RANSOM Consulting, Inc.

Memo

400 Commercial Street, Suite 404, Portland, Maine 04101, Tel (207) 772-2891, Fax (207) 772-3248
Byfield, Massachusetts □ Portsmouth, New Hampshire □ Hamilton, New Jersey □ East Providence, Rhode Island
www.ransomenv.com

Date: May 20, 2014
To: Stu Marckoon, Adm. Asst. to the Selectmen
From: Robert Gerber, P.E. & C.G.
Subject: Response to Questions in letter of May 5, 2014

At your request I am providing my answers to the questions that you pose in the letter of May 5, 2014. Those questions were generated by the working group that is developing a revision of the Lamoine gravel extraction ordinance. I have agreed to provide my answers to these questions and attend a meeting of the working group to discuss these matters in more detail.

- Does removing gravel over the aquifer affect the level of the underlying water table?

Technically, yes, although the magnitude of the effect is small and the effect could be to either raise or lower the groundwater table elevation.

First, the effect could be to change the timing of the seasonal high and low water table position, depending on the change from the original thickness of gravel to the final thickness of gravel over the water table. In round numbers, the delay between the response of the water table to a precipitation or snowmelt event is about one week for every 10 feet of unsaturated thickness. So, as an example, if there is a 50-foot unsaturated zone between ground surface and the water table, there is a 5 week delay in water table response after a recharge event. So if 50' of gravel are removed, the timing of the seasonal high water table will be earlier by 5 weeks at the end of the mining than it was at the beginning of the mining.

If a gravel pit starts out as a rounded hill or ridge form and is then excavated to a closed contour pit, recharge would be theoretically increased and the water table would rise (as long as the excavation did not create a pond exposed to evaporation). This is because there would be no runoff in the final condition whereas some runoff would inevitably occur during in the pre-excavation condition.

Finally, the change of land cover through the stripping of vegetative cover from the original pit surface will reduce leaf interception (usually about 10% of precipitation) and some plant transpiration, so the overall effect is to increase the water table elevation until such time as the pit is reclaimed and the vegetative cover comes back to near the state it was before the excavation was started.

The magnitude of these changes in sand and gravel aquifers is unlikely to be more than a foot or two. As you can see from the above, except for shifts in the timing of the seasonal highs and lows, the most likely effect is to raise the water table.

- What separation level in a gravel pit is recommended to protect water quality?
- Is 5 feet of separation in a gravel pit to the seasonal high water table enough to protect the water quality?

There are a number of considerations in determining the protective nature of unsaturated sand and gravel to the underlying aquifer. These need to be separated between travel through *unsaturated* soil and travel through *saturated* sand and gravel. For most practical purposes we can assume that the horizontal travel distances to receptors is going to remain about the same in the saturated zone so I will focus on the change in the thickness and nature of the unsaturated zone.

The unsaturated zone provides several different functions that are beneficial to the protection of underlying aquifers. First, the greater the thickness of the unsaturated zone, the greater the amount of time it takes for a contaminant to travel downward to the water table. So if there is a fuel tank leak onto the ground, the amount of response time one has to try to recover the leaked fuel in the unsaturated zone is directly proportional to the unsaturated thickness.

The other important function of an unsaturated zone is the nature of the treatment it can provide for some types of contaminants. The unsaturated zone is well aerated and thus certain contaminants that require oxygen to break down to less harmful types are reduced more efficiently in the unsaturated zone. Similarly, the unsaturated zone provides suitable media surfaces for biological degradation and reduction of bacteria and virus concentrations.

The range of recommended unsaturated thickness in these situations that I have seen is a minimum of 2’ and a maximum of 10’. The Maine DEP reached the conclusion a long time ago after reviewing a lot of the literature and taking comments on proposed regulations that 5’ was a reasonable compromise that provides adequate protection. This assumes, of course, that there really will be 5 feet of unsaturated zone and that the depth to the water table will be accurately estimated. So, if that can be assured, then I would support the 5’ separation to the seasonally high water table.

- How many monitoring wells should there be in a pit for a given acreage to monitor separation?

First, realize that water table elevations are a reflection of: 1) the distribution of permeability in the aquifer; and, 2) the distribution of recharge and discharge locations and elevations. The more variable the permeability distribution, the less predictable the water table is just on the basis of scattered water table elevation measurements. Also, if the distribution of the discharge zones of the aquifer is irregular, that will induce less predictability into the water table surface shape.

The required density of monitoring wells is a question that is amenable to some degree of quantitative analysis. Having just obtained and reviewed a set of water level elevation data for the deep water table in the expansion area of the MacQuinn pit, I have run a series of analyses to show how one can predict the error in the estimate of the water table elevation based on a given distribution (and density) of monitoring wells.

There are 7 existing deep monitoring wells in the proposed MacQuinn Pit expansion area, somewhat irregularly distributed around the pit. If we look at a 74-acre area that encloses 7 wells, the well density is 10.6 acres/well. The SURFER™ software provides an ability to contour data in a number of ways and then also estimate the error in the estimating if you systematically remove one data point at a time and then re-contour the data and calculate the difference between the removed actual data value and the estimated value generated by the contouring algorithm, then do statistical analyses on these differences for all the individual points. I used the 4 most common contouring algorithms for this type of data: 1) triangulation with linear interpolation; 2) minimum curvature; 3) kriging; and, 4) inverse distance contouring (with an exponent of 2). There is a lot of complex theory and math behind this analysis which I will not go into here but rather just present the results of the analysis.

The actual measured groundwater table elevation range across the pit is from 87.5’ to 26’. The average or “mean” elevation error *residual* (difference between actual measured elevation and estimated elevation when contouring done with that point removed) for each type of contouring algorithm is given in the following table:

Contouring Algorithm	**Mean Residual Error**	**Standard Deviation of Residual Error**
Triangulation with Linear Contouring	-6.7’	9.9’
Minimum Curvature	-0.8’	3.1’
Kriging	1.7’	12.5’
Inverse Distance to a Power	3.6’	14.2’

I have artificially invented an additional 7 data points with at least plausible water elevations, giving an approximate density of 5.2 acres/well.

Contouring Algorithm	**Mean Residual Error**	**Standard Deviation of Residual Error**
Triangulation with Linear Contouring	-2.5’	8.4’

Minimum Curvature	-1.4'	8.8'
Kriging	.05'	7.0'
Inverse Distance to a Power	1.7'	11.3'

These evaluations show several things. First, just looking at a contouring of the existing seven data points, I have attached two of the contour plots: minimum curvature and kriging. Based on the sparse data in that set, in the eastern part of the site the two different contour plots suggest different directions of groundwater flow. When you double the number of data points the direction of flow becomes more certain (see plot of contoured water table based on kriging with 14 points). Second, you can see that when the number of data points is doubled for the same area, the average residual error of the four methods decreases to less than half what it was with 7 points (1.4' versus 3.2'). However, there is still a relatively large standard deviation error[1] (only decreasing from 9.9' to 8.9') for the residual, meaning the estimate of the water table elevation based on contouring between known points of data could still have one or more areas that are significantly in error.

I conclude from this type of analysis that for a real Lamoine example one well per every 10 acres is not sufficient. Even one well per 5 acres will produce potential average errors in water table estimates between data points of a foot or two on average.

- Should the separation monitoring wells extend into the water table as opposed to being just deep enough to ensure that the 5-foot separation is maintained?

If the only thing one is concerned about is water table separation, then shallower wells could be used. However, there are other reasons for knowing the water table elevation, namely, to estimate the general groundwater flow direction so water quality monitoring locations can be planned. As you see from the above analysis, if a well does not intersect the water table then that point produces no data that can be used in contouring the water table, making the groundwater flow direction determination less reliable.

- Should the town require water quality monitoring in a gravel pit to protect the water quality? If so:
- How many monitoring wells should there be in a pit for water quality testing?

In my opinion, yes. There are two reasons for this: one to protect the gravel pit owner and one to protect the town. In the first case it is very common for abutting property owners with wells to claim that a new gravel pit or quarry operation next to them somehow damaged the abutter's well. Therefore, the gravel pit operator needs to protect himself by developing data on baseline quality and water elevation before the excavation starts and then monitor changes with time in order to have data to evaluate any abutter's damage claim.

---

[1] In simplistic terms, if the residuals were normally distributed in typical bell-curve fashion, then about 1/3rd of the monitoring well residuals would be outside the range of the mean plus or minus the standard deviation. However, in the case of having only a few residuals, the distribution is probably skewed by one or two points that have high residual errors.

In the second case, the town is the entity providing the gravel pit operator with a license to mine the resource. It should provide some assurance to the rest of the town property owners that it has minimized the chances that operation of the pit will not harm them.

Water quality can change due to: 1) general geochemical changes due to the removal of large amounts of overburden, or 2) by accidental introduction of contaminants into a pit (most likely as petroleum products). In the first instance, the general geochemical changes could occur in naturally-occurring anion and cation concentrations such as iron, manganese, and arsenic concentrations. In the second instance, accidental or slow leak gasoline, diesel fuel, or hydraulic fluid could likely be the constituents of concern. The sooner a spill like diesel fuel is identified, the easier it is to capture it and/or mitigate any potential well contamination. Although petroleum spills and leaks are very low probability events, the cost of dealing with these types of contaminants in aquifers can be extremely large. Low probability events with large consequences still require planning and a mitigation strategy.

The number of monitoring wells required and where they are placed is a function of how well characterized the direction of groundwater flow is. The better the characterization, the fewer the wells that may be needed. In some instances groundwater flow is focused toward a discharge area such as a spring or stream. These types of features tend to focus flow and make it easier to be sure that detect/non-detect discriminations can be made. Therefore, the sampling locations for water quality monitoring points should only be made after the water table elevations are sufficiently characterized to give a good understanding of flow directions.

As to minimum number of water quality monitoring wells, I would recommend at least one upgradient well and 3 downgradient wells. As with the error involved in choosing the number of wells for monitoring groundwater table separation, I could produce some hypothetical cases to quantify possible errors in catching or missing changes in water quality. There is ample experience in the statistics of monitoring landfills, hazardous waste sites and petroleum spill sites to state some general principles of monitoring. The statistical methods of detecting significant changes in groundwater due to what is happening between upgradient and downgradient areas are well developed and certain methods produce less likelihood of producing what are called “false positives” where contamination is suggested but has not really occurred. False positives are more likely with geochemical parameters such as naturally-occurring arsenic which will vary typically over an order of magnitude over a long period of time. One has to develop estimates of both the mean and standard deviation of measurements with time. Using more than one background well, with other things being equal, is more likely to reduce the reporting of false positives when comparing upgradient and downgradient wells (inter-well comparisons) by using special statistics to group the upgradient results together rather than relying on a single well. Looking at a time series of chemical concentrations in an individual well (intra-well comparison) is often used but without a comparison to upgradient water quality results taken at the same time, one could report a false positive if the contaminant actually entered the pit from the upgradient side and is traveling through it.

- How often should water quality testing take place?

This is another area where examples could be generated to illustrate some general points. Again, studies with landfills and hazardous waste sites have already produced the basic answers and it has to do with the statistics of trend analysis. Baseline water quality must be established in order to do trend analysis. Without going into the statistics, good baseline data sets include about 12 data points from 3 years of quarterly sampling. After that, I would suggest semiannual sampling at the times of year of high groundwater and low groundwater. As a general rule of thumb the rate of travel of a conservative (not adsorbed or attenuated) contaminant in sand and gravel aquifers is about 1 foot per day. Therefore, a contaminant would travel about 180 feet between sampling episodes. So if a monitoring well were located at least 100 feet inside the boundary of a pit and the closest residential well on the outside were 100' from the boundary, then the semi-annual sampling should catch an indication of contamination before it gets to the well.

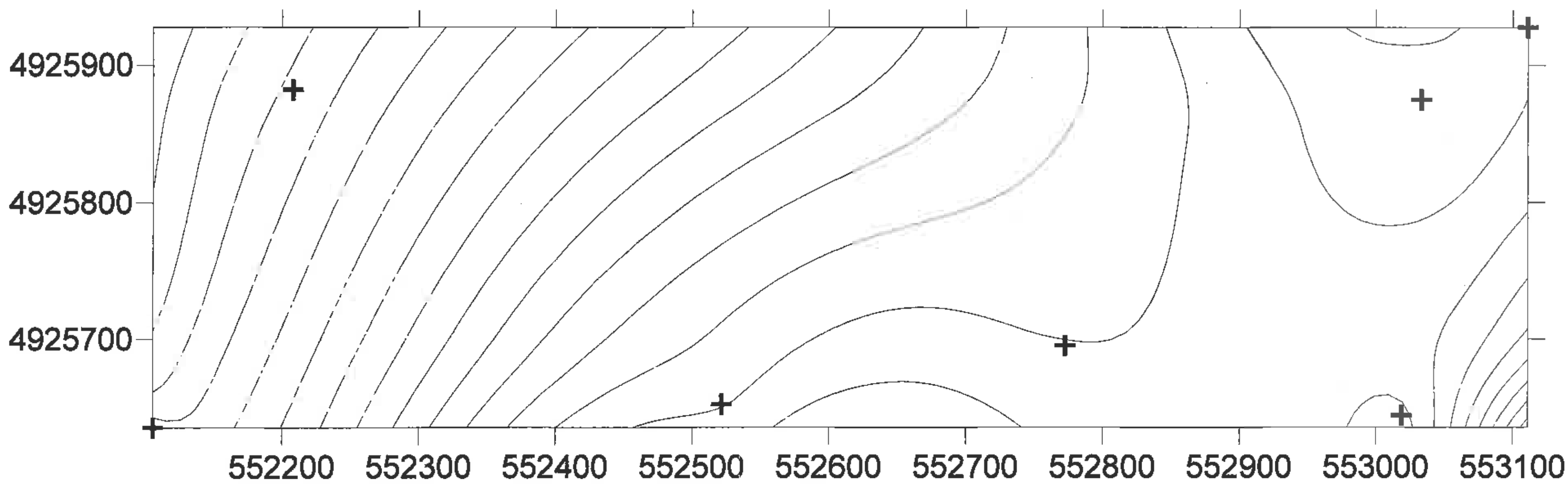
- What should the town do with the water quality testing data?

Because the protocols for water quality sampling are well developed for other potential sources such as landfills and hazardous waste sites, the operators should have no trouble finding laboratories and consultants capable of taking and reporting reliable water quality sampling results. There are fewer consulting resources in Maine, however, that have the knowledge and software to create and maintain the water quality databases and do the appropriate statistical tests to do the upgradient/downgradient comparison and time series trend analyses. The best statistical methods to use to prevent the reporting of "false positives" are sophisticated and require some skill to set up and interpret.

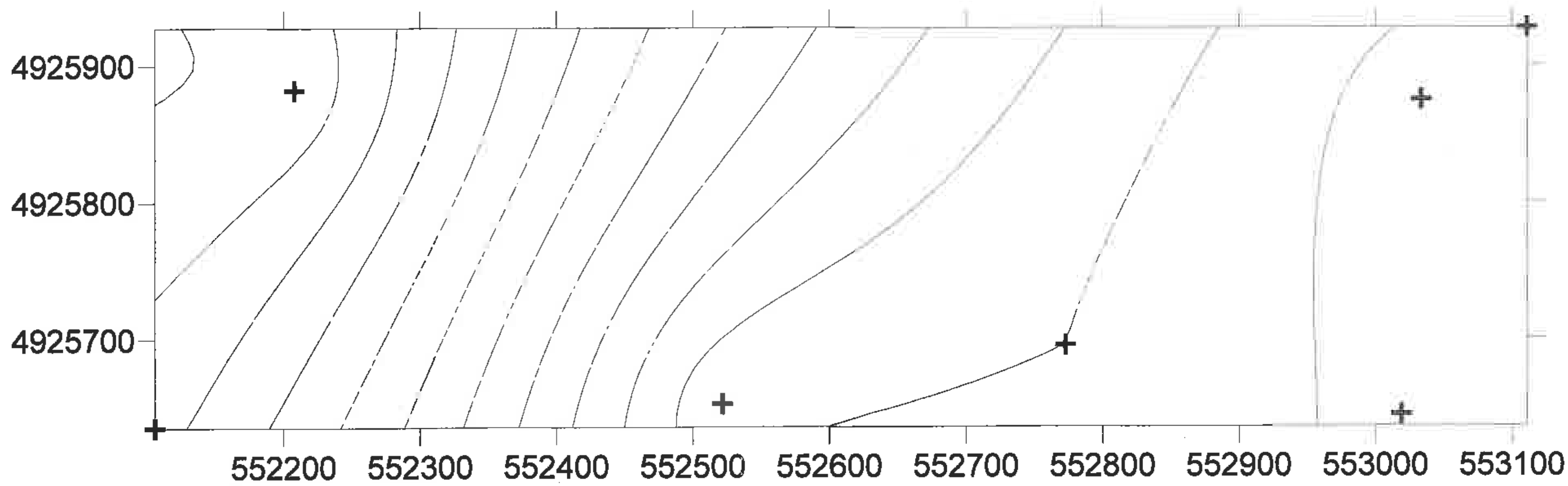
If all individual pit owners do their own analyses, then it is less likely, too, that a unified town-wide database could be developed that will give the town information on the overall state of the groundwater resource. Therefore, it might be best if the results are reported to the Town in a specific format suitable for entry into specialized water quality statistical analysis packages, and let a single consultant do the analysis and report that back to the town and the operators.

- What imposition should there be on the pit operators should water quality degrade?

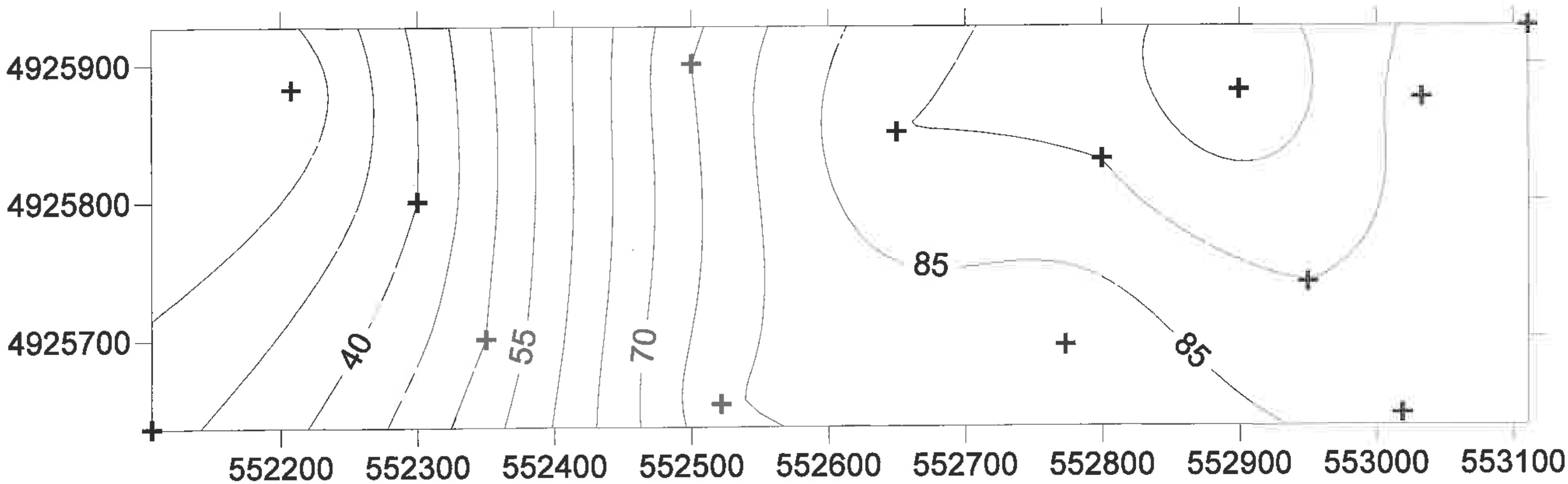
If water quality degrades and a combination of upgradient/downgradient and trend analysis suggests that the source is a particular pit, then the usual procedure is to: 1) simultaneously look for a source and re-test to confirm the first test; 2) based on the known groundwater table elevations and expected flow directions, determine where downgradient receptors (e.g., domestic wells) might be located and how much time it would take for a contaminant to travel from the monitoring well or known spill location to the receptor; 3) do an assessment of the nature and magnitude of risk (e.g., considering



Contouring with Minimum Curvature



Contouring with Kriging



Kriged Groundwater Contours, 14 points

the toxicity and concentration of the contaminant); 4) if the nature of the impact is a geochemical change, a treatment system (e.g., water softener) may be needed to be installed on receptor wells; 5) if the impact is a petroleum source or other point source, the source must be found through insitu exploration and then the source must be remediated and/or its migration controlled, and temporary treatment of receptor locations may be needed or drinking water provided in bottled form. The presumption is that the gravel pit operator will be liable for all expenses in the above steps and should normally be responsible for hiring consultants and contractors to follow the above steps with town oversight. Since the town is licensing these pits, it should not force neighbors to file lawsuits to cure contamination problems generated by the licensees.

That being said, there may be instances when an offsite well or surface water is contaminated, yet no spill source nor any contamination in any monitoring well in an upgradient licensed pit has been identified. There may be a possibility that there is either a source on the offsite property, or that some contamination occurred in the pit but escaped detection. An option in this case is to call in the Maine DEP's Emergency Spill Response Team and let them do the initial response and investigation. If it is ultimately found that the contamination originated in a licensed pit, then the DEP and the Town can recover costs from the pit operator.

- Should shallow gravel pits outside the mapped sand/gravel aquifer be required to test for water quality?

In my opinion, yes. It is not a well-known or appreciated fact but thick sand and gravel aquifers are actually more resilient in adsorbing and diluting contamination than other non-aquifer terrains such as borrow pits in glacial till, glaciomarine fine sands, or glaciomarine clay. The latter pits are more likely to have water tables much closer to ground surface and water tables that either mimic the ground surface contours or that of underlying bedrock surfaces. So it may be easier to install wells in areas of converging groundwater flow and reduce the number of downgradient wells to 2 or 1 through a variance procedure if the right conditions exist.

Attachments: 1) groundwater contour map based on 7 data points in 74 acres using minimum curvature method of contouring; 2) contour map based on 7 data points in 74 acres using kriging method of contouring; and, 3) groundwater contour map based on 14 data points in 74 acres using kriging method of contouring