APPENDIX H

Current Landfill
Groundwater Modeling
Fate and Transport of TVOC Plume

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Brookhaven National Laboratory

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Groundwater modeling simulations were performed by P.W. Grosser Consulting (PWGC) to aid BNL in estimating the transport and attenuation of a total volatile organic contaminant (TVOC) plume that originates at the Current Landfill. PWGC utilized BNL's existing regional 3-dimensional numerical groundwater model (GMS v10.1.3, 64 Bit, MODFLOW 2000 by Aquaveo, LLC) with modifications noted below to characterize flow conditions at the Current Landfill and in the downgradient area to the south to evaluate the potential migration of the TVOC plume, MT3DMS, a modular three-dimensional transport model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems (developed for the USACE (United States Army Corps of Engineers) by S.S. Papadopulos & Associates, Inc. and the University of Alabama) was used in conjunction with the groundwater flow model.

Key Assumptions and Model Modifications

The key assumptions made for the modeling effort are:

- The 'onsite' model inherited hydraulic/hydrogeologic properties from the calibrated regional model. Modifications to the original model included converting the regional model to a local model. **Figure 1** depicts the model layering along with associated horizontal hydraulic conductivities assigned to the layers in the vicinity of the Current Landfill TVOC plume.

- The regional model was converted to a local model so that steady state conditions fate and transport modeling could be conducted. An area roughly 2,800 ft (east-west direction) by 5,900 ft (north-south direction) was delineated around the Current Landfill TVOC plume and subdivided into 25 ft by 25 ft grid spacings (see **Figure 2**). Constant head boundary conditions were created at the north and south boundaries of the local model to match regional model heads. **Figure 3** depicts the local model in relation to the BNL site boundary. **Figure 4** illustrates regional/local water table groundwater head contours.

- Layer 1 of the local model was divided into two separate layers to more accurately represent and model the contaminant plume volume. Layer 1 of the model is the water table layer. After dividing the top layer of the local model into two separate layers the new layer 1 was adjusted to have a saturated thickness of approximately 20 feet.

- MT3DMS was utilized to simulate migration of the Current Landfill TVOC plume. Plume concentrations (initial conditions) were generated using the most recent data available (April 2016). Plume concentrations ranged between 5 and 165 ug/l and were input individually into model cells within the horizontal extents of the plume boundary (5 ug/l contour). The plume was initialized only in layer 1 of the local model (approximate top elevation of layer 1 = 50 ft AMSL and approximate bottom elevation of layer 1 = 22 ft AMSL, water table elevation approximately 43 ft AMSL) consistent with actual sampling results. The model is based on the concept that there is a continuing or constant source of TVOCs at the Current Landfill with a peak or maximum concentration of 165 ug/l.

- No changes were incorporated into the model simulations that would have altered groundwater flow directions or rates over time. No new or revised pumping rates (i.e. remedial wells), recharge rates, boundary flow changes, etc. were considered. All flow conditions were considered to be steady state and imported from the original regional model.

- Fate and transport simulations were run using the advection, chemical reaction and dispersion modeling packages. Advection along with adsorption and dispersion are the dominant mechanisms with regards to fate and transport based on experience with site conditions.

- The advection package solution scheme was changed from the GMS default scheme of Third Order TVD scheme (ULTIMATE) to the Method of Characteristics (MOC). The basis for the change was that the MOC scheme is highly effective for eliminating numerical dispersion in strongly advection dominated situations where as the Third Order TVD scheme does minimize numerical dispersion but not to the same degree as the MOC scheme.

- The chemical reaction package was used to simulate retardation effects and adsorption. GMS calculates a retardation factor R for each layer based on the distribution coefficient of the specific contaminant and the bulk density and porosity of the material (layer) the contaminant is traveling through. The basic equation used by GMS to calculate the retardation factor is $R = 1 + (\rho_b K_d/n)$ where ρ_b is the soil bulk density, K_d is the distribution coefficient and n is the soil porosity. A soil bulk density of 100 lb/ft^3 was input for all layers as this is a typical or common value for regional sands. K_d was estimated based on actual observed or monitored conditions for VOCs traveling through shallow Upper Glacial materials. Field observations indicate an approximate travel rate slightly less than groundwater for VOC plumes on site, with an effective groundwater velocity in the area of the Current Landfill of between 1 to 1.5 ft/day, with an average of 1.25 ft/day. A VOC travel rate of 1.0 ft/day then equates to a retardation of approximately 1.25 (R=1.25). Solving for K_d using the equation $R = 1 + (\rho_b K_d/n)$ yields a value of 0.0006 ft^3/lb. The regional model porosity of 0.24 was used in the calculations as that is what the model was calibrated to.

- Inputs for the dispersion package included; longitudinal dispersivity (a_L), the ratio of horizontal transverse dispersivity to longitudinal dispersivity (TRPT) and the ratio of vertical transverse dispersivity to longitudinal dispersivity (TRVT). Dispersivity is scale dependent and values will vary with distance, thus the longer the travel distance of the contaminant is the greater its longitudinal dispersivity value will be. A longitudinal dispersivity value for each layer the plume migrates through was calculated using the equation $a_L = 0.83[\log(L_p)]^{2.414}$, where a_L is the longitudinal dispersivity in feet and L_p is the travel distance in feet. An average value of all the plume layers was computed and then input into the model as a constant value for all cells of the local model. An average value of 15 ft was calculated and input. The values of TRPT and TRVT were taken from previous BNL fate transport models and were input as 0.1 and 0.01 respectively also corresponds to the default values provided by the GMS software.

- Groundwater flow and transport were simulated under steady-state conditions. A 20 year time period with 4 time steps per stress period (1 year = 1 stress period) was selected to determine how long the modeled groundwater system would take to reach equilibrium with a constant or continuous source of TVOCs. One time step equates to 91.25 days or approximately 3 months.

Discussion of Model Simulations and Predictions

Modeling simulations were conducted using MT3DMS to predict durations to achieving equilibrium TVOC plume concentrations based on a continuous source originating at the Current Landfill. A maximum TVOC concentration of 165 ug/l was used as the continuous source concentration. TVOC concentrations have been observed to be fluctuating with one of the highest recorded detections being 162 ug/l. Thus using a value slightly higher than this and under continuous conditions for 20 years will produce plume conditions that are very conservative. **Figures 5** through **9** depict the plume over the course of 20 years as it migrates southwards and reaches equilibrium. The plume eventually reaches equilibrium as opposed to growing infinitely because of adsorption/degradation and dispersion. Both of these two modeled phenomena continually act to naturally attenuate or reduce contaminant concentrations so that the plume eventually reaches a state where it is no longer growing or expanding as long as conditions remain unchanged. **Figure 5** depicts the initial plume conditions in the top layer or water table layer of the model (layer 1) on day 1. Here two distinct plume areas can be seen. The northern plume contains the continuous TVOC source right at the Current Landfill while the southern plume is a low concentration slug that is focused in the area of the site boundary extraction wells EW-1 and EW-2. The model simulations are performed with the extraction wells not pumping. **Figure 6** is after one year of travel. Here the southern plume can be seen to be migrating southward but also rapidly decreasing in size due to natural attenuation. The northern plume in **Figure 6** is seen migrating southward.

The next figure in the sequence is **Figure 7** which is the model after 2 years. The southern plume is now predicted to have completely attenuated to below a TVOC concentration of 5 ug/l and the northern plume is shown to be continuing its advancement southward.

Figure 8 shows the model after 10 years. The model predicts continued growth of the plume primarily in a southerly direction.

Around year 14 is when the plume is predicted to reach equilibrium with no major changes in size, shape or concentrations occurring beyond this time. At this time the plume is seen to have migrated deeper into the aquifer and traveled over 3,100 feet horizontally from the source or original plume location. The plume is also estimated to have reached a depth of between -60 and -70 ft AMSL

Figure 9 depicts the plume at 20 years. By this time the model simulations have reached equilibrium with no significant or notable changes in plume size, shape/orientation or concentrations occurring.

Conclusion

A conservative modeling approach was utilized to predict the extents of a plume of TVOCs originating at the water table from a continuous source at the Current Landfill and how long it will take to reach equilibrium while being naturally attenuated. A maximum source concentration of 165 ug/l of TVOCs was conservatively selected and modeled over a 20 year time period. The model predicts that after 14 years the plume will reach equilibrium and extend to the site boundary at an elevation of -70 ft AMSL or approximately 134 feet below ground surface at the boundary. Concentrations for the TVOCs at this location and depth are predicted to be just above 5 ug/l. A new monitoring well is recommended to be installed approximately 1,500 ft south-southeast of the modeled source area at the Current Landfill to enable better monitoring and tracking of the TVOC plume (NYS Plan Coordinates 1299553, 254174 in ft). This location would place the monitoring well in line with the predicted plume migration path and aide BNL in future monitoring efforts of groundwater quality in the area (see **Figure 10** for proposed monitoring well location).

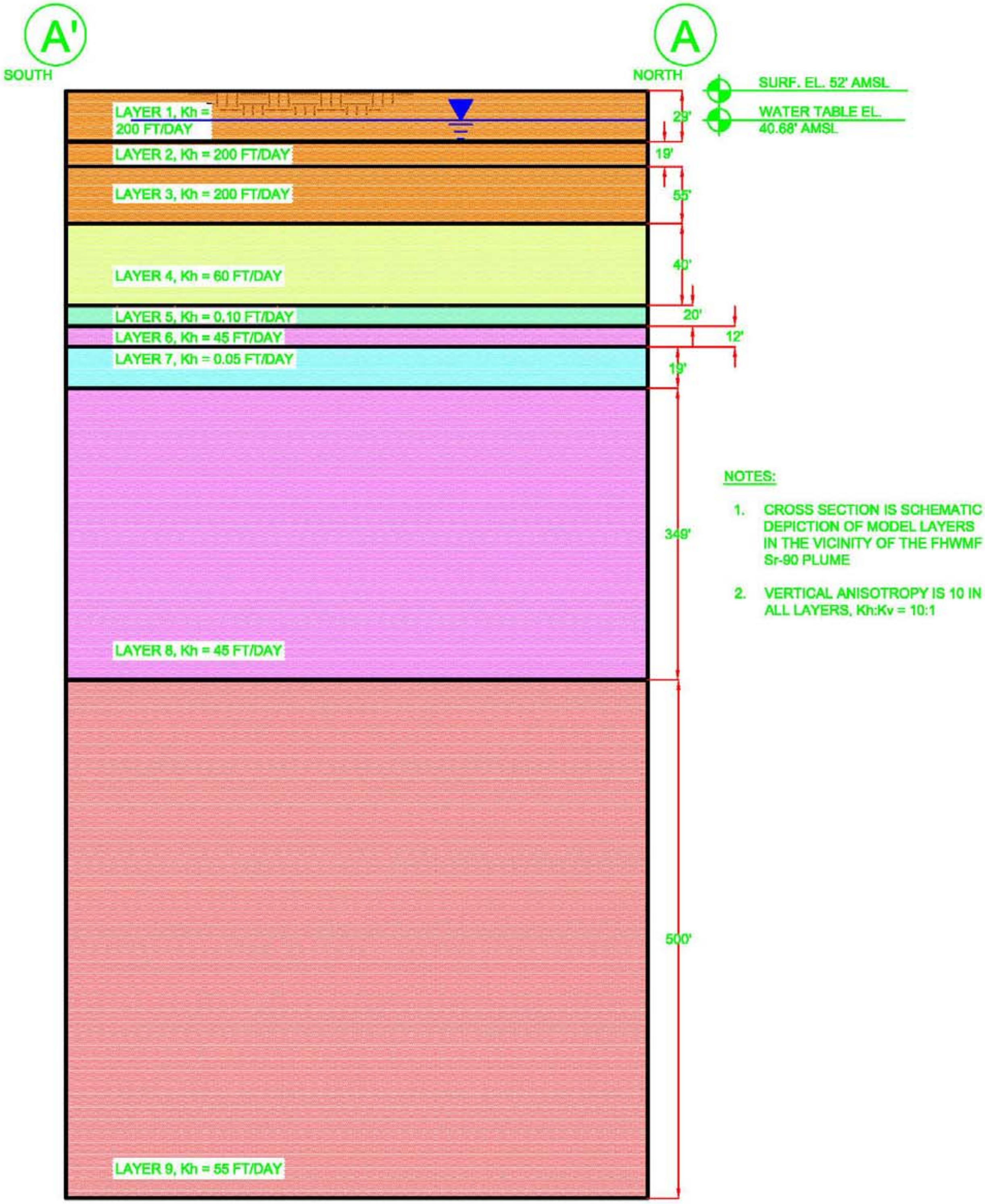

Figure 1 – Model Layering Structure in Vicinity of Current Landfill TVOC Plume – NOT TO SCALE

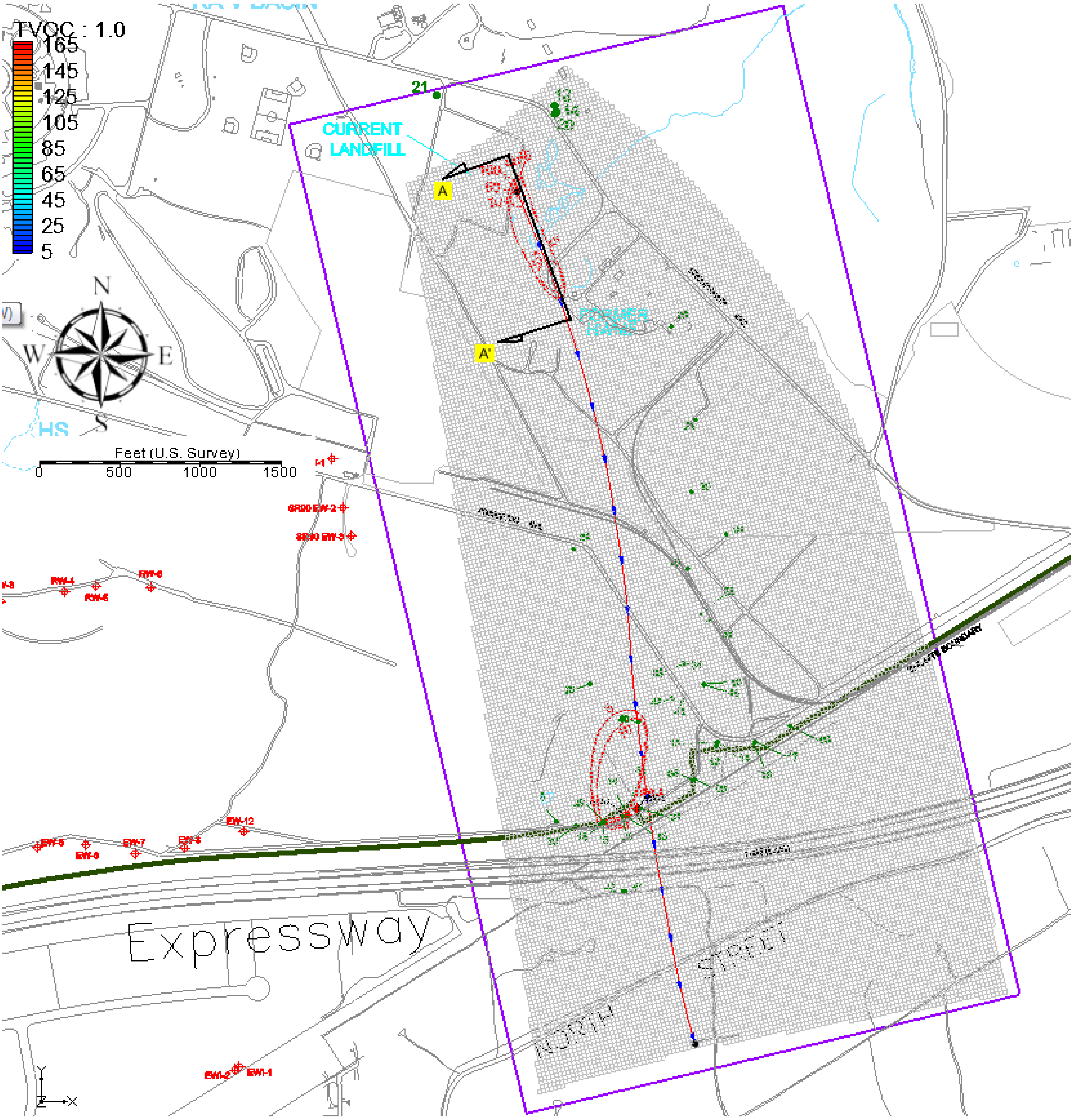

Figure 2 – Figure 1 cross-section line and extents of local model

Local grid spacing is approximately 25' x 25'.

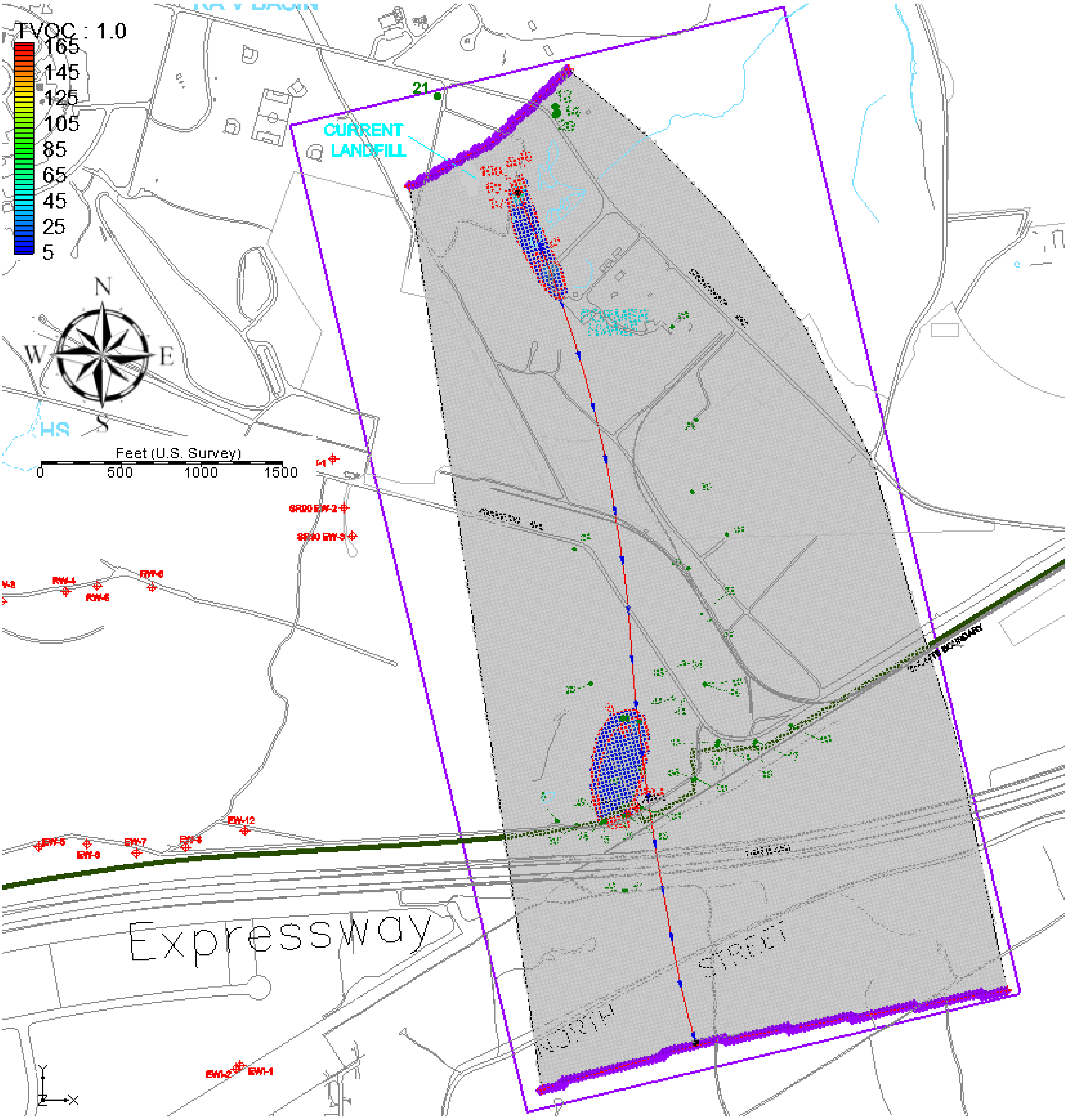

Figure 3 – Model Study Area in Relation to BNL Site Boundary

Local grid spacing is approximately 25’ x 25’.
Gray shaded represents the limits of the local model.
Magenta border is extents of grid frame.
Magenta lines at north and south of gray shaded area are constant head boundaries imported from regional model.
Single red line with blue arrowheads is a particle track with particle released at the water table at the Current Landfill.

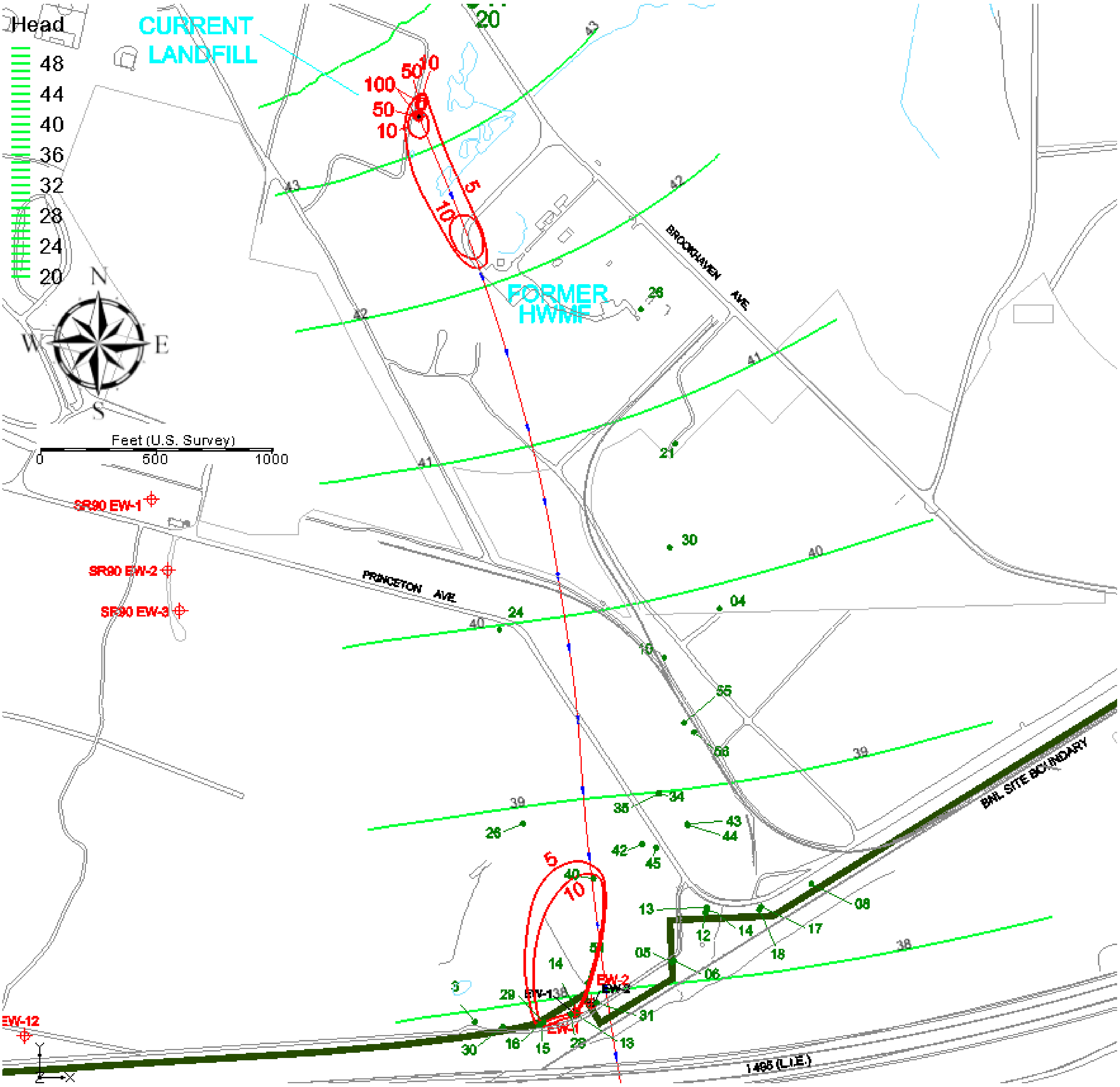

Figure 4 – Layer 1 Groundwater Head Contours

Green lines represent groundwater head contours, head is in feet.
Red outlines represent original plume location at beginning of model simulations.
Single red line with blue arrowheads is a particle track with particle released at the water table at the Current Landfill.

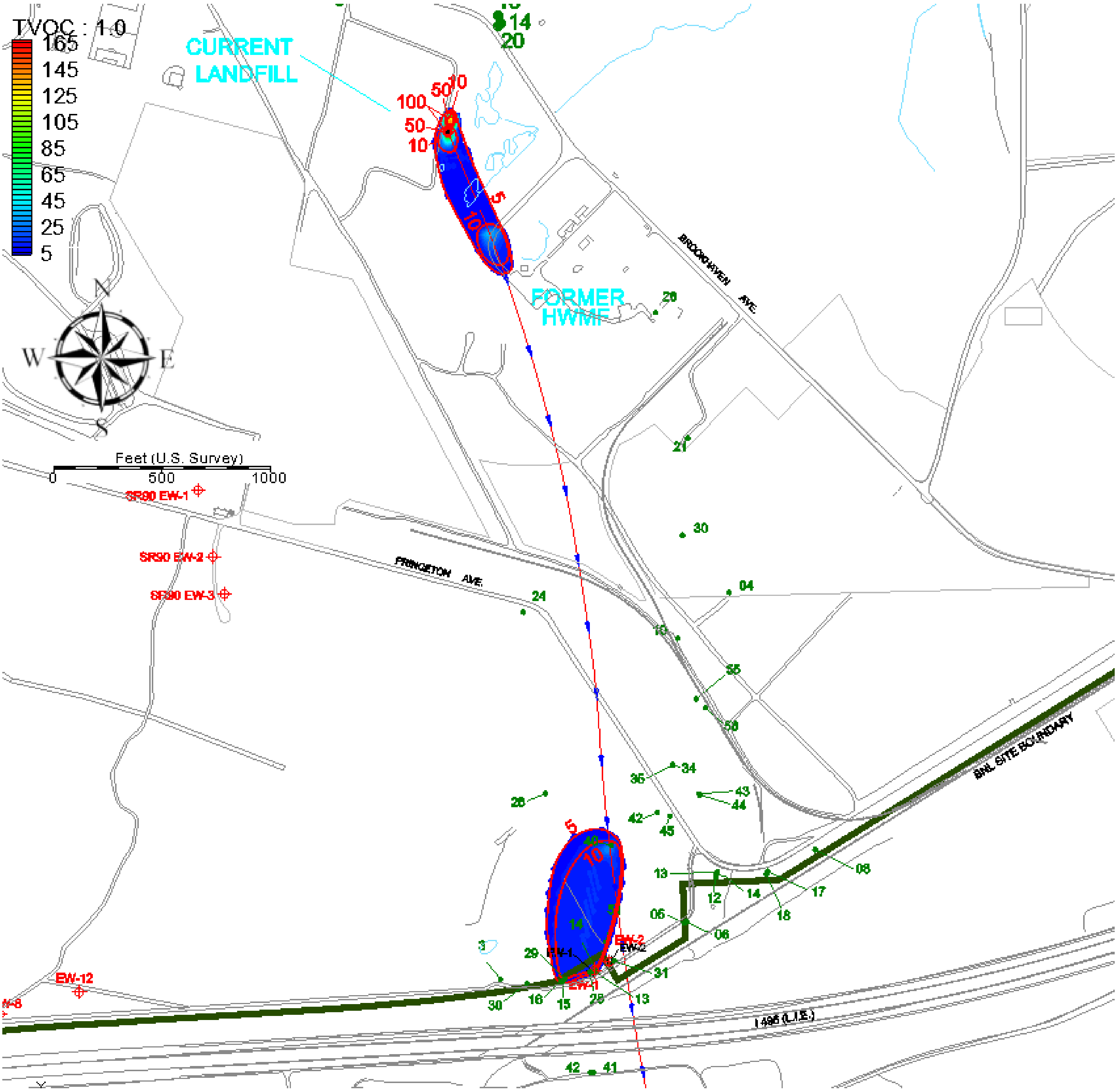

Figure 5 – Current Landfill TVOC Plume at t = 1 day

Color chart at upper left presents TVOC concentrations in ug/l.
Number in extreme upper left above color chart is time since start in days.
Red outline is original plume definition.
Single red line with blue arrowheads is a particle track with particle released at the water table at the Current Landfill.

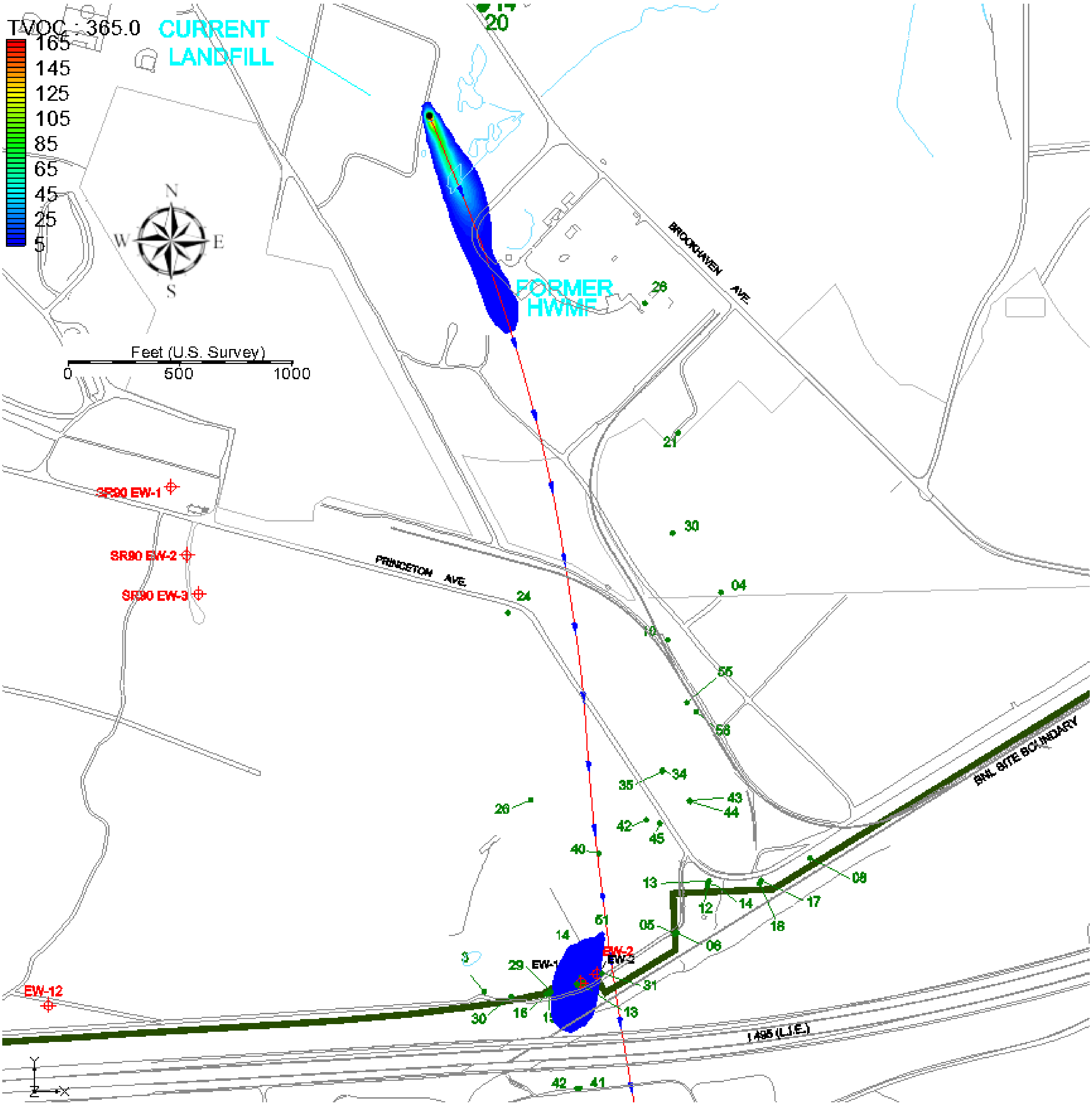

Figure 6 – Current Landfill TVOC Plume at t = 1 year

Color chart at upper left presents TVOC concentrations in ug/l.
Number in extreme upper left above color chart is time since start in days.
Single red line with blue arrowheads is a particle track with particle released at the water table at the Current Landfill.

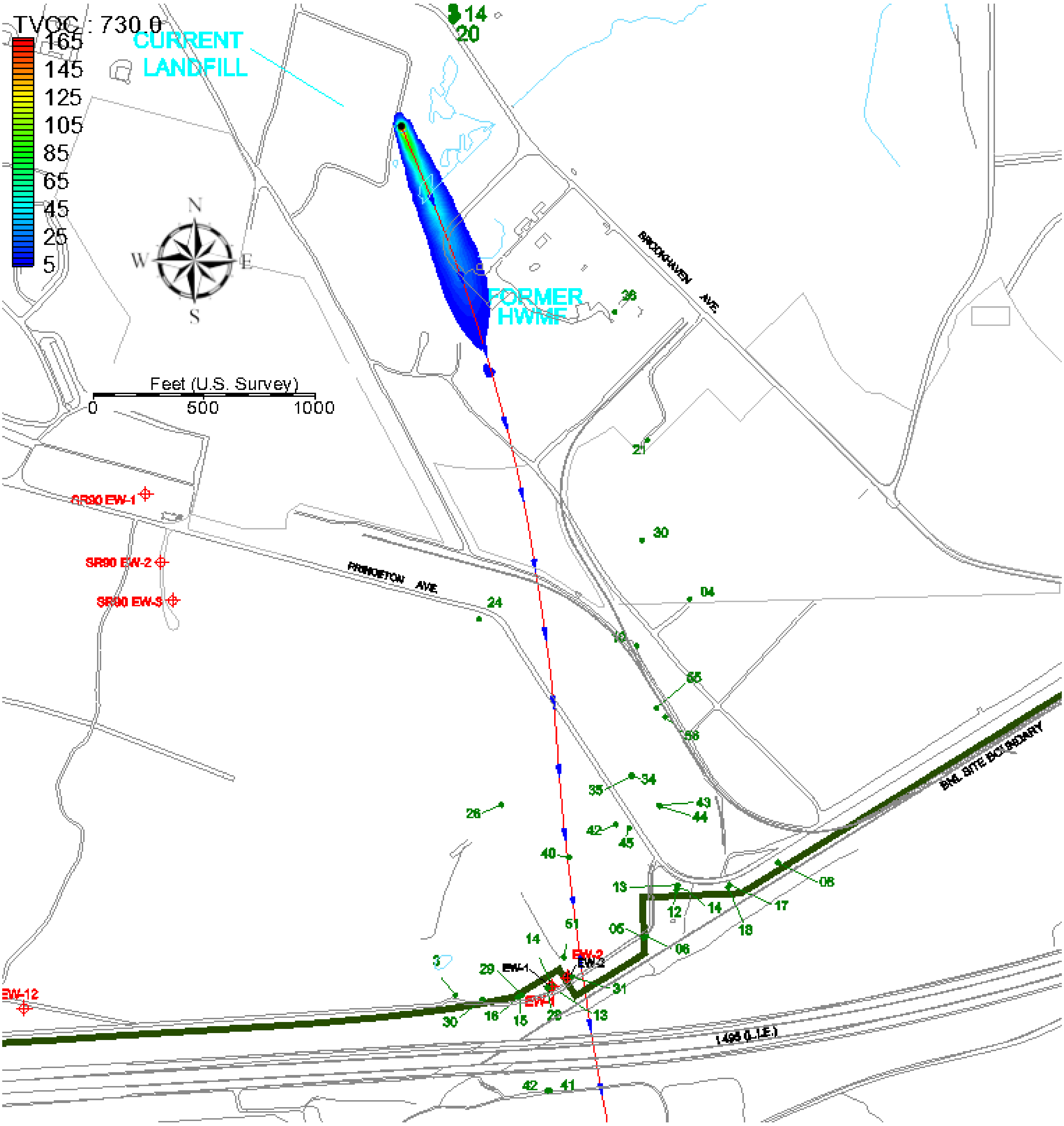

Figure 7 – Current Landfill TVOC Plume at t = 2 years

Color chart at upper left presents TVOC concentrations in ug/l.
Number in extreme upper left above color chart is time since start in days.
Single red line with blue arrowheads is a particle track with particle released at the water table at the Current Landfill.

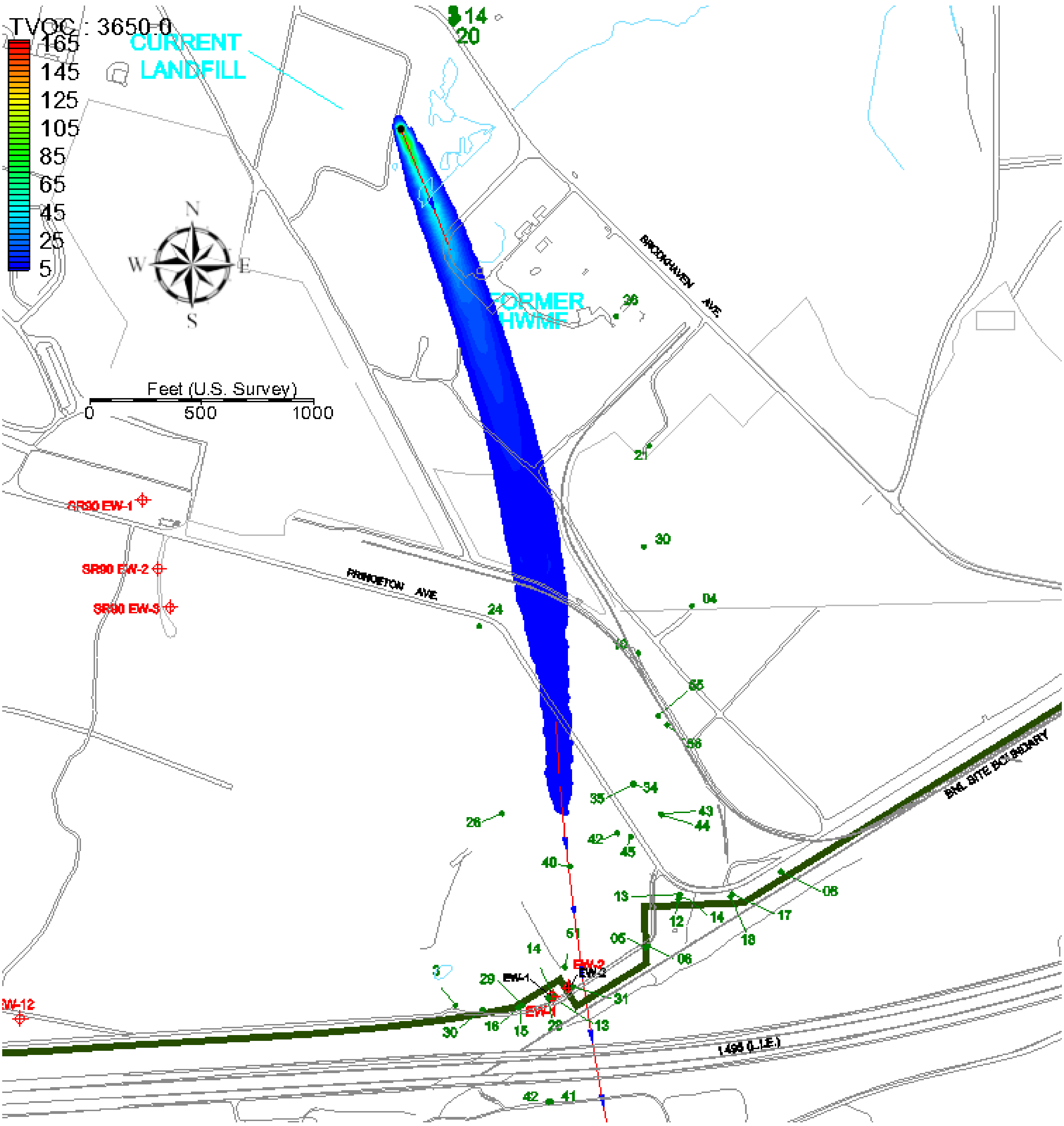

Figure 8 – Current Landfill TVOC Plume at t = 10 years

Color chart at upper left presents TVOC concentrations in ug/l.
Number in extreme upper left above color chart is time since start in days.
Single red line with blue arrowheads is a particle track with particle released at the water table at the Current Landfill

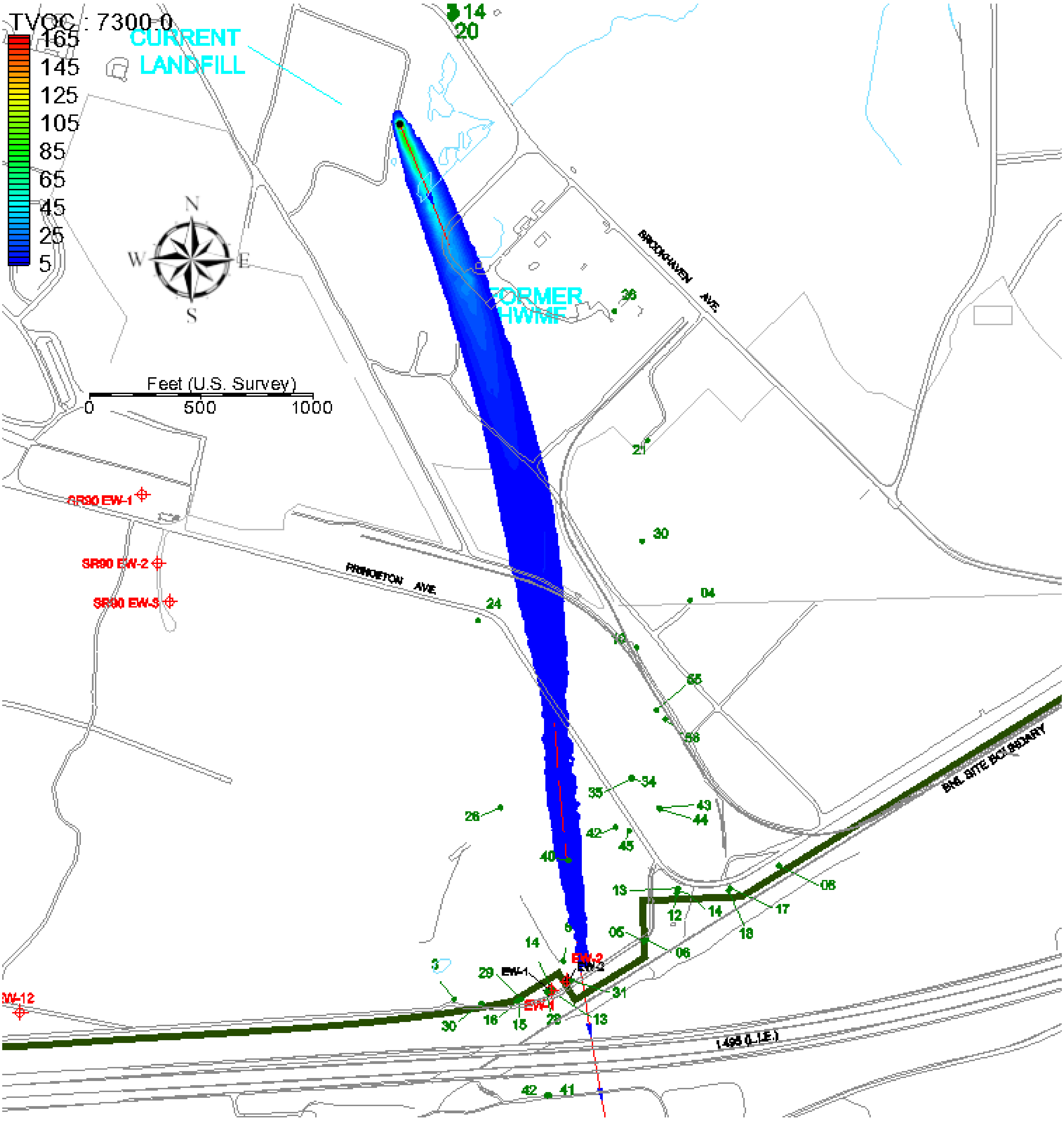

Figure 9 – Current Landfill TVOC Plume at t = 20 years

Color chart at upper left presents TVOC concentrations in ug/l.
Number in extreme upper left above color chart is time since start in days.
Single red line with blue arrowheads is a particle track with particle released at the water table at the Current Landfill.

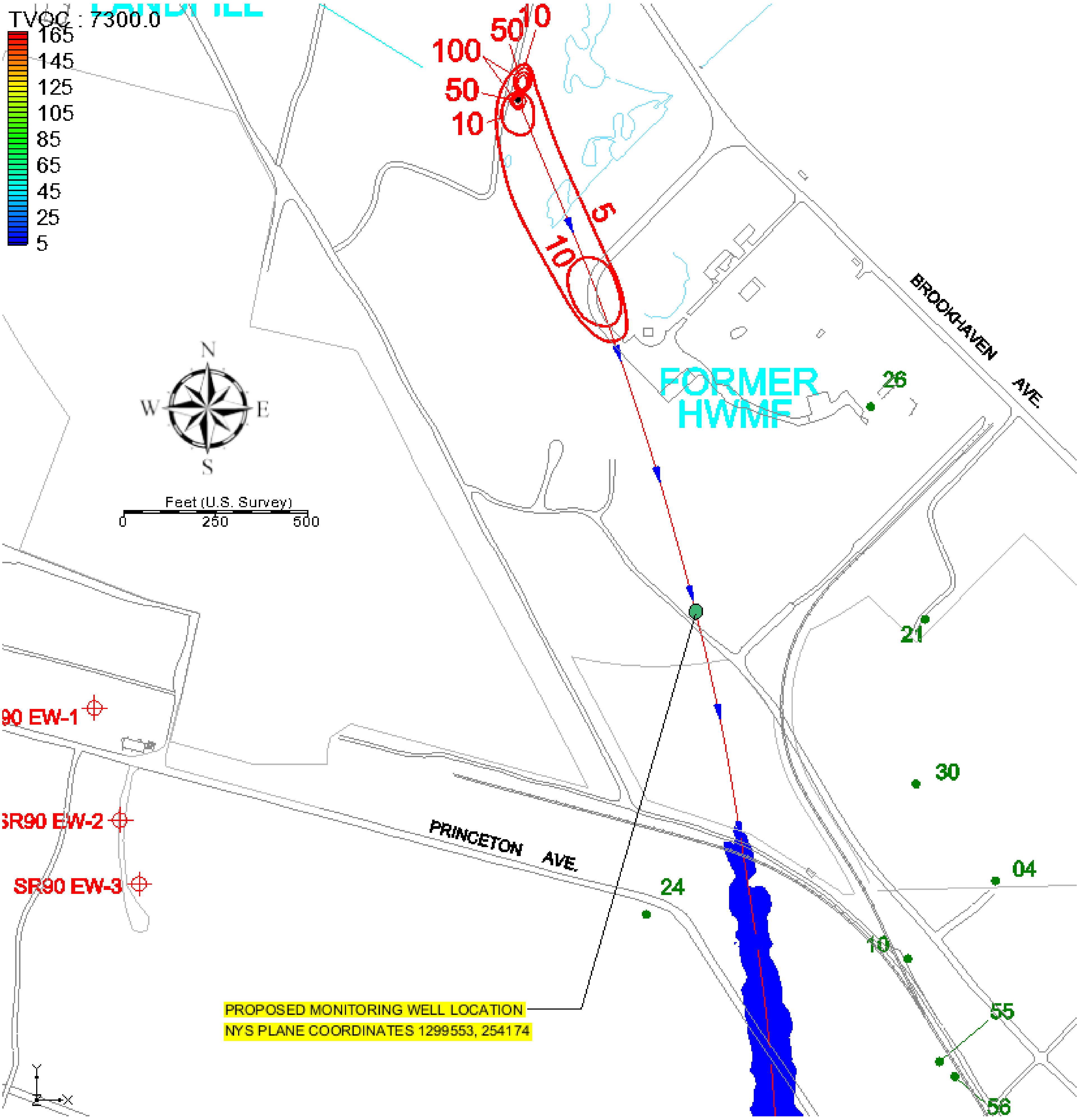

Figure 10 – Proposed Monitoring Well Location

Color chart at upper left presents TVOC concentrations in ug/l.
Number in extreme upper left above color chart is time since start in days.
Red outline is original plume definition.
Single red line with blue arrowheads is a particle track with particle released at the water table at the Current Landfill.

Groundwater Modeling Report

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