Proceedings of ETCE/OMAE 2000:
"ENERGY FOR THE NEW MILLENNIUM"
February 14-17, 2000 New Orleans, Louisiana

ETCE2000-10156

OVERLAY MAPPING TECHNIQUE FOR ESTIMATING LNAPL THICKNESS AND DISTRIBUTION IN SUBSURFACE

Mehmet Pehlivan, R.G., C.H.
Tait Environmental Management, Inc.

Keywords: LNAPL, free floating product, free phase hydrocarbon, free product thickness, overlay mapping

ABSTRACT

This paper presents a method of calculating the thickness and mapping the aerial distribution of light non-aqueous phase liquid (LNAPL) in the subsurface using the overlay mapping technique. The measured thickness of the LNAPL resting on the water table in a well is greater than the actual thickness present in the aquifer. The modified Zilliox and Muntzer equation has been widely used to calculate the corrected elevation of the groundwater and actual thickness of LNAPL. This equation uses the apparent LNAPL thickness as measured in the wells, and the density of the LNAPL. Although this equation yields a reasonable approximation, there is still a need for a tool to estimate the aerial distribution of the LNAPL based on the groundwater gradient and the source areas of the LNAPL. The overlay mapping technique is used in oil exploration and development to calculate and map net oil thickness in petroleum reservoirs. Using the overlay mapping in estimating LNAPL thickness and aerial distribution requires that the LNAPL be completely assessed, with non-LNAPL wells surrounding the LNAPL wells. The technique involves preparation of a groundwater elevation map and a LNAPL elevation map. These two maps are superimposed on each other; and from the contour crossing points, the thickness of the LNAPL is calculated. By connecting the points where the elevation of the groundwater and LNAPL are equal, a contour showing the LNAPL boundary (zero thickness) is drawn. This technique allows better assessment of the LNAPL plume in subsurface.

INTRODUCTION

This paper presents a method of estimating the thickness and aerial distribution of light non-aqueous phase liquid (LNAPL) in the subsurface. The LNAPL thickness measured in a well is approximately 4 to 5 times higher than the actual thickness outside the well within the aquifer. It is important to estimate the actual thickness and distribution of the LNAPL in the subsurface to estimate the quantity of the LNAPL and the extent of the LNAPL plume for remediation.

This paper provides a brief description of LNAPL migration, followed by a discussion of the proposed overlay mapping technique, a case example, the limitations of the method and the conclusions.

BACKGROUND

The LNAPL released to the subsurface usually originates from leaking underground fuel storage tanks, leaking above ground bulk fuel storage tanks, piping leaks or from surface spills. The LNAPL typically travels vertically through the subsurface material until it reaches the water table. Because the density of the LNAPL (also referred as *"free phase hydrocarbons"*) is less than the density of water, it creates a floating layer above the water table. This layer of LNAPL depresses the water table in the subsurface. A separate capillary zone consisting of both LNAPL and water is also formed at the interface (Figure 1).

Assuming there was no LNAPL resting above the water table, the elevation contour of the groundwater will reflect the natural gradient and flow direction. When a layer of LNAPL is present at the water table, it will depress the water table to compensate for the weight of the LNAPL. The depression of the water table is partially compensated for by the LNAPL - water capillary zone. Water levels in a well located in the LNAPL plume will be further depressed by the full weight of the LNAPL accumulating in the well. The thickness of the capillary zone between the LNAPL and the water will further contribute to the water level depression in the well. The modified Zilliox and Muntzer equation (Hampton 1988) has been widely used to estimate the corrected elevation of the groundwater in the wells with free product and to estimate the actual thickness of LNAPL zone above the water table. The modified Zilliox and Muntzer equation uses the apparent thickness of the LNAPL measured in the wells and density of the LNAPL to estimate the depression of the water level in the well.

The modified Zilliox and Muntzer equation can be simply expressed as:

$$h = \frac{H(\rho_w - \rho_o)}{\rho_o} \qquad (1)$$

Where:
h = Estimated thickness of free product in the aquifer
H = Measured thickness of free product in the well
ρ_w = Specific gravity of water (1.0 gram/cc)
ρ_o = Specific gravity of LNAPL

Although the modified Zilliox and Muntzer equation yields a reasonable approximation of the actual thickness of the LNAPL, there is a need for a tool to estimate the aerial distribution of the LNAPL based on the groundwater gradient and the source areas of the LNAPL.

Later studies addressed the relationship between the LNAPL measured in the well and LNAPL present outside the well in the pore space (Hughes et al 1988, Lenhard; and Parker 1990, Ballestero et al, 1994, Huntley et al 1994, Lundegard and Mudford, 1998). It was suggested that no discrete floating layer of LNAPL exists in the formation but that a zone of pore space exists that is partially filled with LNAPL and water.

METHOD DESCRIPTION

Although, the earlier studies provide valuable information and models for establishing relationships between the measured LNAPL in the well and the LNAPL in the pore space, there is still a need for a practical tool to estimate the aerial distribution and the thickness of the mobile LNAPL (with the highest degree of saturation) zone in the pore space using commonly available data. The most commonly available/obtainable data in the field for the practicing scientists and engineers are the depth to groundwater and the depth to LNAPL as measured in wells. Using this information and well elevation data, one can easily calculate the elevation of the groundwater and the LNAPL in the wells. In most cases, the elevation of the LNAPL in the well should reflect the elevation of the free flowing LNAPL in the porous medium outside the well. The challenge is the estimation of the groundwater elevation outside the well in the porous medium. I suggest using the overlay mapping technique to simplify the problem and to map the distribution of the LNAPL in the subsurface. The overlay-mapping technique does not take into account the capillary zone thickness and LNAPL saturation (% of pores that filled with LNAPL) in the porous medium. However, it provides a reasonable estimation for thickness and aerial distribution of the LNAPL zone that has the highest saturation and mobility.

The overlay mapping technique has been used in oil exploration and development to map the net oil thickness in petroleum reservoirs . The application of the overlay mapping technique for LNAPL involves the following steps:

- Preparing a groundwater elevation contour map using the wells without LNAPL.
- Preparing a LNAPL elevation contour map using the wells with measurable LNAPL.
- Superimposing these two maps on a light table and marking contour crossing points. The superimposing can be done in CAD by assigning each contour to a different layer and changing the layer's visibility.
- Calculating the LNAPL, thickness by subtracting the groundwater elevations from the product elevation at the LNAPL and water elevation contour crossing points.

METHOD APPLICATION

I will illustrate the preparation of these maps with a case history from Buena Park, California. The site was a former auto repair and sale facility with a 2000-gallon (7570 liters) fuel underground storage tank (UST). The depth to perched groundwater at the site is 10 feet (3.05 meters) below ground surface (BGS). The UST was removed and the extent of the dissolved and LNAPL plume was assessed with several rounds of drilling and well installation. I applied the overlay-mapping technique to estimate the aerial distribution and the thickness of the LNAPL at this site. As shown in the Figure 2, first a groundwater elevation map was prepared using the wells without the measurable LNAPL. Although the wells with the measurable LNAPL will not be used in contouring, they should be used to get a general idea about interpreted groundwater elevation at the well points. The interpreted groundwater elevation at wells with LNAPL should fall between the elevation of the measured LNAPL and measured groundwater in the well. For example, in well MW-5, the measured LNAPL elevation is 55.10 feet (16.79 meters) above mean sea level (MSL) and measured groundwater elevation is 54.04 feet (16.47 meters) above MSL (Figure 2). The interpreted elevation of the groundwater will be greater than the measured groundwater elevation of 54.04 but less than the measured LNAPL elevation of 55.10 feet above MSL. In the case shown in Figure 2, the interpreted groundwater elevation is 54.79 feet (16.70 meters) above MSL.

Secondly, a LNAPL elevation map was prepared (Figure 3). When there is no measurable LNAPL in the well the LNAPL elevation should be interpreted as being equal to the elevation of the groundwater. As shown in the Figure 3, the LNAPL elevation will curve, forming an ellipsoidal mound. The LNAPL contour should terminate when it crosses a groundwater contour with the same elevation. The LNAPL contour should never be drawn for the elevations lower than the elevation of the groundwater at a given point.

Finally, using the contour crossing points of LNAPL and groundwater, thickness of the LNAPL zone is calculated. (Figure 4 and 5) At each contour crossing point the groundwater elevations are subtracted from the LNAPL elevations to get the LNAPL zone thickness. It is recommended that the user of this method should work on the map that contains both groundwater and LNAPL elevation map to fine tune the LNAPL zone thickness contours.

DISCUSSION AND CONCLUSION

Using overlay-mapping technique requires the knowledge of the subsurface formation where LNAPL and groundwater present. The overlay mapping technique is best when used for the steady state condition in uniform porous media. Changes in the porous media will result erroneous interpretation. Additionally, if the LNAPL is spread over a wide area, the interpreted groundwater contours may not be correct toward the center of the LNAPL plume. It is not recommended to use the overlay mapping in fractured, heterogeneous, confined and semi-confined aquifers. Where groundwater elevation fluctuates seasonally, the overlay-mapping method may results erroneous interpretation of the LNAPL plume. A rapidly declining groundwater elevation may leave LNAPL plume in the porous media above the water table. On the contrary, the rapidly increasing groundwater may trap the LNAPL within the saturated zone. When calculating the total volume of the LNAPL in the porous media, the LNAPL saturation must be taken into consideration. It is advised that several core samples be collected from the LNAPL zone and be tested for LNAPL saturation by a qualified laboratory prior to estimating LNAPL volume in the porous media.

In conclusion, the overlay mapping technique is another tool to estimate the aerial distribution of the LNAPL. When used with care and in conjunction with the other methods and calculations, it will provide valuable information about the LNAPL plume. The method may not work for every situation. However, going through the exercise will benefit to project managers significantly for understanding the distribution of the LNAPL plume.

ACKNOWLEDGEMENT

The author is grateful to Dr. Andrew K. Wojtanowicz, PhD, PE, for critical review and valuable comments in finalizing this paper.

REFERENCES

Ballestero, T.P., F. R. Fiedler, and N.E. Kinner, 1994, "An Investigation of the Relationship Between Actual and Apparent Gasoline Thickness in a Uniform Sand Aquifer", " Ground Water, Vol. 32, pp. 708-718.

Hampton, D. R., and P. D. G. Miller, 1988, "Laboratory Investigation of the Relationships Between Actual and Apparent Product Thickness in Sands", in Proceedings of the Conference on Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention Detection and Restoration, Houston, Texas, pp. 157-181.

Hughes, John P, Clay R. Sullivan and Ronald E. Zinner, 1988, "Two Techniques for Determining the True Hydrocarbon Thickness in an Unconfined Sandy Aquifer" in Proceedings of the Conference on Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention Detection and Restoration, Houston, Texas, pp. 291-314.

Lundegard, P.D. and B.S. Mudford, 1998 "LNAPL Volume Calculation: Parameter Estimation by Nonlinear Regression of Saturation Profiles" Groundwater Monitoring and Remediation, Vol. XVIII, No. 3, pp: 88-93.

Huntley, D., R.N. Hawk, and H.P. Corley. 1994, "Non-aqueous phase hydrocarbon in a fine–grained sandstone: 1. Comparison between measured and predicted saturation and mobility". Ground Water, Vol. 32, pp. 626-634.

Lenhard, R.J. and J.C. Parker, 1990. "Estimation of free hydrocarbon volume from fluid levels in monitoring wells", Ground Water, Vol. 28, No.1 pp: 57-67.

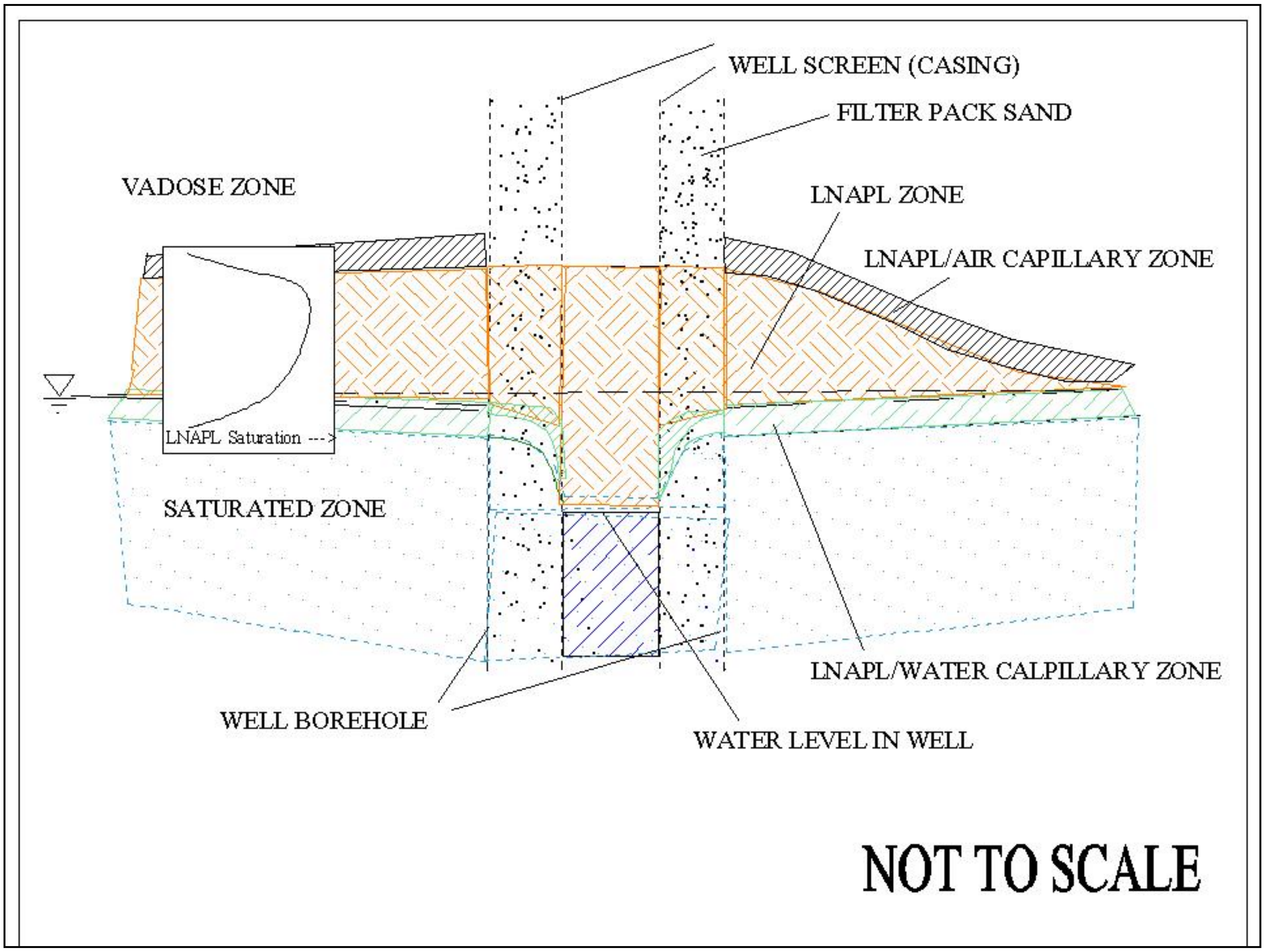

Figure 1. Schematic representation of LNAPL and water interface in the subsurface. The thickness of the capillary zone between water and LNAPL and between air and LNAPL varies based on the subsurface media (sand/gravel/silt etc.), and the age of the product release. (Revised 3-15-00)

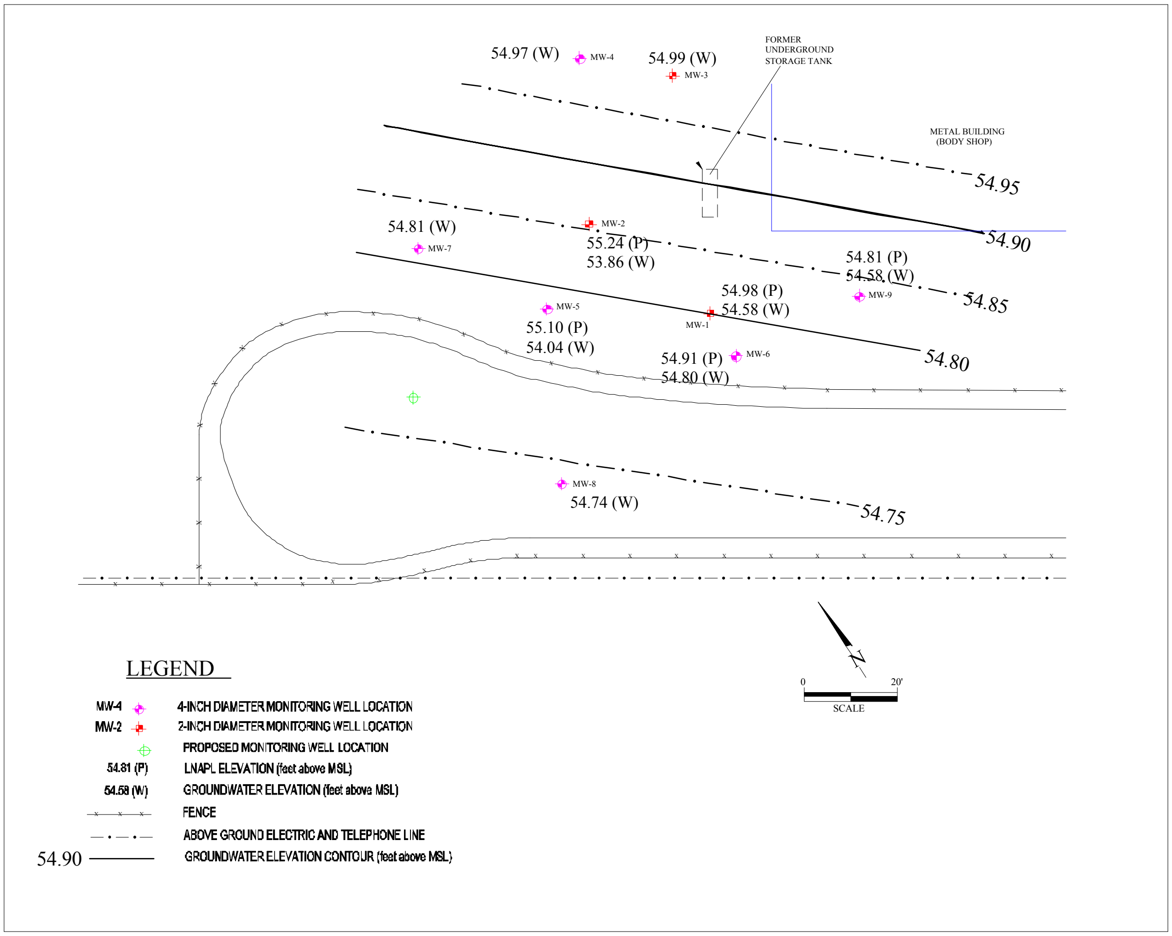

Figure 2. Groundwater elevation contour map. The map was prepared using the groundwater elevation value calculated from the wells without LNAPL (MW-3, MW-4, MW-7, and MW-8).

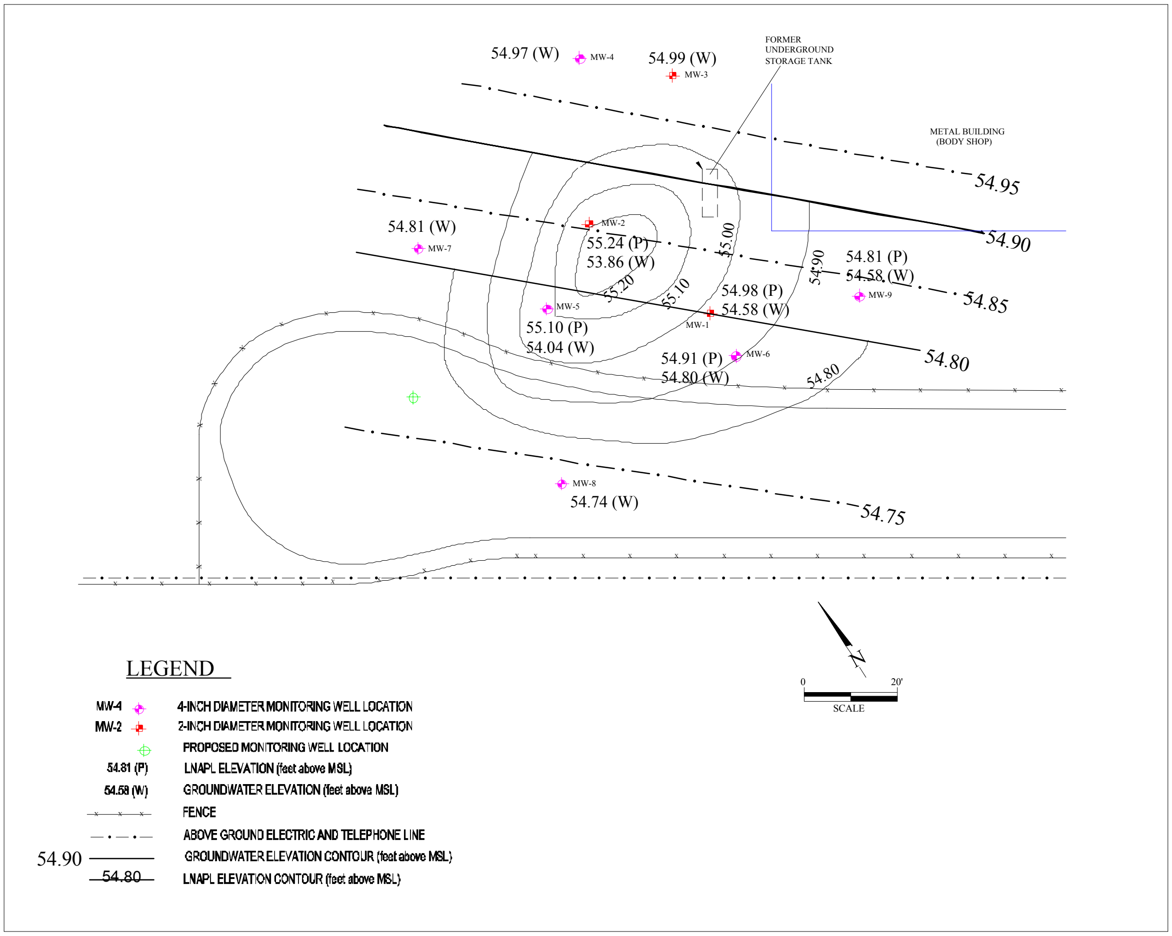

Figure 3. The LNAPL and the groundwater elevation contour maps. The LNAPL elevation contour map is prepared using the top of LNAPL elevations calculated from the measurements taken in the wells with measurable LNAPL (MW-1, MW-2, MW-5, MW-6, and MW-9).

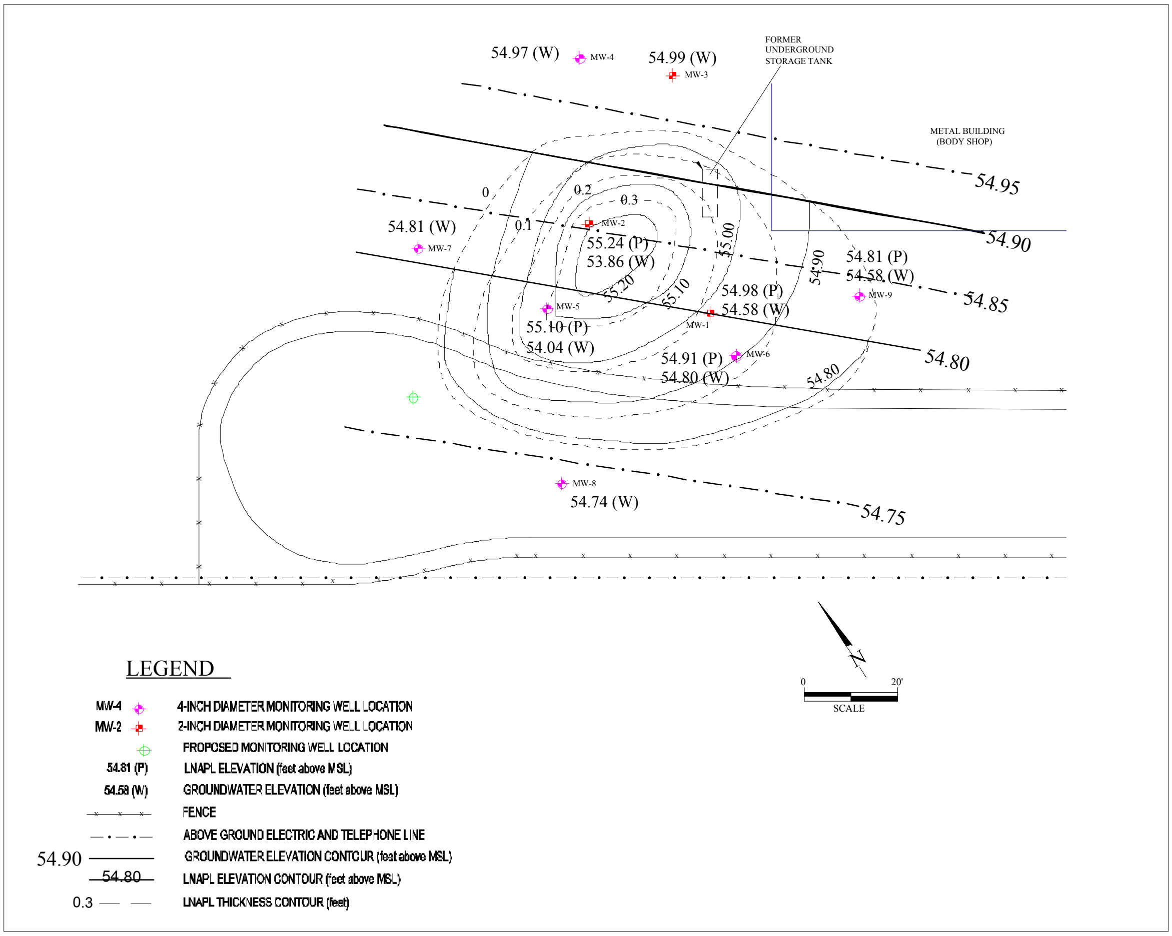

Figure 4. LNAPL Thickness, groundwater and LNAPL elevation maps. The LNAPL thickness map (dashed) was prepared using the contour crossing points of LNAPL elevation and groundwater elevation maps. The proposed well was installed after this study and no LNAPL was observed during the subsequent groundwater monitoring activities.

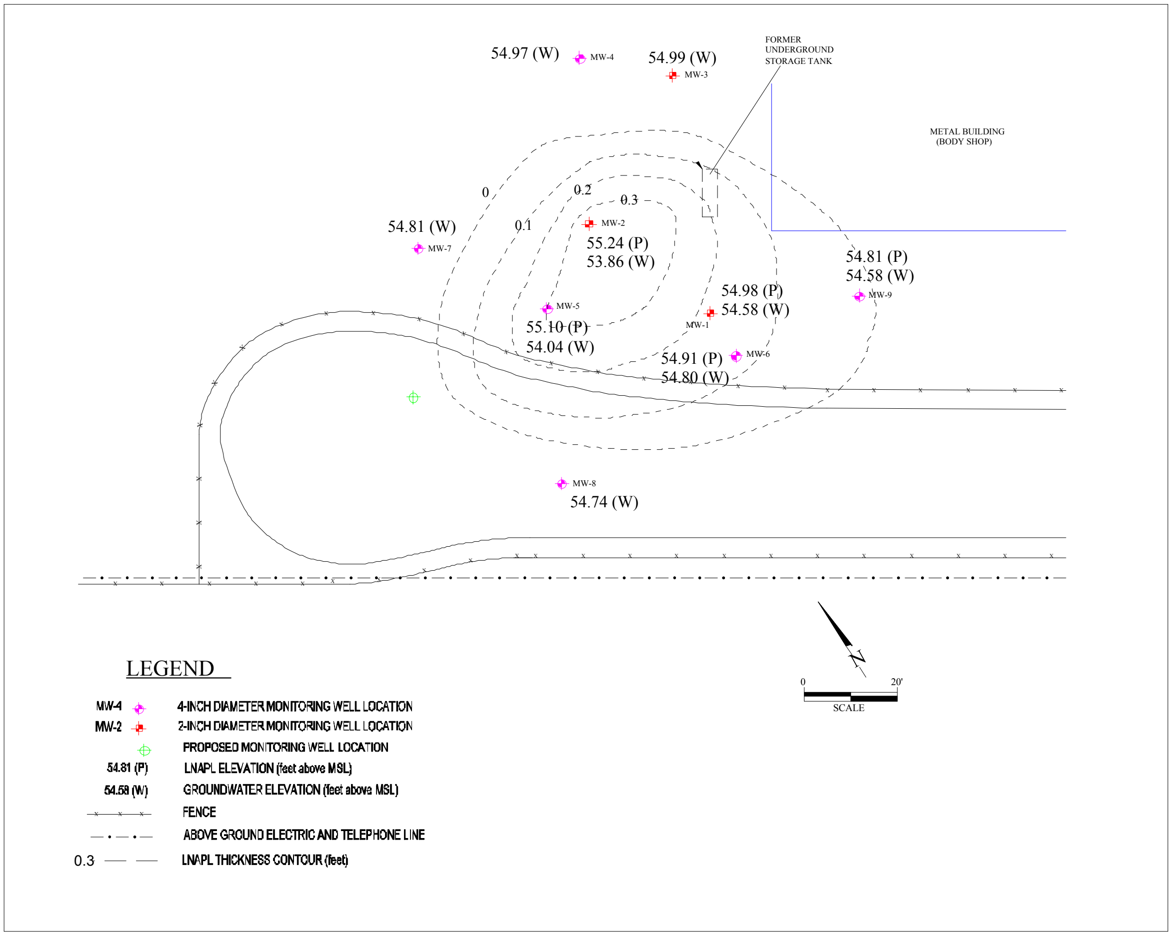

Figure 5. The LNAPL thickness map. This map can be used in calculating the volume of LNAPL zone and placing additional groundwater monitoring wells to further assess the LNAPL plume.