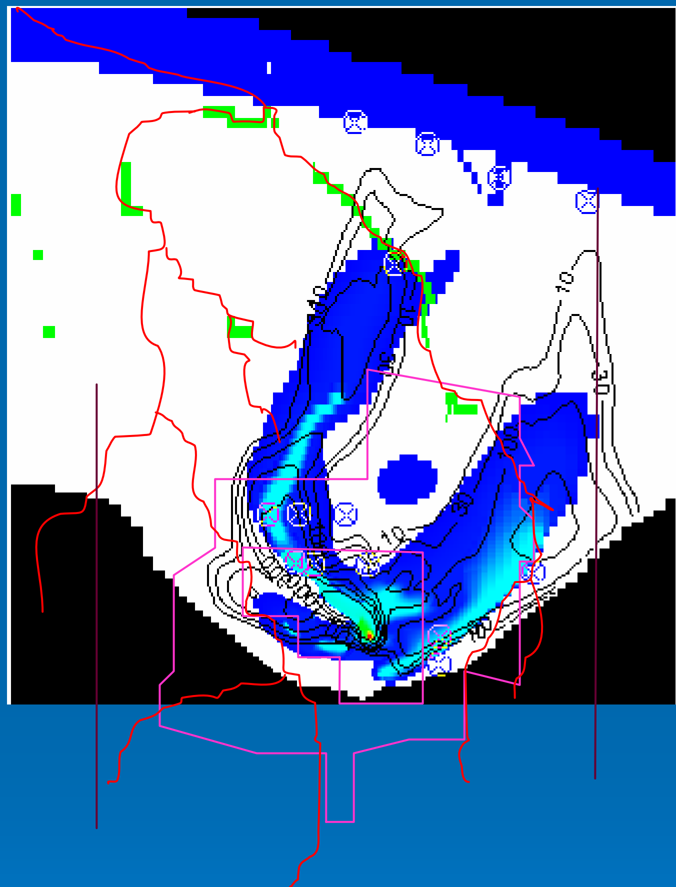


At the end of 20 years

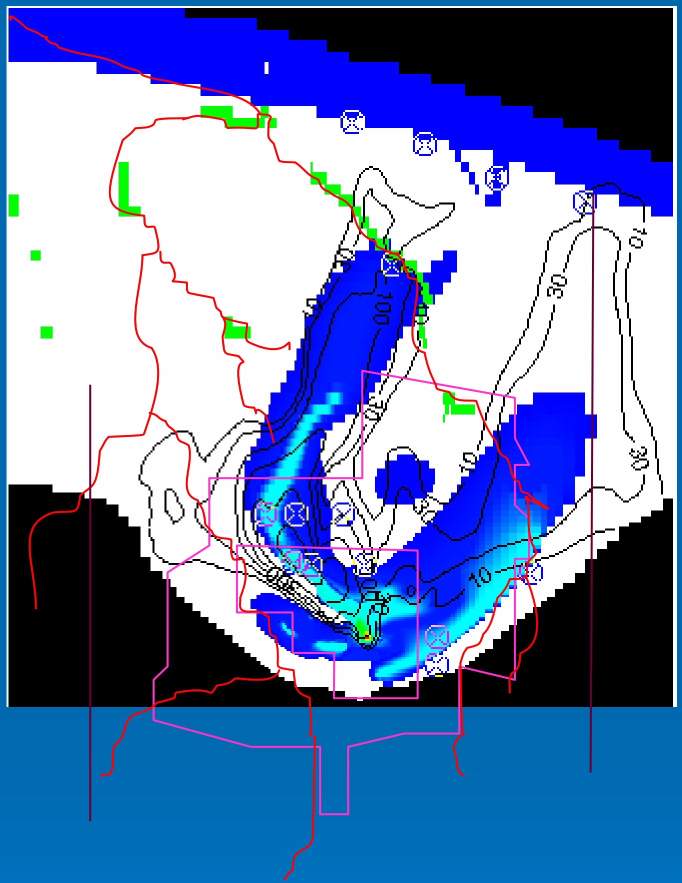


At the end of 30 years

Runs with 15 years Half Life

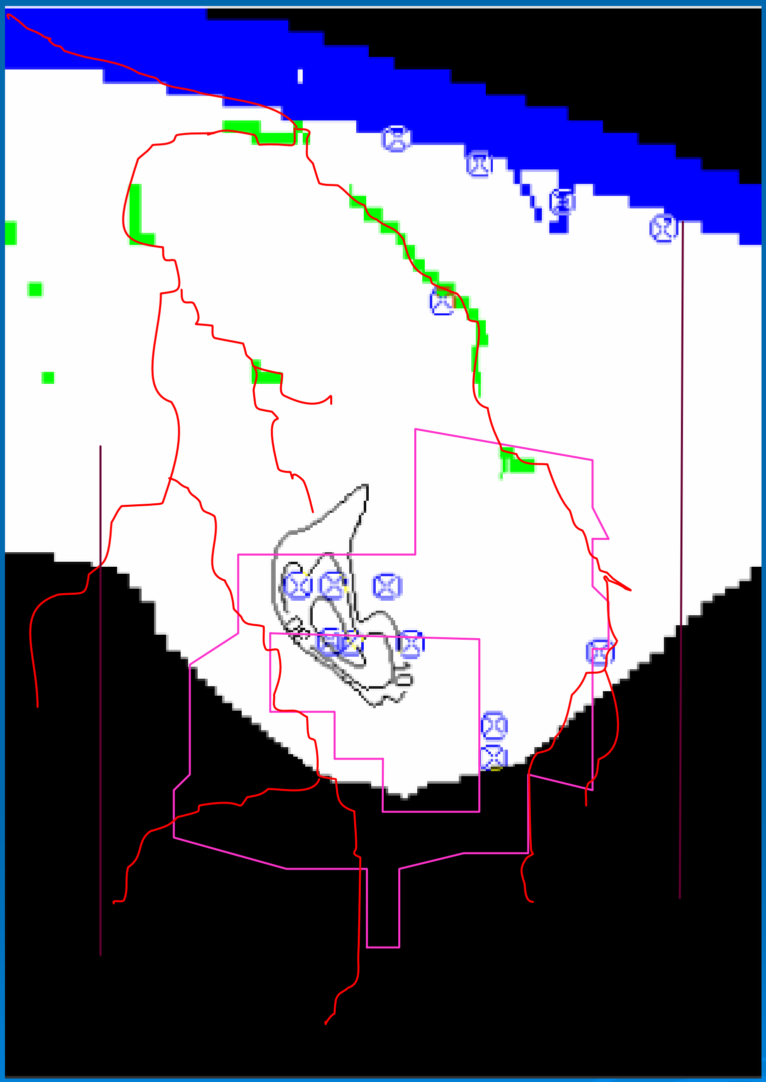


At the end of 10 years

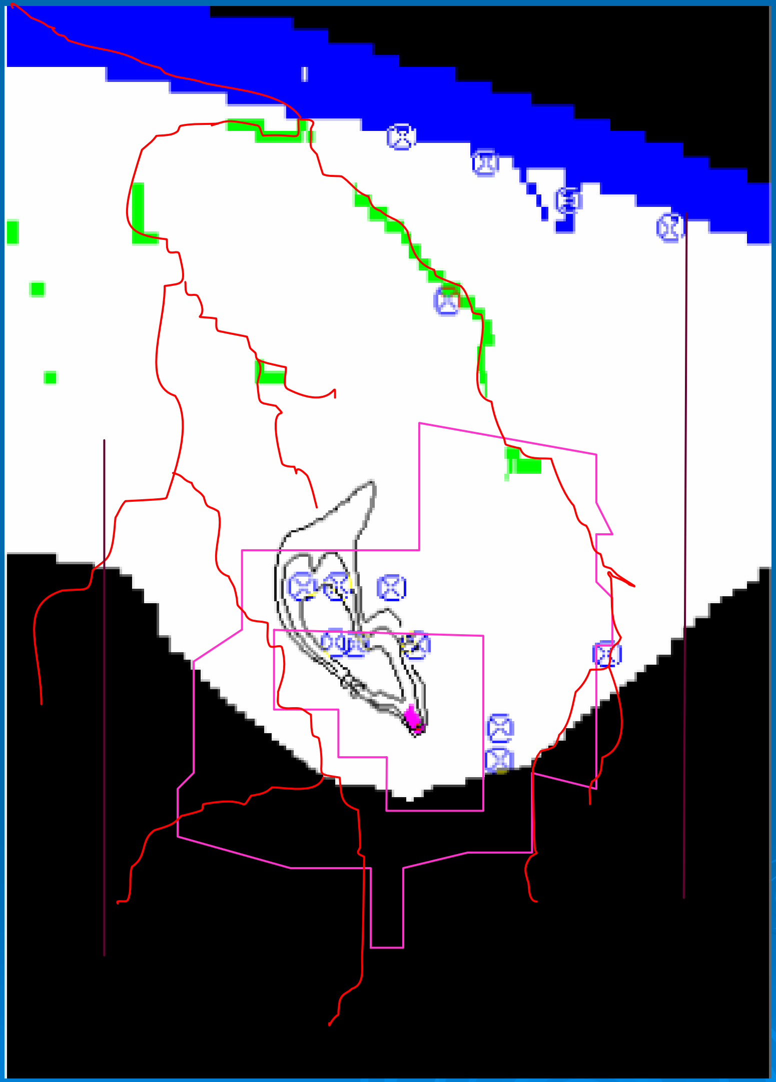


At the end of 30 years

Baseline model with 26.65 years Half Life

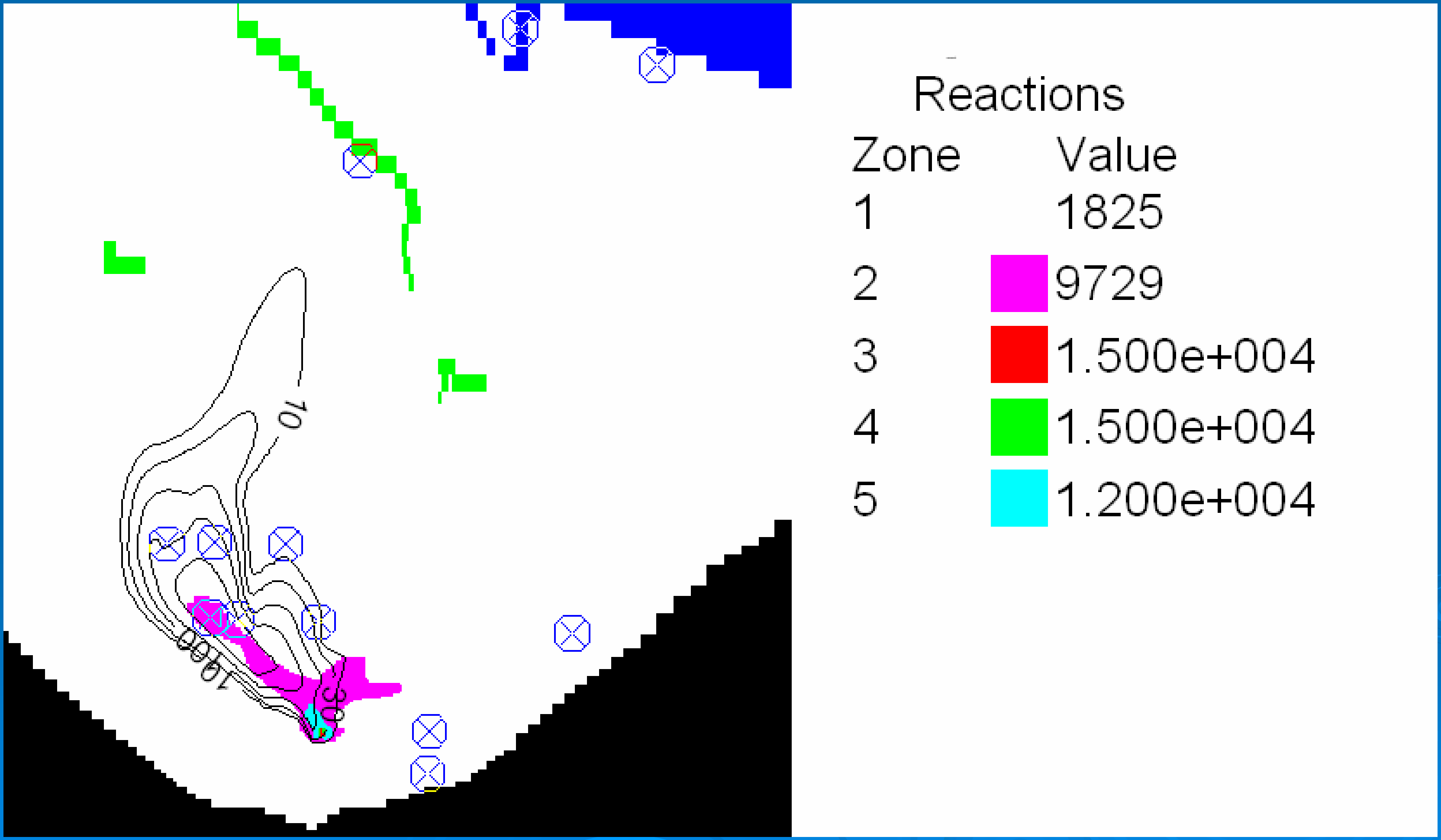


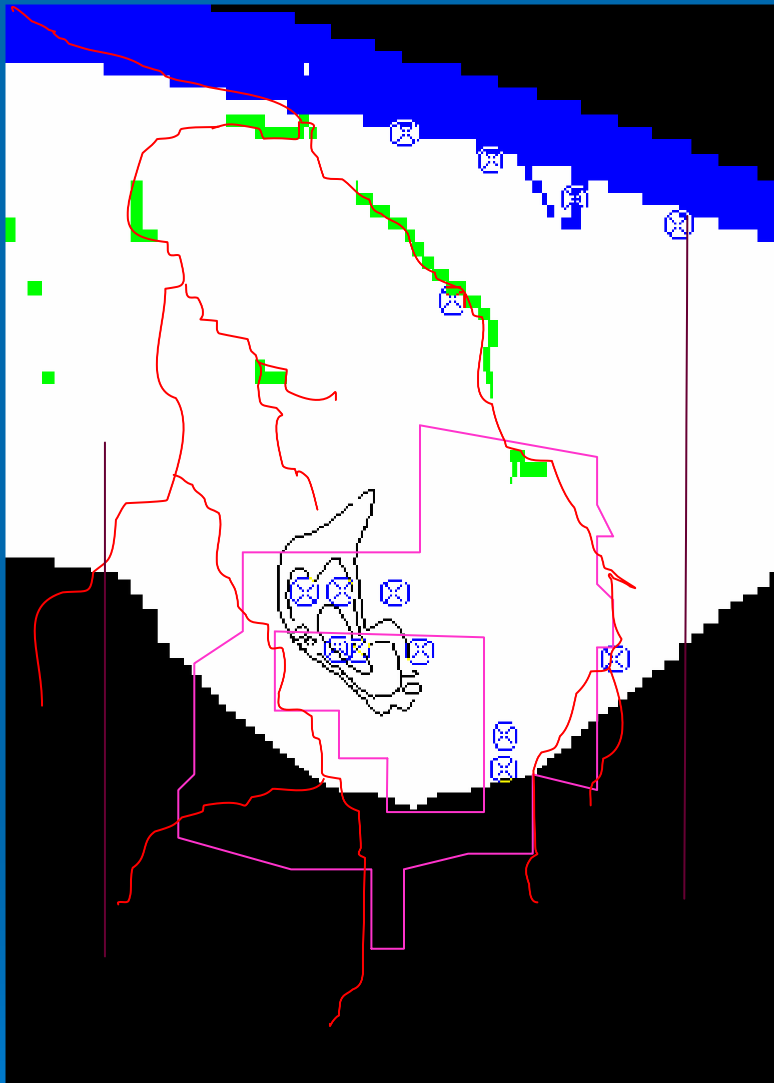
Model with 5 years Half Life period at the end of 30 Years



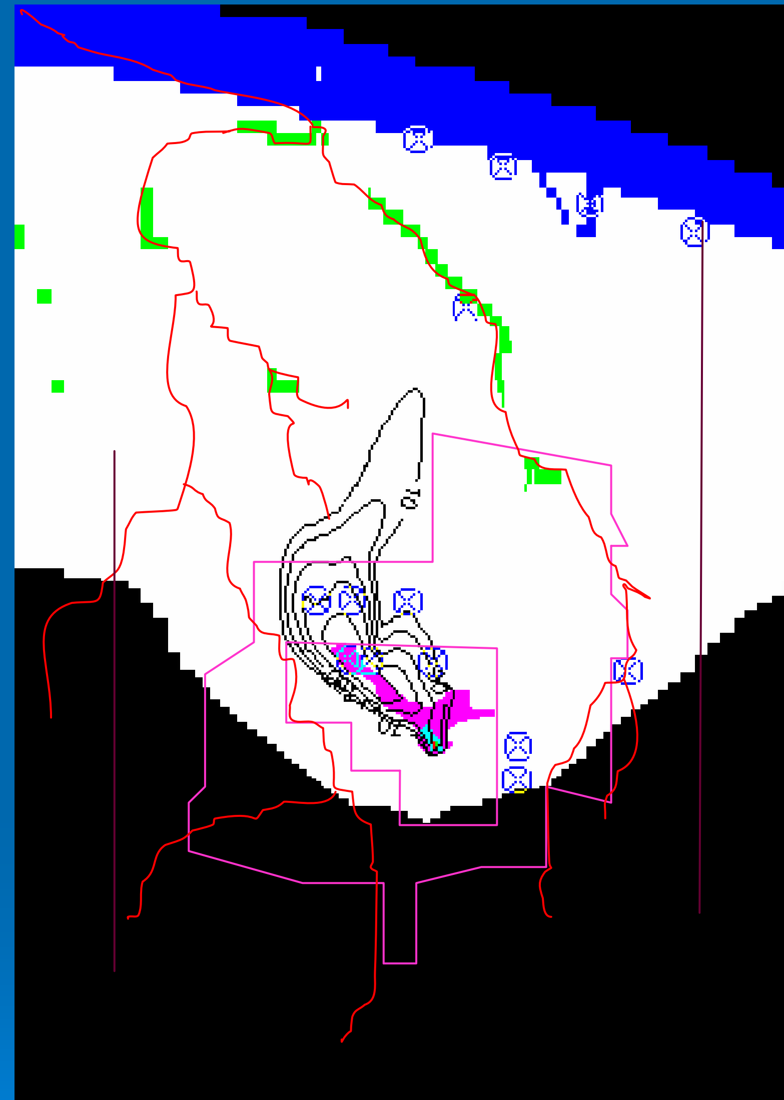
Model with Half Life periods declared in 2 zones (Pink – 26.65 years, Rest of the Area in white - 5 Years)

Model with
Half Life periods declared in 4 zones based on TCE Initial Concentration.

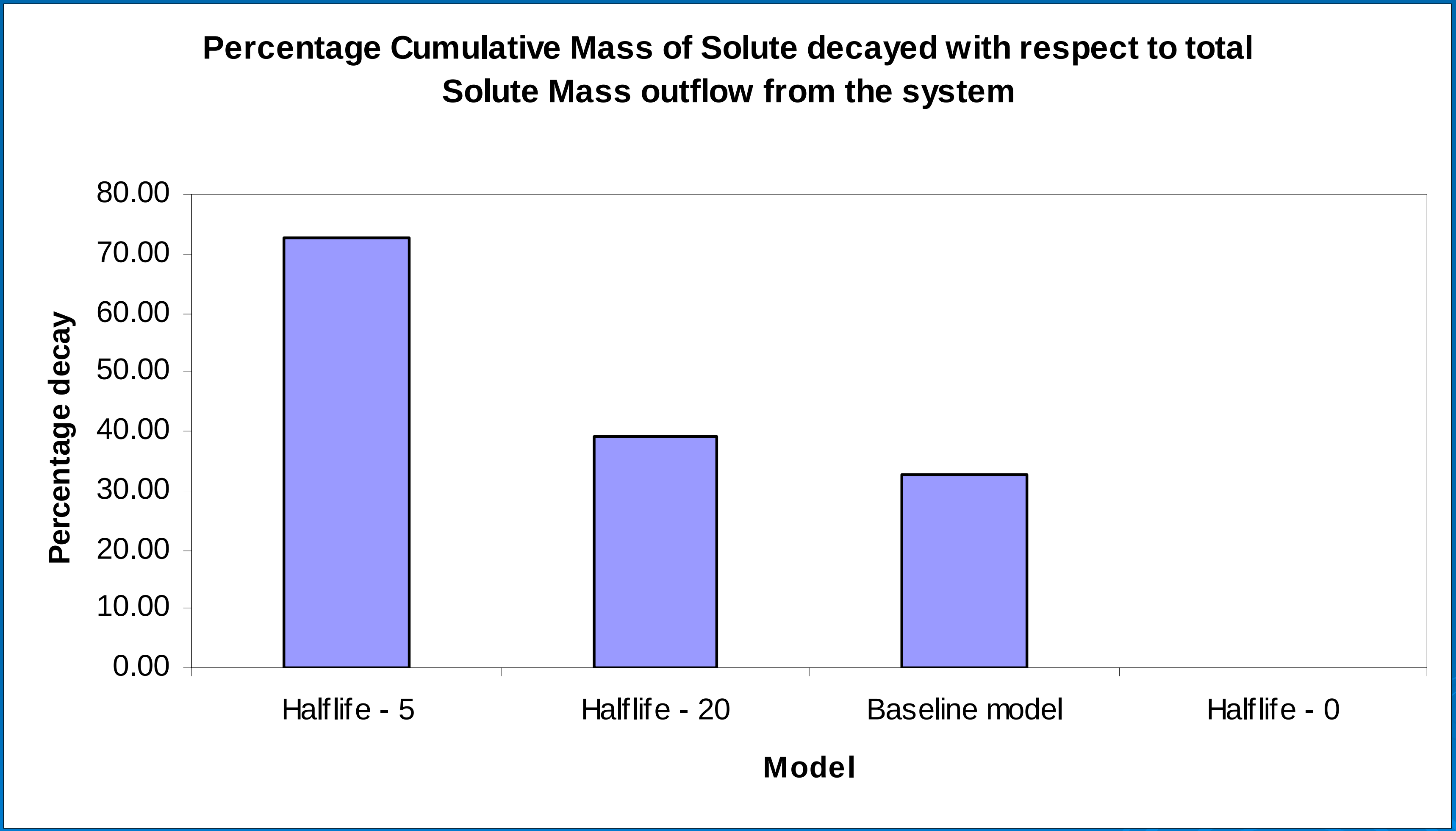




Model with 5 years Half Life period at the end of 30 Years



Model with Half Life periods declared in 4 zones at the end of 30 Years



Percentage Cumulative Mass of Solute decayed with respect to total Solute Mass outflow from the system
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Percentage decay
Halflife - 5
Halflife - 20
Baseline model
Halflife - 0
Model

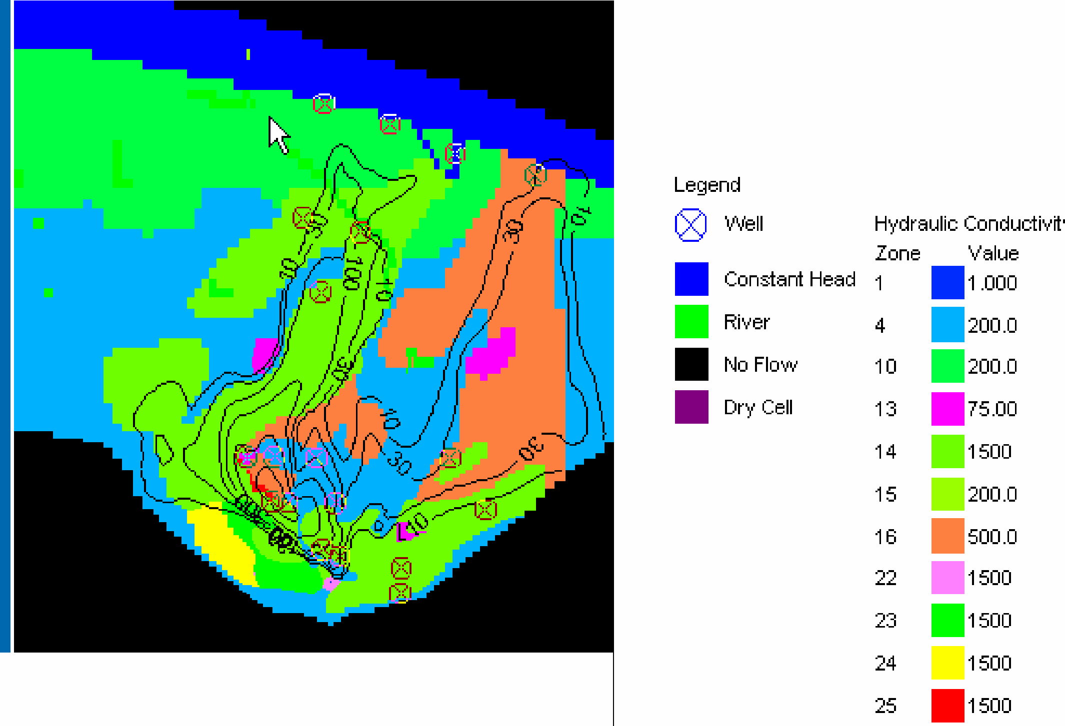
Inferences

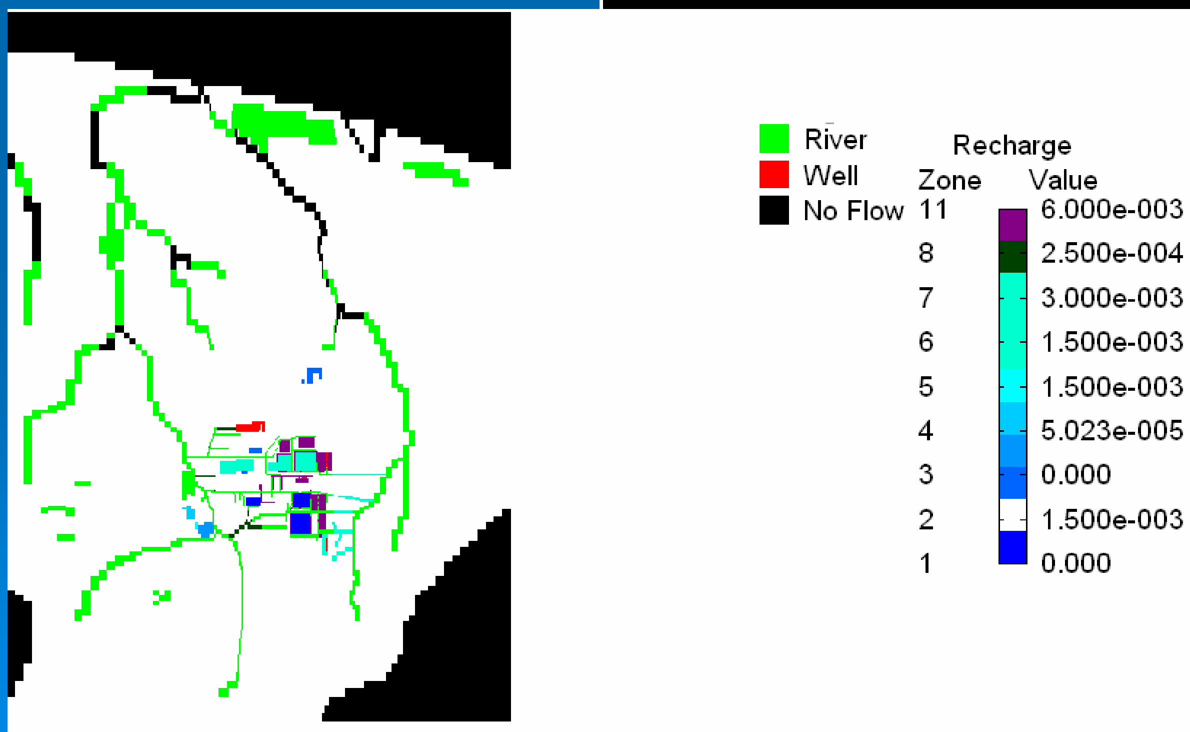
- Different model runs with varying Half Life Periods indicate significant variations in the temporal domain. It needs to be examined further with recent plume maps with further calibration of the transport model.

3.2.9 Model Sensitivity to Simultaneous Changes to Multiple Parameters

Multi-parameter sensitivity analysis

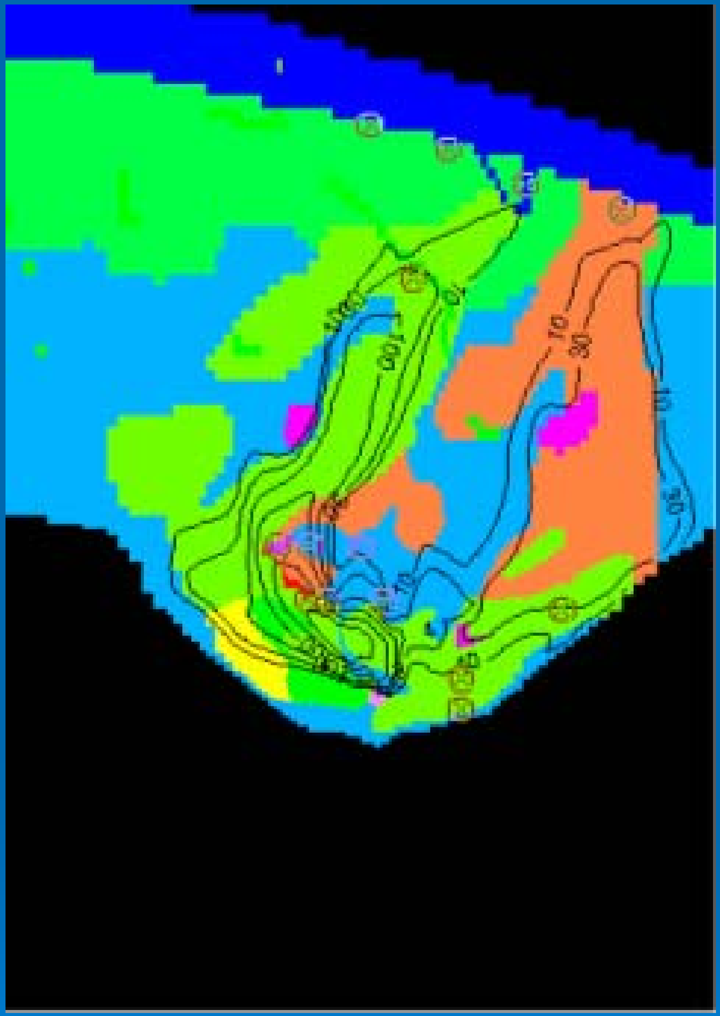
Property / Boundary Conditions	Ranges in the Baseline model :	Completed sensitivity analysis	Remarks	Plan for multi-parameter analysis
Hydraulic Conductivity:	1 ft/day to 1500 ft/day is used in the baseline model.	10 %, 20 % and 30 % reductions.	Reduction of K reduced the plume movement towards Ohio river.	Upper bound : 30 % red Lower bound : 10 % increase
Stream boundary conditions:	2.5 ft depth in most of the stream portions (for both Little Bayou Creek and Big Bayou Creek)	Reduced it in steps to 0.5 ft for both the creeks to see the influence.	The (2.0 ft.) reduction makes the north west plume to move more closer to the north east plume.	Upper bound : 3 ft Lower bound : 0 ft
Recharge:	The recharge values are varied between 0 and 0.006 ft/day maximum in Layer 1. (spatially varying)	25 %, 100 %, 200 % and 400 % increases in plant recharge run. Few cases of reduction also were studied.	changes were noticed in 200 % and 400 % increase IN RECHARGE	Upper bound : 300 % inc Lower bound : 10 % reduction
Ohio river stage:	300.6 and 306.86 ft are used in stress periods I and II in the baseline model.	Ohio river stage varied between 250.04 to 356.86 ft in the analysis	Less influence	Upper bound : 306.6 ft Lower bound : 290 ft
Vertical leakage	Adopted as 1/10th of K	-		
Pipe leakage	Nil	With 1, 5, 10 and 20 % leakage	20 % leakage shows slight changes in the north west plume	Uniform leakage can be attempted.


Legend
Well
Constant Head
River
No Flow
Dry Cell
Hydraulic Conductivity
Zone Value
1 1.000
4 200.0
10 200.0
13 75.00
14 1500
15 200.0
16 500.0
22 1500
23 1500
24 1500
25 1500

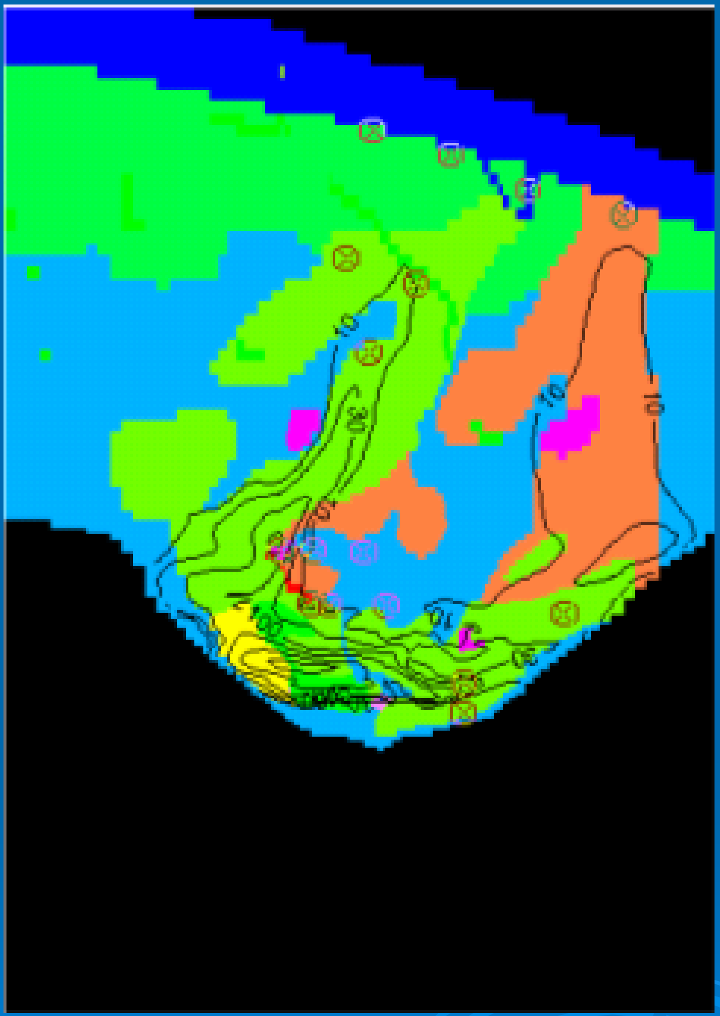

River
Well
No Flow
Recharge
Zone Value
11 6.000e-003
8 2.500e-004
7 3.000e-003
6 1.500e-003
5 1.500e-003
4 5.023e-005
3 0.000
2 1.500e-003
1 0.000

Multi-parameter sensitivity analysis

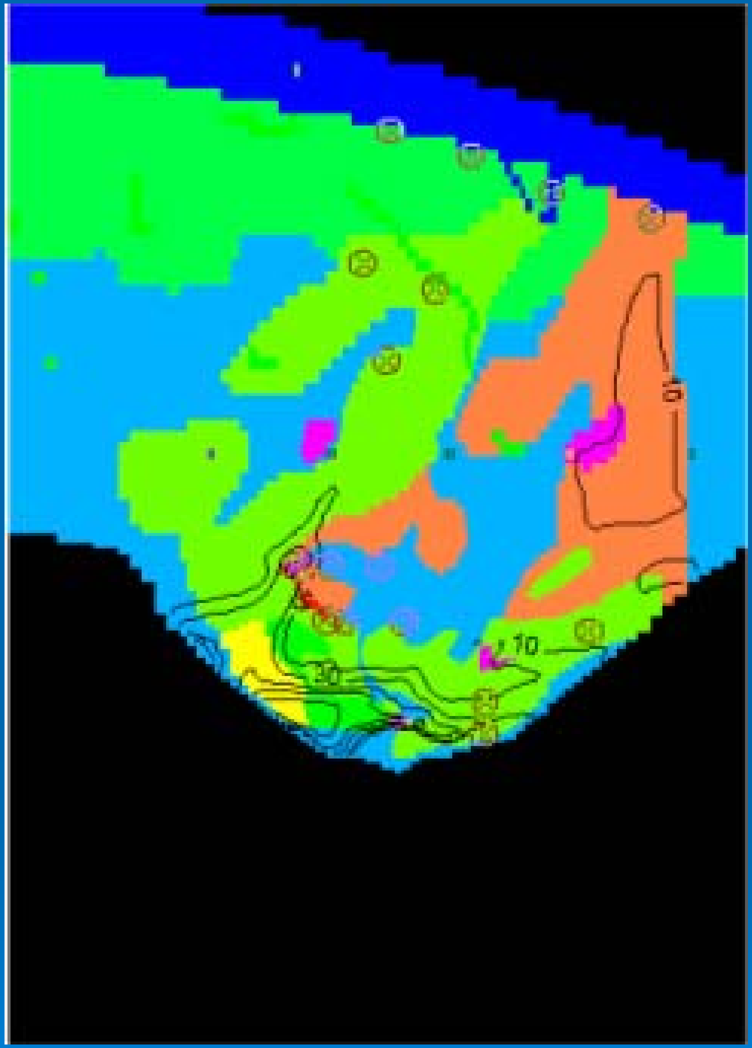
Run	K	River Boundary Conditions (II^{nd} stress period)	RECHARGE (II^{nd} stress period)	OHIO STAGE (ft. msl)	VERTICAL LEAKANCE (% K)	PIPE LEAKAGE	REMARKS
Run1	30 % RED	0.5 FT	10 % Reduction	293 FT I^{st} stress period 295 FT II^{nd} stress period	$1/20^{TH}$	5 %	
Run2	20 % Red	1	100 % Increase	295 FT I^{st} stress period 297 FT II^{nd} stress period	1/18	10	
Run3	10 % Red	2	200 % Increase	297.5 FT I^{st} stress period 300 FT II^{nd} stress period	1/15	15	
Run4	0 % Red	2.5	Actual	300 FT I^{st} stress period 306.6 FT II^{nd} stress period	1/10	0	Base Line



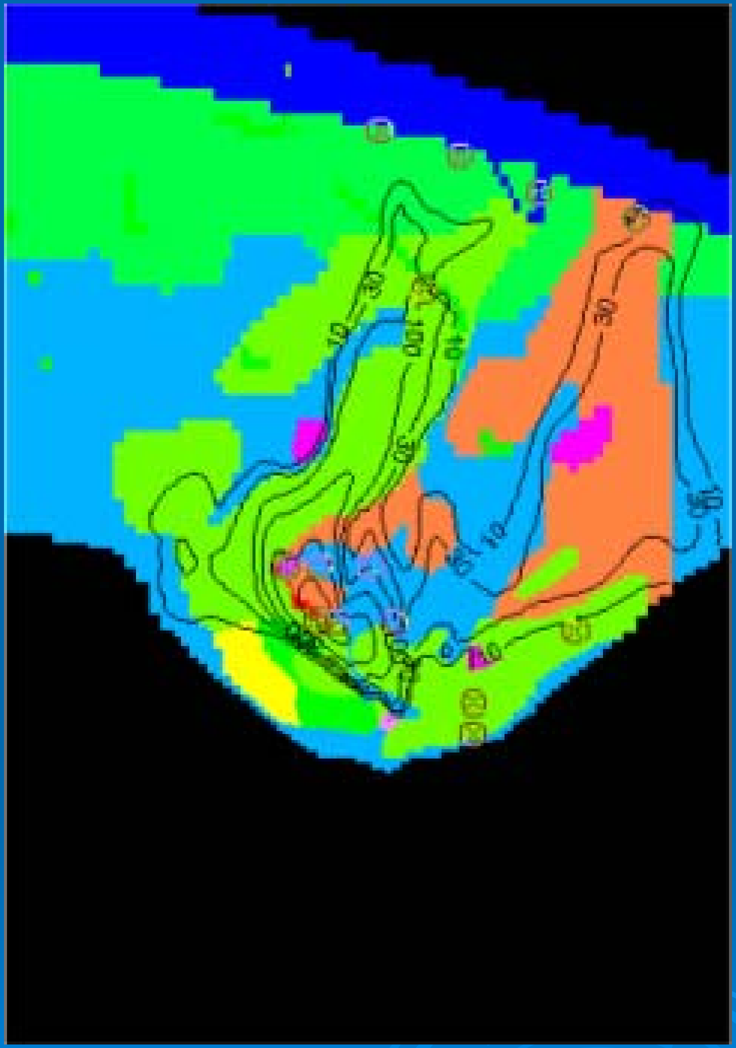
Run1



Run2

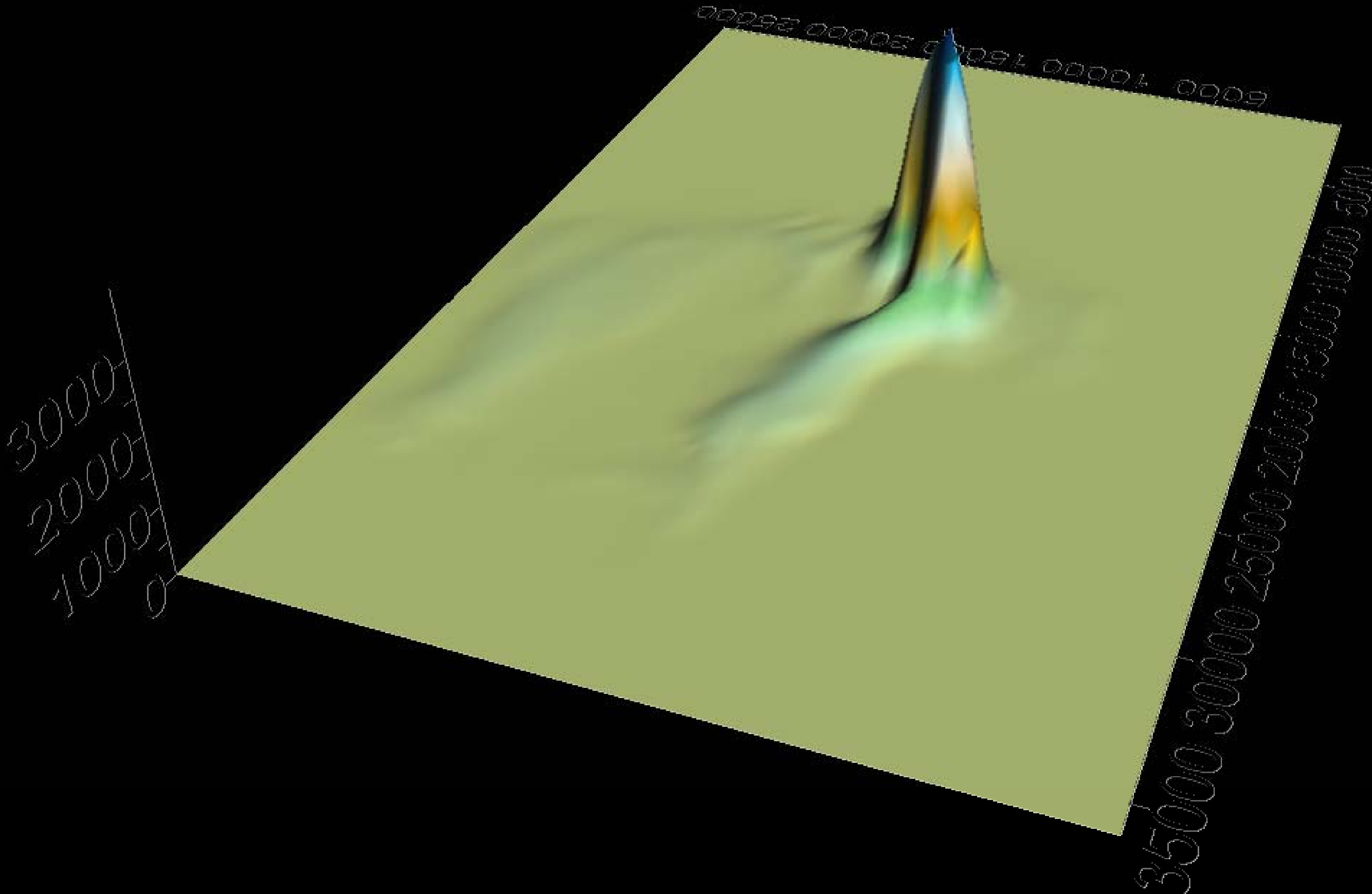


Run3

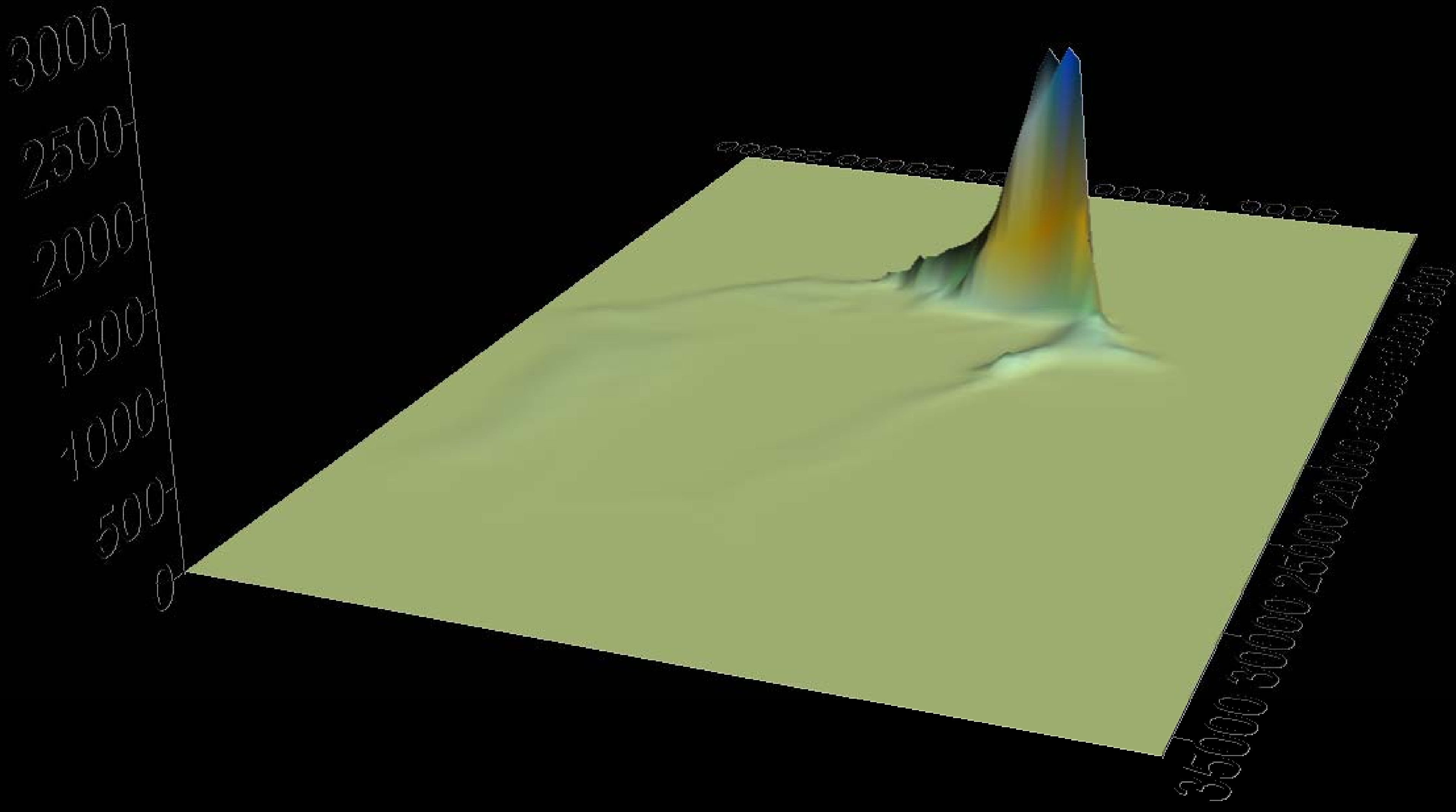


Run4 - Baseline

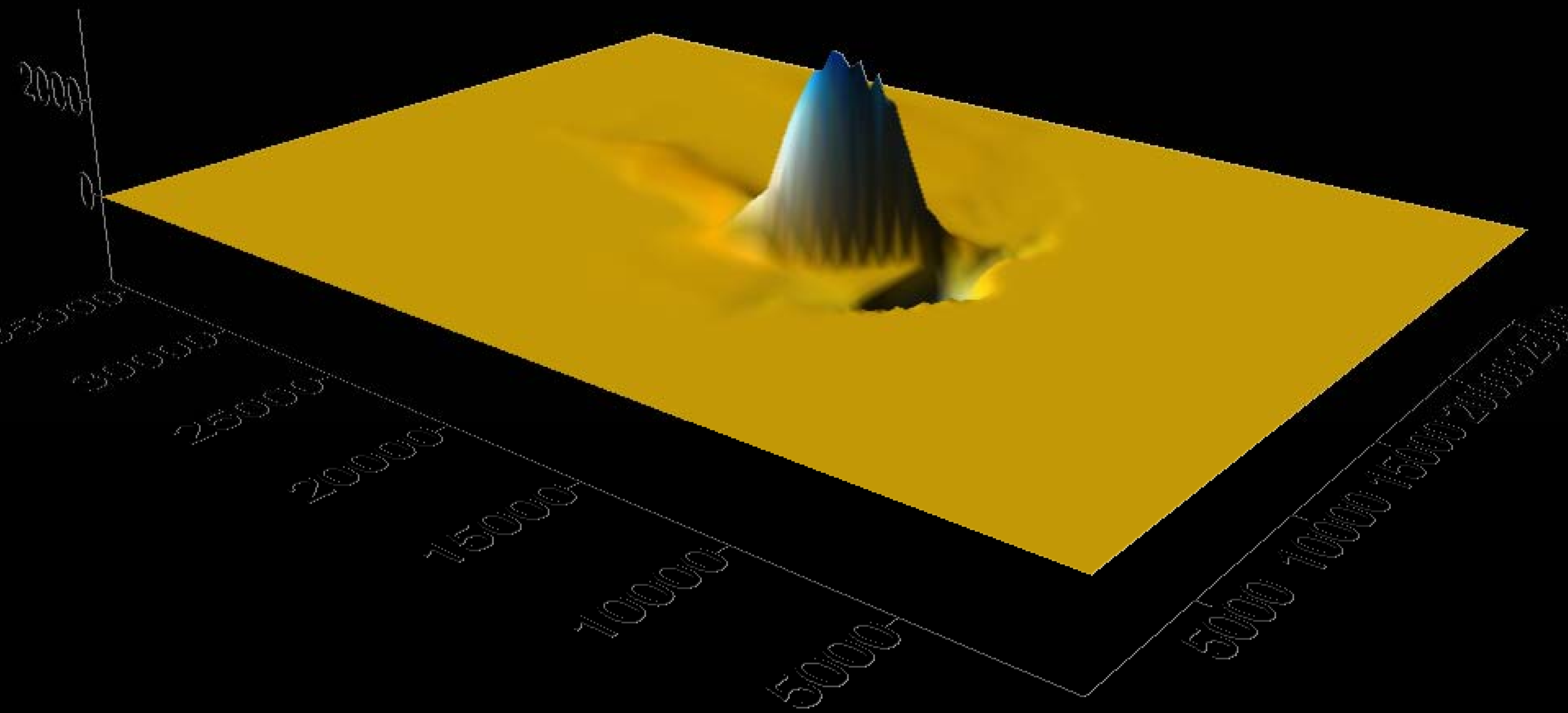
Baseline Model – TCE Concentration after Second Stress Period



Run 3 – TCE Concentration after Second Stress Period



Delta Difference between Baseline Model and Run 3 TCE concentrations



Multi-parameter sensitivity analysis : Runs performed

- With an increase of 200 % in the recharge and increase in pipe leakage to 15 % (with lesser hydraulic conductivity), the TCE contours diminishes and exist around plant only. But when the calibration of 4 wells were tested for this condition, (MW-075, MW-007, MW-147 and MW201) they indicated hike of 1 m level in all the wells. It differ from the existing well observations used for the calibration.

Effect of Pump and Treat on Contaminant Plume

3.3 Pump and Treat Study

- Two Stress Periods
  - SP-1: 1993 – 2003 (10 years)
    - Steady state hydraulics
    - Time-varying TCE concentrations
    - No additional pumping during this period
  - SP-2: 2003 – 20?? (5-50 years)
    - Time-varying hydraulics and transport
    - Different pumping scenarios
  - No further release of TCE from landfills or other sources to the aquifers

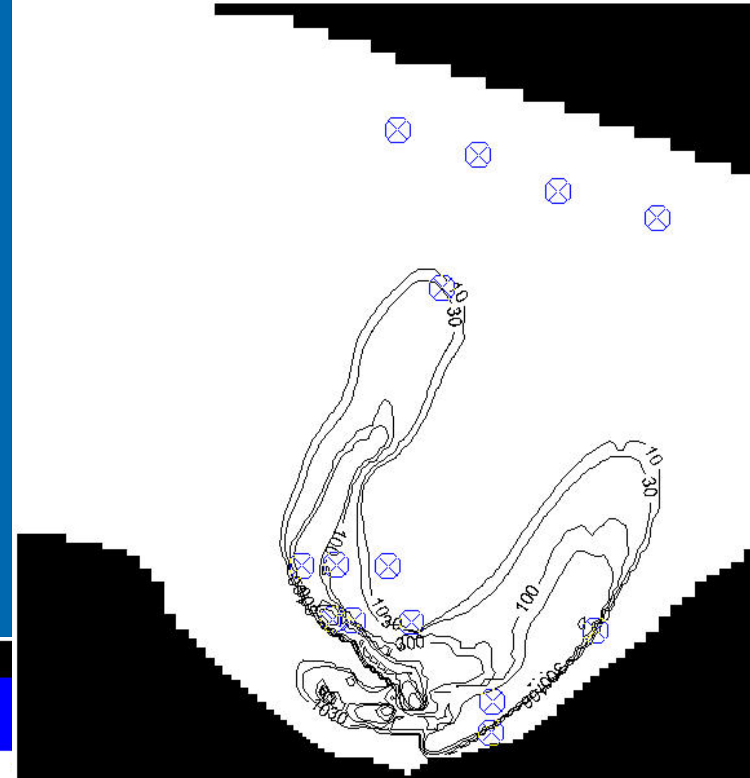
Pump and Treat Study

- Scenario 1
  - Number of wells 3
  - SP-1: 10 years
  - SP-2: 20 years

Well no	Grid position	Pumping rate (ft3/day)		Pumping rate (gpm)	
		SP-1	SP-2	SP-1	SP-2
1	45,160	0	150,000	0	779.25
2	45,170	0	150,000	0	779.25
3	45,180	0	150,000	0	779.25

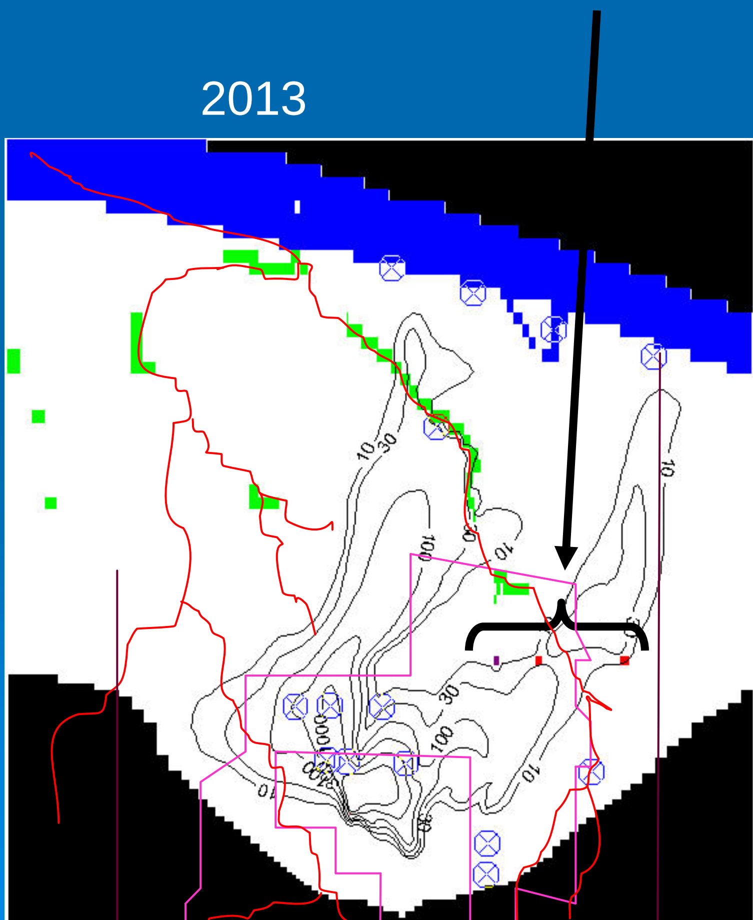
Scenario 1

1993

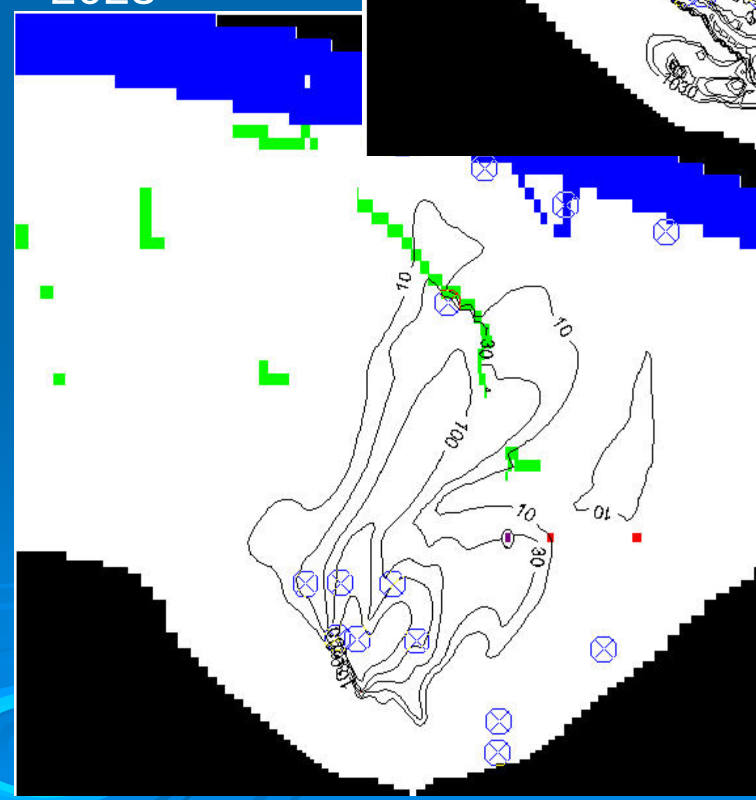


Pumps

2013



2023



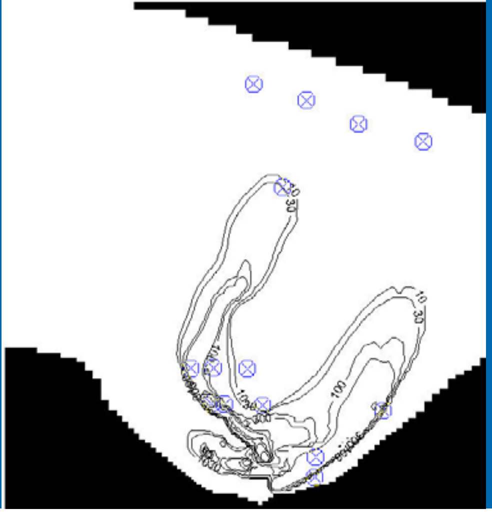
Pump and Treat Study

- Scenario 4
  - Number of wells 18
  - SP-1: 10 years
  - SP-2: 20 years

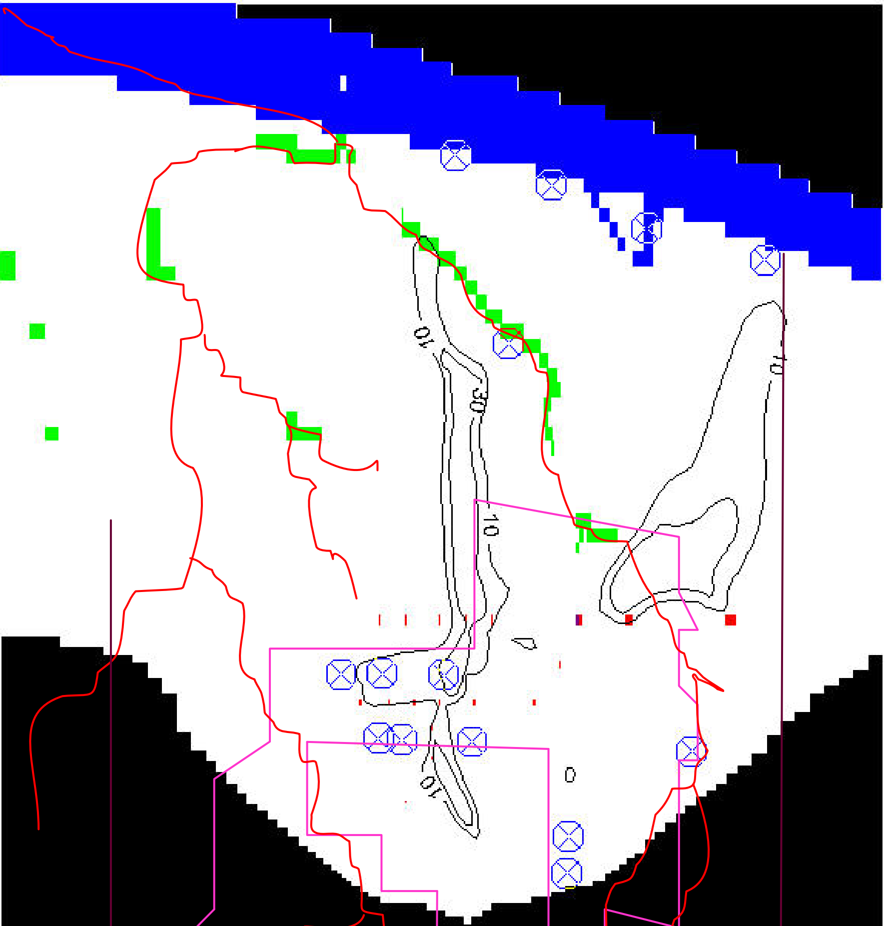
Well no	Grid position	Pumping rate (ft3/day)		Pumping rate (gpm)	
		SP-1	SP-2	SP-1	SP-2
1	50,150	0	90,000	0	467.55
2	45,45	0	90,000	0	467.55
3	45,60	0	70,000	0	363.65
4	45,80	0	80,000	0	415.60
5	45,95	0	70,000	0	363.65
6	45,110	0	70,000	0	363.65
7	45,100	0	70,000	0	363.65
8	45,160	0	70,000	0	363.65
9	45,170	0	130,000	0	675.35
10	45,180	0	130,000	0	675.35
11	55,35	0	80,000	0	415.60
12	55,50	0	80,000	0	415.60
13	55,65	0	80,000	0	415.60
14	55,80	0	80,000	0	415.60
15	55,100	0	70,000	0	363.65
16	55,135	0	50,000	0	259.75
17	60,75	0	90,000	0	467.55
18	70,75	0	90,000	0	467.55

Scenario 4

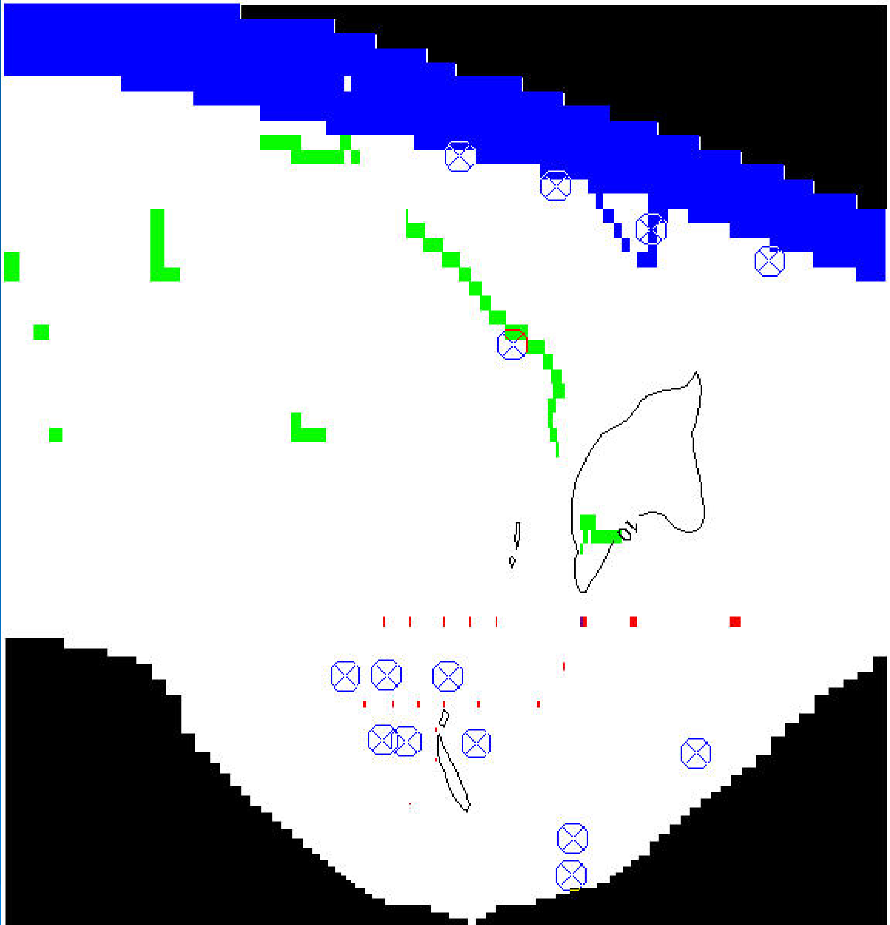
1993

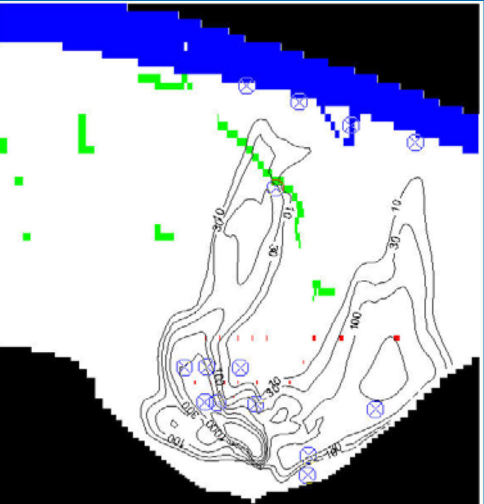


2013

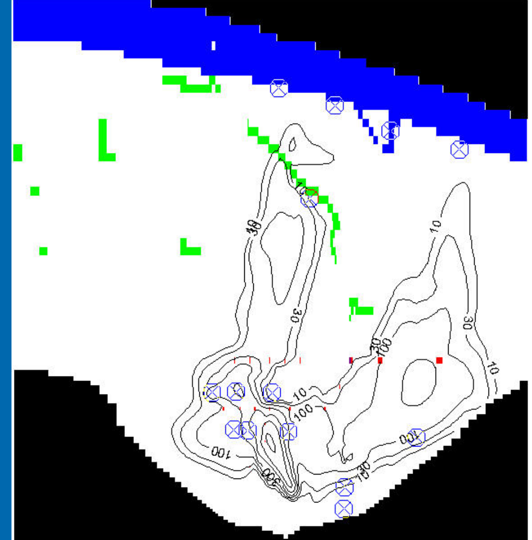


2023

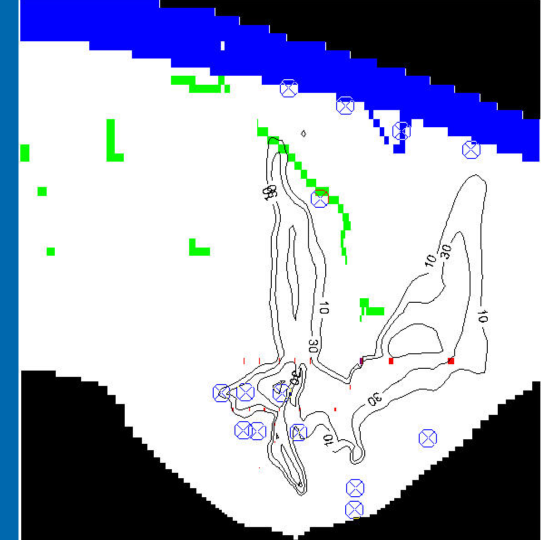




3650 days

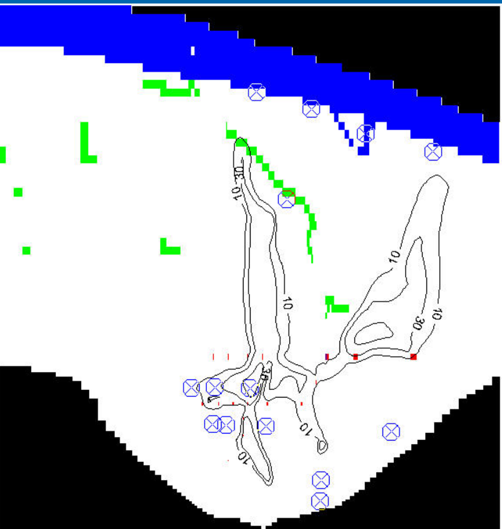


4022 days

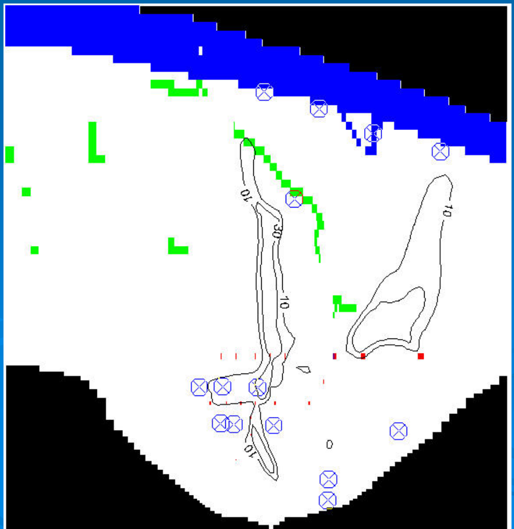


5489 days

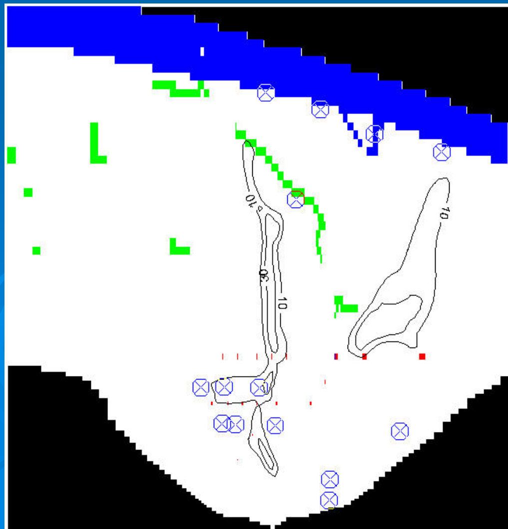
6217 days

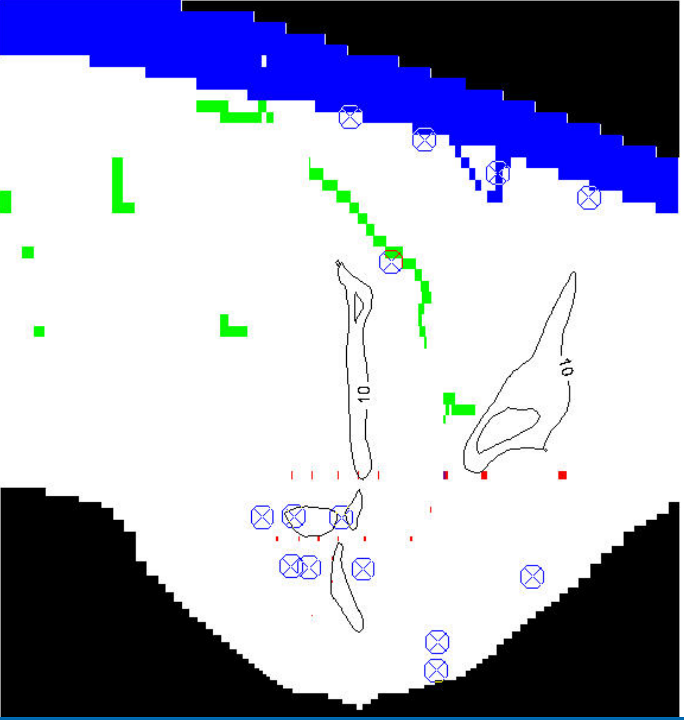


7309 days

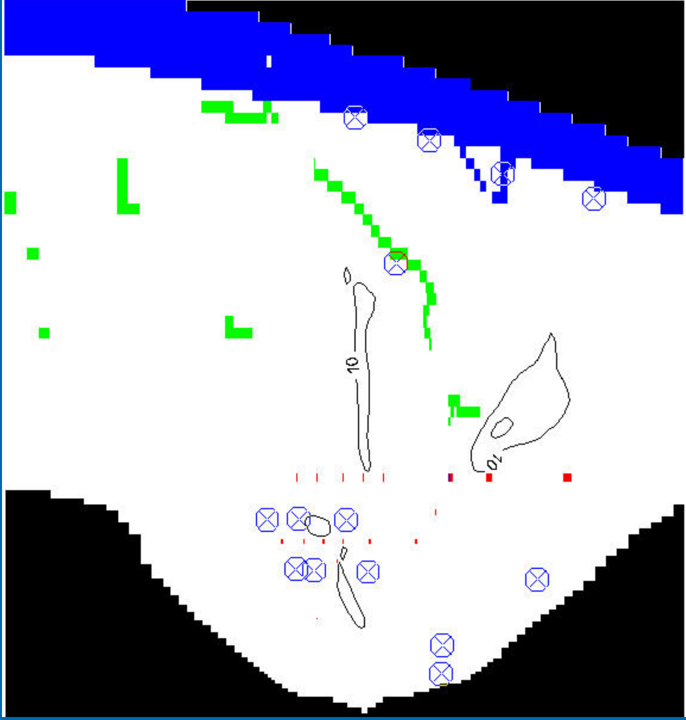


8037 days

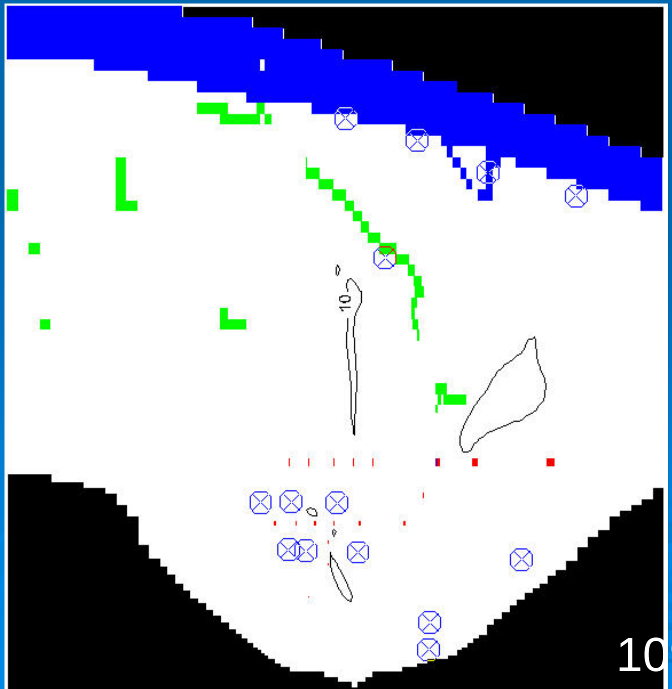




9125 days

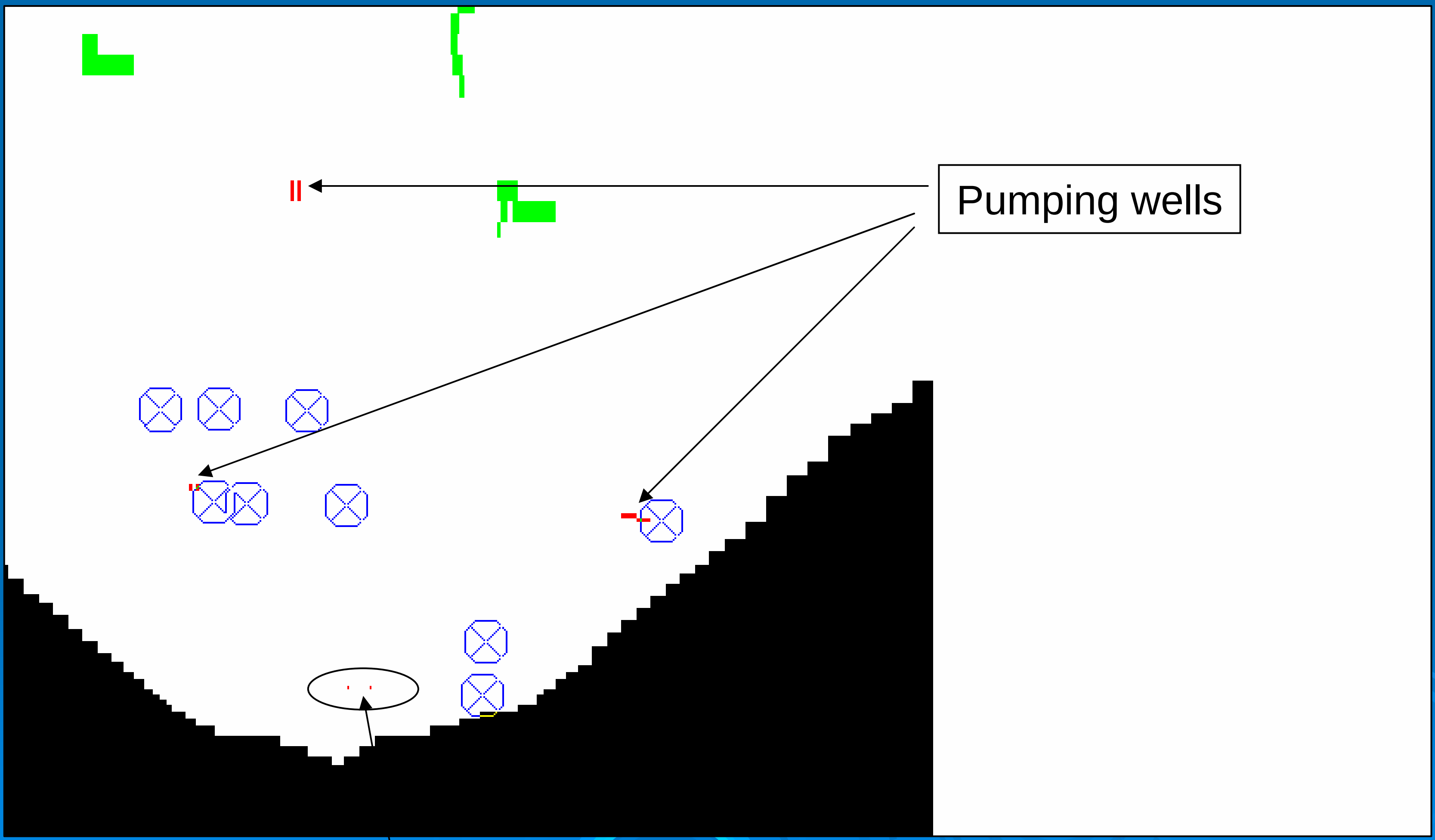


10220 days

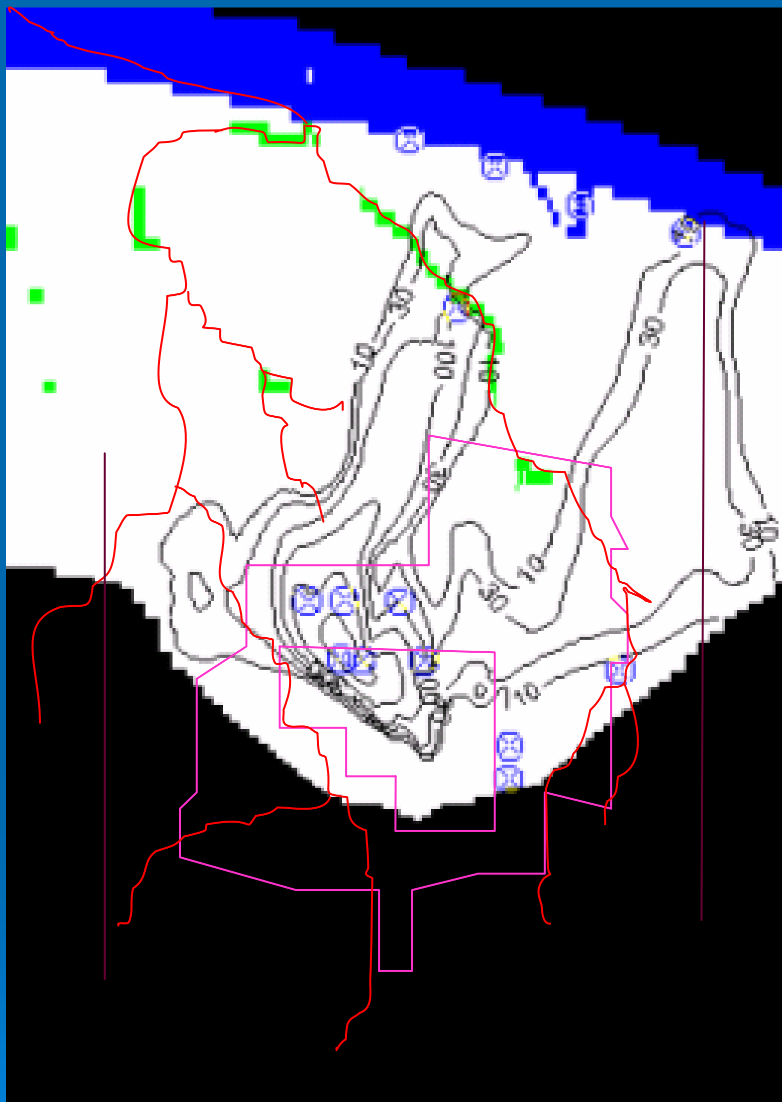


10950 days

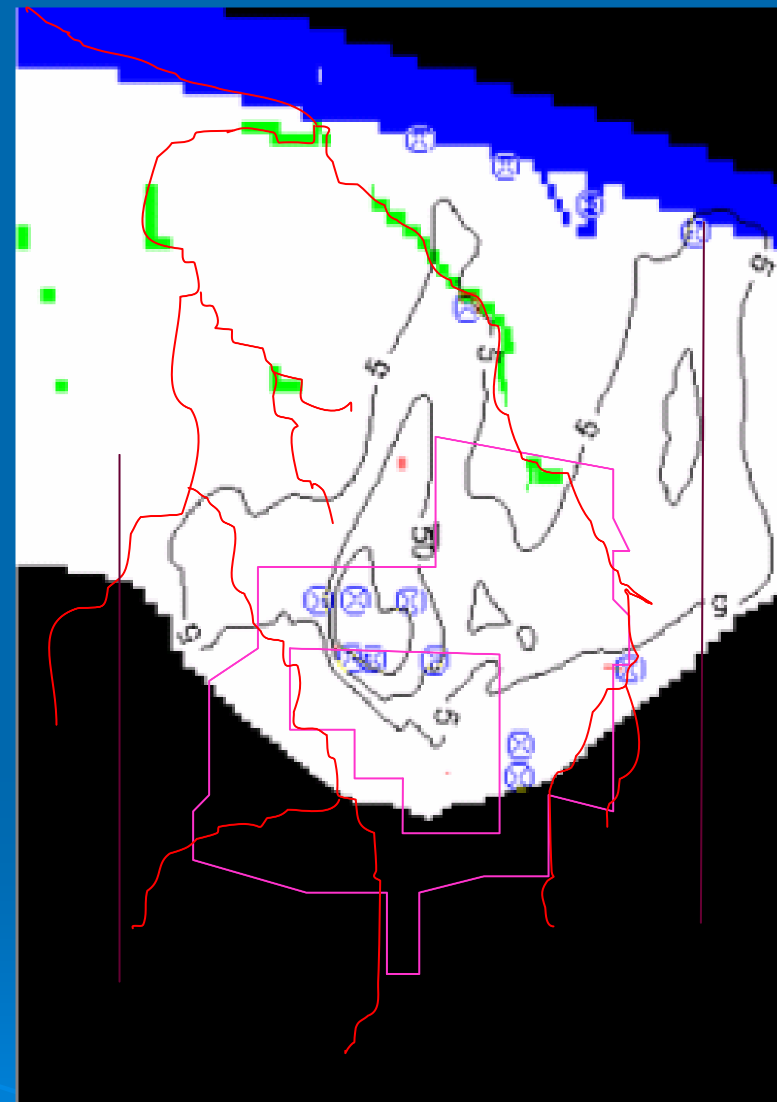
Pumping & Recharge – Combined trials
Trial 1



Two Recharge wells (100 GPM each)

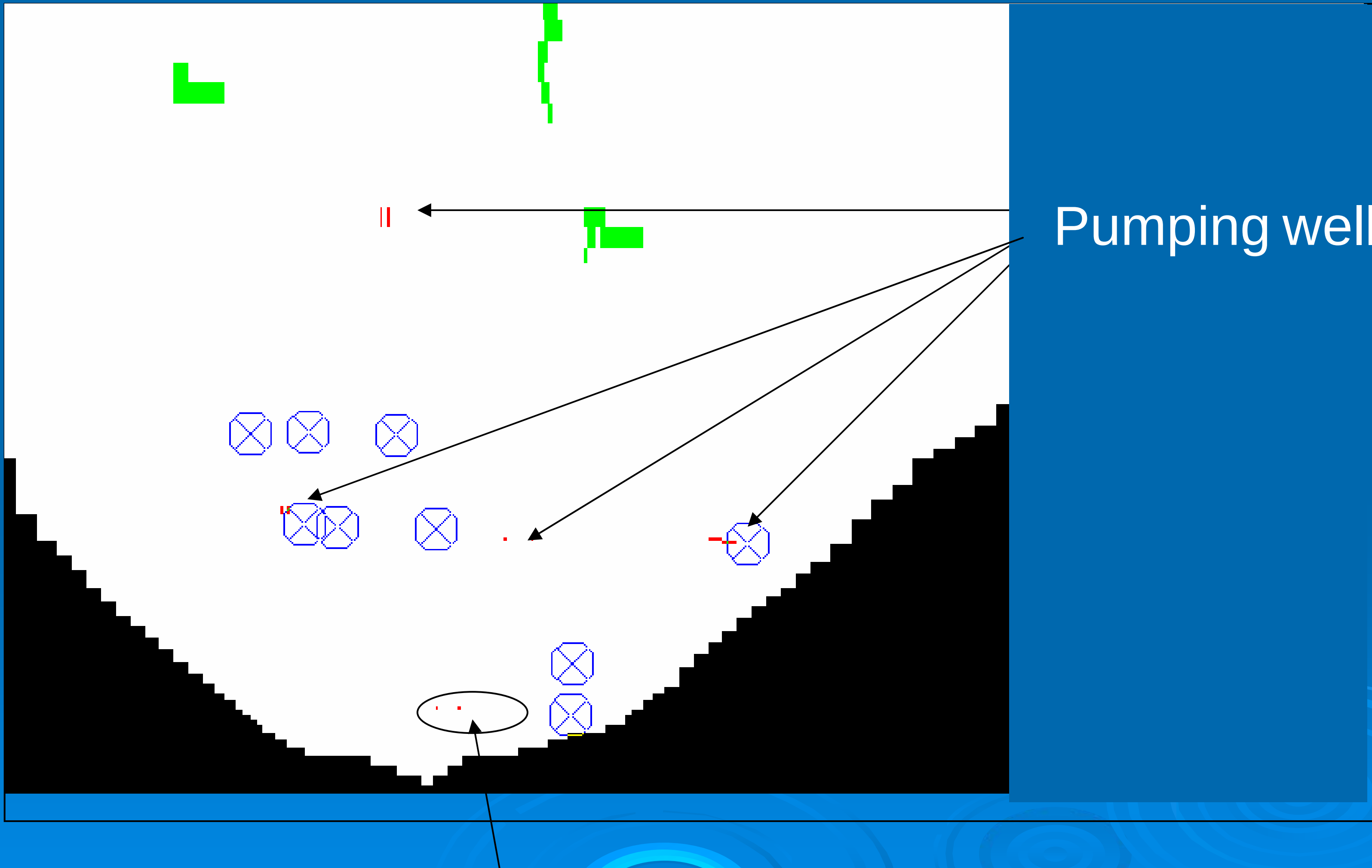


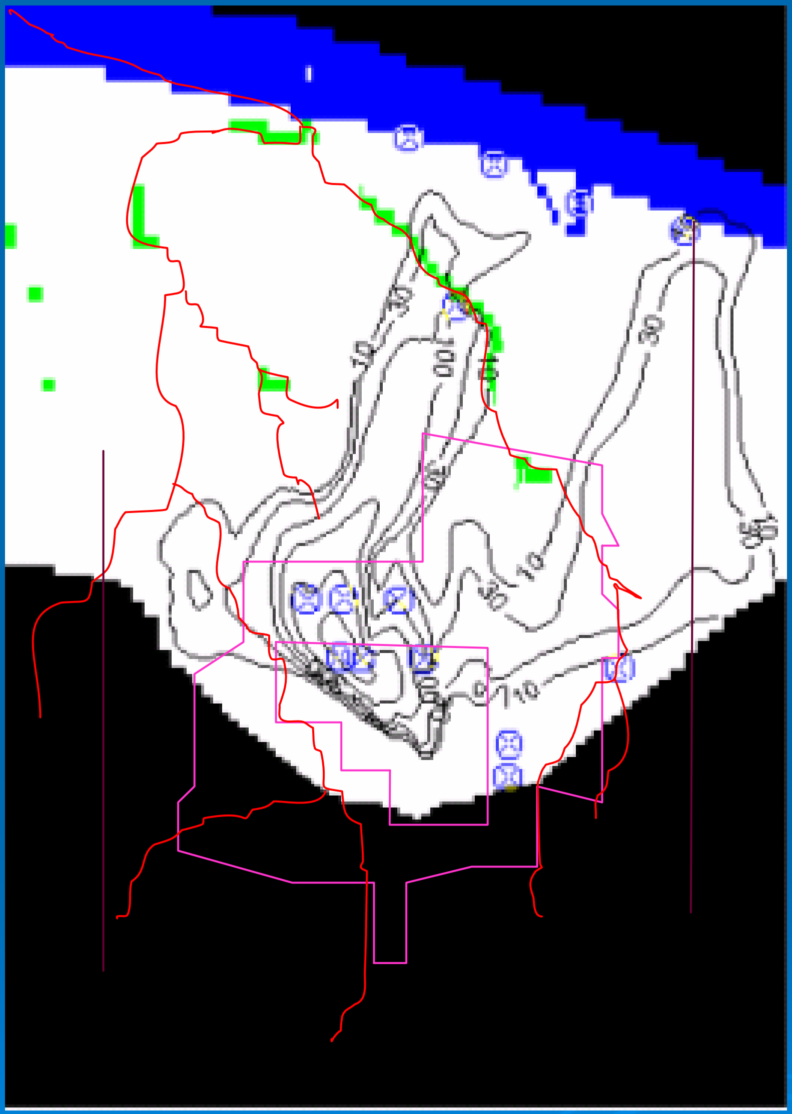
Baseline model



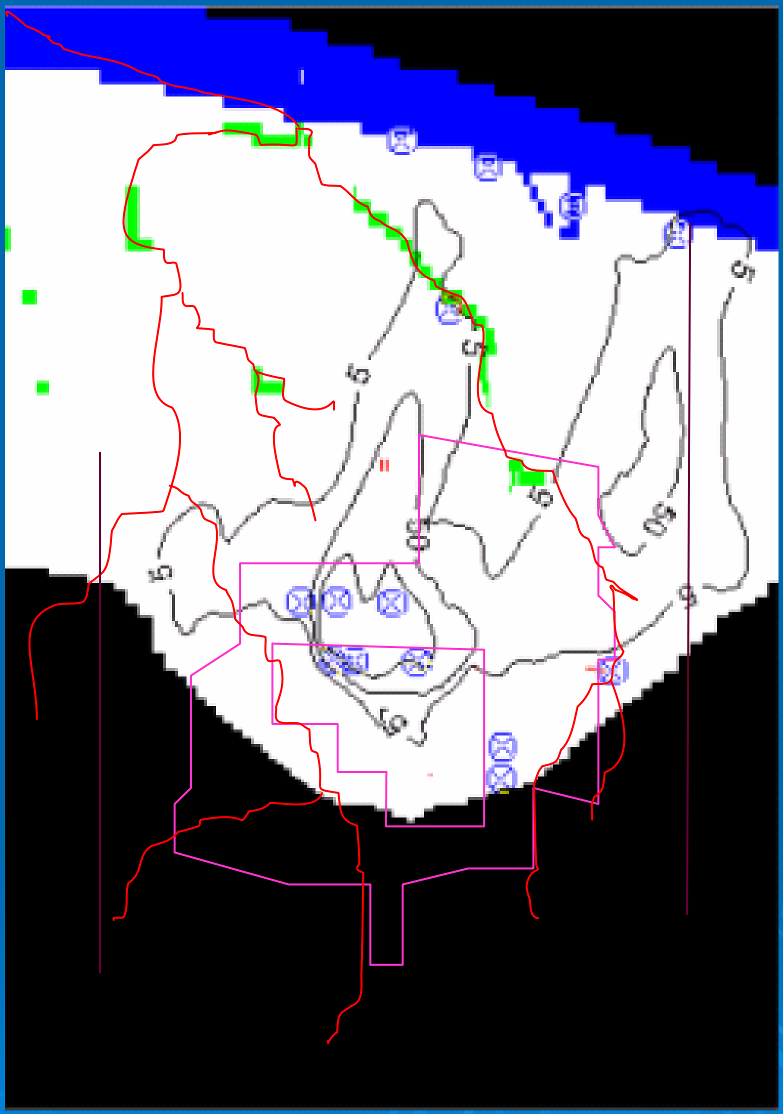
Model with Six pumping wells and Two recharge wells

Trial II





Baseline model

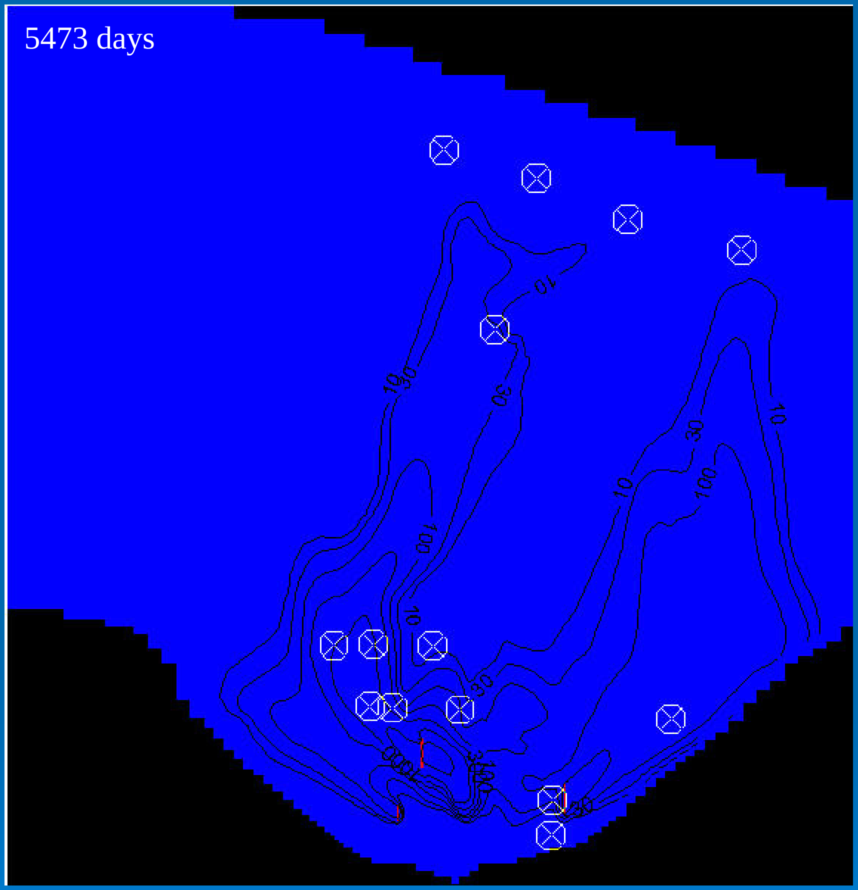


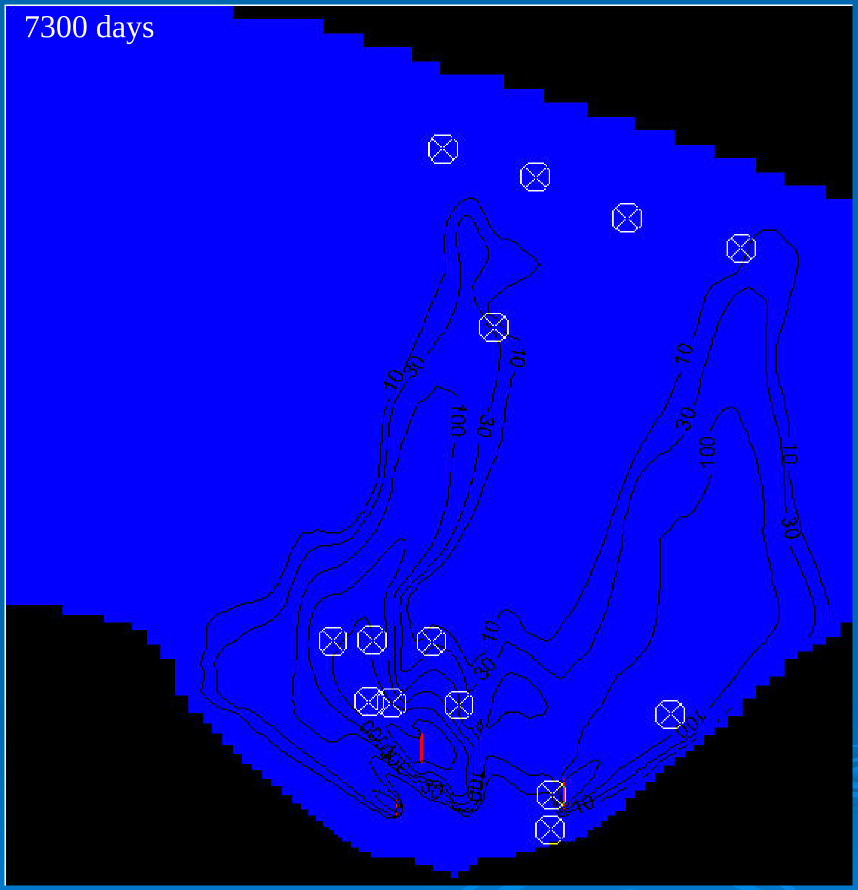
Model with Eight pumping wells and Two recharge wells

3.4 Effect of Reactive Barrier on Plume Movement

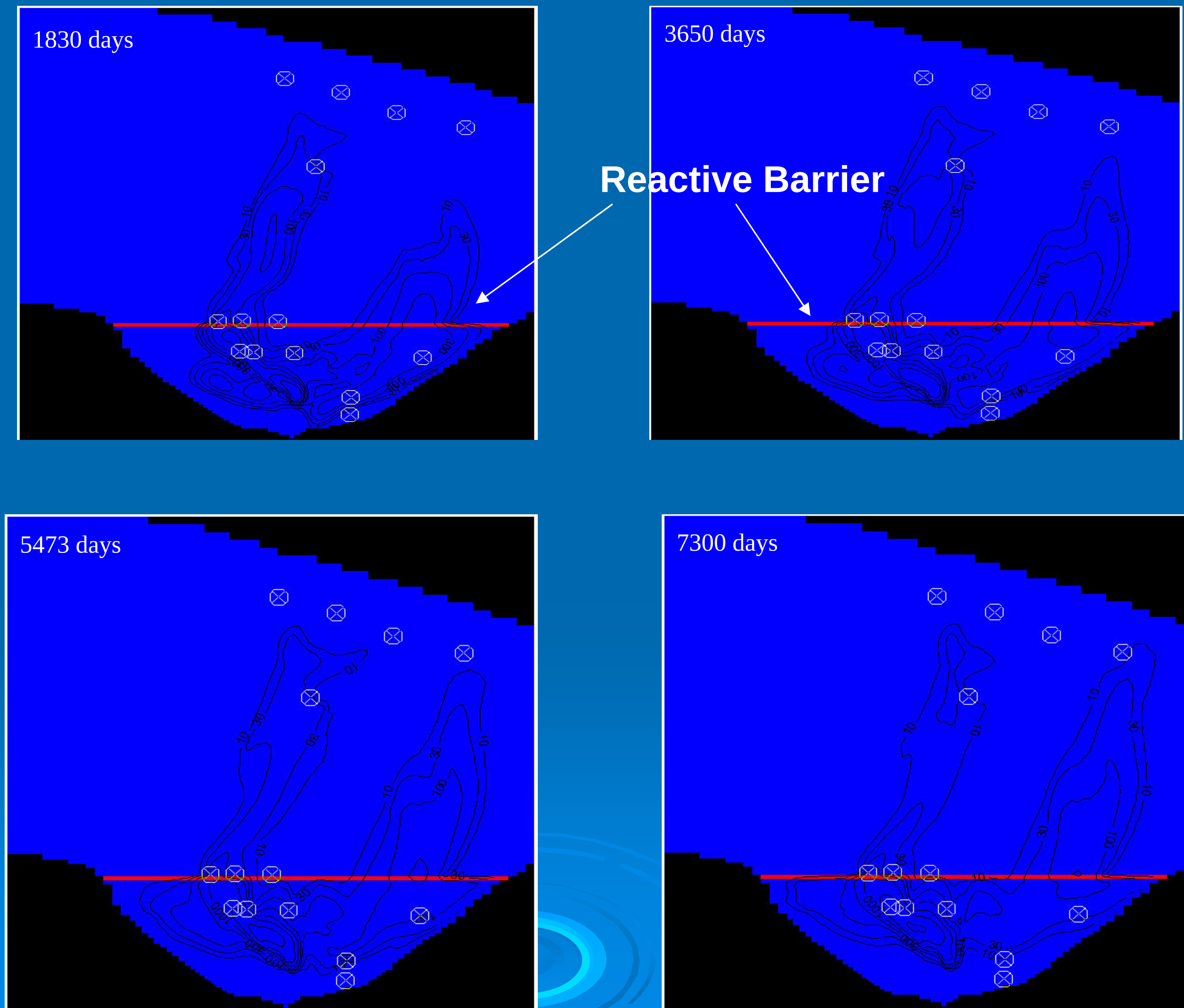
TCE Concentration Contours

Baseline Model (No reactive Barrier)

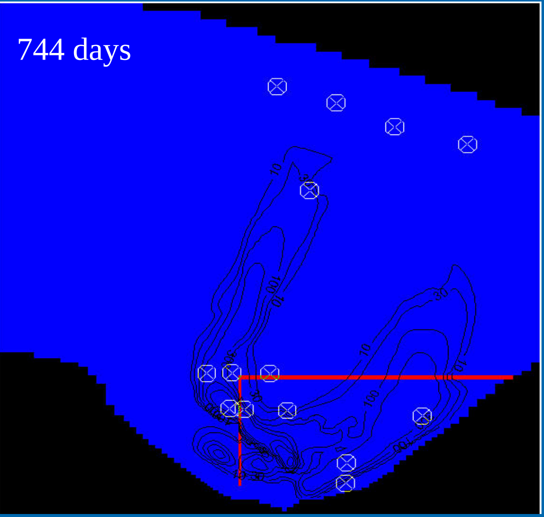


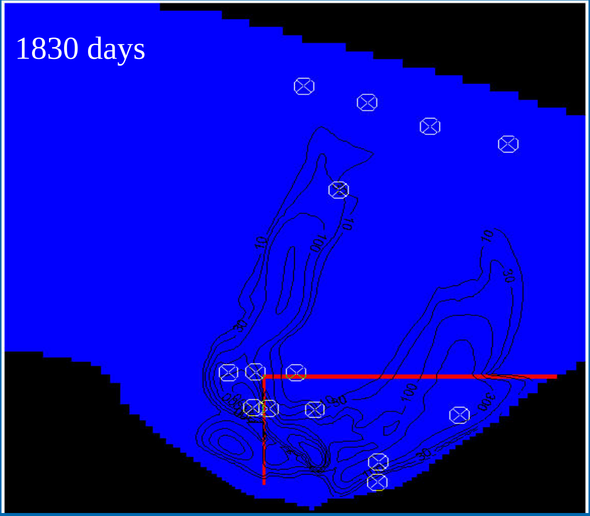


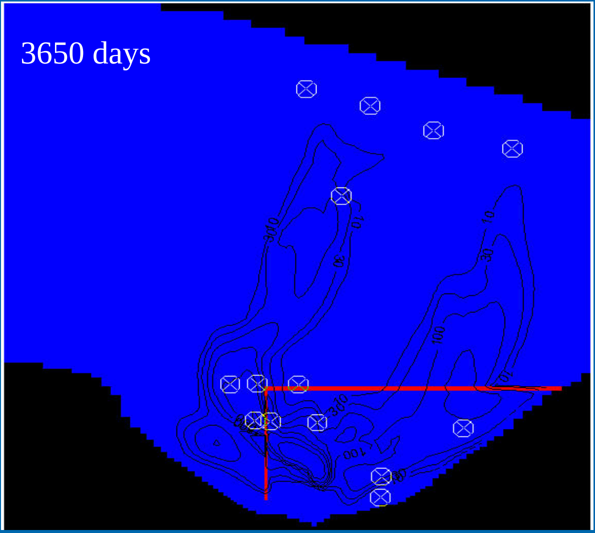
TCE Concentration Contours

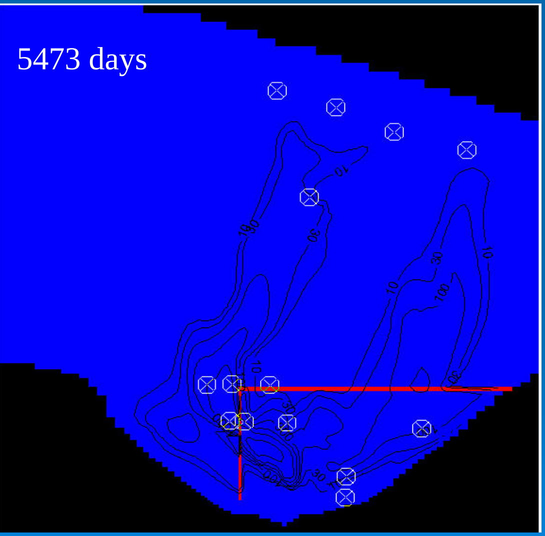


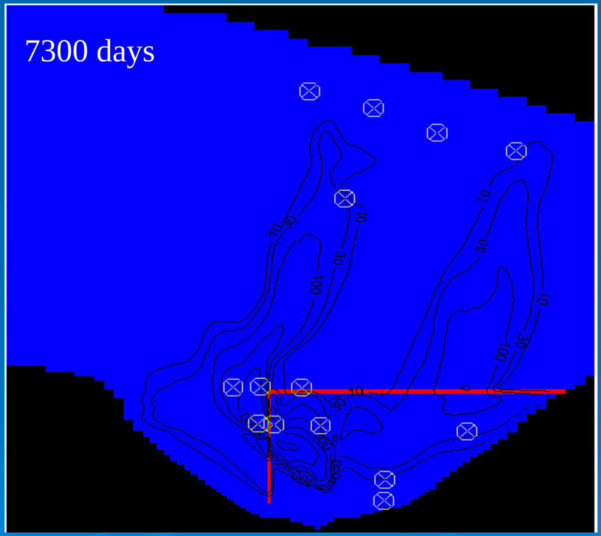
TCE Concentration Contours











5. Future Direction

- Update and recalibrate the flow model based on the latest Lithological data
- Recalibration of transport model based on 2005 TCE plume data
- FEM model
- Coupling the model with optimization tools