Project 1 Report

Groundwater Contamination Design

ENE 421 - Engineering Hydrology

Professor Pokhrel

Due Date: 10/31/2018

Big Dog Consulting

(woof woof)

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Executive Summary

Leaking underground contaminants, left untreated can spread and pose a threat to the environment and human health. Contaminants can leak into local aquifers and flow into local water wells as is the case on the site in question. This reports describes and evaluates the range of different design capture wells that the team has generated. Big Dog Consulting looked at many different options for removing the contaminant that is leaking out of the storage tank. Both single well and double well options were looked at with a range of pumping rates, durations, and locations. It is recommended that a single-pump capture well at location B (see Figure 7) be installed. Location B at the highest pumping rate (-.009 m^3/s) was the best economic choice. Pumping rate and cost are inversely proportional therefore, the recommended well configuration is Location B trial 5 or location B with a increased pumping rate past -0.009 m^3/s.

Problem Statement

It has been found that a storage tank has been leaking dense non-aqueous phase liquid (DNAPL) underground north of State Street. The tank has caused groundwater contamination that has recently passed through the clay layer into the unconfined aquifer. Twelve different monitoring wells have been installed on site in order to roughly show the location of the contamination.The monitoring well data is shown in Table 1. Monitoring well 2 in particular shows high level of contamination (C=4000 ug/L). The data from the well was used in determining both the hydraulic conductivity and gradient of the aquifer, and its thickness.

A capture well will be used as a remediation plan in order to collect and control the liquid that has been leaking out of the tank. Several different pumping rates and locations of wells will be designed in order to choose the optimal solution while minimizing the operating costs. The remediation plan will be created using the program Groundwater Modeling System (GMS), which will show contours of the contaminant plume in the aquifer, the groundwater flow for the site in question, and which capture well will be the most economic. Finally, the costs for each capture well designed will need to be calculated and assessed to determine the best method for the given situation.

Area Map

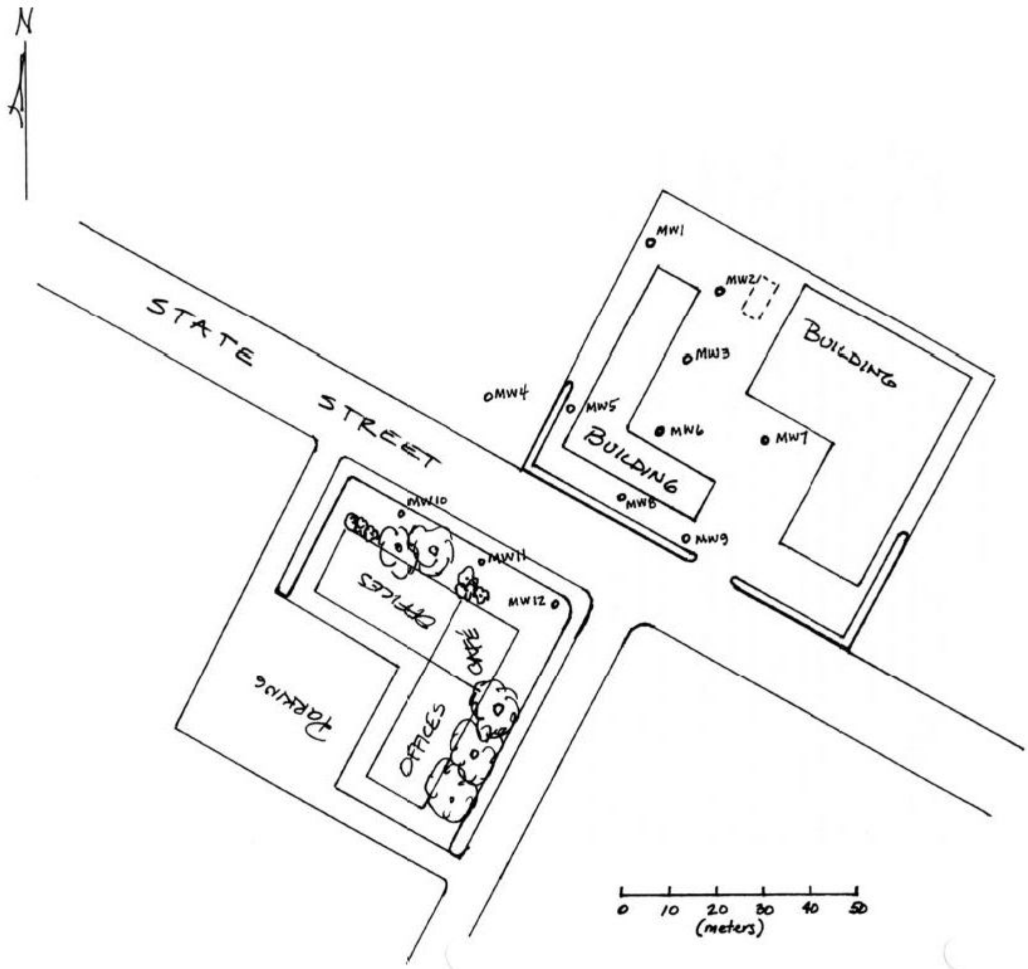


Figure 1: Aerial Map of Site and Well Locations

Other Info

The monitoring wells on site are used to show the concentration levels of contaminants and the depth of water shown in Table 1. These values were used in GMS program to develop contours for the site to show areas that are affected by the tank. However, to continue with the analysis of the property, more data will need to be calculated and located. For three of the wells (1,9, and 12), data was provided in Table 2 about the wells, including the length, diameter, time, head, volume, and temperature. This data can be used to calculate several different required values. The first is the flow rate (Q) which is simply the sum of the three volumes divided by the time, giving an average value in meters cubed per second.

$$Q = \frac{\Sigma V}{t} \text{ (m^3/s)}$$

Where,
Q= Flow Rate (m^3/s)
∑V= Volume (m^3)
t= Time (s)

The calculated value for flow rate (Q = 3.57 * 10^(-2)) can then be plugged into the confined aquifer equation to solve for the hydraulic conductivity (k = 1.178*10^(-4)). The thickness of the aquifer (b) = 7.9 m, was determined by averaging the grey fine sand layer in each of the monitoring wells. The distances of the observation wells (r,R) and the piezometric heads (h,H) were determined using the values at wells 1,9, and 12, where observation well 1 was the well of interest. These values can be found in Table 2.

Using the hydraulic conductivity and aquifer thickness values that were found, they were multiplied to determine the Transmissivity (T = 9.31*10^(-4)).

$$T = bk = \frac{Q}{2pi(H-h)}\, ln(\frac{R}{r})$$

Where,
k = Hydraulic conductivity (m/s)
b = Average gray fine sand thickness in the bore loss
T = b*k = Transmissivity of aquifer (m^2/s)
Q = Flow rate (m^3/s)
r = Distance of closer observation well from well of interest (m)
R = Distance of further observation well from well of interest (m)
h = Piezometric head at any distance r (m)
H = Piezometric head at radial distance R (m)

All of these values will need to be used in the GMS program to run the MODFLOW package.

Table 1:DNAPL Concentration, Elevation of the top of well casing (T.O.C, and depth to water

M.W. #	C (ug/L)	El. T.O.C (m)	Depth to water (m)
1	<1	46.300	28.230
2	4000	45.300	26.989

3	1150	43.110	26.054
4	<1	41.150	23.651
5	85	41.330	24.214
6	315	41.750	24.574
7	11	42.750	25.211
8	120	40.053	22.948
9	5	39.850	22.799
10	<1	39.201	22.153
11	3	39.505	22.451
12	6	40.111	21.950

Table 2: Hydraulic Conductivity data for samples from the aquifer at monitoring wells 1,9,12

M.W	L(cm)	D(cm)	t(s)	h(cm)	V(cm^3)	T(C)
1	30	10	60	30	230	25.6
9	30	10	60	30	162	25.6
12	30	10	60	30	250	25.6

Table 3: Aquifer Thickness

M.W #	Tan Fine Sand (m)	Depth to Water (m)	Aquifer Thickness(m)
2	53.5	26.989	26.511
4	54.90	23.651	31.249
6	57.00	24.574	32.426
9	57.8	22.799	35.001

Method/Procedures

To evaluate the most cost-efficient way to remove the contaminant a GMS (Groundwater Modeling System) was utilized. This program can simulate the flow of groundwater and the contaminated particles.

First, the approximate location of twelve observation wells were given and the coordinate locations of these wells were found using AutoCAD and a scale given (See appendix for coordinate system in AutoCAD.) The well coordinates were transcribed into a text file with the concentration values so they could be opened in the GMS program. Once opened the programs contained 12 points; one for each observation well with their corresponding C value. A 200m by 200m 2D grid was then created based off the origin point selected in AutoCAD and contour lines for the contamination levels were interpolated in the GMS program. See Figures 2 and 3. Figure 2 will remain to be the key for the rest of the GMS figures.

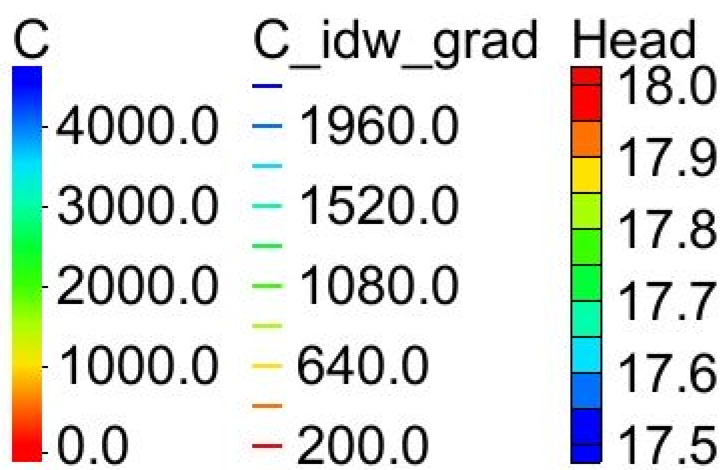


Figure 2: Key for GMS figures

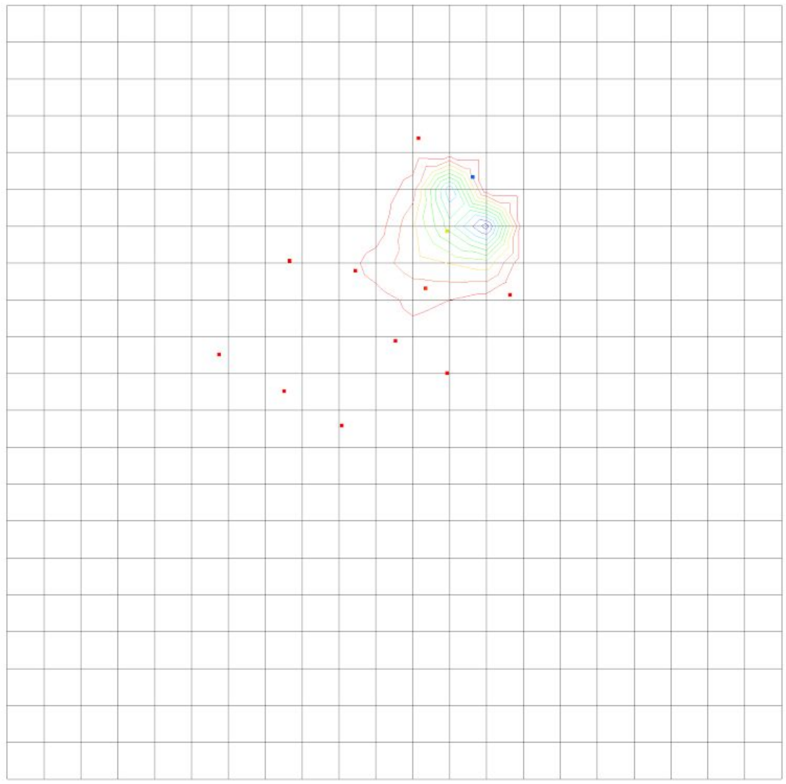


Figure 3: The Observation Wells and Contaminant Plume

A 3D grid was then created on top of the 2D grind with the same x-y values and a added z value of 70m. 70m was selected because the bore logs showed that the bottom of the confined aquifer was roughly 70m below the surface. The water table values at each well were calculated by subtracting the ‘Depth to water’ values from the ‘Elevation of the top of well casing’ values. The water table height ranged from 17.5m on the left side of the grid to 18m on the right side.

At this point the water head and contaminant data have been accurately recreated in GMS. The next step was to run MODFLOW to simulate the change in the water table based on different well locations and their varying pumping rates. First MODFLOW was run without a well inplace see Figure 4 located below.

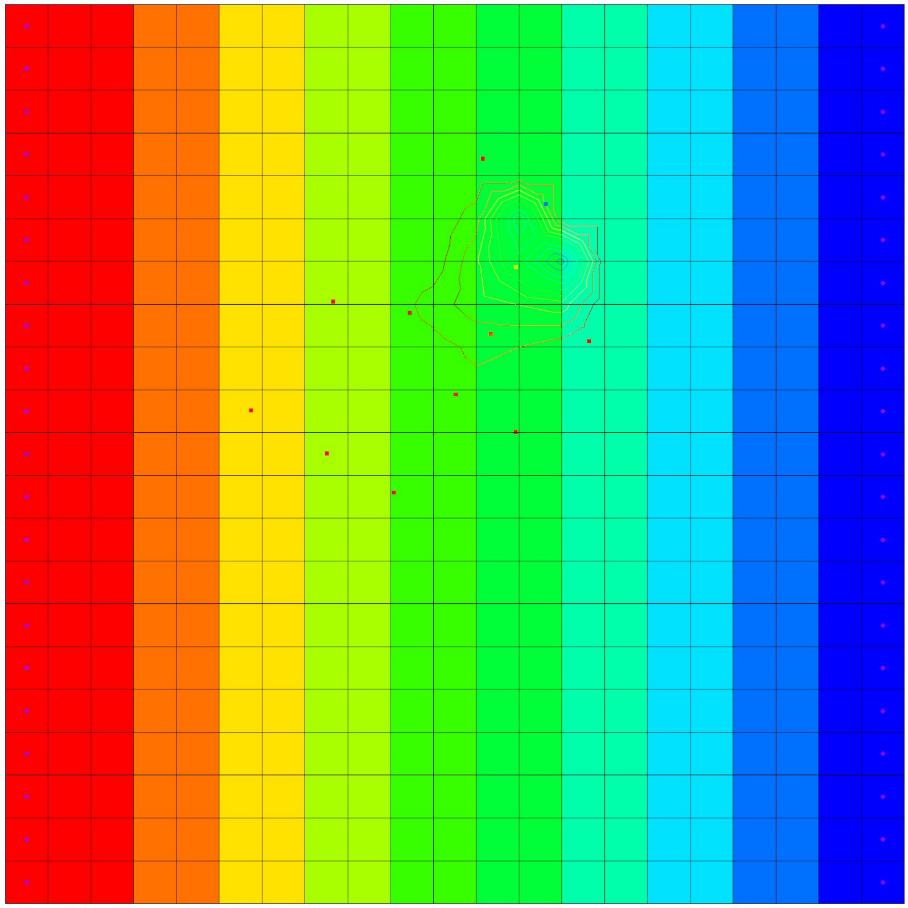


Figure 4: MODFLOW prior to a well being placed

Then, three different scenarios and 5 trials per scenario were run in total; two single-well cases at different locations and one dual-well case with wells at both locations. Pump rates of -0.001 m^3/s to -0.009 m^3/s were used in the simulations with a step of -.002. Once these wells were placed, the new water table levels were produced in MODFLOW and the MODPATH program was ready to be implemented. Please see Figure 5 to see how a well affects the MODFLOW. Figure 5 uses a -.001m^3/s pump rate the MODFLOW would be more affected with a higher pump rate.

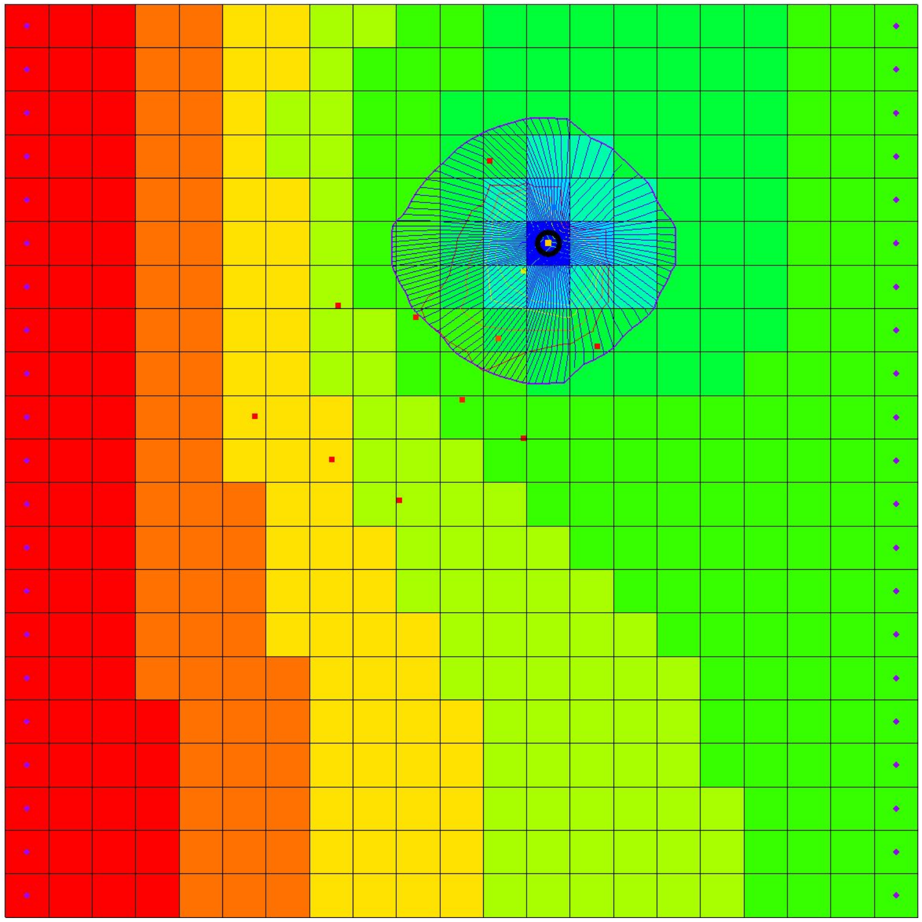


Figure 5: Example of the change in MODFLOW once a well is introduced - Location A Trial 1

The next step was to run the MODPATH program. In each scenario a pumping rate was determined for the well(s) in that scenario and the MODFLOW program was run iteratively to determine the duration it would take for the particle net to cover the contamination plume. Once the plume was covered it was assumed that all contamination was extracted. This resulted in a graph with the pumping rate on the x-axis, duration on the y-axis, and data points which showed how long it would take each scenario to clear the contamination based on pumping rate. See Figure 6.

Results

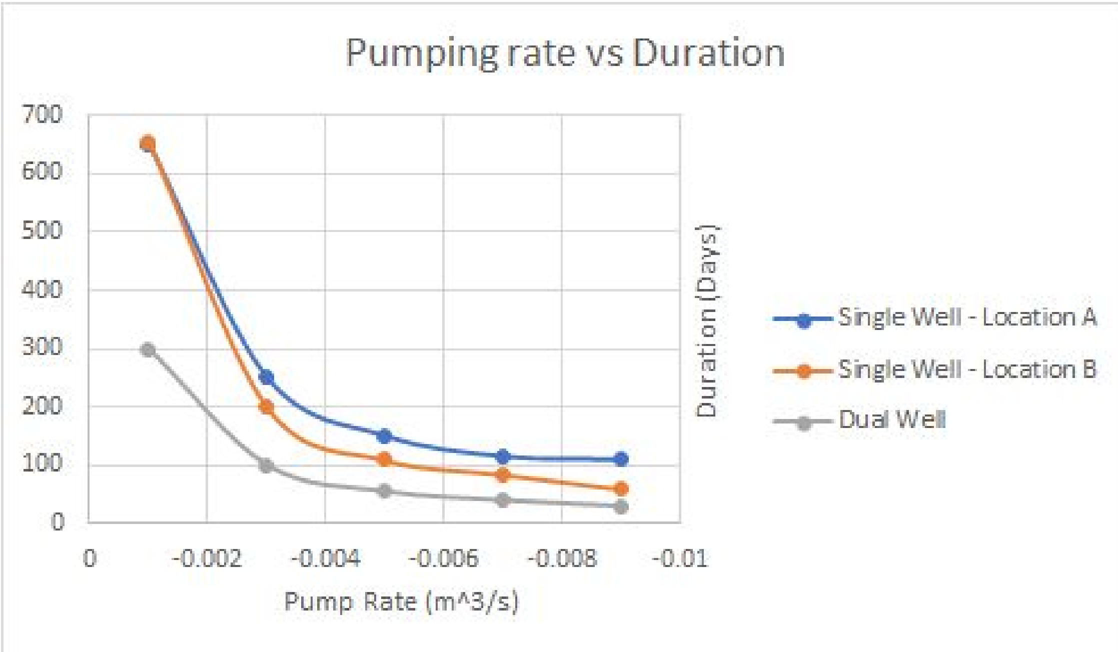


Figure 6: Scenario Pumping Comparison

Table 4: Well Solutions

Single Well Soultions				
Location	Trial	Pump Rate (m^3/s)	Duration (s)	Duration (Days)
A	1	-0.001	56160000	650
A	2	-0.003	21600000	250
A	3	-0.005	12960000	150
A	4	-0.007	9936000	115
A	5	-0.009	9504000	110
B	1	-0.001	56592000	655
B	2	-0.003	17280000	200
B	3	-0.005	9504000	110
B	4	-0.007	7344000	85
B	5	-0.009	5184000	60

Dual Well Soultion				
Location	Trial	Pump Rate (m^3/s)	Duration (s)	Duration (Days)
C	1	-0.001	25920000	300
C	2	-0.003	8640000	100
C	3	-0.005	4752000	55
C	4	-0.007	3456000	40
C	5	-0.009	2592000	30

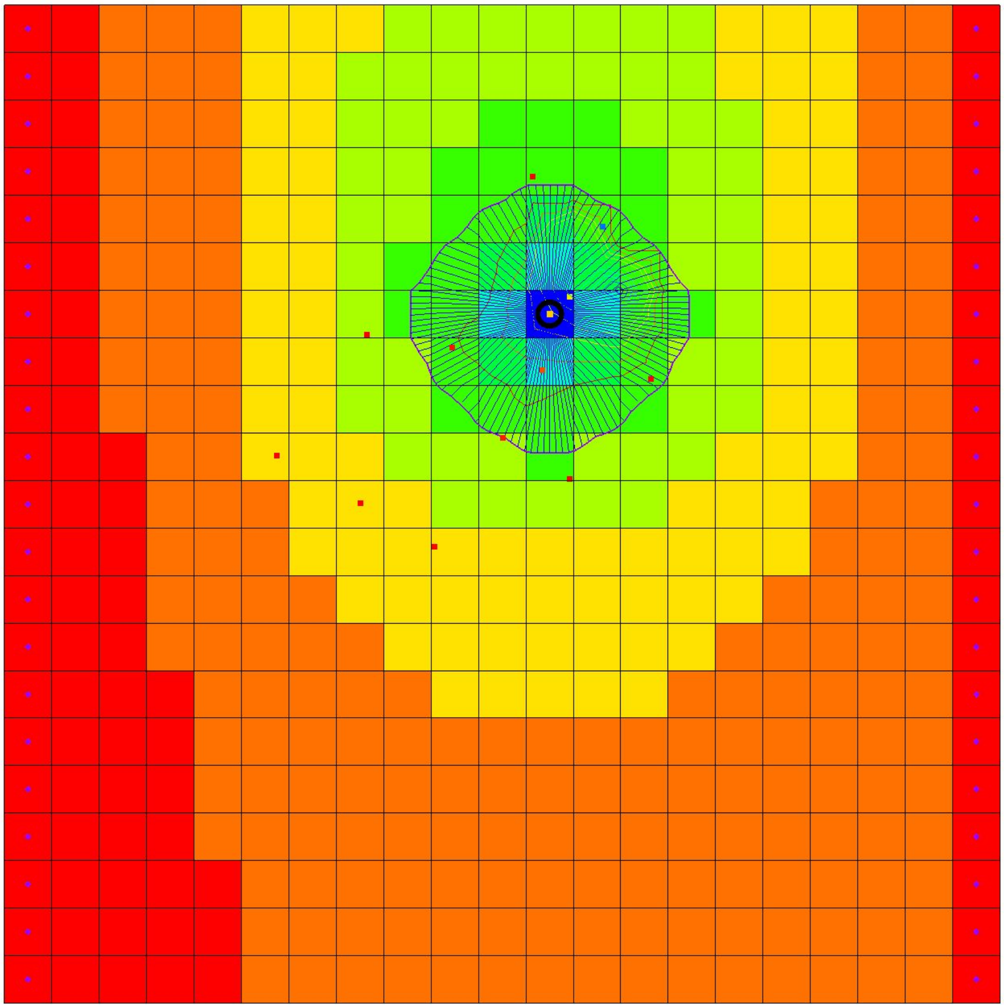


Figure 7: The Most Economical Well - Location B Trial 5

Economic Estimation

The team analysed the different cases for removing the contaminated groundwater from the site with a cost analysis.The team considered multiple factors in determination of the cost. Those factors include the pumping rate, time, unit energy costs, manpower, and the one-time installation and purchase of the well. The equation for cost analysis is shown below.

$$f(Q,T)= A+B+M+CR*Q*T*E \quad \text{Eq.3}$$

Where,
Q= Pumping Rate
T= Total Duration
E= Unit Energy Costs
M= Manpower
A= One-time installation/construction cost for wells
B= One-time purchase and setup cost for pumps
CR= Ratio of Power

The initial cost for the purchase and setup of a well pump was set at a fixed cost of $2,500 per well. The well installation/construction cost was assumed to be $1,000 per well. The cost of electricity was also fixed at $0.15(KiloWatts- hour). A fixed ratio for power usage of pumping was set at 1.5. The team determined that one highly-trained engineer must be at each well site to monitor the progress. The team estimated the pay rate to be $115. The well will run for 24 hours per day so a rotation of engineers will need to be employed to cover three eight-hour shifts per day. The cost of disposing the contaminated mixture was not considered in the cost analysis.

Discussion

The results of the cost analysis provided insight into the most cost-efficient way to remove the contamination plume. The bulk of the cost came from the labor associated with monitoring the pump as shown below in Table 5 below. The pumping rate and installation costs were relatively low when compared to labor. In scenarios where there were two wells all of the associated costs (pumping, installation, labor) were doubled. This made two well scenarios less viable unless the pumping duration was drastically shorter. The best solution to remove the contamination is a single well at location B during trial 5 due to its higher pumping rate which drove down duration. See Figure 7 for the wells MODFLOW and MODPATH data. At this location, the capture well runs for 60 days at a total cost of about $180,000.00.

Table 5: Single Well Solutions

Location	Trial	Pump Rate (m^3/d)	Duration (Days)	Pumping Cost ($)	Labor Cost($)	Total Cost ($)
A	1	-3.6	650	12,636	1,794,000	1,810,136
A	2	-10.8	250	14,580	690,000	708,080
A	3	-18	150	14,580	414,000	432,080
A	4	-25.2	115	15,649.20	317,400	336,549.2
A	5	-32.4	110	19,245.60	303,600	326,345.6
B	1	-3.6	655	12,733.20	1,807,800	1,824,033
B	2	-10.8	200	11,664	552,000	567,164
B	3	-18	110	10,692	303,600	317,792
B	4	-25.2	85	11,566.80	234,600	249,666.8
B	5	-32.2	60	10,497.60	165,600	179,597.6

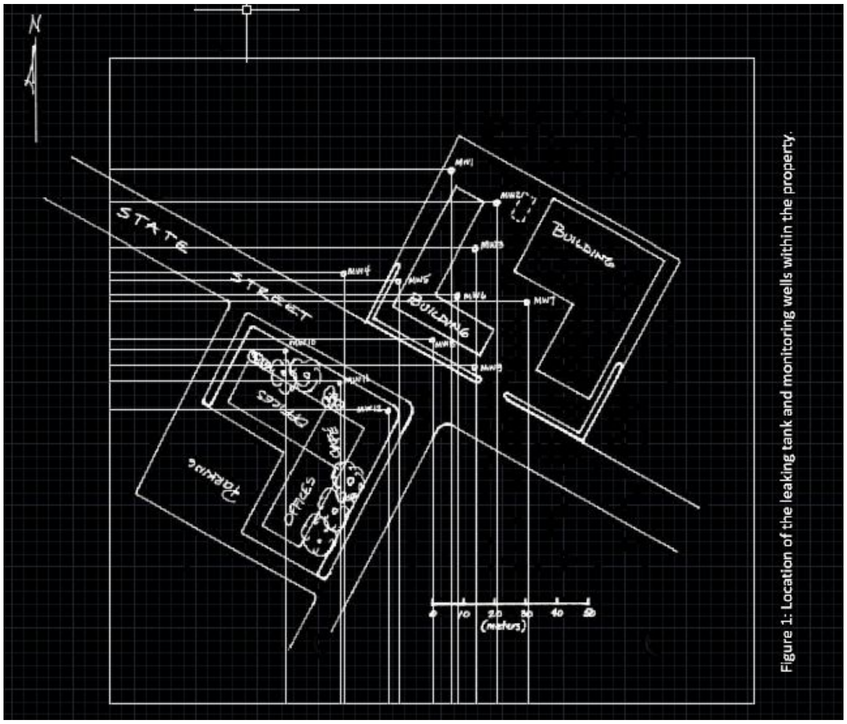
Table 6 Two Well Solutions

Location	Trial	Pump Rate (m^3/d)	Duration (Days)	Pumping Cost ($)	Labor Cost($)	Total Cost ($)
C	1	-3.6	300	11,664	828,000	1,674,664
C	2	-10.8	100	11,664	276,000	570,664
C	3	-18	55	10,692	151,800	321,292
C	4	-25.2	40	10,886.40	110,400	238,686.4
C	5	-32.4	30	10,497.60	82,800	183,097.6

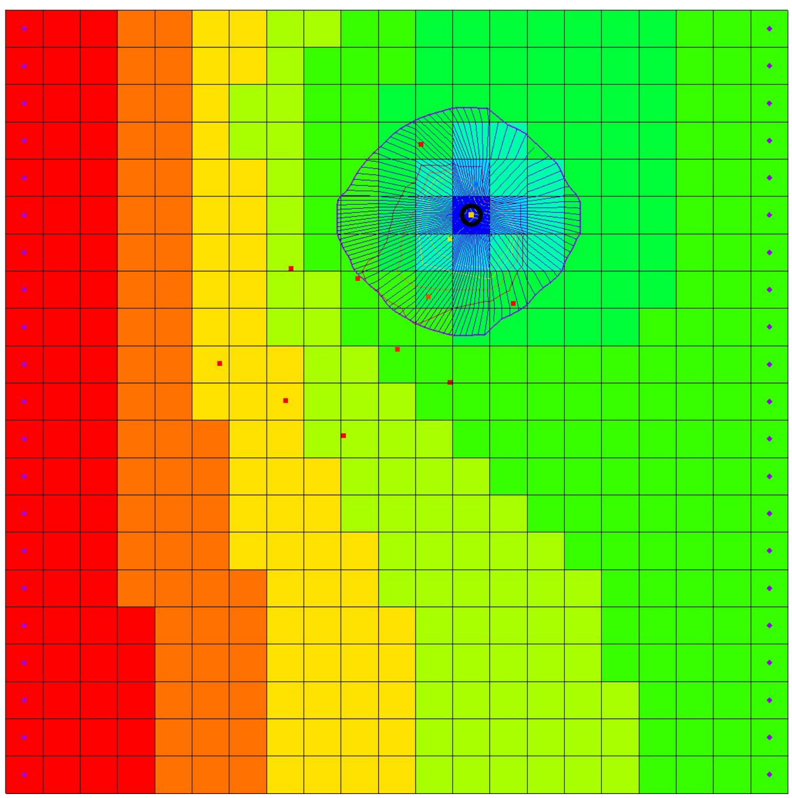
Conclusions/Recommendations

The leaking contaminant could have dangerous effects on the environment and human health, and thus needs to be cleaned up. A remediation plan will be put into place in the form of a capture well to remove any contaminated water. The team worked to find many locations and trials with both a single-well-pump and a dual-well-pump system. The biggest cost to the well was the labor as it would require ($115/hr) to have a certified engineer monitoring the progress of the capture well 24 hours per day. Of the simulations ran, as seen in Table 6, Location B trial 5 was the best economic choice. Due to the inverse relationship of cost and pumping rate. We would recommend using Location B trial 5 or a pumping rate beyond -0.009 m^3/s to yield the best economic value.

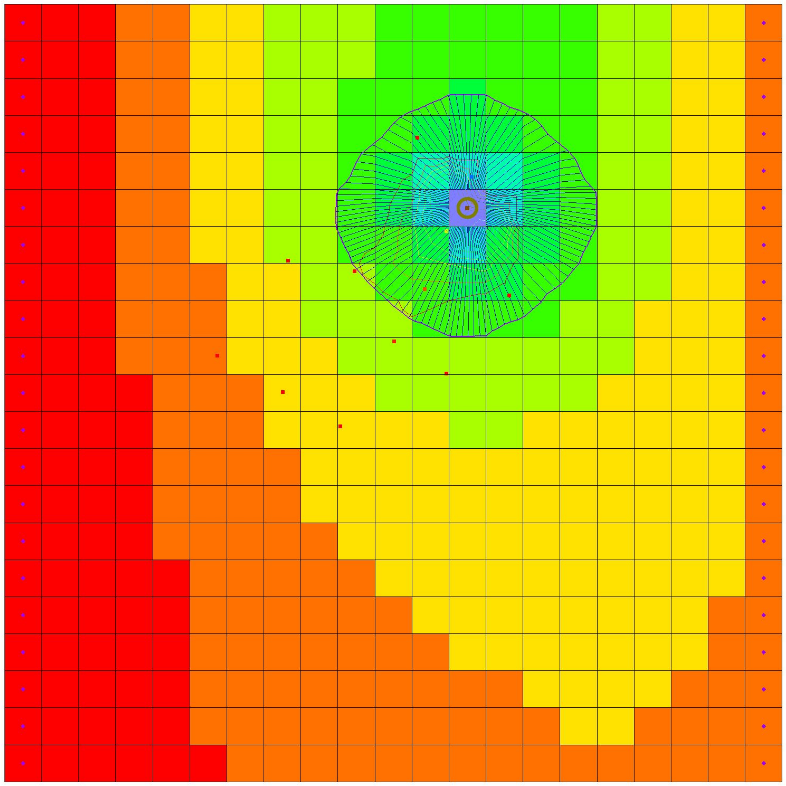
Appendix



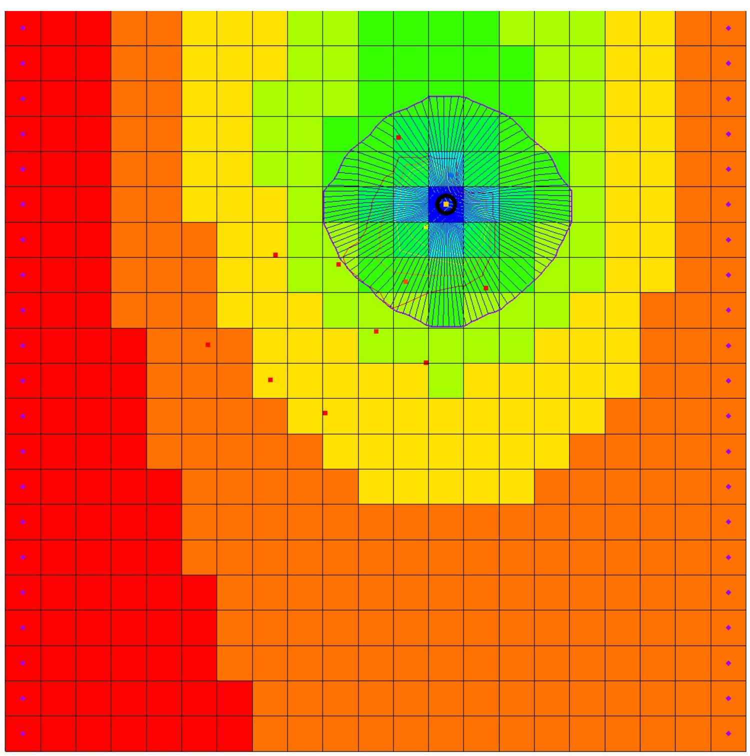
AutoCAD Coordinate System



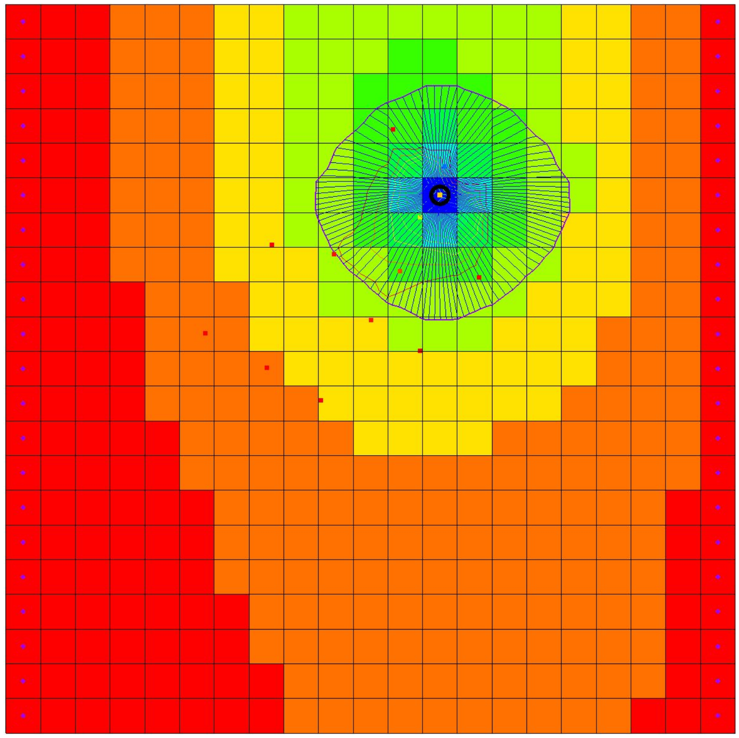
Location A: Trial 1



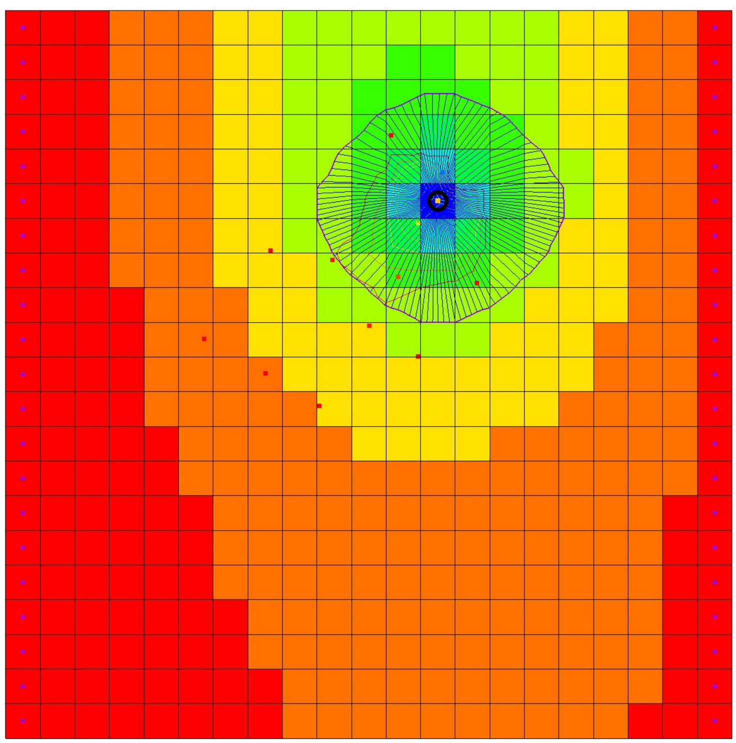
Location A: Trial 2



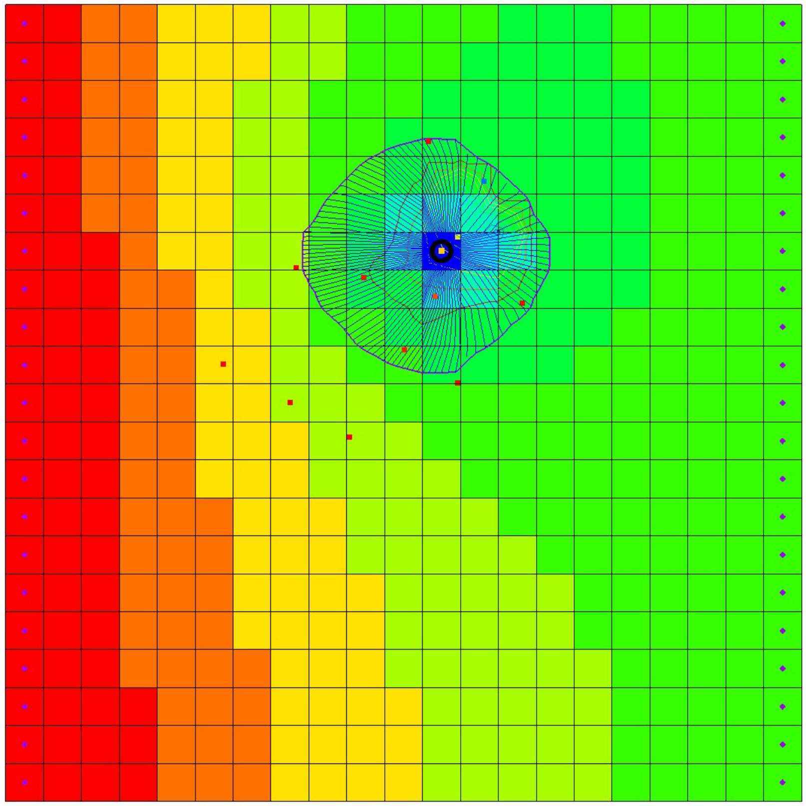
Location A: Trial 3



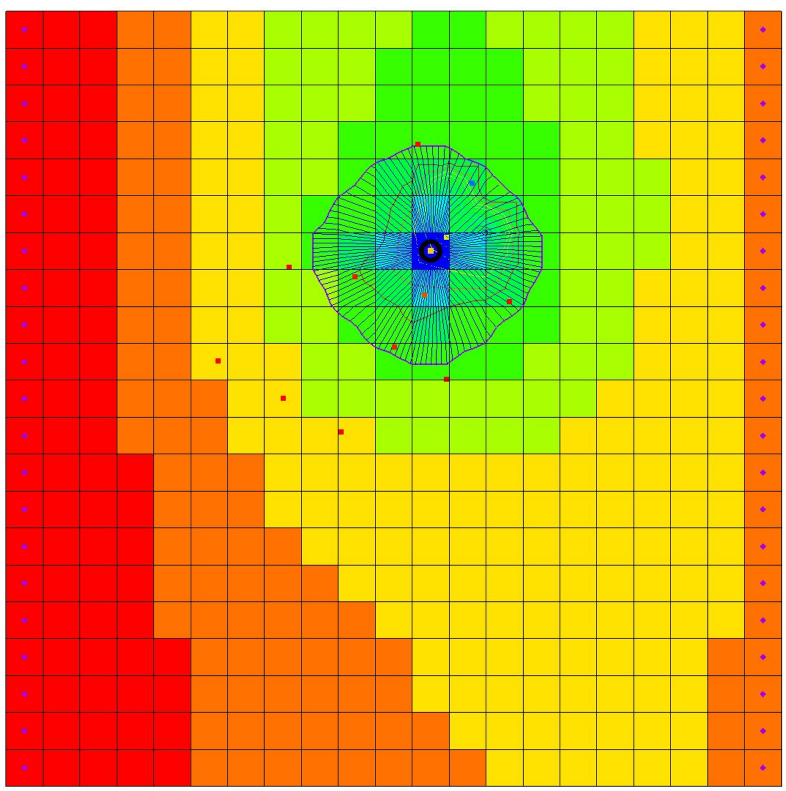
Location A: Trial 4



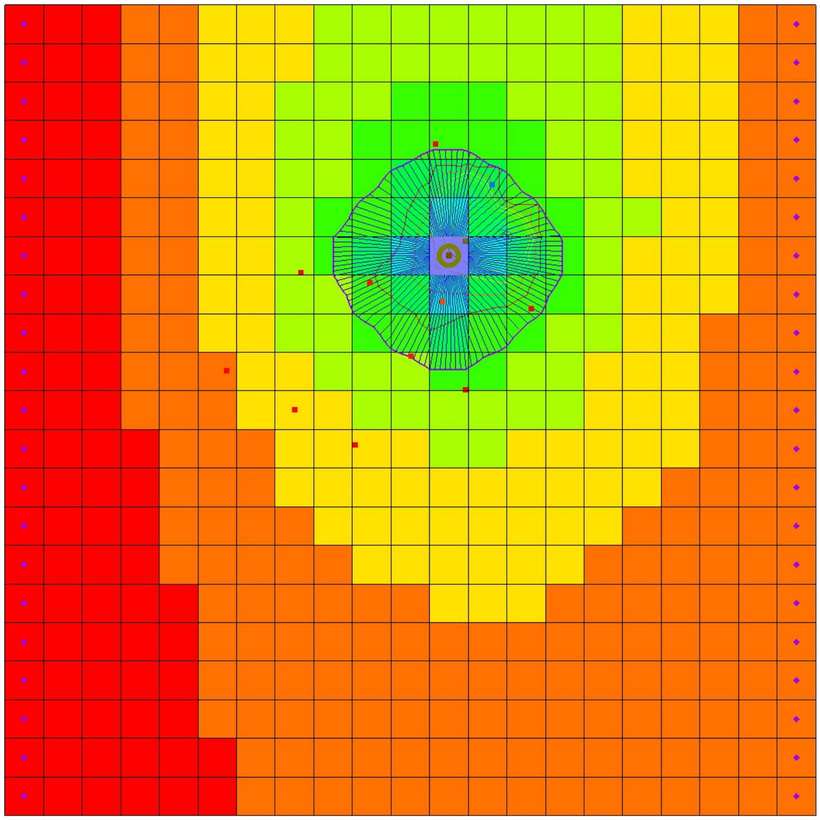
Location A: Trial 5



Location B: Trial 1



Location B: Trial 2



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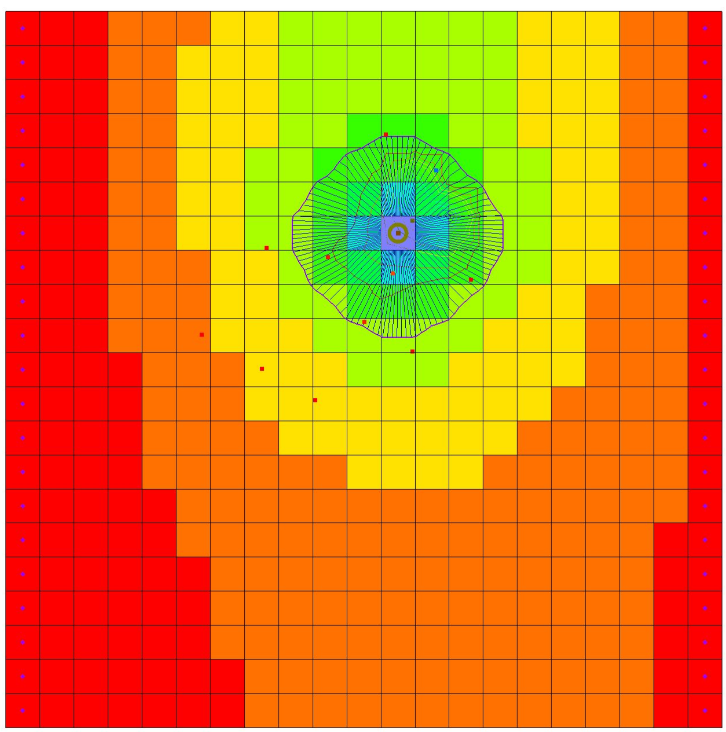

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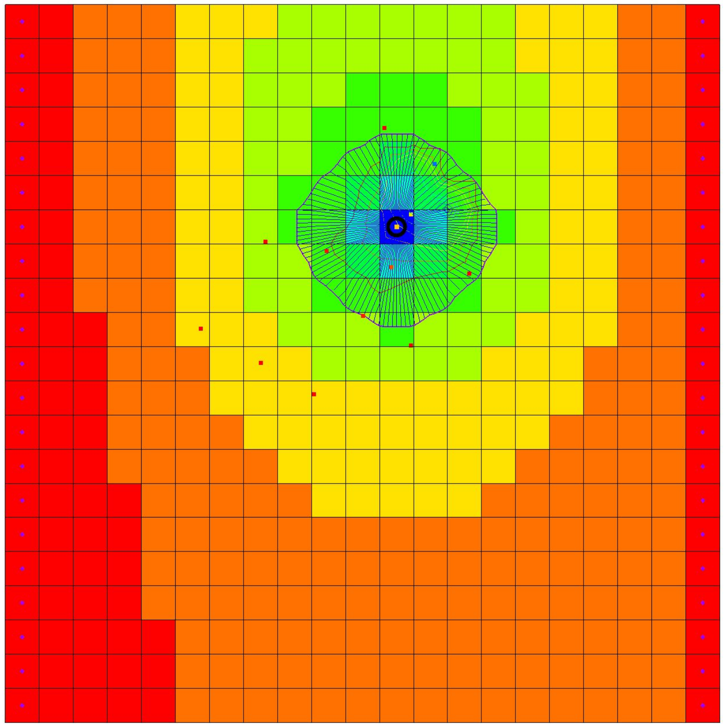

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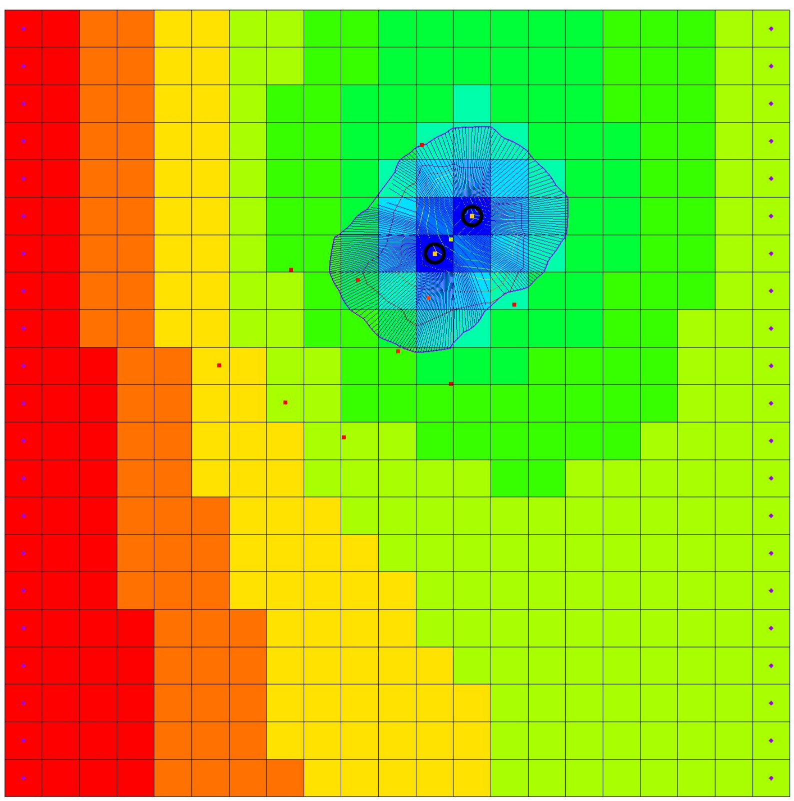
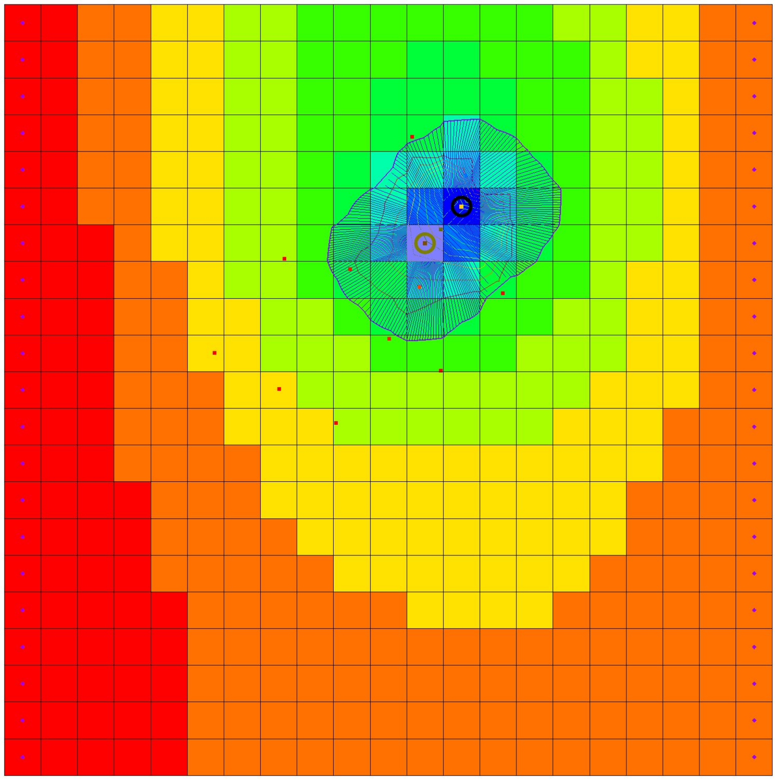
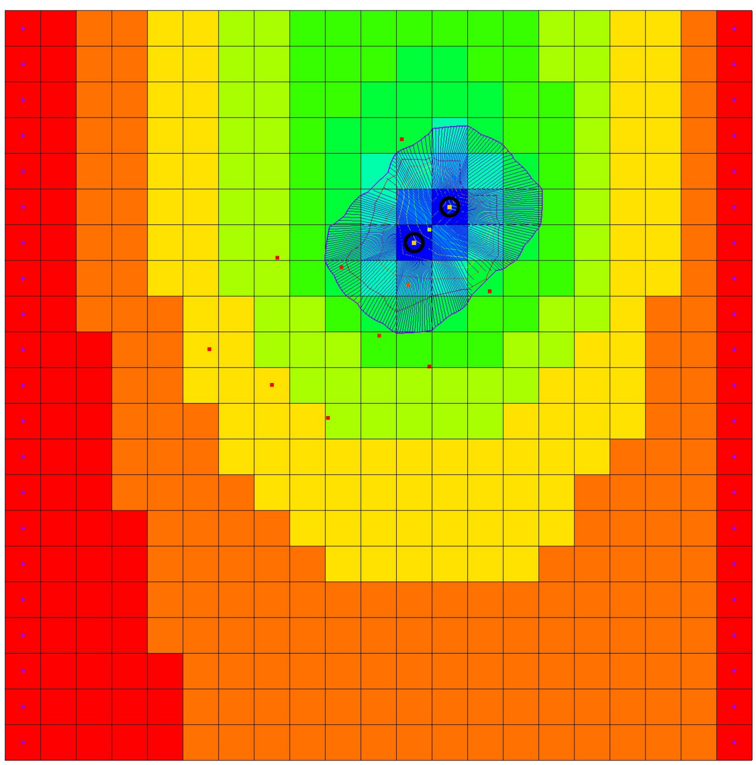


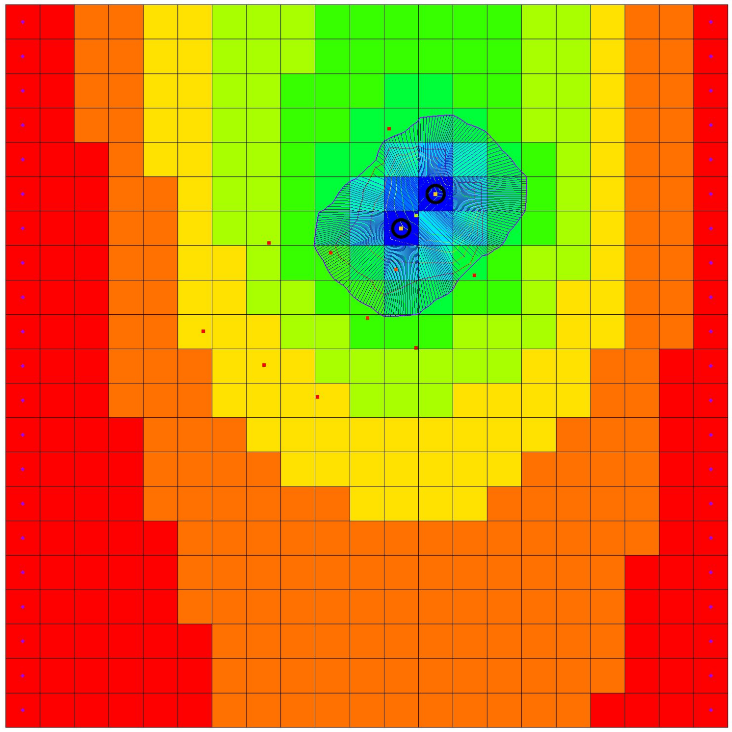
Location C: Trial 1



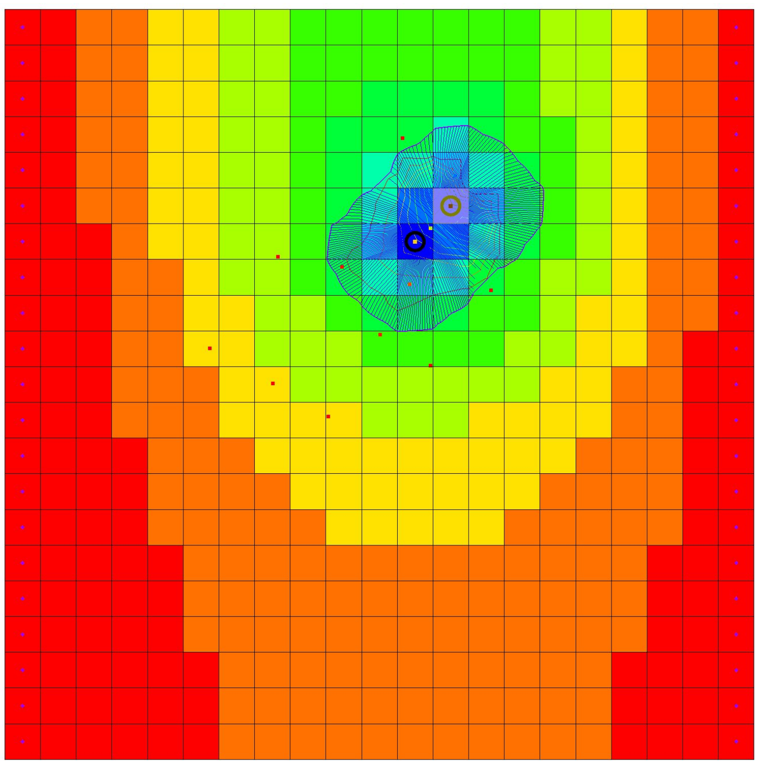
Location C: Trial 2



Location C: Trial 3



Location C: Trial 4



Location C: Trial 5

References

"Click Here to Support TEAM BIG DAWG Organized by Micky Sederburg." *Gofundme.com*, www.gofundme.com/1n60ic.

"Project 1 ENE 421." *Homepage - Michigan State University*, d2l.msu.edu/d2l/le/content/696338/viewContent/6684200/View?ou=696338.

"Well Data." *Homepage - Michigan State University*, d2l.msu.edu/d2l/le/content/696338/viewContent/6684202/View.