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# TRIGGER VALUES DEVELOPMENT ADDENDUM 2 OPERABLE UNIT 2 (OU 2) OFFSITE GROUNDWATER PUBLIC WATER SUPPLY CONTINGENCY PLAN NWIRP BETHPAGE NY

08/01/2016
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**From:** Brian Caldwell, P.G., Resolution Consultants

**Subject:** **Trigger Values Development - Addendum #2 to the Operable Unit 2 (OU2) Offsite Groundwater Public Water Supply Contingency Plan (PWSCP)**

**Date:** August 2018

## Introduction

Operable Unit 2 (OU2) consists of volatile organic compounds (VOCs) that have contaminated groundwater beneath the Navy's former 105 acre parcel, and VOC-contaminated groundwater that has migrated south and east off-property. It becomes mixed with contamination originating on the Northrop Grumman (NG) property and forms a 3,000-acre plus area of VOC-contaminated groundwater plumes at varying depths that extend south of Hempstead Turnpike. The groundwater contamination extends to a depth of approximately 750 feet (ft) but is not continuous throughout this area and is not present at all depths. Other non-OU2 sources of groundwater contamination that are known or believed to be contributing to the OU2 plumes include the Bethpage Community Park OU3 groundwater, Hooker Ruco Superfund Site, and potentially other smaller releases.

The Navy is conducting environmental investigation and cleanup under the Navy's Environmental Restoration Program (ERP), in compliance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The OU2 groundwater contamination was addressed in the Navy 2003 Record of Decision (ROD) (Naval Facilities Engineering Command [NAVFAC], 2003). The ROD specifies that the selected remedy includes institutional controls, groundwater remediation, and a Public Water Supply Protection Program as defined in the Public Water Supply Contingency Plan (PWSCP, Arcadis, 2003).

Outpost monitoring wells, designed and located to serve as early warning wells, are to be installed and monitored as an element of the 2003 PWSCP. One component of the outpost monitoring well system is the development of "trigger values", or concentration values for contaminants of concern in the OU2 ROD (NAVFAC 2003).

The 2003 PWSCP included trigger values for nine proposed outpost wells to provide early warning for the following wells: South Farmingdale Water District (SFWD) Plant 1 wells 4043, 5148 and 7377 and Plant 3 well 6150; New York American Water (NYAW) wells 8480 and 9338; and Levittown Water District (LWD) well 5303 (Table 1 section A and Figure 1). These wells were subsequently installed and are monitored quarterly by NG.

In 2014 and 2015, 13 outpost wells were installed to provide early warning for the SFWD Plant 6 wells 8480 and 9338 and Massapequa Water District (MWD) wells 6442 and 6443 (Table 1 section B and Figure 1). Trigger values for these wells were developed by Resolution Consultants (2016).

In 2011 and 2014, a total of eight outpost wells were installed to supplement (or replace) outpost wells included in the 2003 PWSCP (Table 1 section C and Figure 1). Three outpost wells (BPOW1-4, BPOW1-5, and BPOW1-6) were installed for SFWD Plant 1 to provide additional evaluation of groundwater north of the plant. One outpost well (BPOW2-3) was installed for SFWD Plant 3 to allow additional evaluation of deeper groundwater north of the plant. Two outpost wells (BPOW3-3 and BPOW3-4) were installed west of SFWD Plant 3 and north of the NYAW (formerly Aqua New York) Seamans Neck Road Plant to allow evaluation of groundwater that may be intercepted by both plants. Outpost wells BPOW4-1R and BPOW4-2R were installed to replace BPOW4-1 and BPOW4-2 (due to failed integrity testing) as early warning wells for LWD well 5303. Trigger values for these outpost wells were to be developed in a subsequent addendum and are provided herein.

The purpose of this report is to develop trigger values for the eight outpost monitoring wells installed since 2011 (described above) to provide an early warning that VOCs from the OU2 plume may impact SFWD Plant 1, SFWD Plant 3, NYAW wells 8480 and 9338 or LWD well 5303 (Table 1 section C and Figure 1). The trigger values should provide a minimum of 5 years notice before the VOCs are detected at a concentration of 0.5 micrograms per liter (ug/L) in the water supply. These trigger values may be replaced with final trigger values when location-specific pumping tests are performed to allow more accurate measurements of connectivity and hydrogeology, similar to that performed for Massapequa Water District outpost wells (Resolution Consultants, 2016).

## Site Hydrogeology

Overburden at the site consists of well over 1,000 ft of unconsolidated deposits overlying crystalline bedrock of the Hartland Formation. Overburden is divided into four geologic units: the upper Pleistocene deposits, the Magothy Formation, the clay member of the Raritan Formation ("Raritan Clay") and the Lloyd Sand member of the Raritan Formation ("Lloyd Sand") (Geraghty and Miller, 1994).

The upper Pleistocene ranges in thickness from approximately 50 to 300 ft and consists of till and outwash deposits of medium to coarse sand and gravel with lenses of fine sand, silt and clay (Smolensky and Feldman, 1988); these deposits form the Upper Glacial Aquifer. Directly underlying this unit is the Magothy Formation with a thickness of 650 to 900 ft, as observed at the former NWIRP and extending southeast to areas south of Southern State Parkway. The Magothy is characterized by fine to medium sands and silts interbedded with zones of clays, silty sands and sandy clays. Sand and gravel lenses are found in some areas between depths of 600 and 880 ft bgs; these deposits form the Magothy Aquifer.

Investigations performed by the Navy since 2012 indicate that the bottom of the Magothy (top of the Raritan Clay) can extend to depths of 700 to greater than 1,000 ft bgs. The Raritan Clay Unit consists of clay, silty clay, clayey silt, and fine silty sand and reportedly acts as a confining layer over the Lloyd Sand Unit.

The Magothy Aquifer is the major source of public water in Nassau County. The most productive water bearing zones are the discontinuous lenses of sand and gravel that occur within the siltier matrix located in the lower portion of the Magothy. Because of the presence of intermittent clay layers and the depths, the Magothy Aquifer is commonly regarded to function overall as an unconfined aquifer at shallow depths and a confined aquifer at greater depths. Groundwater flow is assumed to be primarily horizontal because of the stratified nature of the sand and gravel lenses and thin silty/clayey layers that are thought to reduce vertical flow. However, water supply wells in the area with high withdrawal rates impose a pumping stress at depth that likely induce some vertical flow within their area of influence.

Trigger values for outpost wells have been developed through groundwater modeling. The complex geology and pumping stresses that exist at the Bethpage site present challenges for estimating contaminant fate and transport. Simulating plume arrival times and concentrations with a model involves many uncertainties and assumptions, and should be regarded as approximate. Using conservative hydraulic parameters, the model can be applied to estimate plume movement and develop an early warning system for public supply wells with outpost wells.

**Modeling Approach and Modeling Platform**

The approach to develop trigger values for the outpost wells is to apply an analytical model to simulate transport from each outpost well to the supply wells. Figure 2 depicts the geometry of the model approach in which the source is located at the outpost well and transport is simulated from the outpost well to the supply well. An analytical model is constructed for each of the eight outpost wells (or well clusters). Applying appropriate aquifer parameters, the model is run iteratively to solve for and estimate what the concentration at the outpost well will be that results in a detection of 0.5 ug/L at the associated supply well, allowing for a 5 year travel time. This approach is consistent with that used for developing the trigger values for SFWD Plant 6 and the northern NED well fields (Resolution 2015).

The primary assumptions of this approach include:

1. Assuming the “source” of the presumed 0.5 ug/L detection at the supply well originates at the upgradient outpost well;

    i. The Source Distance parameter is the distance from outpost well to nearest supply well;

ii. The Source Width parameter is one half the Source Distance; this approach was taken because the outpost wells are clustered and it was not possible to use the distance from the midpoints between outpost wells (as was done in the 2015 Trigger Value document). One half the Source Distance was used in order to assign a consistent proportional Distance to Width configuration to the sources. This approach is consistent with the overall morphology of the offsite plume; that is, longitudinal dispersion is greater than transverse dispersion;

iii. The Source Thickness parameter is approximated as the screen length of the supply well;

2. Assuming no retardation and no decay; and
3. The model simulates advective travel and attenuation through longitudinal and transverse dispersion.

This approach is conservative for the following reasons:

- No retardation or decay;
- Negligible vertical dispersion; and
- Does not account for the dilution of plume concentrations with other non-contaminated water in the capture zone of the supply well.

The Quick Domenico (QD) analytical fate and transport model was used to develop trigger values. The analytical steady state solution to the groundwater flow equation was first proposed by P. A. Domenico (Domenico, 1987). The software platform for the QD Domenico solution is provided for download by the Pennsylvania Department of Environmental Protection (PADEP).

QD calculates the concentration of contaminant species at any point and time downgradient of a source area of known width, thickness and strength. The kinds of contaminants for which QD is intended are dissolved organic contaminants whose fate and transport can be described or influenced by advection and lateral and vertical dispersion. For spatial resolution within the model, QD calculates the concentrations in a two dimensional 5x10 grid network whose length and width are set by the user.

Key assumptions within the modeled area are:

1. Aquifer properties are homogeneous and isotropic;
2. Groundwater flow field is homogeneous and unidirectional;
3. Groundwater flow is steady state; and
4. Contaminant source remains constant in time.

Details of the solution in the Quick Domenico software and input parameters are provided in Appendix 1.

**Model Development and Input Parameters**

Model inputs were a combination of site-specific data for the OU2 offsite groundwater data and literature values as appropriate (PADEP, 2014). Where a range of values were available, conservative values were chosen. Table 2 provides a summary of the input parameters required within the model software. A few key aquifer parameters are discussed below.

*Hydraulic conductivity (K):*

Groundwater velocity (distance over time) is proportional to hydraulic conductivity (K), thus higher values of K predict faster travel time. To achieve conservative results, the highest reasonable K value of 75 ft/day was chosen based on the following references:

- The average K for the Magothy aquifer on Long Island is 56 ft/day (McClymonds and Franke, 1972);
- The K used in the calibrated United States Geological Survey (USGS) Bethpage model is 50 ft/day for the Upper Magothy and is 75 ft/day for the Basal Magothy (Misut, 2013);
- A pumping test conducted in 2013 at BWD6-2 yielded a K of 35 - 55 ft/day, based on 400 ft saturated thickness (TetraTech, 2014).
- A pumping test conducted in 2017 at RE137 yielded a K of 77 - 92 ft/day, based on 580 ft saturated thickness (Resolution Consultants, 2018).

*Gradient:*

Groundwater velocity (distance over time) is also proportional to hydraulic gradient (i), thus higher gradient values predict faster travel time. Numerous gradients were calculated between wells at the site using the synoptic water levels measured on March 29, 2018 (Figure 3). An average of (0.002) was selected as a representative gradient for the model.

*Porosity:*

Groundwater velocity (distance over time) is inversely proportional to porosity, thus lower porosity (n) values predict faster travel time. The USGS DRAFT report on the calibrated numerical groundwater model for the Bethpage site references values ranging from 0.15 and 0.35 (Misut, 2013). A value of 0.15 was chosen as conservative value within this range.

*1$^{st}$ order decay:* The model assumes no decay (biodegradation) thus a value of zero was assigned.

*Fraction organic carbon (foc) and organic carbon partition coefficient (FOC):* The model assumes no retardation (sorption) thus these two parameters used to estimate retardation were assigned a value of zero.

## Model Results

The model simulations provide an estimate of the trigger concentrations at each outpost well predicted to result in a detection of 0.5 ug/L in the down gradient supply well in 5 years. The following inputs were selected to provide a conservative estimate of trigger values:

- Hydraulic conductivity of 75 ft/day is on the high end of the range of composite Ks;
- Gradient of 0.002 is within the range of estimated gradients on-site; and
- Porosity of 0.15 is on the low end of the range of estimated porosities for the site.
- No biodegradation or adsorption;
- Negligible vertical dispersion;

The resultant groundwater (seepage) velocity calculated by the QD model based on the above aquifer parameters is 365 ft/yr (1 ft/day).

Table 3 shows model simulated trigger values for SFWD Plant 1 outpost wells (BPOW1-4, BPOW1-5, BPOW1-6), SFWD Plant 3 outpost wells (BPOW2-3, BPOW3-3, BPOW3-4), New York American Wells 8480 and 9338 outpost wells (BPOW3-3, BPOW3-4) and Levittown Water District Well 5303 outpost wells (BPOW4-1R, BPOW4-2R). Table 3 also summarizes the dimensional inputs unique to each supply well: the distance from each outpost well(s) to the nearest downgradient supply well, the source width, and the source thickness. Model output is provided in Appendix 2 through 5.

Trigger concentration at outpost wells upgradient of the SFWD Plant 1 wellfield (BPOW1-4, BPOW1-5, BPOW1-6) is estimated to be 0.67 ug/L. Trigger concentrations at outpost wells upgradient of SFWD Plant 3 are estimated to be 0.54 ug/L at BPOW2-3 and 1.14 ug/L at BPOW3-3 and BPOW3-4. Trigger concentration at outpost wells upgradient of the New York American wells 8480 and 9338 (BPOW3-3 and BPOW3-4) is estimated to be 1.13ug/L. Trigger concentrations at outpost wells upgradient of Levittown Water District Well 5303 are estimated to be 0.54 ug/L at BPOW4-1R and 0.57 ug/L at BPOW4-2R.

Aquifer parameters (k, n, i) were constant for all the simulations thus differences in predicted trigger values are due to source dimensions (width, thickness) and distance to supply well. Trigger values are directly proportional to the distance between the outpost well and the supply well: the further away the outpost well, the more lead time is provided and thus the higher the "warning" concentration can be before a detection of 0.5 ug/L is predicted at the supply well. Source width and thickness contribute to the contaminant mass; the larger the contaminant mass, the greater the plume concentration which requires a lower trigger concentration.

## Sensitivity Analysis

Given that K and porosity were the same for all simulations, a sensitivity analysis was conducted using a surrogate scenario model to determine how sensitive model predictions are to changes in input parameters. The surrogate model used for the sensitivity analysis was the NYAW Wells 8480 and 9339 trigger values simulation for outpost wells BPOW3-3 and BPOW3-4. Inputs were varied one at a time by increasing and decreasing each input by a 1.5 multiplier. The resulting trigger values and % change in values are reported in Table 4. The following observations can be made about the effect of the parameter changes on predicted trigger values:

A sensitivity analysis was conducted on a base simulation to determine how much the model predictions of trigger values changed in response to changes in input parameters. Table 4 summarizes the sensitivity analysis based on the surrogate model simulations of the BPOW3-3 and BPOW3-4 well cluster. The following observations can be made about the effect of the parameter changes on predicted trigger values:

- Source thickness is related to source mass and has an inverse relationship to trigger concentration. Increasing source thickness by a factor 1.5 resulted in a 3% decrease in the trigger concentration. Decreasing source width by a factor of 1.5 resulted in a 2% increase in the trigger concentration.
- Source width is related to source mass and has an inverse relationship to trigger concentration. Increasing source width by a factor 1.5 resulted in a 7% decrease in the trigger concentration. Decreasing source width by a factor of 1.5 resulted in a 21% increase in the trigger concentration.
- Dispersion:
    - Increasing lateral dispersion by a factor of 1.5 caused the plume to broaden in all directions, reducing concentrations at the plume front, and increasing the trigger concentration by 8%.
    - Reducing lateral dispersion by a factor of 1.5 steepened the plume front, increasing concentrations at the plume front and decreasing the trigger concentration by 4%.
- Hydraulic conductivity (K), gradient (i) and porosity (n) are aquifer parameters that control groundwater (seepage) velocity and have a significant effect:
    - Increases in groundwater velocity (resulting from increases in K or i or decreases in n) result in higher downgradient concentrations, thus reducing the trigger concentration.
    - Increasing/decreasing any of the aquifer parameters by a factor of 1.5 resulted in the groundwater (seepage) velocity, originally 1 ft/day, to range from 0.66 to 1.5 ft/day. The resulting trigger concentration ranged from 0.67 ug/L (41% decrease) to 3.28 ug/L (190% increase), respectively.

To determine the sensitivity of trigger values to high velocity conditions, a scenario was run with k = 75 ft/day, porosity = 0.1 and gradient = 0.003 (v = 2.25 ft/day). The model predicted a 50% decrease in the trigger concentration from 1.5 to 0.75 ug/L.

## Model Limitations

The following are limitations to applying the QD model:

- The model assumptions discussed above describe the approach of the Quick Domenico model and constrain the model's ability to represent site conditions.
- There is a significant volume of data for the Bethpage site, but understanding the fate and transport of the OU2 plume is very complex. Small-scale heterogeneities over the scale of a deep 700+ foot aquifer can influence plume fate and transport, thus predicting plume arrival times is uncertain in settings such as Bethpage. Such small scale heterogeneities are not represented in the model.

If the above limitations are understood, the modeling is constructive in that it applies a uniform set of conservative parameters to estimate plume movement and to develop early warning values for public supply wells with associated outpost wells.

## References

Arcadis, 2003. Public Water Supply Contingency Plan (NYSDEC Doc 743)

Domenico, P.A., 1987. An Analytical Model For Multidimensional Transport of a Decaying Contaminant Species, Journal of Hydrology, 91, pp 49-58.

Geraghty and Miller, Inc., 1994. *Remedial Investigation Report, Grumman Aerospace Corporation, Bethpage, New York*. Revised September 1994.

McClymonds N.E and Franke, O.L. 1972. Water Transmitting Properties of Aquifers on Long Island New York, Hydrology and Some Effects of Urbanization on Long Island, NY pppE9

Misut, P., 2013. DRAFT Simulation of zones of contribution to wells at Navy Water Treatment plant GM-38, Bethpage, NY, USGS.

Naval Facilities Engineering Command (NAVFAC), 2003. Record of Decision of Operable Unit 2 Groundwater NYS Registry: 1-30-003B Naval Weapons Industrial Reserve Plant Bethpage, New York, April.

Pennsylvania Department of Environmental Protection, 2014. User's Manual for the Quick Domenico Groundwater Fate-and-Transport Model, Version No. 3b, February.

Resolution Consultants, 2015. Memorandum: Aquifer Conductivity Between Massapequa Supply Wells #4 and #5 and BPOW Series 6 Wells, NWIRP Bethpage, NY. October.

Resolution Consultants, 2016. Memorandum: Trigger Values Development - Addendum to the Operable Unit 2 (OU2) Offsite Groundwater Public Water Supply Contingency Plan (PWSCP), NWIRP Bethpage, NY. August.

Resolution Consultants, 2018. Aquifer Test and Capture Zone Analysis for Well RE137, RE108 Hot Spot, Naval Weapons Industrial reserve Plant Bethpage, New York, March.

Smolensky, D., and Feldman, S., 1988. *Geohydrology of the Bethpage-Hicksville-Levittown Area, Long Island, New York, U.S*. Geological Survey Water-Resourced Investigations Report 88-4135, 25 pp.

Tetra Tech, 2014. Technical Memo: BWD 6-2 Aquifer Pumping Test/Capture one Analysis, NWIRP Bethpage, NY, March.

<u>Attachments:</u>

Table 1 ……. Outpost Well Construction Summary
Table 2 ……. Input Parameters for Quick Domenico Analytical Model
Table 3 ……. Quick Domenico Model Results
Table 4 ……. Sensitivity Analysis

Figure 1 …… Well Location Map
Figure 2 …… Approach to Trigger Value Analytical Modeling
Figure 3 …… Synoptic Water Levels March 29, 2018 in Deep Wells (screened >500 ft bgs)

Appendix 1 ... Quick Domenico Model Documentation
Appendix 2 … Model Output, South Farmingdale Water District Plant 1, Outpost Wells BPOW1-4, BPOW1-5, BPOW1-6
Appendix 3 … Model Output, South Farmingdale Water District Plant 3, Outpost Wells BPOW2-3, BPOW3-3, BPOW3-4
Appendix 4 … Model Output, Levittown Water District Well 5303, Outpost Wells BPOW4-1R, BPOW4-2R
Appendix 5 … Model Output, New York American Water Wells 8480 and 9338, Outpost Wells BPOW3-3, BPOW3-4

**Table 1**
**Outpost Well**
**Construction Summary**

| PWS Affiliation | Outpost Well | Total Depth (ft bgs) | Top of Screen (ft bgs) | Bottom of Screen (ft bgs) | VPB affiliation | Outpost Well | Total Depth (ft bgs) | Top of Screen (ft bgs) | Bottom of Screen (ft bgs) | VPB Affiliation |
|---|---|---|---|---|---|---|---|---|---|---|
| | **A. Wells with trigger values developed in PWSCP (Arcadis, 2003)** | | | | | **C. Wells installed in 2011 & 2014; trigger values developed by Resolution Consultants in this Addendum (2018)** | | | | |
| SFWD Wells 4043, 5148, 7377 (Plant 1) | BPOW1-1 | 241 | 196 | 241 | VPB45 | BPOW1-4 | 405 | 340 | 400 | VPB127 |
| | BPOW1-2 | 335 | 310 | 335 | | BPOW1-5 | 655 | 600 | 650 | |
| | BPOW1-3 | 419 | 374 | 419 | | BPOW1-6 | 755 | 700 | 750 | |
| SFWD Well 6150 (Plant 3) | BPOW2-1 | 400 | 360 | 400 | VPB130 | BPOW2-3 | 599 | 564 | 594 | VPB130 |
| | BPOW2-2 | 495 | 455 | 495 | | BPOW3-3 | 625 | 580 | 620 | VPB128 |
| | | | | | | BPOW3-4 | 695 | 640 | 690 | |
| NYAW Wells 8480, 9338 | BPOW3-1 | 516 | 446 | 516 | none | BPOW3-3 | 625 | 580 | 620 | VPB128 |
| | BPOW3-2 | 647 | 612 | 647 | | BPOW3-4 | 695 | 640 | 690 | |
| LWD Well 5303 | BPOW4-1 | 692 | 652 | 692 | VPB46 | BPOW4-1R | 697 | 652 | 692 | VPB46 |
| | BPOW4-2 | 765 | 725 | 765 | | BPOW4-2R | 770 | 725 | 765 | |
| | **B. Wells installed in 2014-2015 with trigger values developed by Resolution Consultants (2016)** | | | | | | | | | |
| SFWD Wells 8664, 8665 (Plant 6) | BPOW5-1 | 515 | 480 | 510 | VPB132 | | | | | |
| | BPOW5-2 | 585 | 540 | 580 | | | | | | |
| | BPOW5-3 | 665 | 620 | 660 | | | | | | |
| | BPOW5-4 | 575 | 545 | 570 | VPB151 | | | | | |
| | BPOW5-5 | 545 | 515 | 540 | VPB152 | | | | | |
| | BPOW5-6 | 615 | 585 | 610 | | | | | | |
| | BPOW5-7 | 555 | 525 | 550 | VPB153 | | | | | |
| MWD Wells 6442, 6443 | BPOW6-1 | 580 | 550 | 575 | VPB145 | | | | | |
| | BPOW6-2 | 785 | 755 | 780 | | | | | | |
| | BPOW6-3 | 780 | 750 | 775 | VPB146 | | | | | |
| | BPOW6-4 | 575 | 545 | 570 | | | | | | |
| | BPOW6-5 | 555 | 525 | 550 | VPB147 | | | | | |
| | BPOW6-6 | 800 | 770 | 795 | | | | | | |

Notes:
- ft bgs = feet below ground surface
- LWD = Levittown Water District
- MWD = Massapequa Water District
- NYAW = New York American Water; formerly Aqua New York (ANY)
- SFWD = South Farmingdale Water District
- PWS = Public Supply Wells
- PWSCP = Public Water Supply Contingency Plan

**Table 2**
**Input Parameters for Quick Domenico Analytical Model**

| Parameter | Value | Explanation of value | Source |
|---|---|---|---|
| Source concentration (ug/L) "Trigger Value" | C | concentration input at source that results in detection of 0.5 ug/L at downgradient supply well after 5 years travel time | Determined by trial through Quick Domenico modeling |
| Source Distance (ft) | unique for each OW; see Table 3 | Distance along simulated plume trajectory from outpost well to supply well (to closest supply well if more than one) | project mapping |
| Source width (ft) | unique for each OW; see Table 3 | 50% of Source Distance | project mapping |
| Source thickness (ft) | unique for each OW; see Table 3 | use total screen length of supply well(s) as approximate thickness of source at concentraton indicated | screen lengths from Arcadis PWS Contengency Plan, 2013 (NYSDEC Doc 743) for all except for LWD 5305 used original log from Town Engineer |
| Time (days) | 1825 | 5 years | In accordance with Arcadis Public Water Supply Contingency Plan (2003) |
| longitudinal dispersivity A(x) | unique for each OW; see Table 3 | typically 1/10 plume length | Estimated utilizing EPA methodology (http://www.epa.gov/athens/learn2model/part-two/onsite/longdisp.html) |
| transverse dispersitivity A(y) | unique for each OW; see Table 3 | typically 1/10A(x) | Quick Domenico Manual, 2014 |
| vertical dispersivity A(z) | unique for each OW; see Table 3 | typically 1/1000 A(x) approximates 2-dimensional transport with minimal vertical dispersion | Quick Domenico Manual, 2014 |
| hydraulic conducitivity (k) (ft/d) | 75 | Applied the highest reasonable i value for conservative results, supported by site data | 1. McClymonds and Franke, 1972; 2. Tetra Tech, 2014; 3. Misut, 2013; 4. Resolution Consultants, 2018. |
| hydraulic gradient (i) | 0.002 | Applied the highest reasonable K value for conservative results, supported by site data | March 2018 synoptic water levels (Resolution Consultants) |
| porosity (n) | 0.15 | conservative value within reasonable range of 0.15 and 0.35 | Misut, 2013 |
| 1st order decay constant (lambda) | 0 | decay or biodegredation; for simulations assuming no decay use lambda = 0 | Quick Domenico Manual, 2014 |
| Fraction organic carbon (foc) | 0 | organic content of soil; a variable in retardation; for simulations assuming no retardation use foc = 0 | Quick Domenico Manual, 2014 |
| Organic carbon parition coefficient (KOC) | 0 | chemical specific parameter; a variable in retardation; for simulations assuming no retardation use KOC = 0 | Quick Domenico Manual, 2014 |

Notes:
ft = feet; ft/d = feet per day
ug/L = micro grams per liter
The QD model simulations for this project assume no biodegredation, adsorption or vertical dispersion.
Resultant groundwater (seepage) velocity: (k x i)/n = 1 ft/day

**Table 3**
**Quick Domenico Model Results**

| SFWD Plant 1 Wells 4043, 5148, 7377 | BPOW1-4, 1-5, 1-6 |
|---|---|
| Distance from BPOW to closest SFWD Well 7377 (ft) | 1260 |
| Source width (ft) | 630 |
| Source thickness (ft) = total screen lengths of SFWD-4043 (312 - 372 ft bgs), SFWD-5148 (309 - 369 ft bgs) and SFWD-7377 (607 - 758 ft bgs) | 214 |
| Dispersion Ax, Ay, Az | 126 / 12.6 / 0.126 |
| **Trigger concentration (ug/L) at BPOW** | **0.67** |

| SFWD Plant 3 Well 6150 | BPOW2-3 | BPOW3-3, 3-4 |
|---|---|---|
| Distance from BPOW to SFWD Well 6150 (ft) | 330 | 1870 |
| Source width (ft) | 165 | 930 |
| Source thickness (ft) = screen length SFWD-6150 (545 - 612 ft bgs) | 67 | 67 |
| Dispersion Ax, Ay, Az | 33 / 3.3 / 0.03 | 187 / 18.7 / 0.187 |
| **Trigger concentration (ug/L) at BPOW** | **0.54** | **1.14** |

| NYAW Wells 8480, 9338 | BPOW3-3, 3-4 |
|---|---|
| Distance from BPOW to closest ANY Well 7377 (ft) | 1870 (from 8480) |
| Source width (ft) | 936 |
| Source thickness (ft) = total screen lengths of well 8480 (570 - 665 ft bgs) and well 9338 (585 - 646 ft bgs) | 95 |
| Dispersion Ax, Ay, Az | 187 / 18.7 / 0.187 |
| **Trigger concentration (ug/L) at BPOW** | **1.13** |

| LWD well 5303 | BPOW4-1R | BPOW4-2R |
|---|---|---|
| Distance from BPOW to LWD Well 5303 (ft) | 600 | 930 |
| Source width (ft) | 300 | 465 |
| Source thickness (ft) = total screen length of LWD-5303 (620 - 736 ft bgs) | 116 | 116 |
| Dispersion Ax, Ay, Az | 60 / 6 / 0.06 | 93 / 9.3 / 0.093 |
| **Trigger concentration (ug/L) at BPOW** | **0.54** | **0.57** |

Notes:
ft = feet; ft bgs = feet below ground surface
ug/L = micro grams per liter
LWD = Levittown Water District
MWD = Massapequa Water District
NYAW = New York American Water; formerly Aqua New York (ANY)
SFWD = South Farmingdale Water District

**Table 4**
**Sensitivity Analysis**

| | Inputs | | | | | | | Model Prediction | |
|---|---|---|---|---|---|---|---|---|---|
| | K (ft/d) | i | n | v (ft/d) | Dispersion: Ax/Ay/Az | Source thickness (ft) | Source width (ft) | OW trigger conc (ug/L) | % change in trigger conc |
| Surrogate scenario: NYAW wells 8480, 9338; trigger at BPOW3-3, 3-4 | 75 | 0.002 | 0.15 | 1 | 187/18.7/0.187 | 95 | 936 | 1.13 | |
| Sensitivity to source thickness (x 1.5, ÷1.5) | 75 | 0.002 | 0.15 | 1 | 187/18.7/0.187 | **142.5** | 936 | 1.10 | -3 |
| | 75 | 0.002 | 0.15 | 1 | 187/18.7/0.187 | **63** | 936 | 1.15 | 2 |
| Sensitivity to source width (x 1.5, ÷1.5) | 75 | 0.002 | 0.15 | 1 | 187/18.7/0.187 | 95 | **1404** | 1.05 | -7 |
| | 75 | 0.002 | 0.15 | 1 | 187/18.7/0.187 | 95 | **624** | 1.37 | 21 |
| Sensitivity to dispersion (x 1.5, ÷1.5) | 75 | 0.002 | 0.15 | 1 | **280/28/0.28** | 95 | 936 | 1.22 | 8 |
| | 75 | 0.002 | 0.15 | 1 | **125/12.5/0.125** | 95 | 936 | 1.09 | -4 |
| Sensitivity to K (x 1.5, ÷1.5) | **112** | 0.002 | 0.15 | 1.5 | 187/18.7/0.187 | 95 | 936 | 0.67 | -41 |
| | **50** | 0.002 | 0.15 | 0.666 | 187/18.7/0.187 | 95 | 936 | 3.25 | 188 |
| Sensitivity to i (x 1.5, ÷1.5) | 75 | **0.003** | 0.15 | 1.5 | 187/18.7/0.187 | 95 | 936 | 0.67 | -41 |
| | 75 | **0.0013** | 0.15 | 0.665 | 187/18.7/0.187 | 95 | 936 | 3.28 | 190 |
| Sensitivity n (x 1.5, ÷1.5) | 75 | 0.002 | **0.225** | 0.666 | 187/18.7/0.187 | 95 | 936 | 3.25 | 188 |
| | 75 | 0.002 | **0.1** | 1.5 | 187/18.7/0.187 | 95 | 936 | 0.67 | -41 |
| High velocity scenario | 75 | 0.003 | 0.1 | 2.25 | 187/18.7/0.187 | 95 | 936 | 0.56 | -50 |

Notes:

ft = feet; ft bgs = feet below ground surface; ft/day = feet per day
K = hydraulic conducitivity
i = hydraulic gradient
n = porosity
v = seepage velocity = (k x i)/n
ug/L = micro grams per liter

**Bolded parameters** indicate parameter that was varied in the sensitivity analysis while leaving remaining parameters the same.
Sensitivity analysis based on varying model inputs to surrogate scenario of BPOW3-3, 3-4 trigger values.
Other BPOW3-3, BPOW3-4 input: Length (distance from OW to MWD) = 1870 feet; time was 5 years.
Trigger concentration = contaminant concentration at BPOW estimated to result in 0.5 ug/L detection at Water supply well after 5 years travel time using analytical Quick Domenico fate and transport model (see text for assumptions and limitations).

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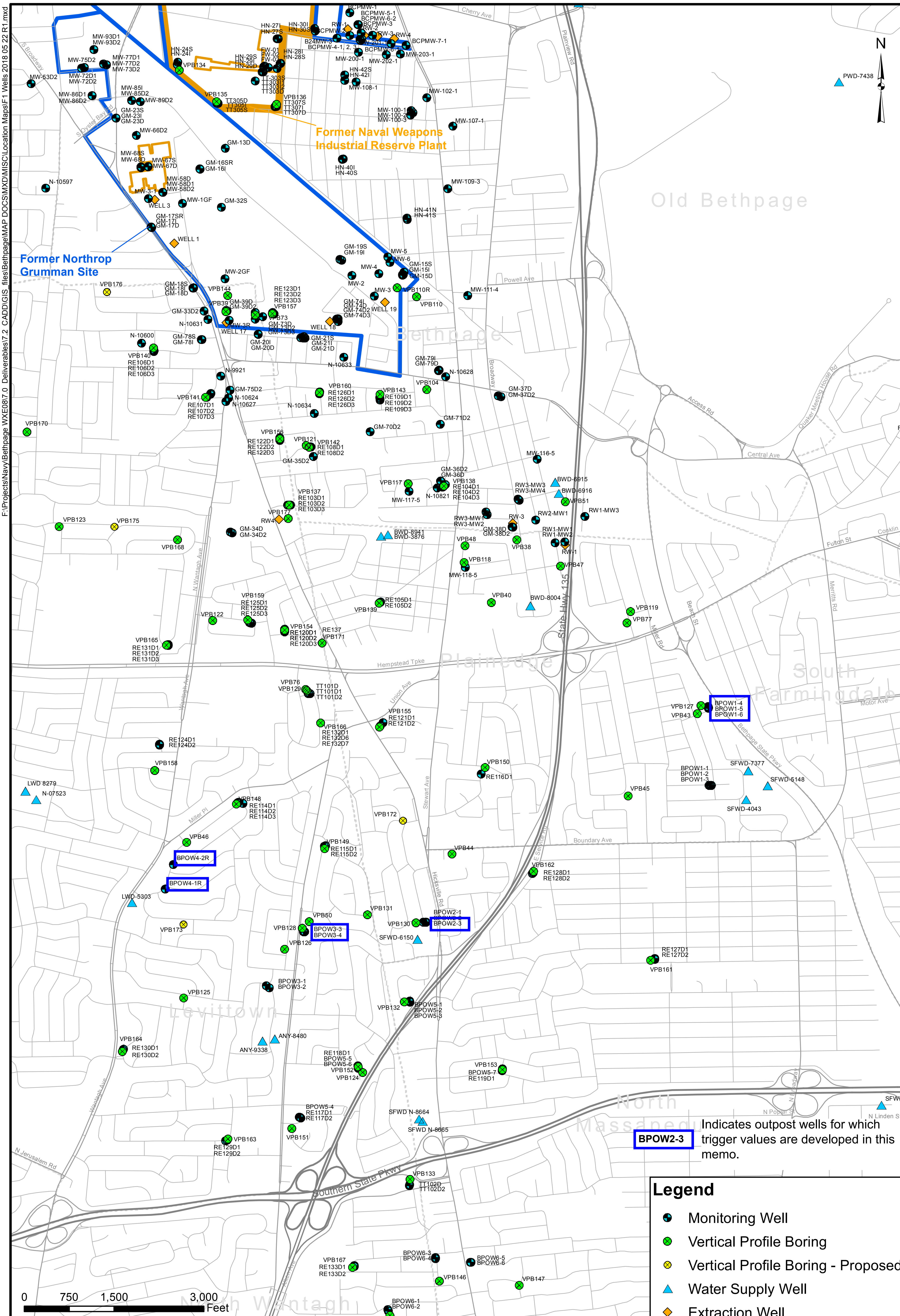



FIGURE 1. WELL LOCATION MAP

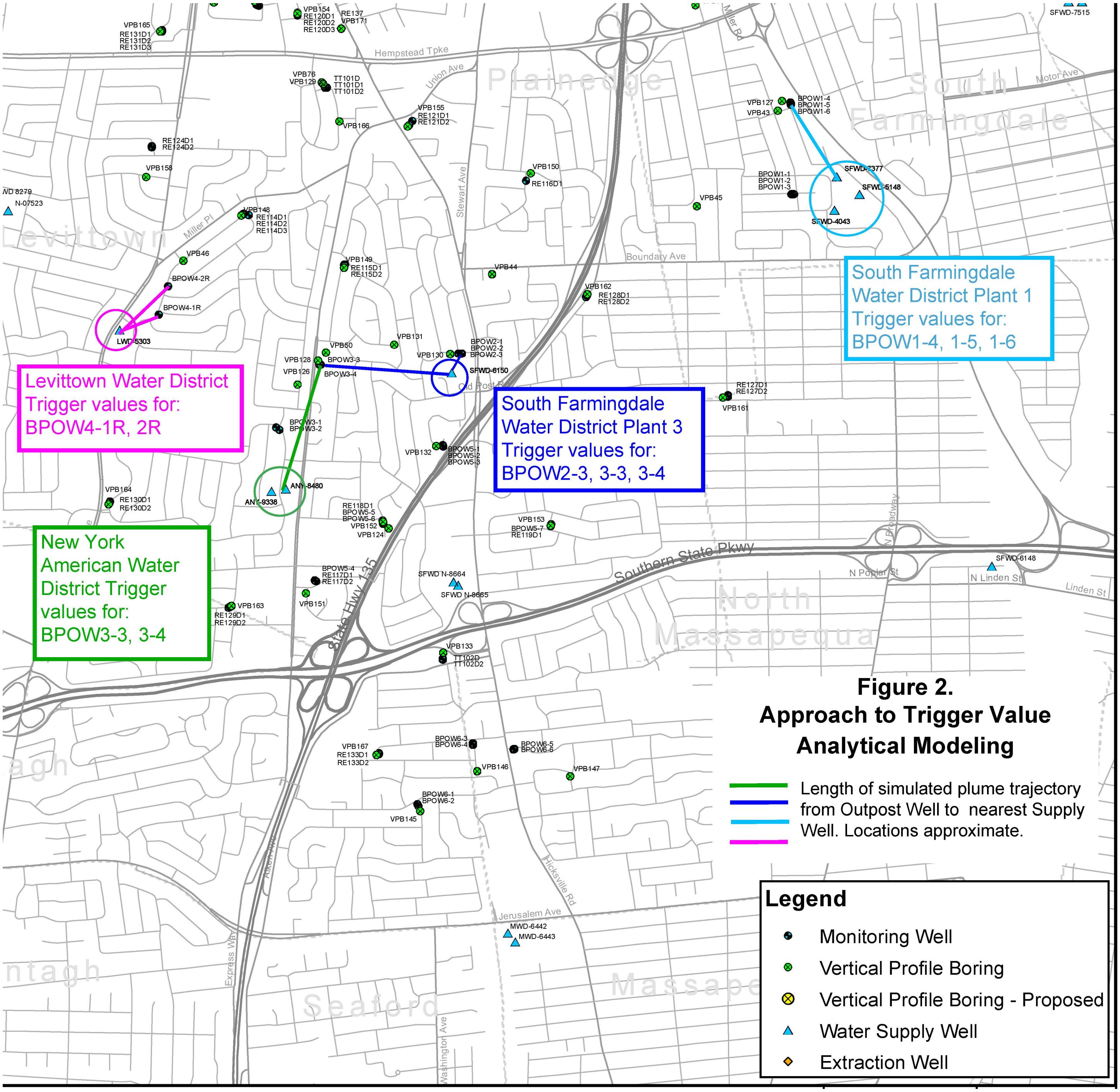
NAVAL WEAPONS INDUSTRIAL RESERVE PLANT

BETHPAGE, NEW YORK

NAVFAC

| CONTRACT NUMBER | CTO NUMBER |
|---|---|
| N62470-11-D8013 | WE15 |
| APPROVED BY: PS | DATE: 5/22/2018 |
| APPROVED BY: __ | DATE: __ |
| FIGURE NO. 1 | REV 0 |

em




Length of simulated plume trajectory from Outpost Well to nearest Supply Well, color coded by water district. Locations approximate.

| | | | |
|---|---|---|---|
| NAVFAC | **Figure 2.** **Approach to Trigger Value Analytical Modeling** NAVAL WEAPONS INDUSTRIAL RESERVE PLANT BETHPAGE, NEW YORK | CONTRACT NUMBER N62470-11-D8013 | CTO NUMBER WE15 |
| | | APPROVED BY PS | DATE 6/8/2018 |
| | | APPROVED BY — | DATE — |
| | | FIGURE NO. 2 | REV 0 |

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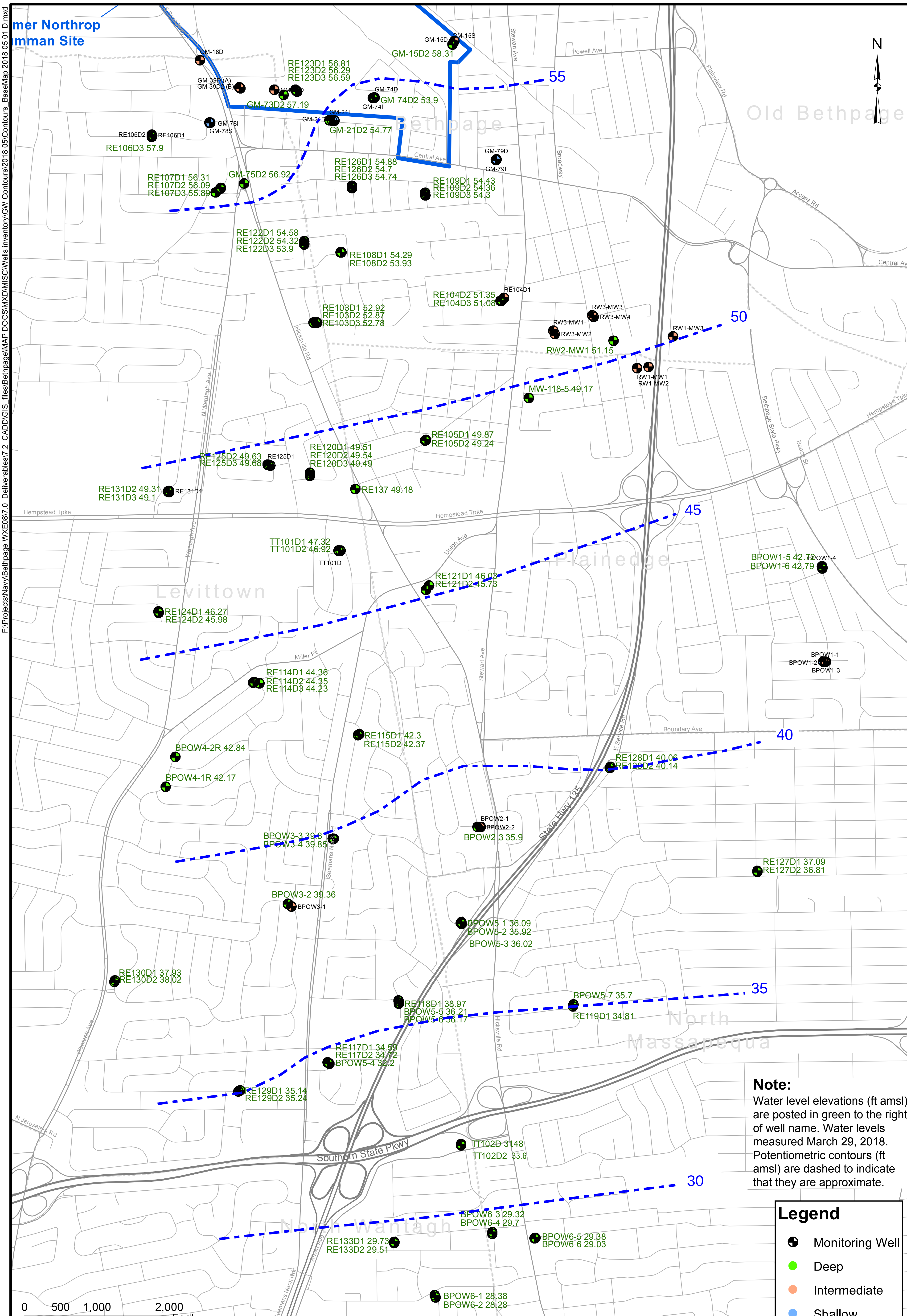



NAVFAC

**Figure 3. Synoptic Water Levels March 29, 2018 in Deep Wells (screened >500 ft bgs)**

NAVAL WEAPONS INDUSTRIAL RESERVE PLANT

BETHPAGE, NEW YORK

| CONTRACT NUMBER | CTO NUMBER |
|---|---|
| N62470-11-D8013 | WE15 |
| APPROVED BY: PS | DATE: 5/1/2018 |
| APPROVED BY: — | DATE: — |
| FIGURE NO. 3 | REV 0 |

## Appendix 1. Quick Domenico Model Documentation

**The following Appendix was taken from the Pennsylvania Department of Environmental Protection QD Manual**

# Appendix 1. QD Model Background

## A1.1. Model Derivation

*Domenico* [1987] published a solution to the three-dimensional differential equation for solute transport in a saturated porous medium with uniform steady-state flow, one-dimensional advection, three-dimensional dispersion, adsorption, and first-order decay [*van Genuchten*, 1985]:

$$\frac{\partial}{\partial t}\left(n_e C + \rho S\right) = \frac{\partial}{\partial x}\left(n_e D_x \frac{\partial C}{\partial x} - qC\right) + n_e D_y \frac{\partial^2 C}{\partial y^2} + n_e D_z \frac{\partial^2 C}{\partial z^2} - \lambda_w n_e C - \lambda_s \rho S \quad \text{(A1-1)}$$

where:

**Table A1.1.**

| Symbol | Definition | Units |
|---|---|---|
| $C$ | solute concentration | M L$^{-3}$ |
| $S$ | adsorbed concentration | M M$^{-1}$ |
| $n_e$ | effective porosity | L$^3$ L$^{-3}$ |
| $\rho$ | bulk density | M L$^{-3}$ |
| $D_i$ | coefficients of dispersion | L$^2$ T$^{-1}$ |
| $q$ | groundwater flux (Darcy velocity) | L T$^{-1}$ |
| $\lambda_w$ | water decay coefficient | T$^{-1}$ |
| $\lambda_s$ | soil decay coefficient | T$^{-1}$ |
| $x$ | longitudinal horizontal distance | L |
| $y$ | transverse horizontal distance | L |
| $z$ | downward vertical distance | L |
| $t$ | time | T |

M: mass, L: length, T: time

The following assumptions apply:

- The dissolved and adsorbed contaminant decay coefficients are equal
  $\lambda = \lambda_w = \lambda_s$.

- Properties ($n_e$ and $q$) are constant in space and time, so there is steady-state flow.

- Adsorption is described by a linear, reversible isotherm
  $S = K_d C$
  where $K_d$ is an empirical distribution coefficient (M$^{-1}$ L$^3$), and for organics
  $K_d = K_{oc} f_{oc}$
  where $K_{oc}$ is the organic carbon partition coefficient and $f_{oc}$ is the fraction of organic carbon.

See Section A.1.2 below for a further discussion of model assumptions.

The transport equation is then expressed as:

$$\frac{\partial C}{\partial t} = \frac{\alpha_x v}{R}\frac{\partial^2 C}{\partial x^2} + \frac{\alpha_y v}{R}\frac{\partial^2 C}{\partial y^2} + \frac{\alpha_z v}{R}\frac{\partial^2 C}{\partial z^2} - \frac{v}{R}\frac{\partial C}{\partial x} - \lambda C = 0 \qquad \text{(A1-2)}$$

where:

**Table A1.2.**

| Symbol | Definition | Expression | Units |
|---|---|---|---|
| $R$ | retardation | $1+\frac{\rho K_d}{n_e}$ | — |
| $\alpha_i$ | dispersivity | $D_i/v$ | L |
| $v$ | interstitial groundwater velocity | $q/n_e$ | L T$^{-1}$ |

The following initial and boundary conditions are applied:

- $C(x, y, z, 0) = 0$ (A1-3)
- $C(0, y, z, t) = C_0$ for $-½Y \le y \le +½Y$ and $0 \le z \le Z$ (A1-4)
- $\lim_{x\to\infty} \frac{\partial C(x,y,z,t)}{\partial x} = 0$ (A1-5)
- $\lim_{y\to\pm\infty} \frac{\partial C(x,y,z,t)}{\partial y} = 0$ (A1-6)
- $\lim_{z\to\infty} \frac{\partial C(x,y,z,t)}{\partial z} = 0$ (A1-7)

The *Domenico* [1987] solution of Equation (A1-2) subject to these boundary conditions, and with the inclusion of adsorption, is as follows:

$$C(x,y,z,t) = \frac{C_0}{8}\exp\left[\frac{x}{2\alpha_x}\left(1-\sqrt{1+\frac{4\lambda R\alpha_x}{v}}\right)\right] \times \mathrm{erfc}\left(\frac{x - vt\sqrt{1+\frac{4\lambda R\alpha_x}{v}}}{2\sqrt{\frac{\alpha_x vt}{R}}}\right)$$
$$\times\left[\mathrm{erf}\left(\frac{y+Y/2}{2\sqrt{\alpha_y x}}\right) - \mathrm{erf}\left(\frac{y-Y/2}{2\sqrt{\alpha_y x}}\right)\right]\times\left[\mathrm{erf}\left(\frac{z+Z}{2\sqrt{\alpha_z x}}\right) - \mathrm{erf}\left(\frac{z-Z}{2\sqrt{\alpha_z x}}\right)\right] \qquad \text{(A1-8)}$$

Note that this is a truncated, and not an exact, solution to the problem. Here it is assumed that contamination resides at the top of the aquifer and the only vertical dispersion is downwards.

Quick Domenico and EPA's Bioscreen apply the above solution, Equation (A1-8). Papadopulos and Associates' Bioscreen-AT application performs an exact analytic solution to Equation (A1-2) using a program called ATRANS.

EPA's Biochlor spreadsheet employs a slightly different approach. First, the longitudinal solution is not truncated, so there is a second (smaller) term with a product of an exponent and complementary error function. This will be slightly more accurate, but will not make a significant difference in practice.

Above it was assumed that the dissolved and adsorbed contaminant decay coefficients are equal. A second difference with the Biochlor solution is that the sorbed phase coefficient is zero:

$\lambda_s = 0$

$\lambda = \lambda_w$.

The resultant transport equation is then:

$$\frac{\partial C}{\partial t} = \frac{\alpha_x v}{R}\frac{\partial^2 C}{\partial x^2} + \frac{\alpha_y v}{R}\frac{\partial^2 C}{\partial y^2} + \frac{\alpha_z v}{R}\frac{\partial^2 C}{\partial z^2} - \frac{v}{R}\frac{\partial C}{\partial x} - \frac{\lambda}{R}C = 0 \qquad \text{(A1-9)}$$

This is identical to Equation (A1-2) except for the last term, where $\lambda$ is divided by $R$. Therefore, if one wishes to run Biochlor *without* assuming zero sorbed-phase decay, values of $R\lambda$ may be entered in place of $\lambda$.

## A1.2. Model Assumptions

Domenico's solution to the advective–dispersive equation incorporates the following assumptions.

- Aquifer properties are homogeneous and isotropic. For instance, porosity and hydraulic conductivity are spatially uniform, and there is no directional dependence.
- The flow field is homogeneous and unidirectional. The hydraulic gradient and groundwater velocity are constant in magnitude and direction throughout the model space. There are no pumping or recharge conditions altering the natural flow. The flow field is not radial, convergent, or divergent. There are no vertical flow gradients.
- Groundwater flow is in steady state. The hydraulic gradient and groundwater velocity are constant in time.
- The source shape is defined as a vertical rectangle perpendicular to groundwater flow.
- The source dimensions and concentration are constant with time.
- The aquifer is initially free of the contaminant, other than at the source.
- Both the aqueous and sorbed contaminant phases may undergo first-order decay, and the decay rate is the same for both.
- There is no transverse or vertical contaminant decay.
- Contaminants undergo linear, reversible, isothermal adsorption.
- Flow velocities are sufficiently high that mechanical dispersion dominates diffusion.

## A1.3. Mathematical Approximations

The approximations inherent to the Domenico solution have been examined by *West* et al. [2007] and *Srinivasan* et al. [2007]. They pointed out three significant mathematical inaccuracies.

- The three-dimensional solution is taken to be the product of three one-dimensional solutions. This approach does not conserve mass.

- The longitudinal solution $C(x,t)$ omits a secondary term in QD and Bioscreen. The error is large when the dispersivity ($\alpha_x$) is large such that $x/\alpha_x$ is relatively small.

- Domenico made the time substitution $t = x/v$, where $v$ is the groundwater velocity. This is only correct when $\alpha_x = 0$. For nonzero longitudinal dispersivity, there are sizable errors especially forward of the advective front. This time reinterpretation also exaggerates the plume width.

*West* et al. [2007] and *Srinivasan* et al. [2007] concluded that contaminant concentrations may be significantly underestimated on the plume centerline. Errors can be minimized when:

- longitudinal dispersivities are low ($\alpha_x$)
- advection velocities are high ($v = Ki$)
- simulation times are long ($t$).

Users must practice caution when making site predictions using fate-and-transport models as discussed by *Konikow* [2010].

# References

Bouwer, H., The Bouwer and Rice slug test—An update; *Ground Water*, *27*, 304–309, 1989.

Domenico, P. A., An analytical model for multidimensional transport of a decaying contaminant species, *Journal of Hydrology*, *91*, 49–58, 1987.

Domenico, P. A., and F. W. Schwartz, *Physical and Chemical Hydrogeology*, 2nd ed., New York: John Wiley, 506 pp., 1998.

Halford, K. J., and E. L. Kuniansky, *Documentation of Spreadsheets for the Analysis of Aquifer-Test and Slug-Test Data*, Open-File Report 02-197, 51 pp., USGS, Carson City, NV, 2002.

Howard, P. H., R. S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, *Handbook of Environmental Degradation Rates*, 725 pp., Boca Raton, Lewis Publishers, 1991.

Konikow, L. F., The secret to successful solute-transport modeling, *Ground Water*, *49*, 144–159, 2011.

Kruseman, G. P., and N. A. de Ridder, *Analysis and Evaluation of Pumping Test Data*, 2nd edition, Publication No. 47, 377 pp., Wageningen, The Netherlands, International Institute for Land Reclamation and Improvement, 1990.

Low, D. J., D. J. Hippe, and D. Yannacci, *Geohydrology of Southeastern Pennsylvania*, Water-Resources Investigations Report 00-4166, 347 pp., USGS, New Cumberland, PA, 2002.

Neuman, S. P., On advective transport in fractal permeability and velocity fields, *Water Resources Research*, *31*, 6, 1455–1460, 1995.

Newell, C. J., H. S. Rifai, J. T. Wilson, J. A. Connor, J. A. Aziz, and M. P. Suarez, Ground Water Issue: Calculation and use of first-order rate constants for monitored natural attenuation studies, EPA/540/S-02/500, U.S. EPA, Cincinnati, OH, 2002.

Schultze-Makuch, D., Longitudinal dispersivity data and implications for scaling behavior, *Ground Water*, *43*, 443–456, 2005.

Srinivasan, V., T. P. Clement, and K. K. Lee, Domenico solution—Is it valid?, *Ground Water*, *45*, 136–146, 2007.

URS, Groundwater fate and transport training course, Pennsylvania DEP, Valley Forge, PA, November 19, 2008.

van Genuchten, M. T., Convective–dispersive transport of solutes involved in sequential first-order decay reactions, *Computers & Geosciences*, *11*, 129–147, 1985.

van Genuchten, M. T., and W. J. Alves, *Analytical solutions of the one-dimensional convective–dispersive solute transport equation*, U. S. Department of Agriculture, Tech. Bull. 1661, 1982.

West, M. R., B. H. Kueper, and M. J. Ungs, On the use and error of approximation in the Domenico (1987) solution, *Ground Water*, *45*, 126–135, 2007.

Xu, M., and Y. Eckstein, Use of weighted least squares method in evaluation of the relationship between dispersivity and field scale, *Ground Water*, *33*, 905–908, 1995.

# Appendix 2. Model Output

## South Farmingdale Water District Plant 1
## Outpost Wells
## BPOW1-4, BPOW1-5, BPOW1-6

**ADVECTIVE TRANSPORT WITH THREE DIMENSIONAL DISPERSION,1ST ORDER DECAY and RETARDATION - WITH CALIBRATION TOOL**

| | | | |
|---|---|---|---|
| Project: | Bethpage SFWD Plant 1, BPOW1-4, 1-5, 1-6 | | |
| Date: | 4/10/2018 | Prepared by: | P. Shattuck |
| | | Contaminant: | |

NEW QUICK_DOMENICO.XLS

SPREADSHEET APPLICATION OF "AN ANALYTICAL MODEL FOR MULTIDIMENSIONAL TRANSPORT OF A DECAYING CONTAMINANT SPECIES"
P.A. Domenico (1987)
Modified to Include Retardation

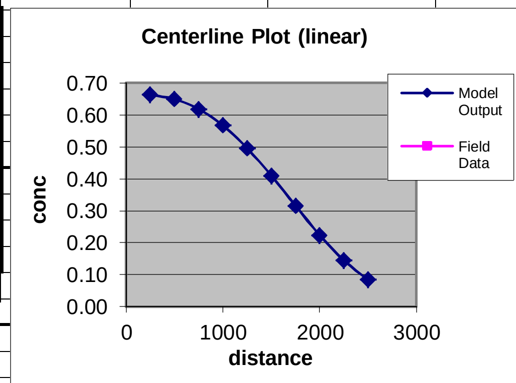
| SOURCE CONC (MG/L) | Ax (ft) | Ay (ft) | Az (ft) >=.001 | LAMBDA day-1 | SOURCE WIDTH (ft) | SOURCE THICKNESS (ft) | Time (days) (days) |
|---|---|---|---|---|---|---|---|
| 0.67 | 1.26E+02 | 1.26E+01 | 1.26E-01 | 0 | 630 | 214 | 1825 |

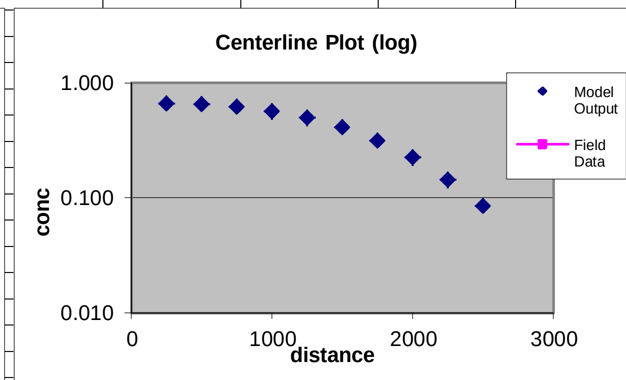
| Hydraulic Cond (ft/day) | Hydraulic Gradient (ft/ft) | Porosity (dec. frac.) | Soil Bulk Density (g/cm³) | KOC | Frac. Org. Carb. | Retard-ation (R) | V (=K*i/n*R) (ft/day) |
|---|---|---|---|---|---|---|---|
| 7.50E+01 | 0.002 | 0.15 | 1.8 | 0 | 0.00E+00 | 1 | 1 |

**Point Concentration**

| x(ft) | y(ft) | z(ft) |
|---|---|---|
| 1260 | 0 | 0 |

| | x(ft) | y(ft) | z(ft) |
|---|---|---|---|
| Conc. At | 1260 | 0 | 0 |
| at | 1825 | days = | **0.493** mg/l |




| AREAL MODEL | CALCULATION DOMAIN |
|---|---|
| Length (ft) | 2500 |
| Width (ft) | 600 |

| | 250 | 500 | 750 | 1000 | 1250 | 1500 | 1750 | 2000 | 2250 | 2500 |
|---|---|---|---|---|---|---|---|---|---|---|
| 600 | 0.000 | 0.004 | 0.012 | 0.022 | 0.029 | 0.033 | 0.032 | 0.027 | 0.021 | 0.014 |
| 300 | 0.381 | 0.361 | 0.344 | 0.320 | 0.287 | 0.243 | 0.192 | 0.140 | 0.093 | 0.055 |
| 0 | 0.663 | 0.650 | 0.618 | 0.567 | 0.496 | 0.410 | 0.316 | 0.224 | 0.145 | 0.085 |
| -300 | 0.381 | 0.361 | 0.344 | 0.320 | 0.287 | 0.243 | 0.192 | 0.140 | 0.093 | 0.055 |
| -600 | 0.000 | 0.004 | 0.012 | 0.022 | 0.029 | 0.033 | 0.032 | 0.027 | 0.021 | 0.014 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Field Data:** | **Centerline C Concentration** | | | | | | | |
| | **Distance from Source** | | | | | | | |

# Appendix 3. Model Output

## South Farmingdale Water District Plant 3
## Outpost Wells
## BPOW2-3, BPOW3-3, BPOW3-4

**ADVECTIVE TRANSPORT WITH THREE DIMENSIONAL DISPERSION,1ST ORDER DECAY and RETARDATION - WITH CALIBRATION TOOL**

| | | | |
|---|---|---|---|
| Project: | Bethpage SFWD Plant 3, BPOW2-3 | | |
| Date: | 4/10/2018 | Prepared by: | P. Shattuck |
| | | Contaminant: | |

NEW QUICK_DOMENICO.XLS

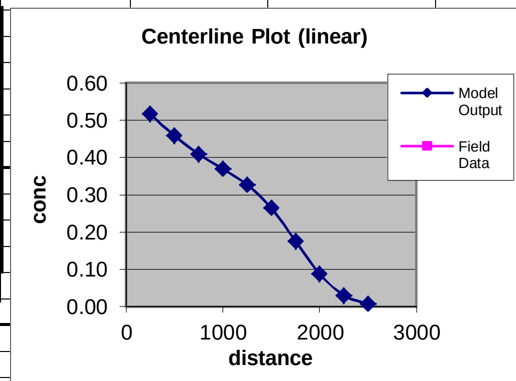
SPREADSHEET APPLICATION OF "AN ANALYTICAL MODEL FOR MULTIDIMENSIONAL TRANSPORT OF A DECAYING CONTAMINANT SPECIES"
P.A. Domenico (1987)
Modified to Include Retardation

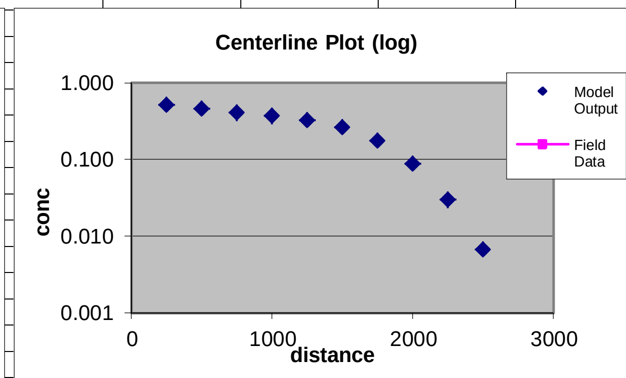
| SOURCE CONC (MG/L) | Ax (ft) | Ay (ft) | Az (ft) >=.001 | LAMBDA day-1 | SOURCE WIDTH (ft) | SOURCE THICKNESS (ft) | Time (days) (days) |
|---|---|---|---|---|---|---|---|
| 0.54 | 3.30E+01 | 3.30E+00 | 3.00E-02 | 0 | 165 | 67 | 1825 |

| Hydraulic Cond (ft/day) | Hydraulic Gradient (ft/ft) | Porosity (dec. frac.) | Soil Bulk Density ($g/cm^3$) | KOC | Frac. Org. Carb. | Retardation (R) | V (=K*i/n*R) (ft/day) |
|---|---|---|---|---|---|---|---|
| 7.50E+01 | 0.002 | 0.15 | 1.8 | 0 | 0.00E+00 | 1 | 1 |

**Point Concentration**

| x(ft) | y(ft) | z(ft) | |
|---|---|---|---|
| 330 | 0 | 0 | |
| | **x(ft)** | **y(ft)** | **z(ft)** |
| Conc. At | 330 | 0 | 0 |
| at | 1825 | days = | **0.498** mg/l |




**AREAL CALCULATION MODEL DOMAIN**

| | |
|---|---|
| Length (ft) | 2500 |
| Width (ft) | 600 |

| | *250* | *500* | *750* | *1000* | *1250* | *1500* | *1750* | *2000* | *2250* | *2500* |
|---|---|---|---|---|---|---|---|---|---|---|
| *600* | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| *300* | 0.000 | 0.000 | 0.001 | 0.002 | 0.004 | 0.006 | 0.007 | 0.005 | 0.002 | 0.001 |
| *0* | 0.517 | 0.458 | 0.409 | 0.369 | 0.327 | 0.264 | 0.176 | 0.087 | 0.030 | 0.007 |
| *-300* | 0.000 | 0.000 | 0.001 | 0.002 | 0.004 | 0.006 | 0.007 | 0.005 | 0.002 | 0.001 |
| *-600* | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| **Field Data:** | **Centerline C Concentration** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Distance from Source** | | | | | | | |

**ADVECTIVE TRANSPORT WITH THREE DIMENSIONAL DISPERSION,1ST ORDER DECAY and RETARDATION - WITH CALIBRATION TOOL**

| | | | |
|---|---|---|---|
| Project: | Bethpage SFWD Plant 3, BPOW3-3, 3-4 | | |
| Date: | 4/10/2018 | Prepared by: | P. Shattuck |
| | | Contaminant: | |

NEW QUICK_DOMENICO.XLS

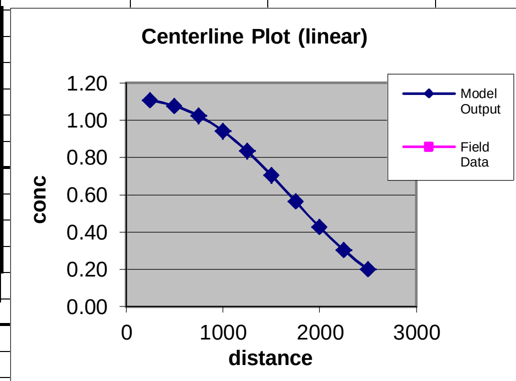
SPREADSHEET APPLICATION OF "AN ANALYTICAL MODEL FOR MULTIDIMENSIONAL TRANSPORT OF A DECAYING CONTAMINANT SPECIES"
P.A. Domenico (1987)
Modified to Include Retardation

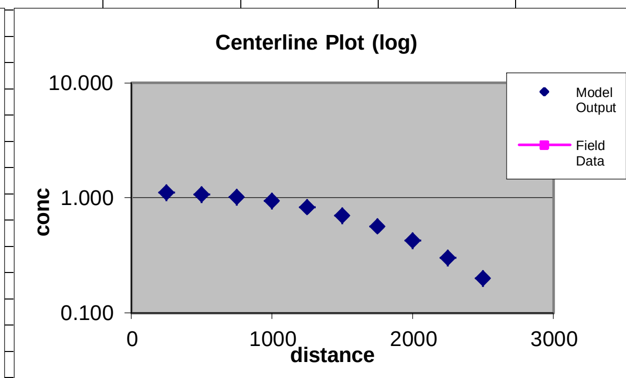
| SOURCE CONC (MG/L) | Ax (ft) | Ay (ft) | Az (ft) >=.001 | LAMBDA day-1 | SOURCE WIDTH (ft) | SOURCE THICKNESS (ft) | Time (days) (days) |
|---|---|---|---|---|---|---|---|
| 1.14 | 1.87E+02 | 1.87E+01 | 1.87E-01 | 0 | 930 | 67 | 1825 |

| Hydraulic Cond (ft/day) | Hydraulic Gradient (ft/ft) | Porosity (dec. frac.) | Soil Bulk Density (g/cm$^3$) | KOC | Frac. Org. Carb. | Retard-ation (R) | V (=K*i/n*R) (ft/day) |
|---|---|---|---|---|---|---|---|
| 7.50E+01 | 0.002 | 0.15 | 1.8 | 0 | 0.00E+00 | 1 | 1 |

**Point Concentration**

| x(ft) | y(ft) | z(ft) | |
|---|---|---|---|
| 1870 | 0 | 0 | |
| | x(ft) | y(ft) | z(ft) |
| Conc. At | 1870 | 0 | 0 |
| at | 1825 | days = | 0.497 mg/l |




**AREAL CALCULATION MODEL DOMAIN**

Length (ft) 2500
Width (ft) 600

| | 250 | 500 | 750 | 1000 | 1250 | 1500 | 1750 | 2000 | 2250 | 2500 |
|---|---|---|---|---|---|---|---|---|---|---|
| 600 | 0.090 | 0.174 | 0.216 | 0.232 | 0.229 | 0.211 | 0.181 | 0.145 | 0.109 | 0.075 |
| 300 | 1.059 | 0.955 | 0.863 | 0.770 | 0.669 | 0.560 | 0.448 | 0.339 | 0.241 | 0.160 |
| 0 | 1.108 | 1.077 | 1.024 | 0.943 | 0.834 | 0.704 | 0.564 | 0.426 | 0.302 | 0.200 |
| -300 | 1.059 | 0.955 | 0.863 | 0.770 | 0.669 | 0.560 | 0.448 | 0.339 | 0.241 | 0.160 |
| -600 | 0.090 | 0.174 | 0.216 | 0.232 | 0.229 | 0.211 | 0.181 | 0.145 | 0.109 | 0.075 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Field Data:** | **Centerline C Concentration** | | | | | | | |
| | **Distance from Source** | | | | | | | |

# Appendix 4. Model Output

## Levittown Water District Well 5303
## Outpost Wells
## BPOW4-1R, BPOW4-2R

**ADVECTIVE TRANSPORT WITH THREE DIMENSIONAL DISPERSION,1ST ORDER DECAY and RETARDATION - WITH CALIBRATION TOOL**

| | | | |
|---|---|---|---|
| Project: | Bethpage LWD WELL, BPOW4-1R | | |
| Date: | 4/10/2018 | Prepared by: | P. Shattuck |
| | | Contaminant: | |

| SOURCE CONC (MG/L) | Ax (ft) | Ay (ft) | Az (ft) >=.001 | LAMBDA day-1 | SOURCE WIDTH (ft) | SOURCE THICKNESS (ft) | Time (days) (days) |
|---|---|---|---|---|---|---|---|
| 0.54 | 6.00E+01 | 6.00E+00 | 6.00E-02 | 0 | 300 | 116 | 1825 |

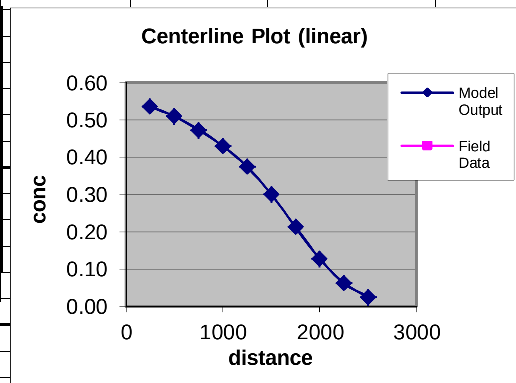
| Hydraulic Cond (ft/day) | Hydraulic Gradient (ft/ft) | Porosity (dec. frac.) | Soil Bulk Density ($g/cm^3$) | KOC | Frac. Org. Carb. | Retard-ation (R) | V (=K*i/n*R) (ft/day) |
|---|---|---|---|---|---|---|---|
| 7.50E+01 | 0.002 | 0.15 | 1.8 | 0 | 0.00E+00 | 1 | 1 |

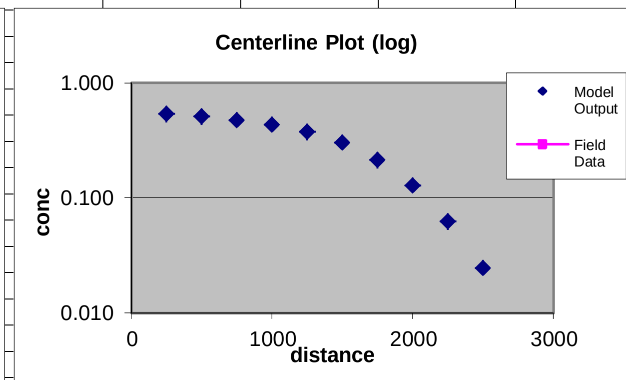
NEW QUICK_DOMENICO.XLS

SPREADSHEET APPLICATION OF "AN ANALYTICAL MODEL FOR MULTIDIMENSIONAL TRANSPORT OF A DECAYING CONTAMINANT SPECIES"
P.A. Domenico (1987)
Modified to Include Retardation

## Point Concentration

| x(ft) | y(ft) | z(ft) | |
|---|---|---|---|
| 600 | 0 | 0 | |
| | x(ft) | y(ft) | z(ft) |
| Conc. At | 600 | 0 | 0 |
| at | 1825 | days = | **0.496** |
| | | | mg/l |




**AREAL CALCULATION MODEL DOMAIN**

Length (ft) 2500
Width (ft) 600

| | 250 | 500 | 750 | 1000 | 1250 | 1500 | 1750 | 2000 | 2250 | 2500 |
|---|---|---|---|---|---|---|---|---|---|---|
| 600 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 300 | 0.002 | 0.014 | 0.030 | 0.044 | 0.053 | 0.054 | 0.045 | 0.031 | 0.017 | 0.008 |
| 0 | 0.536 | 0.510 | 0.473 | 0.430 | 0.375 | 0.301 | 0.213 | 0.128 | 0.063 | 0.025 |
| -300 | 0.002 | 0.014 | 0.030 | 0.044 | 0.053 | 0.054 | 0.045 | 0.031 | 0.017 | 0.008 |
| -600 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Field Data:** | **Centerline C Concentration** | | | | | | | |
| | **Distance from Source** | | | | | | | |

**ADVECTIVE TRANSPORT WITH THREE DIMENSIONAL DISPERSION,1ST ORDER DECAY and RETARDATION - WITH CALIBRATION TOOL**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Project: | Bethpage LWD WELL, BPOW4-2R | | | | | | |
| Date: | 4/10/2018 | Prepared by: | P. Shattuck | | | | |
| | | Contaminant: | | | | | |
| **SOURCE CONC (MG/L)** | **Ax (ft)** | **Ay (ft)** | **Az (ft) >=.001** | **LAMBDA day-1** | **SOURCE WIDTH (ft)** | **SOURCE THICKNESS (ft)** | **Time (days) (days)** |
| 0.57 | 9.30E+01 | 9.30E+00 | 9.30E-02 | 0 | 465 | 116 | 1825 |
| **Hydraulic Cond (ft/day)** | **Hydraulic Gradient (ft/ft)** | **Porosity (dec. frac.)** | **Soil Bulk Density (g/cm³)** | **KOC** | **Frac. Org. Carb.** | **Retard-ation (R)** | **V (=K*i/n*R) (ft/day)** |
| 7.50E+01 | 0.002 | 0.15 | 1.8 | 0 | 0.00E+00 | 1 | 1 |

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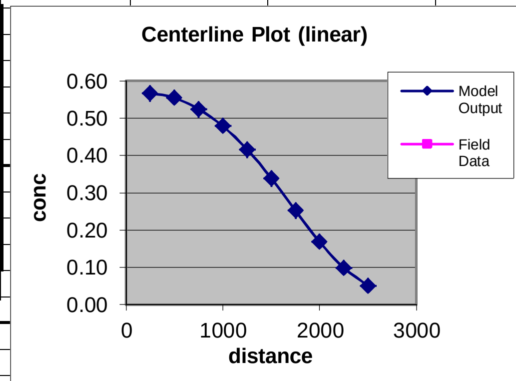
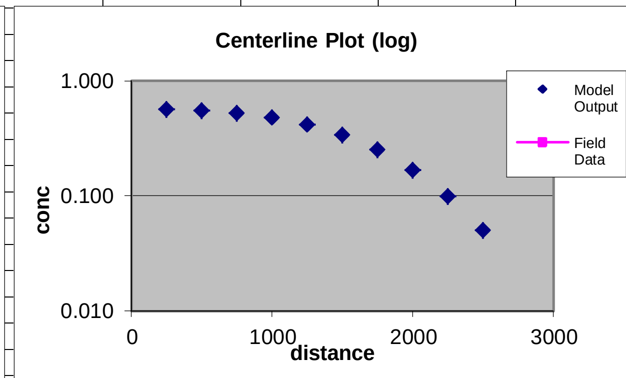
## Point Concentration

| x(ft) | y(ft) | z(ft) | |
|---|---|---|---|
| 930 | 0 | 0 | |
| | **x(ft)** | **y(ft)** | **z(ft)** |
| **Conc. At** | 930 | 0 | 0 |
| **at** | 1825 | days = | **0.493** mg/l |




**AREAL CALCULATION MODEL DOMAIN**

| | |
|---|---|
| Length (ft) | 2500 |
| Width (ft) | 600 |

| | 250 | 500 | 750 | 1000 | 1250 | 1500 | 1750 | 2000 | 2250 | 2500 |
|---|---|---|---|---|---|---|---|---|---|---|
| 600 | 0.000 | 0.000 | 0.001 | 0.002 | 0.004 | 0.006 | 0.007 | 0.006 | 0.005 | 0.003 |
| 300 | 0.092 | 0.136 | 0.157 | 0.163 | 0.157 | 0.139 | 0.111 | 0.078 | 0.049 | 0.026 |
| 0 | 0.568 | 0.554 | 0.524 | 0.479 | 0.417 | 0.339 | 0.252 | 0.168 | 0.099 | 0.051 |
| -300 | 0.092 | 0.136 | 0.157 | 0.163 | 0.157 | 0.139 | 0.111 | 0.078 | 0.049 | 0.026 |
| -600 | 0.000 | 0.000 | 0.001 | 0.002 | 0.004 | 0.006 | 0.007 | 0.006 | 0.005 | 0.003 |

| | | |
|---|---|---|
| **Field Data:** | **Centerline C Concentration** | |
| | **Distance from Source** | |

# Appendix 5. Model Output

## New York American Water Wells 8480 and 9338
## Outpost Wells
## BPOW3-3, BPOW3-4

**ADVECTIVE TRANSPORT WITH THREE DIMENSIONAL DISPERSION,1ST ORDER DECAY and RETARDATION - WITH CALIBRATION TOOL**

Project: Bethpage NYAW WELLS, BPOW3-3, 3-4

Date: **4/10/2018** Prepared by: P. Shattuck

Contaminant:

| SOURCE CONC (MG/L) | Ax (ft) | Ay (ft) | Az (ft) >=.001 | LAMBDA day-1 | SOURCE WIDTH (ft) | SOURCE THICKNESS (ft) | Time (days) (days) |
|---|---|---|---|---|---|---|---|
| 1.13 | 1.87E+02 | 1.87E+01 | 1.87E-01 | 0 | 936 | 95 | 1825 |

| Hydraulic Cond (ft/day) | Hydraulic Gradient (ft/ft) | Porosity (dec. frac.) | Soil Bulk Density ($g/cm^3$) | KOC | Frac. Org. Carb. | Retardation (R) | V (=K*i/n*R) (ft/day) |
|---|---|---|---|---|---|---|---|
| 7.50E+01 | 0.002 | 0.15 | 1.8 | 0 | 0.00E+00 | 1 | 1 |

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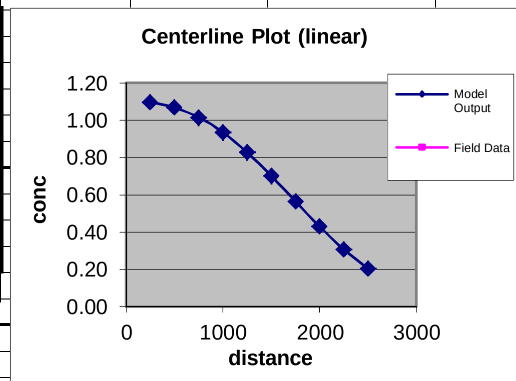
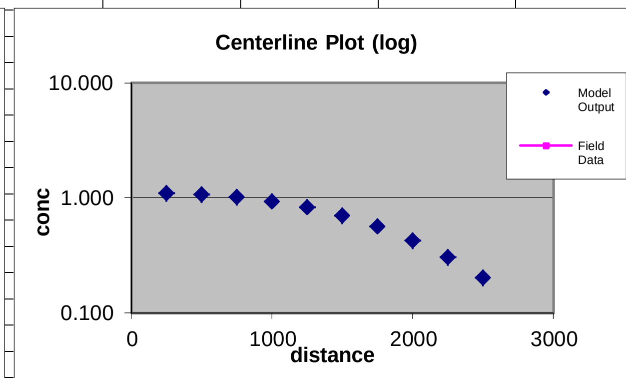
P.A. Domenico (1987)
Modified to Include Retardation

**Point Concentration**

| x(ft) | y(ft) | z(ft) |
|---|---|---|
| 1870 | 0 | 0 |

| | x(ft) | y(ft) | z(ft) |
|---|---|---|---|
| Conc. At | 1870 | 0 | 0 |
| at | 1825 | days = | **0.499** mg/l |




**AREAL CALCULATION MODEL DOMAIN**

Length (ft) 2500

Width (ft) 600

| | 250 | 500 | 750 | 1000 | 1250 | 1500 | 1750 | 2000 | 2250 | 2500 |
|---|---|---|---|---|---|---|---|---|---|---|
| 600 | 0.095 | 0.179 | 0.220 | 0.235 | 0.232 | 0.213 | 0.183 | 0.148 | 0.111 | 0.078 |
| 300 | 1.053 | 0.951 | 0.860 | 0.767 | 0.668 | 0.561 | 0.450 | 0.342 | 0.245 | 0.164 |
| 0 | 1.098 | 1.068 | 1.016 | 0.936 | 0.829 | 0.702 | 0.565 | 0.429 | 0.306 | 0.204 |
| -300 | 1.053 | 0.951 | 0.860 | 0.767 | 0.668 | 0.561 | 0.450 | 0.342 | 0.245 | 0.164 |
| -600 | 0.095 | 0.179 | 0.220 | 0.235 | 0.232 | 0.213 | 0.183 | 0.148 | 0.111 | 0.078 |

| Field Data: | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Centerline Concentration | | | | | | | | |
| Distance from Source | | | | | | | | |

**NEW YORK PROFESSIONAL GEOLOGIST SEAL**

As a New York-licensed Professional Geologist, I have reviewed and approve this Trigger Value Development Addendum #2 to the Operable Unit 2 Offsite Groundwater Public Water Supply Contingency Plan, and seal it in accordance with Article 145 Section 7209 of the New York State Education Laws. In sealing this document, I certify it was prepared under my direction, the geological information contained in it is true to the best of my knowledge and the geological methods and procedures included herein are consistent with currently accepted geological practices.

It is a violation of this law for any person to alter the contained drawings or the report in any way, unless he or she is acting under the direction of a NY-licensed Professional Geologist.

Name: Brian E. Caldwell
NY PG License Number: 000511
State: New York

STATE OF NEW YORK ★ BRIAN E CALDWELL ★ 511 ★ LICENSED PROFESSIONAL GEOLOGIST

Signature: ________________

Date: 9/7/18