Prepared for:
Midco Remediation Corporation
c/o Barnes & Thornburg LLC
Chicago, IL 60606

Prepared by:
AECOM
Warrenville, IL
Project # 60279033
February 2013

Midco I and II
1,4-Dioxane Natural Attenuation Model Documentation

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List of Acronyms

AECOM	AECOM Technical Services, Inc.
AS	air sparging
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
cm/sec	centimeters per second
COCs	contaminants of concern
ESDs	Explanation of Significant Differences
gpd/ft2	gallons per day per square foot
gpm	gallon per minute
GWETS	groundwater extraction and treatment system
IDEM	Indiana Department of Environmental Management
INDOT	Indiana Department of Transportation
kg	kilogram
MCR	Midco Remedial Corporation
NPL	National Priorities List
PCBs	polychlorinated biphenyls
RI	Remedial Investigation
ROD	Record of Decision
SVE	soil vapor extraction
SVOCs	semi-volatile organic compounds
ug/L	micrograms per liter
USEPA	United States Environmental Protection Agency
VOCs	volatile organic compounds

1.0 Introduction

On behalf of the Midco Remedial Corporation (MRC) and Settling Defendants, AECOM Technical Services, Inc. (AECOM) presents this documentation of 1,4-dioxane fate and transport modeling for the former Midwest Solvent Recovery, Inc. sites (Midco I and II) in Gary, Indiana (the sites). This model documentation is being presented to the U.S. Environmental Protection Agency to demonstrate the natural attenuation of residual 1,4-dioxane observed at Midco I and II following extensive remediation for volatile organic compounds (VOCs) in soil and groundwater. 1,4-Dioxane was not identified as a constituent of concern in the 1992 Consent Decree and subsequent Explanation of Significant Differences (ESDs) and is outside the scope of the Respondents' obligations; it is presented on behalf of the MRC on a voluntary basis for inclusion in a future ESD should the parties agree that the 1,4, dioxane present at the sites will be resolved by natural attenuation.

1,4, Dioxane was first observed in localized areas of groundwater at the sites after the MRC agreed to voluntarily update analytical methodology for Appendix IX volatile organic compounds (including 1,4, dioxane) in the annual groundwater sampling event in 2009 . Those groundwater analyses identified 1,4-dioxane in localized areas of groundwater at the Midco I and II sites. These observations followed approximately 14 years of a pump and treat groundwater remedy for VOCs in groundwater in combination with soil vapor extraction and, at Midco II, air sparging operations for groundwater. The MRC agreed to voluntarily proceed with a field investigation at the Midco II site to delineate the extent of 1,4-dioxane to the southwest of monitoring wells Q-50 and P-1 to improve understanding of its localized occurrence in the vicinity of the site.

Given the limited occurrence of 1,4-dioxane observed at the Midco I and II sites and co-incidental VOC source remediation activities from 1996 to 2012 that likely addressed 1,4-dioxane which may have been present, these fate and transport models were developed to provide the basis for a voluntary natural attenuation remedy at the Midco I and II sites. Recent trends indicate the stability or decrease of 1,4-dioxane concentrations from 2009 to 2012 which are a result of dispersion and advection, and possibly biodegradation. Provided in this report are conceptual site descriptions for 1,4-dioxane occurrence, a description of a conservative basis for fate and transport model parameters used to represent the Sites, and a summary of analytical model results and conclusions.

2.0 Background Information

2.1 Property Locations and Description

The Midco I and II sites are located in Gary, Indiana. The two sites are separated by approximately 3.5 miles. The Midco I site is located north of 15th Avenue in Section 11, Township 36 North, and Range 9 West in the City of Gary, Lake County, Indiana. The Midco I site is surrounded by industrial and commercial properties. Midco I is bordered on the west by the Indiana Department of Transportation (INDOT) equipment yard and salt storage facility; on the north by the original dune ridge and swale topography, beyond which is the 9th Avenue Dump Superfund site; on the east by former cut-and-fill land that is occupied by a concrete recycling operation that is currently stockpiling large quantities of concrete debris; and on the south by small commercial buildings. Several residential properties exist west and south of the site and approximately 3,500 feet to the northeast.

The Midco II site is located on approximately 9 acres located at 5900 Industrial Highway in Section 36, Township 37 North, and Range 9 West in the City of Gary, Lake County, Indiana. The site is surrounded by industrial and commercial properties. Midco II is bordered on the northwest by a former auto salvage yard; on the north and northeast by a drainage ditch and railroad; on the east and southeast by vacant filled-in land owned by the Gary-Chicago Airport Development Zone, and Industrial Highway to the south and southwest, beyond which is the Gary-Chicago Municipal Airport. The area further north of the site towards Lake Michigan is occupied by steel related industry. Between the site and Lake Michigan, much of the land has been in-filled with iron-ore slag material, with areas along the Lake having up to 30 to 40 feet of buried slag. Several residential properties are located approximately 1 mile southeast of the site at the intersection of Industrial Highway and Clark Street. Prior to Midco II operations, up to 10 feet of saline aluminum reprocessing (smelting) waste was buried across much of the northern part of the site and adjoining properties.

2.2 Midco I Site History

In the mid- to late-1970s the Midco I site was used for industrial waste storage, recycling, and disposal. In 1976, a large fire destroyed an estimated 14,000 drums containing chemical wastes, with an estimated additional 14,000 drums brought to the site from 1977 to 1979. Based upon subsequent investigations, site operations resulted in soil and groundwater contamination. The USEPA identified the following constituents at the site: VOCs, semi-volatile organic compounds (SVOCs), pesticides, polychlorinated biphenyls (PCBs), and inorganic constituents.

In 1981, the USEPA installed a fence around the initial source area of Midco I. In 1982, removal and offsite disposal of surficial wastes, soils, and installation of an interim clay cover was completed by the USEPA. The site was placed on the National Priorities List (NPL) in 1983. From 1985 to 1989 the Settling Defendants completed a Remedial Investigation (RI). The USEPA issued a ROD and ROD Amendment in 1989 and 1992, respectively.

A Consent Decree was entered into agreement in 1992 specifying the final remedial actions required for the site. At that time the Settling Defendants formed the MRC to complete the required remedial actions. Remedy components completed at Midco I to date include: wetland mitigation settlements in 1993, interim sediment removal operations in 1993, startup of the GWETS in 1997, installation of a groundwater barrier wall surrounding the source area in 2004, and startup and operation of the SVE system in 2006 with completion in 2010 after achieve 97% reduction in baseline organic vapors. Operation of the SVE system from 2010 to 2012 has been a voluntary action of the MRC to further reduce organic vapors within the barrier wall prior to final remedial construction activities.

2.3 Midco II Site History

Midco II began waste operations in 1976 after operations were moved from the Midco I facility following a fire that destroyed Midco I. Midco II was used for temporary bulk liquid and drum storage of waste materials, neutralization of acids and caustics, and onsite disposal of liquids into pits, including an unlined filter bed with an overflow pipe discharging directly into the northern ditch. In 1977, a large fire destroyed equipment, buildings, and an estimated 50,000 to 60,000 drums containing chemical wastes, resulting in additional spillage. Releases of waste materials from these activities resulted in soil and groundwater contamination. The USEPA identified the following constituents at the site: VOCs, semi-volatile organic compounds (SVOCs), pesticides, polychlorinated biphenyls (PCBs), and inorganic constituents.

In 1981, USEPA installed a fence around the initial source area of Midco II. In 1984 and 1985, removal of drums, tanks, and surficial wastes was completed by USEPA. In 1985, contaminated soil and sludge material impacted by PCBs and cyanide was excavated from the sludge pit and filter bed and temporarily staged on-site for disposal during remediation activities completed between 1985 and 1989. The site was placed on the National Priorities List (NPL) in 1986. From 1985 to 1989 the Settling Defendants completed a Remedial Investigation (RI). USEPA issued a ROD and ROD Amendment in 1989 and 1992, respectively.

A Consent Decree was entered into agreement in 1992 specifying the final remedial actions required for the Midco II site. At that time the Settling Defendants formed the MRC to complete the required remedial actions. Since that time various remedial activities have been completed at the site. In 1993 to 1994, partial sediment excavation and onsite containment of the northern ditch was completed. Startup and operation of the GWETS was from 1996 to 2010. Startup and operation of an air sparging and soil vapor extraction (AS/SVE) system from 2006 to 2009 to achieve the required 97% reduction in baseline organic vapors, and continued operation of the AS/SVE for groundwater remediation from 2009 to present.

3.0 Midco I

Groundwater fate and transport modeling was conducted by AECOM for the MRC for the Midco I site in Gary Indiana. Based on data from the last four annual groundwater monitoring events (2009, 2010, 2011, and 2012), fate and transport modeling of 1,4-dioxane was completed using a set of conservative input parameters and analytical equations as described in this report.

The BIOSCREEN-AT natural attenuation model, developed by S.S. Papadopulos & Associates, Inc. was used (Karanovic, et. al., 2007) to complete the modeling. BIOSCREEN-AT is an updated, conservative enhancement of the standard U.S. Environmental Protection Agency (USEPA) BIOSCREEN program that uses a second, exact solution method. This enhanced program does not introduce the numerical error that is associated with the approximate Domenico solution used in the BIOSCREEN program. The BIOSCREEN-AT program uses a solution method that is an exact three-dimensional analytical solution for solute transport from a patch boundary condition within a semi-infinite aquifer. Like BIOSCREEN, the enhanced BIOSCREEN-AT program is built in an Excel user interface that requires the user input site-specific parameters to determine groundwater flow velocity, contaminant flow velocity, and downgradient extent of dissolved-phase constituents.

3.1 Completed Source Remediation

In accordance with the 1992 Consent Decree, source remediation actions for VOCs and SVOCs in soil and groundwater were completed at the Midco I Site. The Midco I groundwater extraction and treatment system (GWETS) provided capture and treatment of groundwater impacted by VOCs from 1997 to 2010. In addition, the main source area was dewatered and treated with soil vapor extraction from 2006 to 2010. Voluntary soil vapor extraction was completed from 2010 to 2012 after shutdown of the GWETS. The barrier wall containment remains in place to contain source area groundwater.

Source control measures were targeted for VOCs and SVOCs, and if 1,4-dioxane had been present with these constituents, it would have been coincidentally captured and treated by soil vapor extraction and groundwater extraction and treatment systems. The Agency for Toxic Substances and Disease Registry (ATSDR) toxicology profile for 1,4-dioxane indicates that it has a vapor pressure and Henry's law constant which is expected to be associated with moderate rates from volatilization from soil and groundwater surfaces.

3.2 Conceptual Site Model

There is no indication of a source area for 1,4-dioxane that is currently present at the Site. The localized occurrence of 1,4-dioxane at the Midco I site in 2009 to 2012 (**Figure 1**) outside of the source area barrier wall is limited to the vicinity of monitoring wells H-30 and O-30. Groundwater extraction wells EW1, EW2, and EW7 were operated in the immediate vicinity of wells H-30 and O-30 from 1997 to 2010 and during this time period, potentially impacted groundwater in the vicinity of these extraction wells would have been captured and treated for disposal in the Midco deep injection well. The concentrations of 1,4-dioxane observed in recent groundwater monitoring results from 2009 to 2012 represent the residual mass that is used in the fate and transport model described in this report. **Figure 1** indicates that 1,4-dioxane concentrations are stable or decreasing at all monitoring wells from 2009 to 2012.

3.2.1 Site Hydrogeology

3.2.1.1 Aquifer Units

Previous investigations of the region have identified four basic hydrologic units of glacial deposits overlying a Silurian-age bedrock aquifer system. Following is a brief description of these units, which were described in more detail in the Remedial Investigation (RI) report completed for Midco I.

The surficial sand unconfined aquifer (Calumet Aquifer-Unit 1) is approximately 30 feet thick at Midco I and comprised primarily of fine sand of lacustrine origin with interbedded organic matter. All of the groundwater monitoring wells currently monitored at the site are screened within the sand aquifer as either water table wells or wells screened at the mid-point or base of the aquifer. Contaminants at the Midco I site are limited to portions of this formation.

The clay glacial tills (regional aquitard above bedrock-Units 2 and 4) are approximately 110 feet thick near the Midco I site, these soils are relatively impermeable clay-rich glacial till deposits. Regionally, these tills are separated by glacial outwash sand and gravel (also known as Unit 3) often used as a water source; however, the interbedded outwash deposits are absent at the site. There are no known impacts in this formation that are attributed to the Midco I site.

Silurian-age carbonate rocks (primarily dolomite) underlie the glacial deposits and were encountered at approximately 140 feet bgs based on available boring logs completed at the Midco I site. Available information indicates the upper bedrock has relatively poor yield locally (1 to 10 gpm) with significant drawdown measured at well heads, resulting in abandonment of many of these wells as a water source. There are no known impacts in this formation that are attributed to the Midco I site.

3.2.1.2 Hydraulic Conductivity

Hydraulic conductivity testing (e.g., slug testing) of eighteen (18) Calumet Aquifer wells at the site during the RI yielded a geometric mean value of hydraulic conductivity of 2.71×10^{-3} centimeters per second (cm/sec) [or 57 gallons per day per square foot (gpd/ft2)], which is consistent with sand aquifers. The RI did not indicate an observable difference in hydraulic conductivity between shallow and deep wells within the Calumet aquifer. The overall value of hydraulic conductivity used for Midco II was 1.23×10^{-2} cm/s; this value was based on previous groundwater modeling calibration (ENVIRON, 2006) and site pumping tests and was recommended by USEPA and the Indiana Department of Environmental Management (IDEM) as being more representative than the slug test results in fate and transport modeling documentation provided in the Midco I and II Site Closure Plans (USEPA, 2011b).

3.2.1.3 Groundwater Gradient

Water level measurements completed at the site during the RI and following investigations indicated that the static (non-pumping) horizontal groundwater flow is toward the northeast across the site at an average gradient of 0.0041 foot per foot. The Midco I site lies north of a regional groundwater divide that is situated between the Grand Calumet River (located to the north) and Little Calumet River (located to the south). The northern flow direction observed during non-pumping conditions is consistent with the regional anticipated flow toward the Grand Calumet River.

3.2.2 1,4-Dioxane Mass Occurrence

A conservatively estimated total in-place mass of 1,4-dioxane located northeast of the source area barrier wall is 1.23 kilograms. Monitoring well data indicate that this mass is present in the lower portion of the Calumet Aquifer. While zones of lower hydraulic conductivity sands were not indicated by geologic logs or slug test data conducted during the RI, it is assumed that 1,4-dioxane occurrence is likely present in highly localized lower permeability sands lenses that would be available to pore flushing.

3.3 Fate and Transport Model

Fate and transport modeling of the residual 1,4-dioxane mass located in the vicinity of monitoring wells H-30, O-30, B-30 and EW-4 was performed using BIOSCREEN-AT (described above). Based on the justification provided in Section 3.1, it is assumed there is no remaining source contributing additional 1,4-dioxane to the subsurface, and concentrations detected at the site are indicative of residual mass. To represent the reduction in residual mass as groundwater moves through the area and transports it downgradient, the mass flux of 1,4-dioxane was modeled by applying a source decay term (i.e. source half life) to the source concentration. The initial source concentration was estimated based on the average maximum concentrations from wells H-30, O-30, B-30 and EW-4.

The source decay term used to represent mass flux depleting the residual mass over time, was the more conservative value estimated using two different approaches. Because of the polarity and recalcitrance of 1,4-dioxane, it is expected to behave like a conservative tracer in groundwater. Therefore, as a dissolved constituent, the flux from the source area can be calculated by multiplying the seepage velocity by the cross sectional area of the downgradient edge of the source area, and the source concentration (i.e. the conservative tracer flushes with groundwater, without sorption, retardation or biodegradation effects). The mass flux is then divided by the total mass of 1,4-dioxane in the source area to estimate a source half-life is as presented in **Appendix A**.

The second, more conservative, approach to estimate the source decay term is to evaluate the trend plots of decreasing concentrations at individual wells (**Appendix A**). The best fit line that represents the decreasing concentrations was used to estimate the source decay term. For the Midco I and II sites, a representative source decay rate was obtained from monitoring well Q-50 at Midco II which was the most conservative half-life estimated using this method.

The primary mechanism for reduction of a conservative constituent downgradient of the residual source area is dispersion. For fate and transport modeling of 1,4-dioxane, sorption (retardation) and biodegradation effects were considered insignificant; dispersion is the only mechanism decreasing the concentration once the constituent leaves the source area. Values for dispersivity were directly calculated by BIOSCREEN-AT based on the plume length; the relationship between dispersivity and plume length is described in detail in the BIOSCREEN User's Manual.

3.3.1 Model Inputs

The following section summarizes the basis of the specific model input parameters used in BIOSCREEN-AT to model conditions at the Midco I site:

<u>*Source concentration*</u>: The source concentration input is based on maximum concentrations measured at wells within the source area. The average of the maximum concentrations observed between 2009 and 2011 at wells H-30 (140 u/L), O-30 (69 ug/L), B-30 (24 ug/L) and EW-4 (31 ug/L) is 66 ug/L; these wells are located within the source area, which was delineated as described below.

Source Area Dimensions: The source width and thickness are required model input; the source area length is used indirectly to estimate source half life. The source area is estimated to be approximately 340 feet long (in the direction of groundwater flow), 430 feet wide and 15 feet thick. The source area thickness is based on average measured groundwater levels and the depth to the bottom of the sandy aquifer. The length and width of the source area were determined based on an overestimation (conservative) of the area encompassing the four wells exhibiting the highest concentrations outside of the cutoff wall at Midco I (H-30, O-30, B-30 and EW-4).

Source Half Life: The source half life, discussed at the beginning of the section, was estimated using two different approaches and selecting the more conservative value. The conservative value (i.e. longer half life) of 5 years was based on a relatively conservative 2009 to 2012 trend plot analyses of monitoring wells, with well Q-50 at Midco II having the most conservative half-life of those wells evaluated. Shorter half lives were modeled as part of a sensitivity analysis described below. As a conservative basis for modeling, no biodegradation was assumed to occur.

Hydraulic Conductivity: Hydraulic conductivity, hydraulic gradient and porosity are used to calculate seepage velocity in the BIOSCREEN-AT model. The value of hydraulic conductivity used for Midco I was 9.74×10^{-3} cm/s; this value was based on previous groundwater modeling calibration (Environ MRC Model) and site pumping tests and was recommended by USEPA as being more representative than the slug test results (USEPA letter to ARCADIS, December 13, 2011).

Hydraulic Gradient: The value for hydraulic gradient used in the Midco I model, 0.004 ft/ft is based on the average groundwater gradient observed at the site since the shutdown of pumping activities. The average hydraulic gradient was estimated based on contour maps developed using annual groundwater level estimates.

Porosity: The modeling input for porosity was 30% and is based on the values used for previous modeling work (Environ MRC Model). The BIOSCREEN User's Manual suggests a range of effective porosity for fine sand between 10% and 30%.

Estimated Plume Length: The plume length is used to directly calculate values for dispersivity in BIOSCREEN-AT; a complete discussion of the relationship between plume length and dispersion can be found in the BIOSCREEN User's Manual. The estimate plume length used as modeling input was a function of the simulation time and was determined based on the following iterative approach: (1) initially use an estimated plume length based on seepage velocity and simulation time; (2) run the model to calculate the extent of the plume; (3) reenter the new plume length and rerun the model; and, (4) repeat iterations until the change in plume length between successive model runs is insignificant. Although no drinking water receptors are located within the plume and none are expected in the future due to municipal institutional controls, the downgradient edge of the plume was considered to extend to the 6.7 ug/L contour which is the Regional Screening Level for tap water for 10^{-5} cancer risk from USEPA correspondence (2011a).

Note that adsorption and biodegradation modeling input parameters were not included to evaluate the fate and transport of 1,4-dioxane, as described above.

3.3.2 Sensitivity Analysis

A sensitivity analysis was performed for selected input to evaluate the variation in modeling results and documentation is provided in **Appendix B**. Source half life, hydraulic conductivity and estimated plume length were varied based on potential variability at the site and/or recommended ranges. Of all modeling input these parameters have a relatively greater potential for variability.

The source half life used in the model was determined based on a trend plot analysis as described above. The source half life calculated based on mass flux depleting the source area was about 0.4 years and is significantly lower than the 5 year half life used in the model. A longer half life of 12 years, based on preliminary BIOSCREEN modeling, was also used to evaluate the sensitivity of modeling results to changes in the source half life (decay) term. The results of this sensitivity analysis are provided in the **Appendix B**. In summary, the shorter source half life of 0.4 years reduces the furthest plume extent and time of attenuation by approximately 70%; the longer half life of 12 years increases the plume length by approximately 20% and time of attenuation by approximately 50%.

The hydraulic conductivity used in the model was based on previous modeling and pumping tests as discussed above; however, slug testing at the nearby Midco II site indicates the potential for the deeper sandy soils to have hydraulic conductivity values approximately 1/3 of the modeled values. A sensitivity modeling run was performed to evaluate the effect of lower hydraulic conductivity on modeling results. Decreasing the hydraulic conductivity from 9.74×10^{-3} cm/s to 3.2×10^{-3} cm/s had the effect of increasing the time of attenuation by approximately 35%, but decreasing the extent of the plume by approximately 35%. The results of this sensitivity analysis are provided in the **Appendix B**.

The BIOSCREEN User's Manual indicates that modeled plume lengths may vary between +/- 25% of the actual plume length in the field. Based on information provided in the BIOSCREEN User's Manual, the plume length was adjusted by this range to evaluate the resulting modeling sensitivity. Plume length had insignificant effect on the time of attenuation (< 1 year), but did affect the distance between source and downgradient plume edge. The furthest extent of the plume varied by approximately 10% to 15%. The results of this sensitivity analysis are provided in the **Appendix B**.

3.3.3 Model Results

The BIOSCREEN-AT modeling results, using the modeling input described in Section 3.2.1, indicate that the time of attenuation of 1,4-dioxane to a concentration less than 6.7 ug/L across the entire site area is approximately 17 years. The model indicates that the greatest extent of the plume (greater than 6.7 ug/L) would be approximately 1,440 feet from the source area after about 13 years. The modeling results are presented in **Appendix B**. These results are based on using conservative values calculated for source half life, a conservative source area size and assume that the target concentration (for plume attenuation) is equal to the Regional Screening Level for tap water of 6.7 ug/L. An interpretation of these results is provided in the Section 5.

4.0 Midco II

Groundwater fate and transport modeling was conducted by AECOM for MRC for the Midco II site in Gary Indiana. Based on data from the last four annual groundwater monitoring events (2009, 2010, 2011, and 2012) and the Midco II May/June 2012 field investigation results, fate and transport modeling of 1,4-dioxane was completed using a set of conservative input parameters and analytical equations as described in this report.

The BIOSCREEN-AT natural attenuation model, developed by S.S. Papadopulos & Associates, Inc. was used (Karanovic, et. al., 2007) to complete the modeling, similar to Midco I.

4.1 Completed Source Remediation

In accordance with the 1992 Consent Decree, source remediation actions for VOCs and SVOCs in soil and groundwater were completed at the Midco II Site. The Midco II groundwater extraction and treatment system (GWETS) provided capture and treatment of groundwater impacted by VOCs from 1996 to 2012. In addition, the main source areas were treated with air sparging and soil vapor extraction from 2006 to 2009. Groundwater remediation by air sparing has been completed from 2010 to present after shutdown of the GWETS. Soil remediation source control measures were targeted for VOCs, and if present, 1,4-dioxane, which has moderate vapor pressure and partitioning to the vapor phase would have been captured by air sparging and soil vapor extraction systems.

Source control measures were targeted for VOCs and SVOCs, and if 1,4-dioxane had been present with these constituents, it would have been coincidentally captured and treated by the air sparging, soil vapor extraction, and groundwater extraction and treatment systems. The Agency for Toxic Substances and Disease Registry (ATSDR) toxicology profile for 1,4-dioxane indicates that it has a vapor pressure and Henry's law constant which is expected to be associated with moderate rates from volatilization from soil and groundwater surfaces.

4.2 Conceptual Site Model

There is no indication of a primary source area of 1,4-dioxane that is currently present at the Site. The areas of occurrence of 1,4-dioxane at the Midco II site in 2009 to 2012 (**Figure 2**) is the vicinity of well Q-50 on the Gary-Chicago International Airport property, well MW-4D in the northeast portion of the site, and shallow well B-10 near the northwest site boundary. Groundwater extraction wells were operated at the Midco II site from 1996 to 2010 and during this time period, and potentially impacted groundwater in the vicinity of these extraction wells would have been captured and treated for disposal in the Midco deep injection well. The concentrations of 1,4-dioxane observed in recent groundwater monitoring results from 2009 to 2012 represents the residual mass that is used in the fate and transport model described in this report.

4.2.1 Site Hydrogeology

4.2.1.1 Aquifer Units

Previous investigations of the region have identified four basic hydrologic units of glacial deposits overlying a Silurian-age bedrock aquifer system. The following is a brief description of these units, which were described in more detail in the Remedial Investigation (RI) report completed for Midco II:

The surficial sand unconfined aquifer (Calumet Aquifer-Unit 1) is approximately 45 to 50 feet thick at Midco II and comprised primarily of fine sand of lacustrine origin with interbedded organic matter. All of the groundwater monitoring wells currently monitored at the site are screened within the sand aquifer as either water table wells or wells screened at the mid-point or base of the aquifer. Contaminants at the Midco II site are limited to portions of this formation.

The clay glacial tills (regional aquitard above bedrock-Units 2 and 4) – Approximately 65 to 70 feet thick near the Midco II site, these soils are relatively impermeable clay rich glacial till deposits. Regionally, these tills are separated by glacial outwash sand and gravel (also known as Unit 3) often used as a water source; however, the interbedded outwash deposits are absent at the site. There are no known impacts in this formation that are attributable to the Midco II site.

Silurian-age carbonate rocks underlie the glacial deposits (primarily dolomite) and were encountered approximately 110 feet bgs based on available boring logs completed at the Midco II site. Available information indicates the upper bedrock has relatively poor yield locally and very few bedrock water wells exist near the site. There are no known impacts in this formation that are attributable to the Midco II site.

4.2.1.2 Hydraulic Conductivity

Hydraulic conductivity testing (e.g., slug testing) of twenty-two (22) Calumet Aquifer wells at the site during the RI yielded a geometric mean value of conductivity of 3.09×10^{-3} centimeters per second (cm/sec) [or 65 gallons per day per square foot (gpd/ft^2)], which is consistent with regional sand aquifers. The Midco II RI indicated that hydraulic conductivity lower portion of the Calumet Aquifer may be approximately one-third of the hydraulic conductivity of shallow monitoring wells in the Calumet Aquifer, however, the overall value of hydraulic conductivity used for Midco II was 1.23×10^{-2} cm/s; this value was based on previous groundwater modeling calibration (Environ MRC Model) and site pumping tests and was recommended by USEPA as being more representative than the slug test results (USEPA letter to ARCADIS, December 13, 2011).

4.2.1.3 Groundwater Gradient

Based on the locality of the Midco II site to the south of a regional groundwater divide crest, which is situated between the Lake Michigan (located to the north) and Grand Calumet River (located to the south), the regional anticipated flow direction is south-southwest towards the Grand Calumet River. However, water level measurements completed at the site during the RI indicated horizontal shallow groundwater flow direction varies due to the location of the site relative to the regional groundwater divide. The dominant groundwater flow direction for the Midco II site based on groundwater elevation data collected since the shutdown of the GWETS, and review of constituent concentration data, is to the southwest.

During other groundwater gauging events from December 15, 2010 through November 28, 2012, the groundwater flow direction varied as shown on **Appendix B**. The groundwater flow direction and gradient was determined for each monitoring event from the average water level elevation of the shallow and deep elevations at each nested well pair, and well piezometers (P-series wells) that are screened across most of the Calumet Aquifer. The calculated average groundwater elevations are presented in **Appendix B**.

4.2.2 1,4-Dioxane Mass Occurrence

Three localized areas of 1,4-Dioxane occurrence were observed at the Midco II site:

1. Monitoring well B-10 (Midco II – North). A conservatively estimated total in-place mass of 1,4-dioxane located northwest portion of Midco II is 0.54 kilograms.

2. In the vicinity of monitoring well Q-50 (Midco II – South) monitoring well data and field data obtained in June 2012 downgradient of this well indicate that this mass is present in the lower portion of the Calumet Aquifer. A conservatively estimated total in-place mass of 1,4-dioxane is 17 kg (1,000 ug/L across the entire area). Lower hydraulic conductivity sands were indicated by geologic logs and slug test data conducted during the RI, it is assumed that 1,4-dioxane occurrence is likely present in lower permeability sand that would be available to pore flushing at a lower rate than upper portions of the aquifer.

3. In the vicinity of monitoring well MW-4D located in the northeast portion of the site, a conservatively estimated total in-place mass of 1,4-dioxane of approximately 4.72 kg. The 2009 to 2012 annual monitoring results for 1,4-dioxane indicate a southwestern gradient in the vicinity of this well toward well Q-50. Concentration trends indicate that the dominant groundwater flow direction affecting this mass is to the southwest (**Figure 2**).

4.3 Fate and Transport Model

Fate and transport modeling of the residual 1,4-dioxane mass located in the vicinity of monitoring wells B-10 in the northern portion of Midco II, and MW-50, V-50, W-50 and Q-50 in the southern portion of Midco II was performed using BIOSCREEN-AT (described above). Based on the justification provided above, there is no indication of a source contributing additional 1,4-dioxane to the subsurface, and concentrations detected at the site are indicative of residual mass that is being depleted in concentration. To represent the reduction in residual mass as groundwater moves through the area and transports it downgradient, the mass flux of 1,4-dioxane was modeled by applying a source decay term (i.e. source half life) to the source concentration. The initial source concentration was estimated based on the maximum concentrations observed in each of the two source areas. A more detailed description of source decay based on mass flux is provided in Section 3.1

4.3.1 Model Inputs

The following section summarizes the basis of the specific model input parameters used in BIOSCREEN-AT to model conditions at the Midco II site:

Source concentration: The source concentration input is based on maximum concentrations measured at wells within the source area. The maximum concentration observed in the northern portion of the site at well B-10 is 89 ug/L; the maximum concentration observed in the southern portion of the site at well Q-50 is 1,000 ug/L.

Source Area Dimensions: The source width and thickness are required model input; the source area length is used indirectly to estimate source half life. The northern source area is estimated to be approximately 200 feet long (in the direction of groundwater flow), 200 feet wide and 18 feet thick. The southern source area is estimated to be approximately 300 feet long (in the direction of groundwater flow), 375 feet wide and 18 feet thick. The source area thickness is based on average measured groundwater levels and the depth to the bottom of the sandy aquifer. The length and width of the source area were determined based on an overestimation (conservative) of the area encompassing the wells exhibiting the highest concentrations.

Source Half Life: The source half life, discussed at the beginning of the section, was estimated using more conservative value of the two approaches. The more conservative value (i.e. longer half life) of 5 years resulted from the trend plot analyses of individual wells (**Appendix A**), with well Q-50 having the most conservative half life of those wells evaluated. Shorter half lives were modeled as part of a sensitivity analysis described below. As a conservative basis for modeling, no biodegradation was assumed to occur.

Hydraulic Conductivity: Hydraulic conductivity, hydraulic gradient and porosity are used to calculate seepage velocity in the BIOSCREEN-AT model. The value of hydraulic conductivity used for Midco II was 1.23 x 10^{-2} cm/s; this value was based on previous groundwater modeling calibration (Environ MRC Model) and site pumping tests and was recommended by USEPA as being more representative than the slug test results (USEPA letter to ARCADIS, December 13, 2011).

Hydraulic Gradient: The value for hydraulic gradient used in the Midco II model, 0.0015 ft/ft is based on the average groundwater gradient observed at the site since the shutdown of pumping activities. The average hydraulic gradient was estimated based on contour maps developed using annual groundwater level estimates.

Porosity: The modeling input for porosity was 30% and is based on the values used for previous modeling work (Environ MRC Model). The BIOSCREEN User's Manual suggests a range of effective porosity for fine sand between 10% and 30%.

Estimated Plume Length: The plume length is used to directly calculate values for dispersivity in BIOSCREEN-AT; a complete discussion of the relationship between plume length and dispersion can be found in the BIOSCREEN User's Manual. The estimate plume length used as modeling input was a function of the simulation time and was determined based on the following iterative approach: (1) initially use an estimated plume length based on seepage velocity and simulation time; (2) run the model to calculate the extent of the plume; (3) reenter the new plume length and rerun the model; and, (4) repeat iterations until the change in plume length between successive model runs is insignificant. Although no drinking water receptors are located within the plume and none are expected in the future due to municipal institutional controls, the downgradient edge of the plume was considered to extend to the 6.7 ug/L contour for the Midco II north area which represents the Regional Screening Level for 10^{-5} cancer risk (the site default risk level) for a drinking water receptor. For the area south of the Midco II site, the downgradient edge of the plume for natural attenuation is 67 ug/L, the Regional Screening Level for 10^{-4} cancer risk for tap water. Due to the presence of the Gary Airport to the south of the Midco II site, the use of a cancer risk level of 10^{-4} to the south is also conservative.

Note that adsorption and biodegradation modeling input parameters were not included to evaluate the fate and transport of 1,4-dioxane, as described above.

4.3.2 Sensitivity Analysis

A sensitivity analysis was performed for selected input to evaluate the variation in modeling results. Source half life, hydraulic conductivity and estimated plume length were varied based on potential variability at the site and/or recommended ranges. Of all modeling input these parameters have a relatively greater potential for variability.

The source half life used in the model was determined based on a trend plot analysis as described above. The source half life calculated based on mass flux depleting the source area was about 0.4 years for the northern Midco II case and 0.8 for the southern Midco II case; these are significantly lower than the 5 year half life used in the model. A longer half life of 11 years (northern site) and 20 years (southern site), based on preliminary BIOSCREEN modeling, was also used to evaluate the sensitivity of modeling results to changes in the source half life (decay) term. The results of this sensitivity analysis are provided in the **Appendix C**. In summary, the shorter source half life reduces the furthest plume extent and time of attenuation by approximately 70%; the longer half life increases the plume length by approximately 20% and time of attenuation by approximately 50%.

The hydraulic conductivity used in the model was based on previous modeling and pumping tests as discussed above; however, slug testing at the site indicates the potential for the deeper sandy soils to have hydraulic conductivity values approximately 1/3 of the modeled values. A sensitivity modeling run was performed to evaluate the effect of lower hydraulic conductivity on modeling results. Decreasing the hydraulic conductivity from 1.23×10^{-2} cm/s to 4.1×10^{-3} cm/s had the effect of increasing the time of attenuation by approximately 35%, but decreasing the extent of the plume by approximately 35%. The results of this sensitivity analysis are provided in the **Appendix C**.

The BIOSCREEN User's Manual indicates that modeled plume lengths may vary between +/- 25% of the actual plume length in the field. Based on information provided in the BIOSCREEN User's Manual, the plume length was adjusted by this range to evaluate the resulting modeling sensitivity. Plume length had insignificant effect on the time of attenuation (< 1 year), but did affect the distance between source and downgradient plume edge. The furthest extent of the plume from the source area varied by approximately 10% to 15%. The results of this sensitivity analysis are provided in the **Appendix C**.

4.3.3 Model Results

The BIOSCREEN-AT modeling results, using the modeling input described in Section 4.2.1, indicate that the time of attenuation of 1,4-dioxane to concentrations less than 6.7 ug/L is approximately 22 years for the northern Midco II source area. The model indicates that the greatest extent of the plume (greater than 6.7 ug/L) would be approximately 1,200 from the northern source area natural attenuation to less than 6.7 ug/L after approximately 21 years.

For the area south of Midco II, the model indicates that the greatest concentration impact in groundwater adjacent to the Grand Calumet River to be 6.1 ug/L and natural attenuation would achieve concentrations in groundwater less than 67 ug/L in 21 years. The model indicates that the greatest extent of the plume (greater than 67 ug/L) would be 1,000 from well Q-50 or approximately 1,200 feet from the Midco II site.

The modeling results are presented in **Appendix C**. These results are based on using conservative values calculated for source half-life, a conservative source area size and assume that the target concentration (for plume attenuation) is equal to the Regional Screening Level for tap water. An interpretation of these results is provided in Section 5.

5.0 Conclusions

Fate and transport model results for the Midco I and II sites indicate that natural attenuation for 1,4-dioxane would be protective of human health and the environment. Groundwater ingestion is currently not a completed exposure pathway, however, the natural attenuation endpoint for 1,4-dioxane is assumed to be a conservative value of 6.7 ug/L for the Midco I site and the north portion of the Midco II site. For the south portion of Midco II and dowgradient areas, the natural attenuation endpoint for 1,4-dioxane is assumed to be value of 67 ug/L and is also conservative due to very limited potential for future drinking water receptors on the Gary Airport property.

For the Midco I site, natural attenuation would result in no exceedances of the 6.7 ug/L concentration goal (representing 10^{-5} cancer risk for tap water) after 17 years. The nearest downgradient well from the Midco I site is approximately 3500 feet to the northeast, and conservative 1,4-dioxane fate and transport model results presented in this report indicate the furthest downgradient of impact to 6.7 ug/L is 1440 feet. There are no on-site drinking water wells present and ongoing maintenance of the Midco I barrier wall will prevent offsite migration of COCs contained within the former source area.

With regard to potential ecological receptors at the Midco I site, the highest observed concentrations of 1,4-dioxane in groundwater (180 ug/L) are far less than the site-specific ecological criteria for groundwater impact to surface water of 58,000 ug/L.

For the area north of the Midco II site, natural attenuation would result in no exceedances of the 6.7 ug/L goal after 21 years. No wells are located within 4,300 feet northeast of the Site, which was the northern extent of the well survey area. The Midco II fate and transport model indicates that the greatest extent of the groundwater impacts (greater than 6.7 ug/L) would be approximately 1,200 feet to the north of Midco II.

For groundwater areas south of Midco II, natural attenuation would result in no exceedances of the 67 ug/L concentration goal (representing 10^{-4} cancer risk for tap water) after 21 years. Downgradient water wells between the Midco II site and the Grand Calumet River (the downgradient receptor) are limited to test/monitoring wells, and non-potable uses on the Gary Airport property; and institutional controls to limit future groundwater use are considered to be easily implementable. The fate and transport model indicates that the extent of groundwater impact for 67 ug/L of 1,4-dioxane is limited to approximately 1,200 feet from the site.

With regard to potential ecological receptors at the Midco II site, the highest observed concentrations of 1,4-dioxane in groundwater (1,600 ug/L) are far less than the site-specific ecological criteria for groundwater impact to surface water of 58,000 ug/L. Fate and transport model results indicate that the highest concentrations of groundwater reaching the Grand Calumet River would be 6.1 ug/L.

The modeled timeframes (17 to 21 years) are considered reasonable based on prior discussions with the USEPA, taking into account the absence of use of the groundwater as a drinking water supply, the reliability of the existing municipal drinking water well installation prohibitions, on-going groundwater monitoring, and MRC’s commitment to this remedy throughout the modeled timeframes.

As described in this fate and transport model documentation, the presence of 1,4-dioxane at the Midco I and II sites will be resolved by a natural attenuation approach. If U.S. EPA and IDEM concur, the MRC will develop a monitored natural attenuation work plan and assist in the development of an ESD or Record of Decision (ROD) amendment toward that end.

6.0 References

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Agency for Toxic Substances and Disease Registry (ATSDR) (2012), Toxicological Profile for 1,4-Dioxane, April.

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Karanovic, M., Neville, C.J., Andrews (2007), C.B., BIOSCREEN-AT, BIOSCREEN with an exact analytical solution, Groundwater, 45(2): 242-245

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U.S. Environmental Protection Agency (2011a), Midco I and II updated procedures for 1,4-dioxane and antimony, Correspondence from Richard Boice to Barbara Coughlin of ENVIRON, dated May 26.

U.S. Environmental Protection Agency (2011b), Midco I and II draft closure plans, Correspondence from Richard Boice to William Bow of ARCADIS, dated December 13.

Figures

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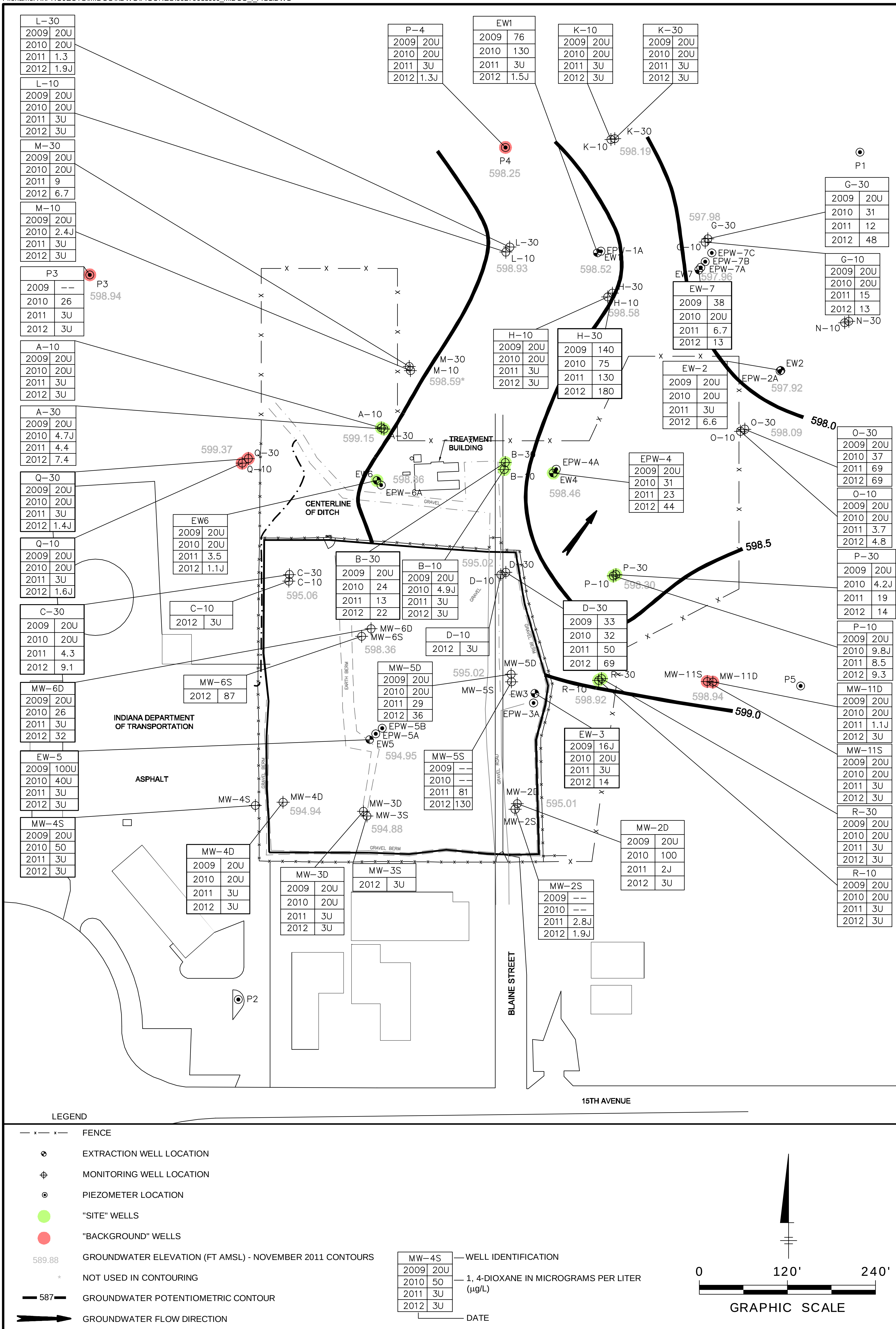
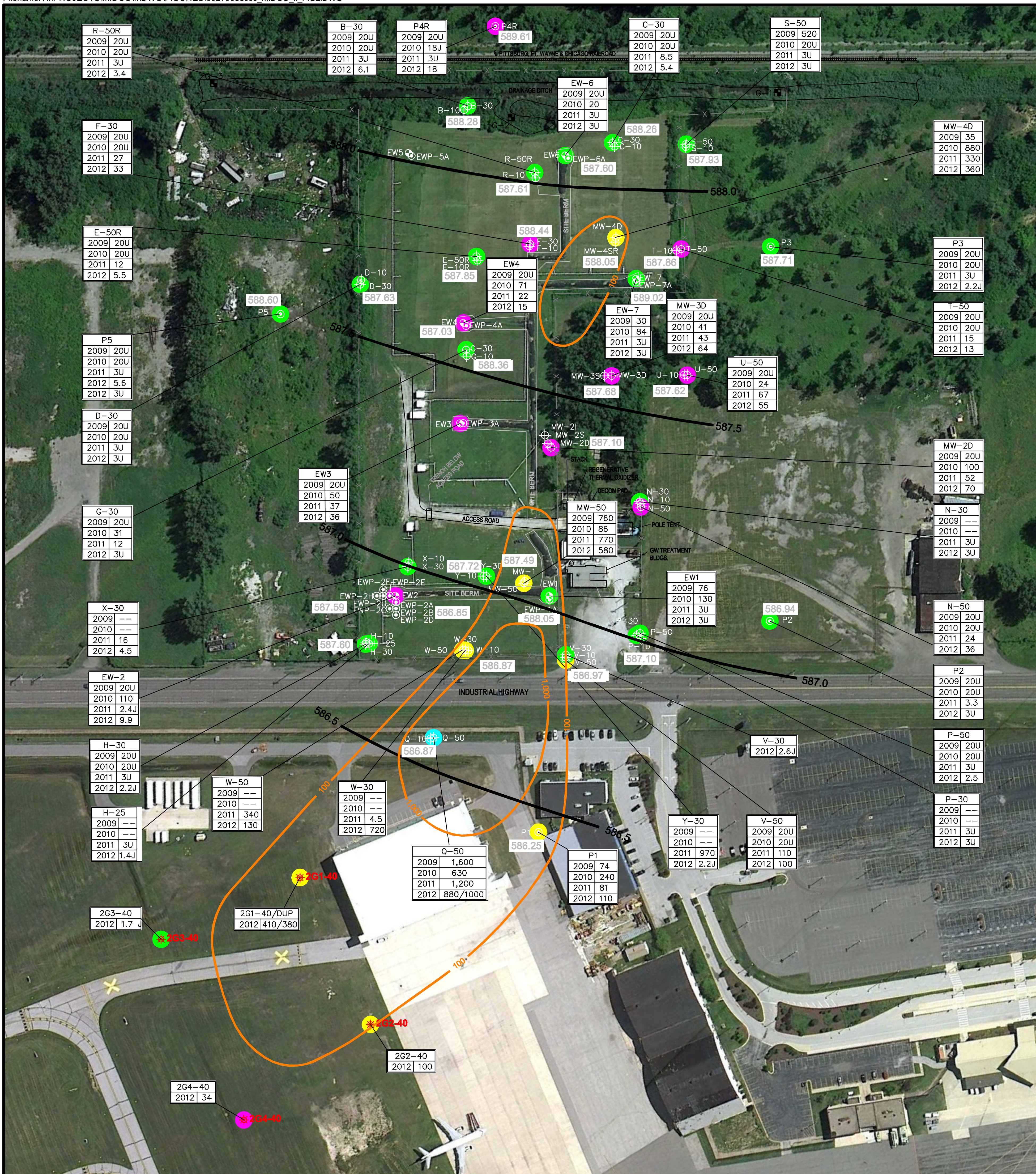


Midco I Site
Gary, Indiana
Project No. 60279033 1/4/2013

1,4-DIOXANE IN GROUNDWATER
2009 TO 2012

AECOM

FIGURE 1



LEGEND

2G2-40 TEMPORARY WELL/GROUNDWATER GRAB SAMPLE LOCATION 2G2 AND DEPTH (40) IN FEET BELOW GROUND SURFACE; COLLECTED JUNE 25-26, 2012

INTERPRETED 1,4-DIOXANE PLUME BASED ON MOST RECENT RESULTS FOR EACH LOCATION

1,4-DIOXANE RESULTS < 6.7 µg/L

1,4-DIOXANE RESULTS ≥ 6.7 µg/L, < 100 µg/L

1,4-DIOXANE RESULT ≥ 100 µg/L, < 1,000 µg/L

1,4-DIOXANE RESULTS > 1,000 µg/L

FENCE

MONITORING WELL LOCATION

EXTRACTION WELL LOCATION

PIEZOMETER LOCATION

586.25 AVERAGE GROUNDWATER ELEVATION (FT AMSL) FOR EACH WELL PAIR OR PIEZOMETER SCREENING ACROSS FULL AQUIFER THICKNESS COLLECTED NOVEMBER 2012

587.0 GROUNDWATER POTENTIOMETRIC CONTOUR (NOVEMBER 2012)

GROUNDWATER FLOW DIRECTION

P-1	
2009	74
2010	240
2011	81
2012	110

— WELL IDENTIFICATION

— 1,4-DIOXANE IN MICROGRAMS PER LITER (µg/L)

DATE (MOST RECENT DATA FOR EACH LOCATION)

0 180' 360'

GRAPHIC SCALE

Midco II Site
Gary, Indiana
Project No. 60279033 1/10/2013

1,4-DIOXANE IN DEEP GROUNDWATER
2009 THROUGH NOVEMBER 2012

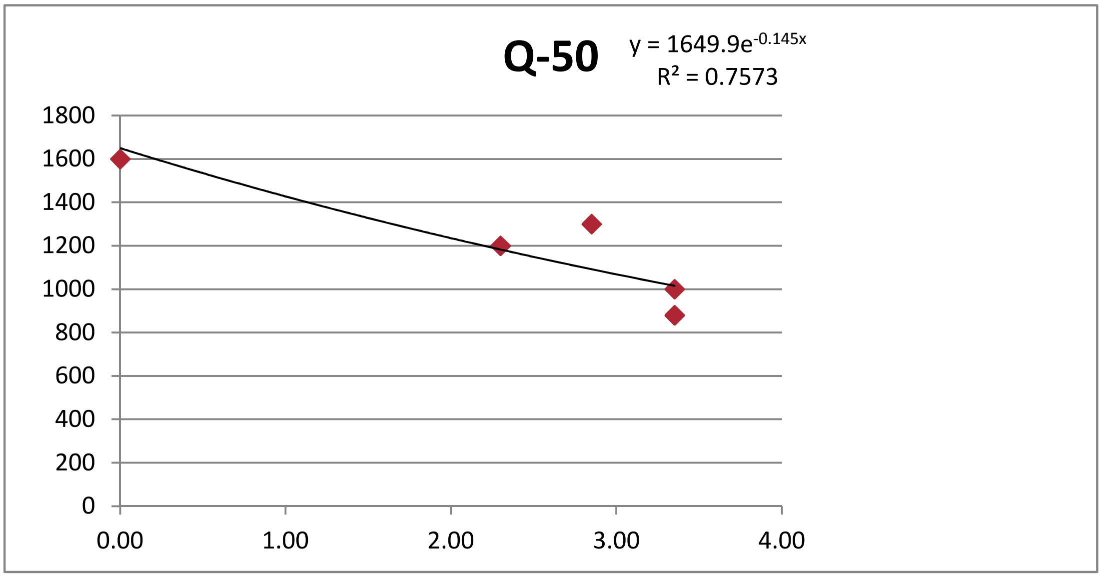
AECOM

FIGURE 2

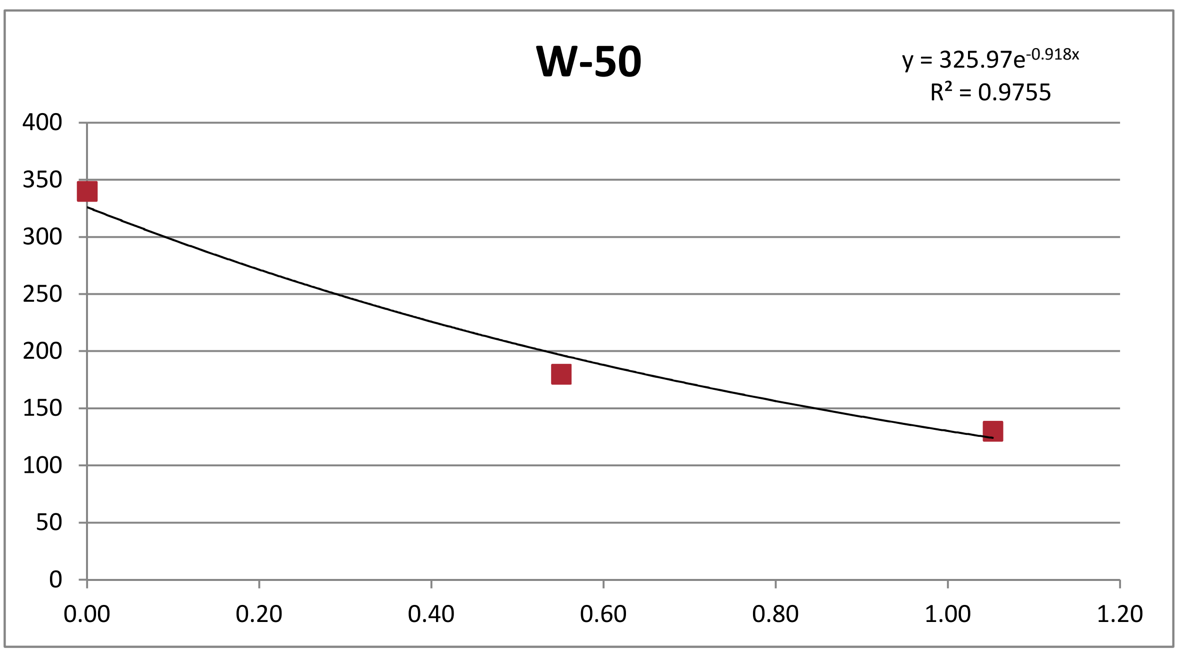
Appendix A

Model Input and Source Decay Rates

Half Life for 1,4-dioxane at well Q-50
ln (C/Co) = -0.693 = -0.145 * t
t = 4.78 years



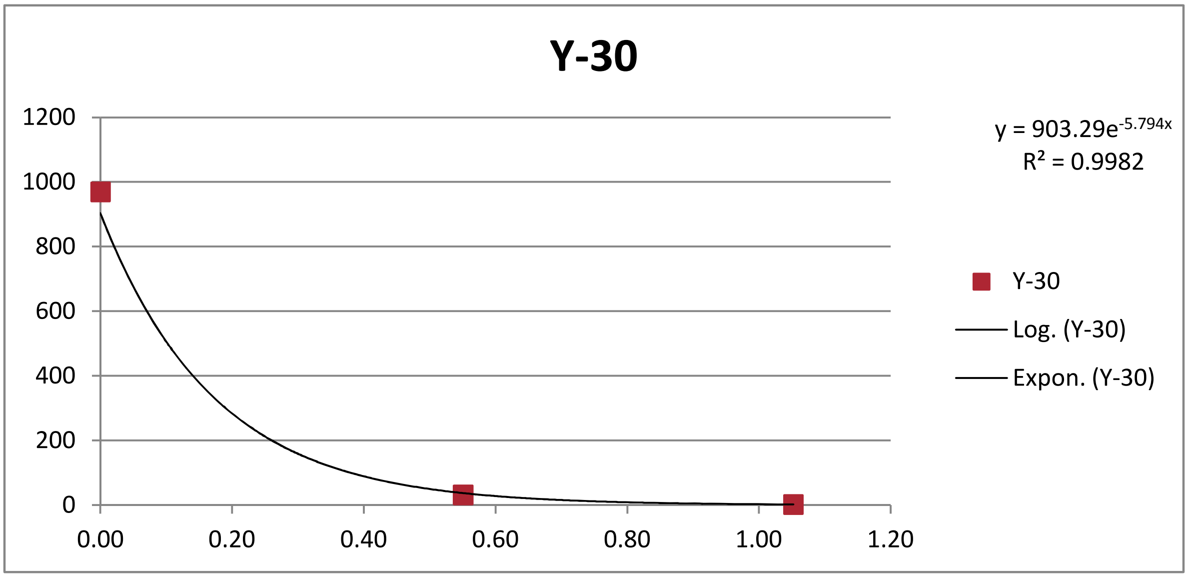
Half Life for 1,4-dioxane at well W-50
ln (C/Co) = -0.693 = -0.918 * t
t =0.75 years



Half Life for 1,4-dioxane at well Y-30

ln (C/Co) = -0.693 = -5.94 * t

t =0.12 years



Model Input and
Flux Based Estimation of Source Half Life

MIDCO I - 1,4-Dioxane Groundwater Model Input Values				
Variable	**Description**	**Value**	**Units**	**Source**
K	Hydraulic Conductivity	27.6	ft/day	ENVIRON MRC Model
i	Hydraulic Gradient	0.004	--	ENVIRON MRC Model
n	Porosity	0.3	--	ENVIRON MRC Model
V_{GW}	Seepage Velocity	0.368	ft/day	calculated = (K i / n)
K_{oc}	Partition Coefficient	1.23	L/kg	Howard, 1990
ρ_b	Bulk Density	1.5	g/cm^3	IDEM RISC default
f_{oc}	Fraction Organic Carbon	0.002	--	IDEM RISC default - results in insignificant adsorption-retardation
λ	First Order Degradation Constant	0	day^{-1}	Conservative value - no degradation
l	Source Length (parallel to groundwater flow)	340	ft	conservative estimate based on site data
w	Source Width (perpendicular to groundwater flow)	430	ft	conservative estimate based on site data
b	Source Thickness (transverse to groundwater flow)	15	ft	conservative estimate based on site data
C_s	Source Concentration	66	ug/L	average maximum concentrations from wells H-30 (140 ug/L), O-30 (69 ug/L), B-30 (24 ug/L), EEW-4 (31 ug/L)
A_{cross}	Cross-sectional area of source at downgradient edge	6450	ft^2	calculated = (w b)
V_{source}	Volume of water in source area	1.86E+07	L	calculated = (l w b n x 28.31685)
M_{source}	Mass of contaminant in source area	1.23E+00	kg	calculated = (C_s V_{souce} x 10^{-9})
GW_{flux}	Flux of contaminant in groundwater exiting source are	4.44E-03	kg/day	calculated = (V_{GW} A_{cross} C_s x 10^{-9})
HL_{est}	Estimated Flux Based Source Half Life	139	days	calculated = (0.5 x M_{source}) / GW_{flux})
HL_{est}	Estimated Flux Based Source Half Life	0.38	years	calculated = (HL_{est} / 365)
HL_{model}	Conservative Source Half Life used in model	5.0	years	based on trendplots for site data 2009-2012

Model Input and
Flux Based Estimation of Source Half Life

MIDCO II North Source Area - 1,4-Dioxane Groundwater Model Input Values				
Variable	**Description**	**Value**	**Units**	**Source**
K	Hydraulic Conductivity	35	ft/day	ENVIRON MRC Model ($1.23x10^{-2}$ cm/s)
i	Hydraulic Gradient	0.0015	--	ENVIRON MRC Model
n	Porosity	0.3	--	ENVIRON MRC Model
V	Seepage Velocity	0.175	ft/day	calculated = (K i / n)
K_{oc}	Partition Coefficient	1.23	L/kg	Howard, 1990
ρ_b	Bulk Density	1.5	g/cm^3	IDEM RISC default
f_{oc}	Fraction Organic Carbon	0.002	--	IDEM RISC default - results in insignificant adsorption-retardation
λ	First Order Degradation Constant	0	day^{-1}	Conservative value - no degradation
l	Source Length (parallel to groundwater flow)	200	ft	conservative estimate based on site data
w	Source Width (perpendicular to groundwater flow)	200	ft	conservative estimate based on site data
b	Source Thickness (transverse to groundwater flow)	18	ft	conservative estimate based on site data
C_s	Average Source Concentration	89	ug/L	maximum concentration from well MW-4D (880 ug/L)
A_{cross}	Cross-sectional area of source at downgradient edge	3600	ft^2	calculated = (w b)
V_{source}	Volume of water in source area	6.12E+06	L	calculated = (l w b n x 28.31685)
M_{source}	Mass of contaminant in source area	5.44E-01	kg	calculated = (C_s V_{souce} x 10^{-9})
GW_{flux}	Flux of contaminant in groundwater exiting source are	1.59E-03	kg/day	calculated = (V_{GW} A_{cross} C_s x 10^{-9})
HL_{est}	Estimated Flux Based Source Half Life	171	days	calculated = (0.5 x M_{source}) / GW_{flux})
HL_{est}	Estimated Flux Based Source Half Life	0.47	years	calculated = (HL_{est} / 365)
HL_{model}	Conservative Source Half Life used in model	5.0	years	based on trendplots for site data 2009-2012

Model Input and
Flux Based Estimation of Source Half Life

MIDCO II South Source Area - 1,4-Dioxane Groundwater Model Input Values				
Variable	**Description**	**Value**	**Units**	**Source**
K	Hydraulic Conductivity	35	ft/day	ENVIRON MRC Model
i	Hydraulic Gradient	0.0015	--	ENVIRON MRC Model
n	Porosity	0.3	--	ENVIRON MRC Model
V	Seepage Velocity	0.175	ft/day	calculated = (K i / n)
K_{oc}	Partition Coefficient	1.23	L/kg	Howard, 1990
ρ_b	Bulk Density	1.5	g/cm^3	IDEM RISC default
f_{oc}	Fraction Organic Carbon	0.002	--	IDEM RISC default - results in insignificant adsorption-retardation
λ	First Order Degradation Constant	0	day^{-1}	Conservative value - no degradation
l	Source Length (parallel to groundwater flow)	300	ft	conservative estimate based on site data
w	Source Width (perpendicular to groundwater flow)	375	ft	conservative estimate based on site data
b	Source Thickness (transverse to groundwater flow)	18	ft	conservative estimate based on site data
C_s	Average Source Concentration	1000	ug/L	average maximum concentrations from wells MW-50 (770 ug/L), V-50 (110 ug/L), W-50 (340 ug/L), Q-50 (1,600 ug/L)
A_{cross}	Cross-sectional area of source at downgradient edge	6750	ft^2	calculated = (w b)
V_{source}	Volume of water in source area	1.72E+07	L	calculated = (l w b n x 28.31685)
M_{source}	Mass of contaminant in source area	17.20	kg	calculated = (C_s V_{souce} x 10^{-9})
GW_{flux}	Flux of contaminant in groundwater exiting source are	3.34E-02	kg/day	calculated = (V_{GW} A_{cross} C_s x 10^{-9})
HL_{est}	Estimated Flux Based Source Half Life	257	days	calculated = (0.5 x M_{source}) / GW_{flux})
HL_{est}	Estimated Flux Based Source Half Life	0.70	years	calculated = (HL_{est} / 365)
HL_{model}	Conservative Source Half Life used in model	5.0	years	based on trendplots for site data 2009-2012

Appendix B

Model Runs and Sensitivity Analysis for Midco I

Midco I Modeling Results Summary

	Scenario	Half Life (years)	RO (ug/L)	K (ft/d)	P_L	Time to Attenuate Below RO	Maximum Plume Distance from Source
	Input					**Output**	
Result:	1	5	6.7	27.6	100%	17 years	1,440 feet
Sensitivity:	2	0.4	6.7	27.6	100%	4 years	420 feet
	3	12	6.7	27.6	100%	36 years	1,760 feet
	4	5	6.7	9.2	100%	26 years	900 feet
	5	5	6.7	27.6	75%	17 years	1,640 feet
	6	5	6.7	27.6	125%	17 years	1,330 feet

Notes:

RO = remediation objective; 6.7 ug/L is the 1,4-dioxane Regional Screening Criteria for tap water for 10^{-5} cancer risk

K = hydraulic conductivity

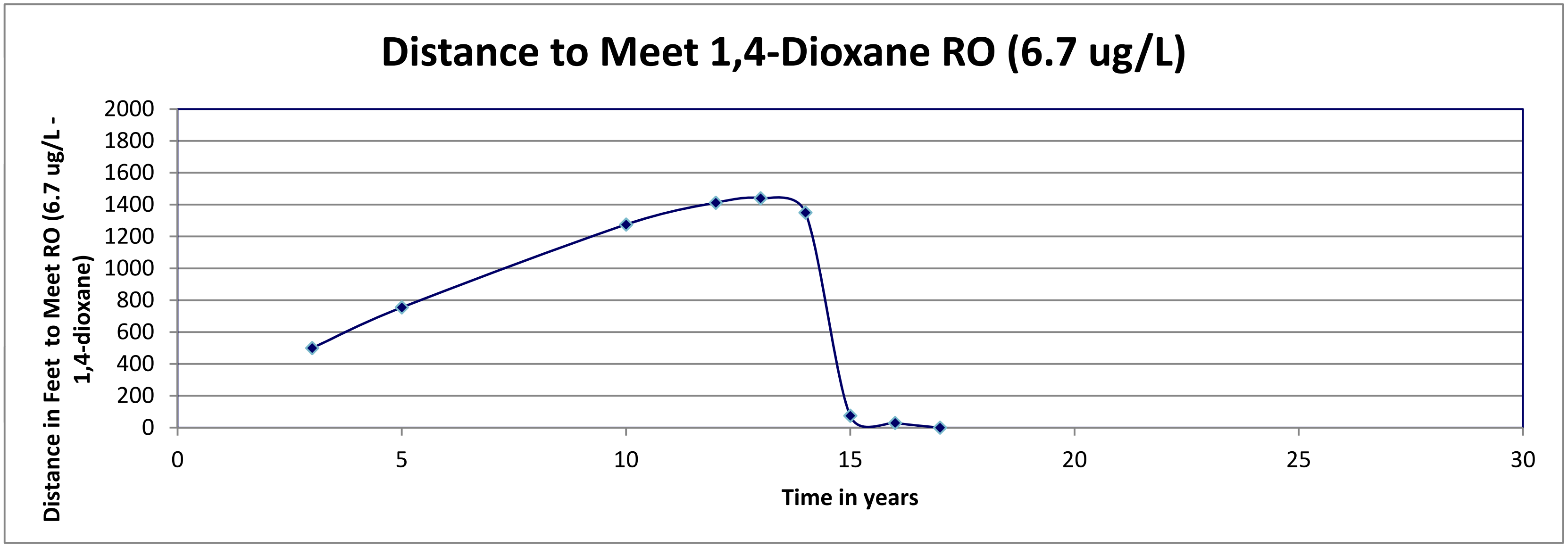
P_L = plume length

Red input parameter indicates the variable changed for the sensitivity modeling run

Modeling input parameters are provided in Appendix A

Midco I Final Modeling Results
5 Year Half Life

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
3	500	near source area	44
5	755	near source area	33
10	1275	near source area	17
12	1412	near source area	13
13	1440	near source area	11
14	1350	near source area	9
15	75	near source area	8.3
16	30	near source area	7.2
17	Meets RO	near source area	6.3



MODEL OUTPUT: Midco I after 17 years

DISSOLVED CONCENTRATIONS IN PLUME (mg/L at Z=0)

Source Midco I - 66 microgram per liter

Target Concentration - 6.7 microgram per liter

Distance from Source (ft)

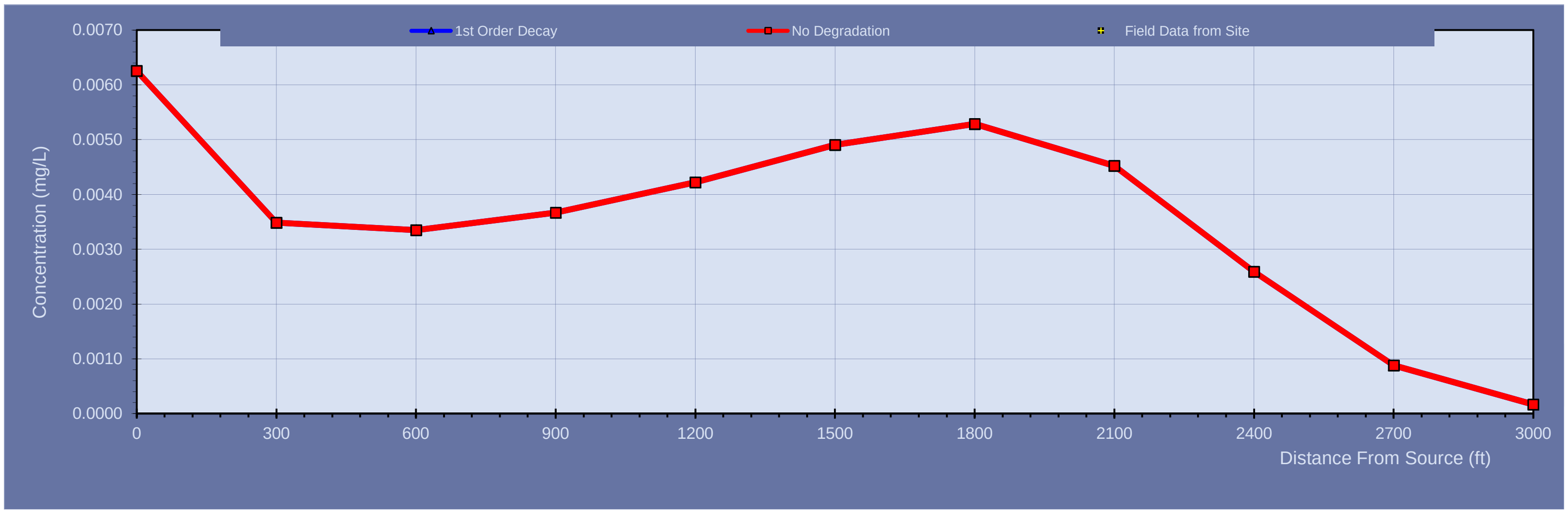
	0	300	600	900	1200	1500	1800	2100	2400	2700	3000
No Degradation	6.26E-03	3.48E-03	3.35E-03	3.67E-03	4.22E-03	4.90E-03	5.29E-03	4.52E-03	2.59E-03	8.81E-04	1.65E-04
No 1st Order Decay	6.26E-03	3.48E-03	3.35E-03	3.67E-03	4.22E-03	4.90E-03	5.29E-03	4.52E-03	2.59E-03	8.81E-04	1.65E-04

# of TimeSteps **20**

Displayed Time=17 years

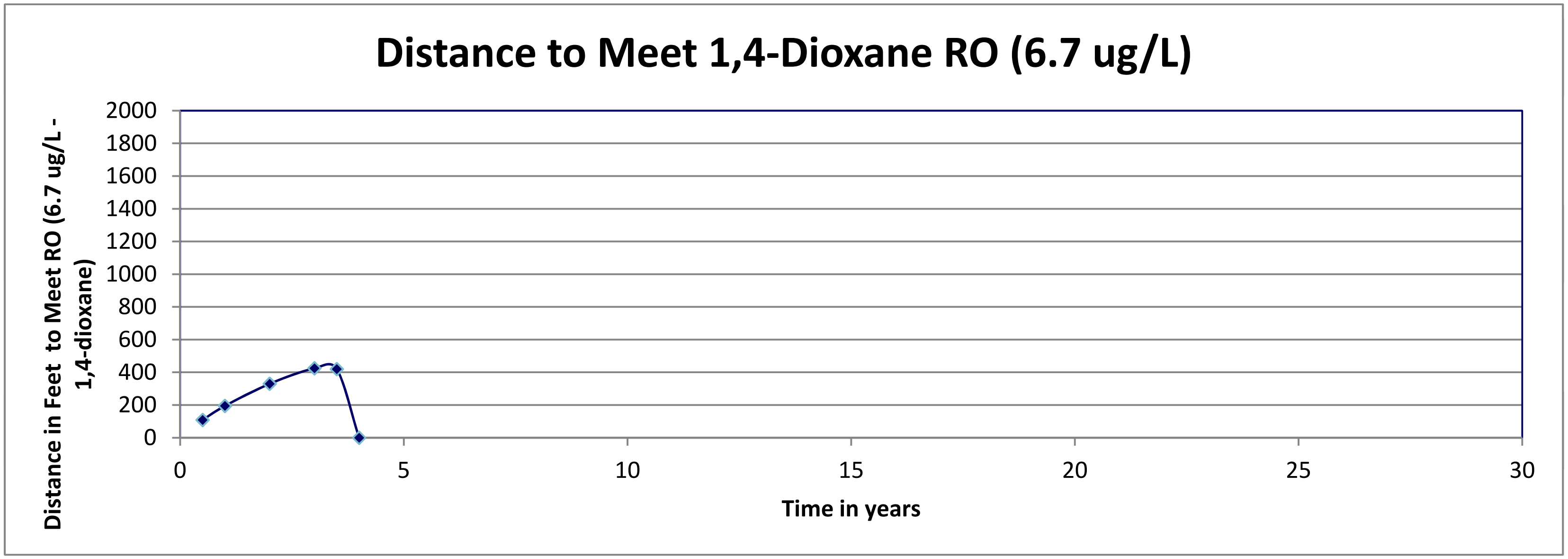
Return to Input

View Plume Output



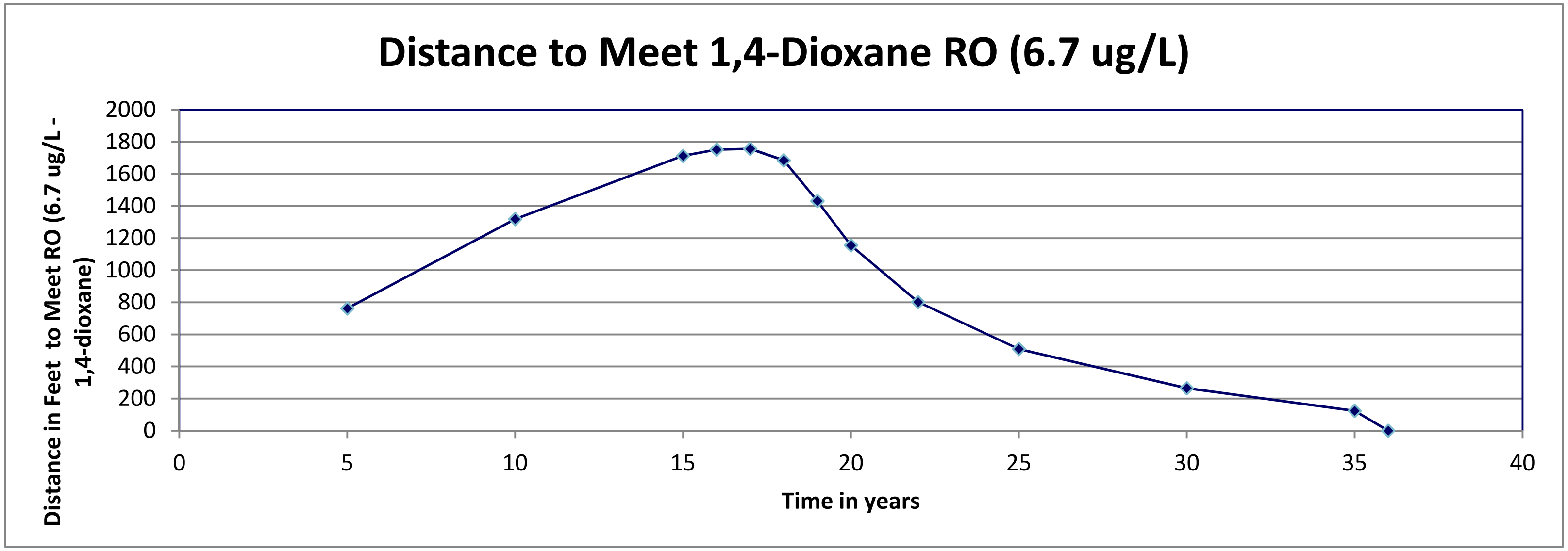
Midco I Sensitivity Evaluation
0.4 Year Half Life

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
0.5	109	45 ft downgradient	38
1	195	100 ft downgradient	25
2	330	230 ft downgradient	13
3	425	340 ft downgradient	7.8
3.5	420	420 ft downgradient	6.7
4	Meets RO	490 ft downgradient	5



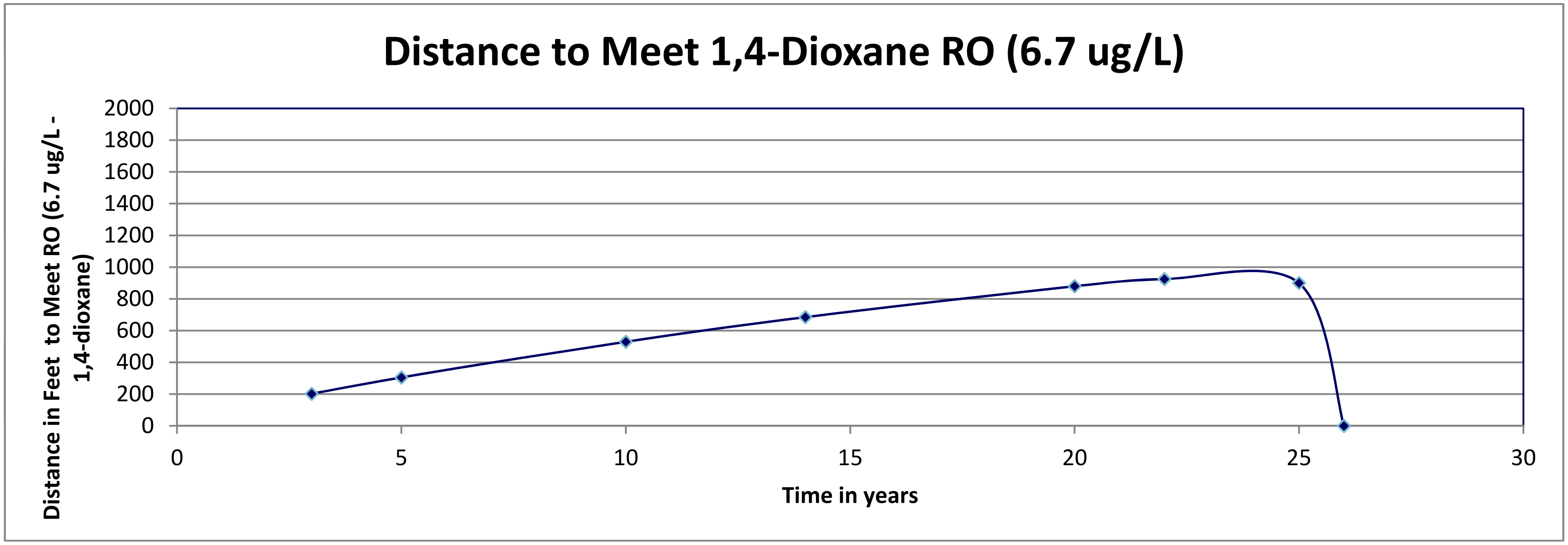
Midco I Sensitivity Evaluation
12 Year Half Life

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
5	762	near source area	48
10	1319	near source area	35
15	1713	near source area	26
16	1752	near source area	24
17	1757	near source area	23
18	1685	near source area	21
19	1432	near source area	20
20	1155	near source area	19
22	802	near source area	17
25	509	near source area	14
30	265	near source area	10
35	124	near source area	7
36	Meets RO	near source area	6.5



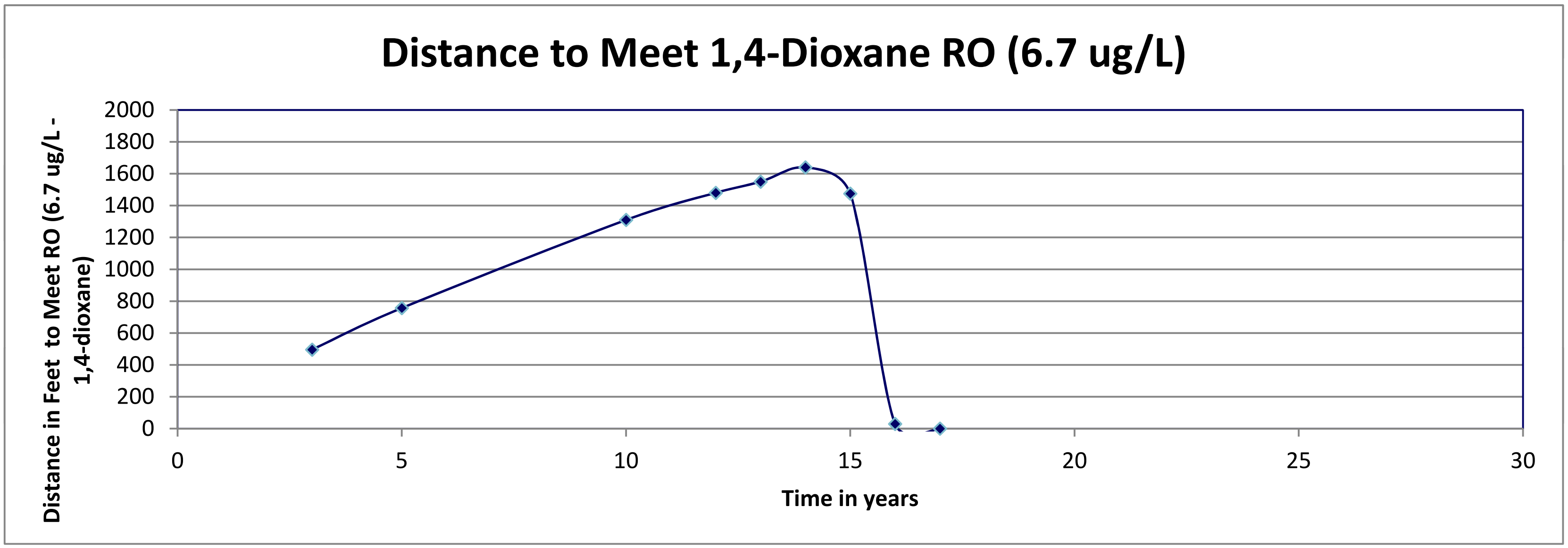
Midco I Sensitivity Evaluation
Reduce K

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
3	202	40 ft downgradient	46
5	305	90 ft downgradient	36
10	530	265 ft downgradient	18
14	685	480 ft downgradient	12
20	880	705 ft downgradient	8.4
22	925	830 ft downgradient	7.5
25	900	900 ft downgradient	6.7
26	Meets RO	950 ft downgradient	6.2



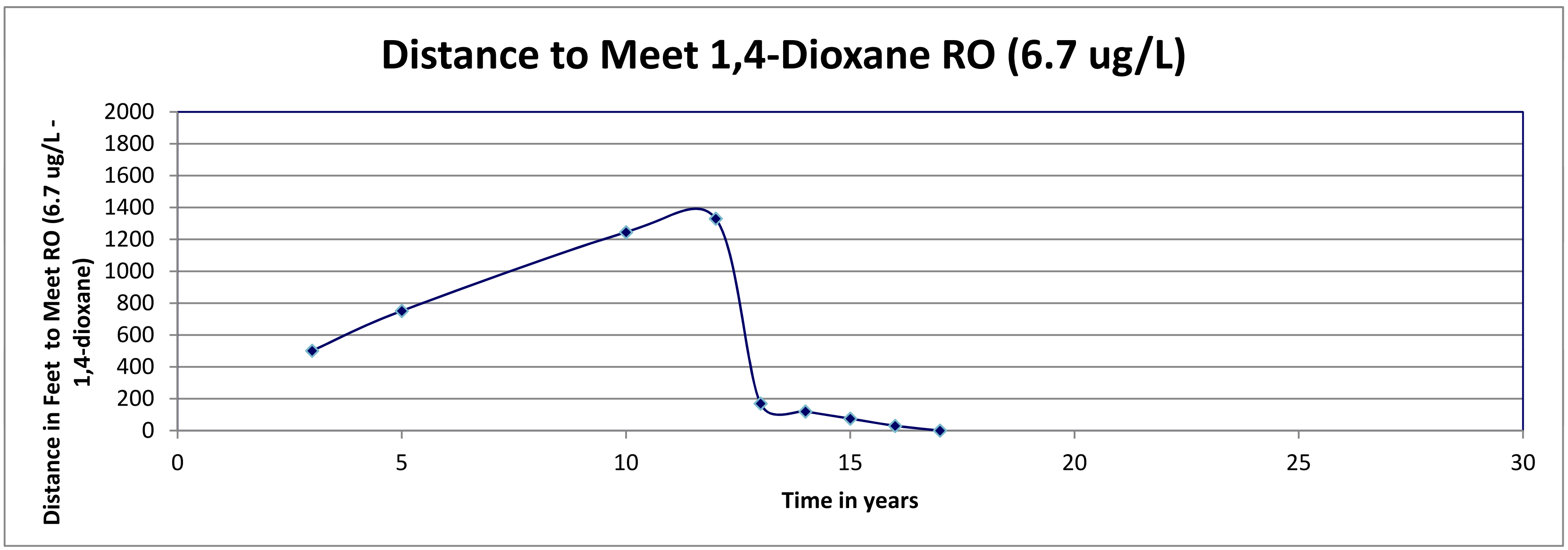
Midco I Sensitivity Evaluation
Reduce plume length by 25% (decreases dispersion)

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
3	496	near source area	44
5	757	near source area	33
10	1310	near source area	17
12	1480	near source area	13
13	1550	near source area	11
14	1640	near source area	9.5
15	1475	near source area	8.3
16	30	near source area	7.2
17	Meets RO	near source area	6.3



Midco I Sensitivity Evaluation
Increase plume length 25% (increases dispersion)

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
3	501	near source area	44
5	751	near source area	33
10	1245	near source area	17
12	1330	near source area	13
13	170	near source area	11
14	120	near source area	9.5
15	75	near source area	8.3
16	30	near source area	7.2
17	Meets RO	near source area	6.3



Appendix C

Model Runs and Sensitivity Analysis for Midco II

Midco II North Source Modeling Results Summary

	Input					Output	
	Scenario	Half Life (years)	RO (ug/L)	K (ft/d)	P_L	Time to Attenuate Below RO	Maximum Plume Distance from Source
Result:	1	5	6.7	35.0	100%	22 years	1,170 feet
Sensitivity:	2	0.4	6.7	35.0	100%	7 years	425 feet
	3	12	6.7	35.0	100%	41 years	1,450 feet
	4	5	6.7	11.6	100%	40 years	780 feet
	5	5	6.7	35.0	75%	24 years	1,265 feet
	6	5	6.7	35.0	125%	21 years	1,100 feet

Notes:

RO = remediation objective; 6.7 ug/L is the 1,4-dioxane Regional Screening Criteria for tap water for 10^{-5} cancer risk

K = hydraulic conductivity

P_L = plume length

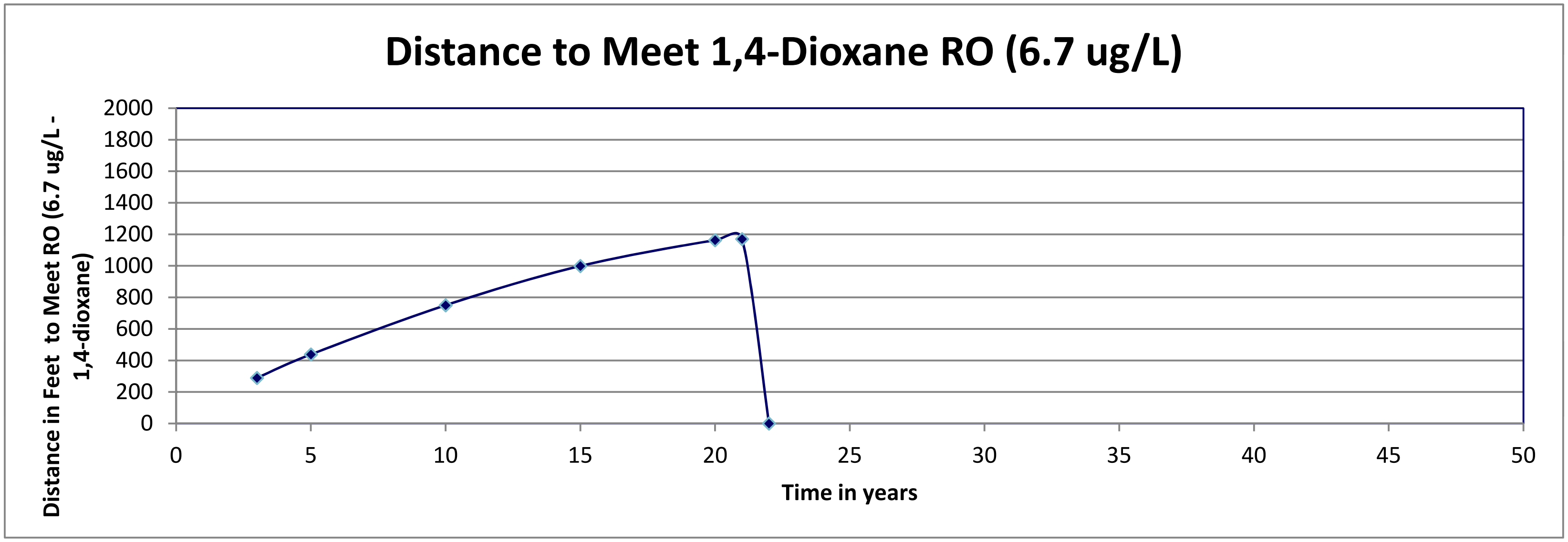
Red input parameter indicates the variable changed for the sensitivity modeling run

Modeling input parameters are provided in Appendix A

Midco II North Final Modeling Result
5 Year Half Life

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
3	289	58	62
5	438	88	47
10	750	source to 450' (flat)*	20
15	999	700	12
20	1163	930	7.6
21	1170	1050	7.1
22	Meets RO	1080	6.6

* middle of peak area about 225'



MODEL OUTPUT: Midco II North after 22 years

DISSOLVED CONCENTRATIONS IN PLUME (mg/L at Z=0)

Source Midco II North - 89 microgram per liter

Target Concentration - 6.7 microgram per liter

Distance from Source (ft)

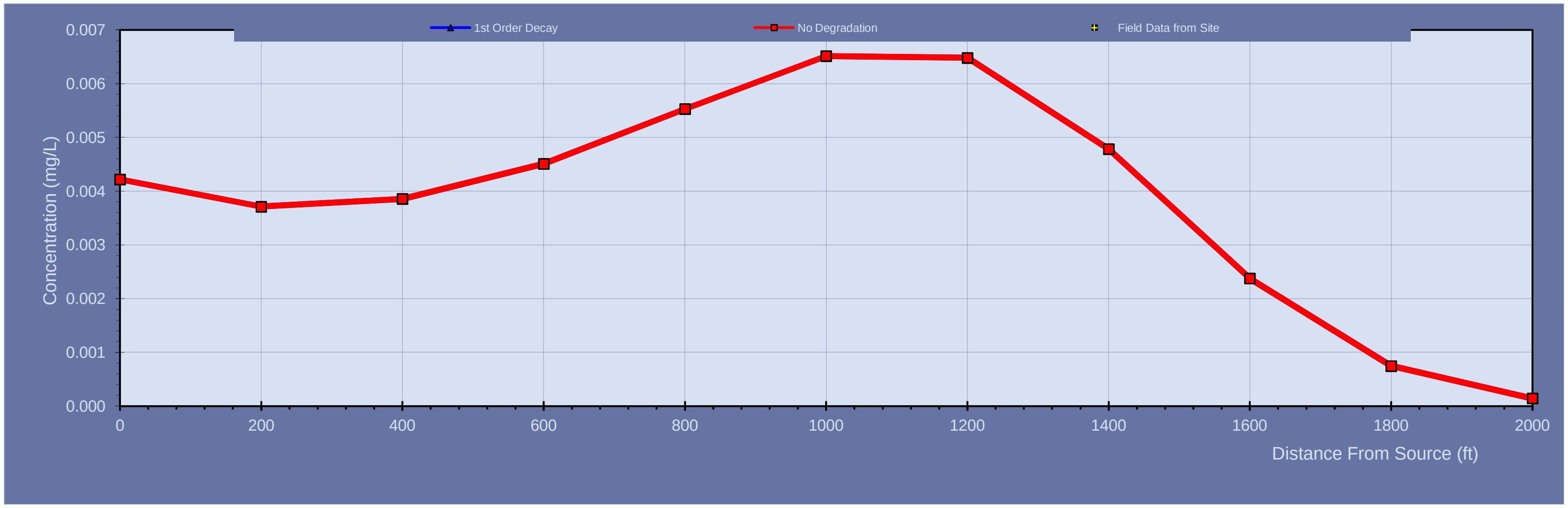
	0	200	400	600	800	1000	1200	1400	1600	1800	2000
No Degradation	4.22E-03	3.71E-03	3.86E-03	4.51E-03	5.53E-03	6.51E-03	6.48E-03	4.78E-03	2.37E-03	7.47E-04	1.44E-04
1st Order Decay	4.22E-03	3.71E-03	3.86E-03	4.51E-03	5.53E-03	6.51E-03	6.48E-03	4.78E-03	2.37E-03	7.47E-04	1.44E-04
Field Data from Site											

# of TimeSteps **50**

Displayed Time=22 years

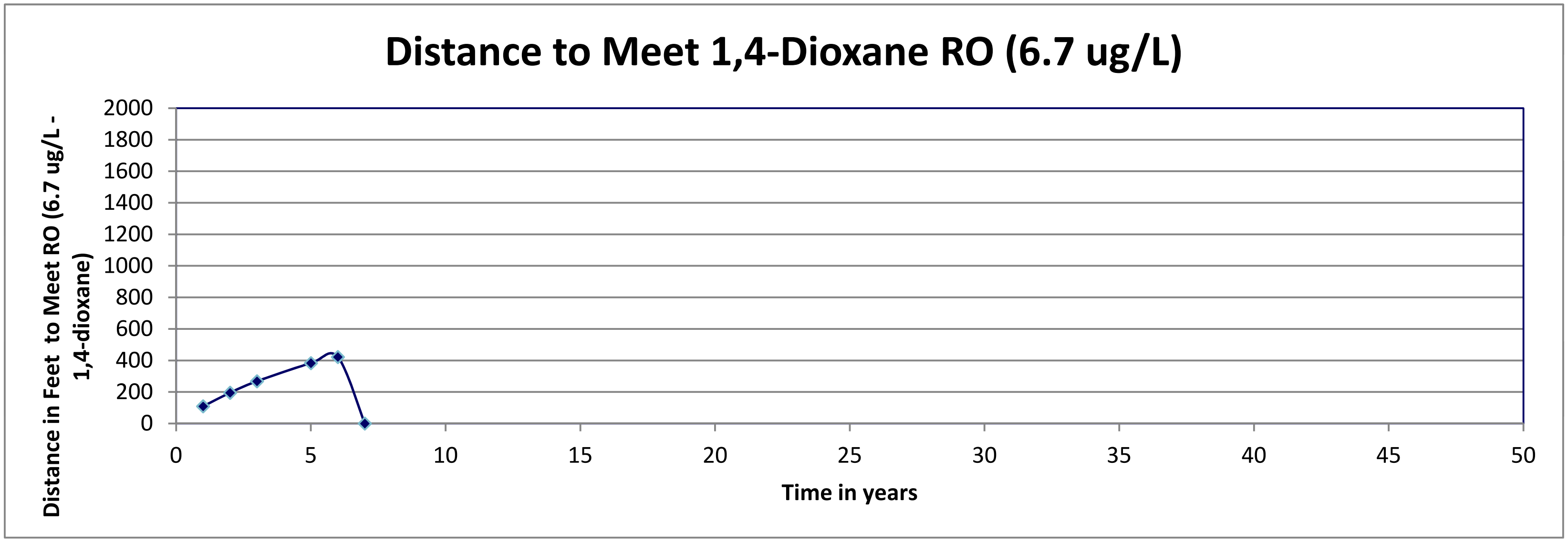
Return to Input

View Plume Output



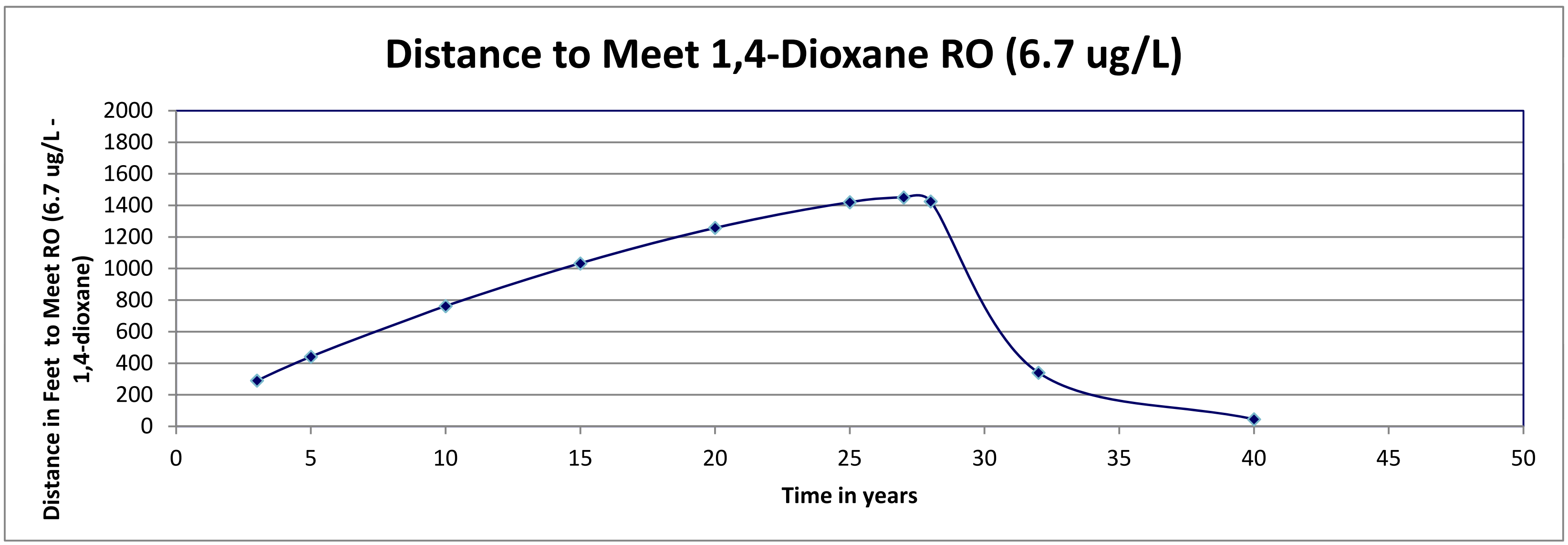
Midco II North Sensitivity Evaluation
0.4 Year Half Life

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
1	109	44	41
2	195	98	26
3	268	160	18
5	383	306	9.8
6	422	380	7.7
7	Meets RO	414	6.3



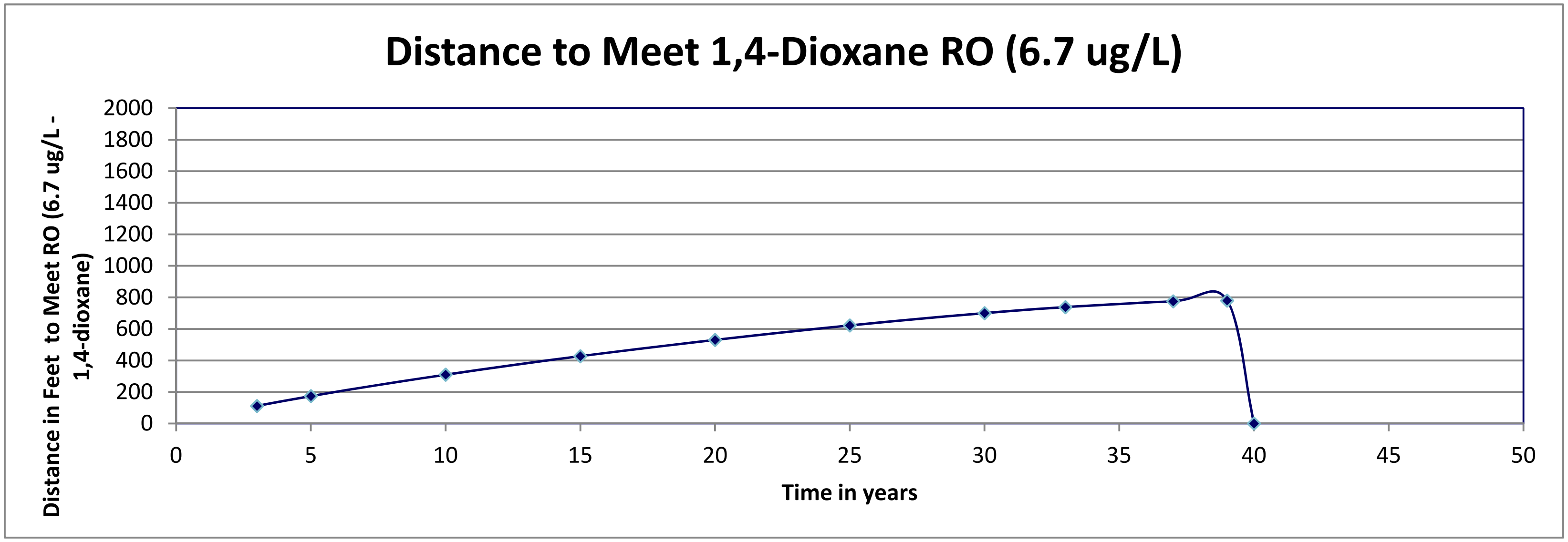
Midco II North Sensitivity Evaluation
11 Year Half Life

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
3	290	near source area	74
5	441	near source area	65
10	762	near source area	47
15	1032	near source area	35
20	1258	near source area	25
25	1420	near source area	18
27	1450	near source area	16
28	1425	near source area	14
32	340	near source area	12
40	45	near source area	7.2
41	Meets RO	near source area	6.6



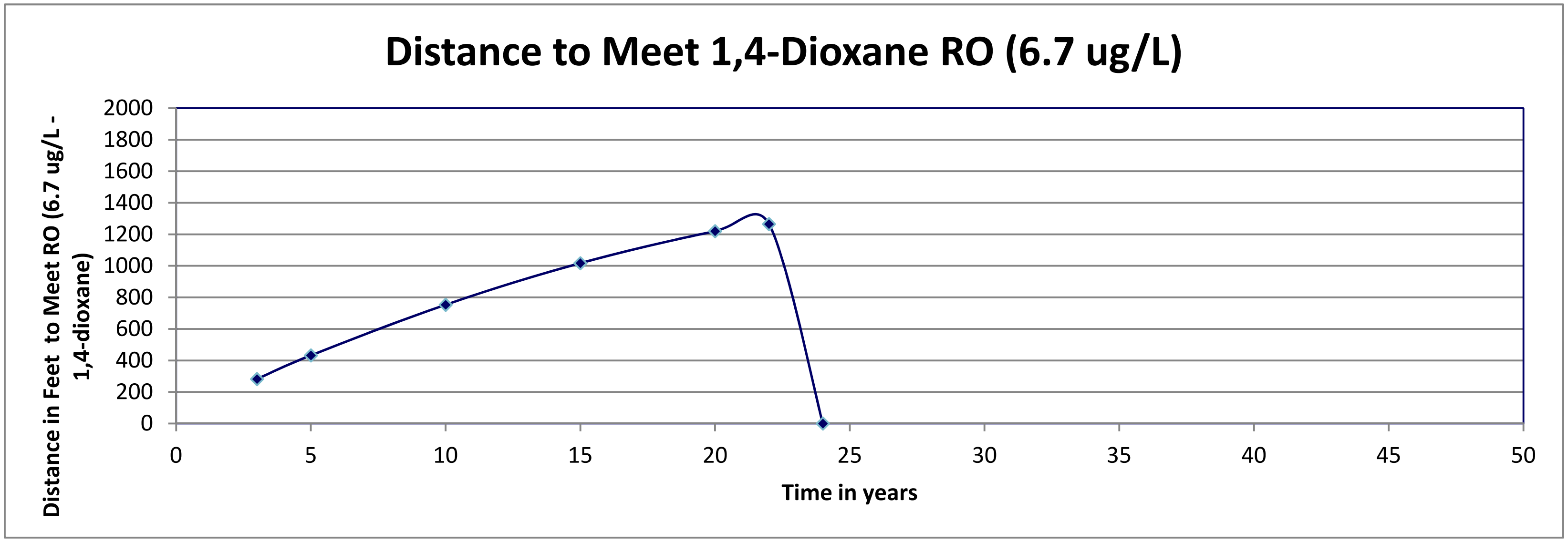
Midco II North Sensitivity Evaluation
Reduce K

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
3	111	22	65
5	174	52	56
10	310	124	37
15	427	214	25
20	530	318	18
25	622	435	13
30	700	560	10
33	738	590	8.9
37	775	698	7.5
39	780	702	7
40	Meets RO	765	6.5



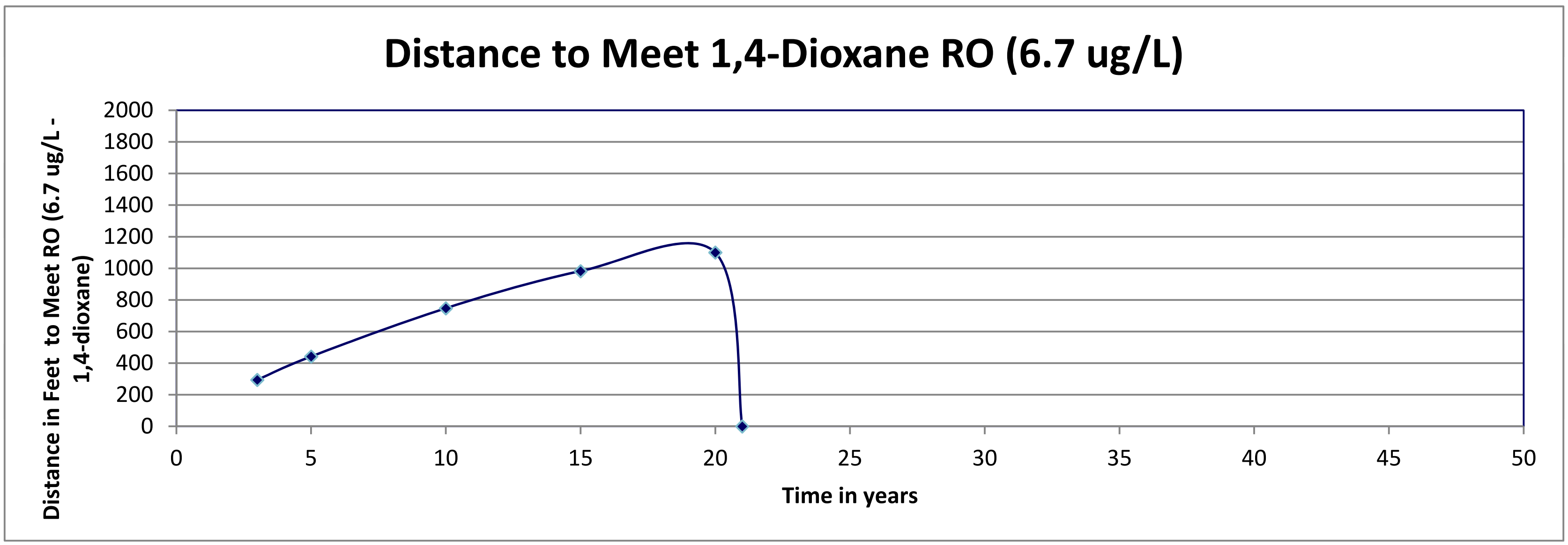
Midco II North Sensitivity Evaluation
Reduce plume length by 25% (decreases dispersion)

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
3	282	85	64
5	432	86	48
10	753	source to 450' (flat)	23
15	1017	710	13
20	1220	976	8.4
22	1265	1138	7.3
24	Meets RO	1188	6.4



Midco II North Sensitivity Evaluation
Increase plume length 25% (increases dispersion)

Time	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration (ug/L)
3	294	59	61
5	442	44	46
10	747	near source area	22
15	982	687	11
20	1100	990	7.1
21	Meets RO	1090	6.6



Midco II South Source Modeling Results Summary

	Input					Output	
	Scenario	Half Life (years)	RO (ug/L)	K (ft/d)	P_L	Time to Attenuate Below RO	Maximum Plume Distance from Source
Result:	1	5	67	35.0	100%	22 years	1,130 feet
Sensitivity:	2	5	6.7	35.0	100%	80 years	4,670 feet
	3	0.8	6.7	35.0	100%	32 years	2,045 feet
	4	20	6.7	35.0	100%	120 years	5,000 feet*
	5	5	6.7	11.6	100%	135 years	2,880 feet
	6	5	6.7	35.0	75%	81 years	4,990 feet
	7	5	6.7	35.0	125%	75 years	4,450 feet

Notes:

RO = remediation objective; 6.7 ug/L is the 1,4-dioxane Regional Screening Criteria for tap water for 10^{-5} cancer risk; 67 ug/L is the 1,4-dioxane Regional Screening Criteria for tap water for 10^{-4} cancer risk

K = hydraulic conductivity

P_L = plume length

Red input parameter indicates the variable changed for the sensitivity modeling run; the RO used for sensitivity analyses was 6.7 ug/L.

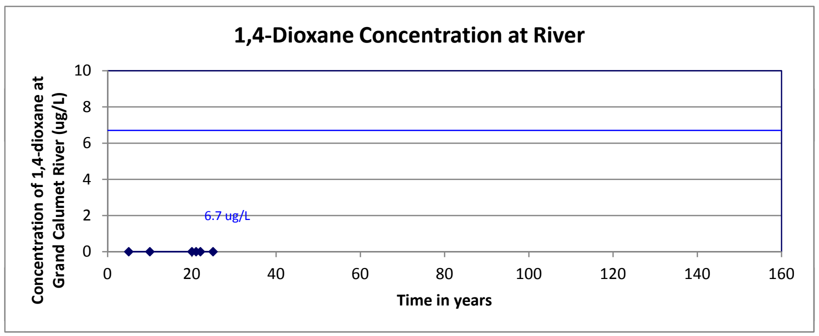
* 5,000 feet is the distance to the river; assume river is receptor and plume does not extend beyond 5,000 feet

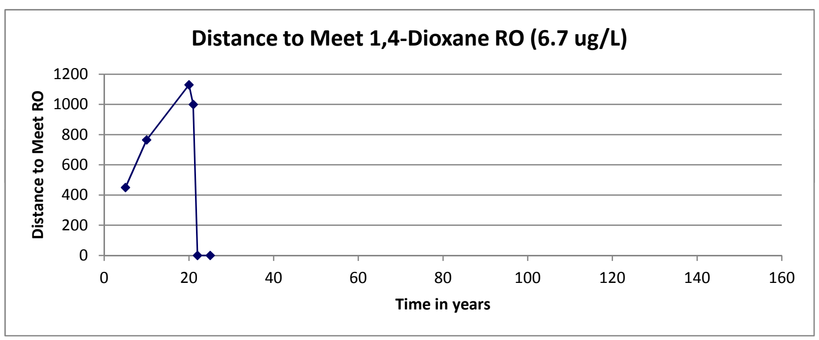
Modeling input parameters are provided in Appendix A

Midco II South Final Model - 10^{-4} cancer risk (67 ug/L criteria)
5 Year Half Life

Time	Concentration at Grand Calumet River at 5,000' (ug/L)	Distance to Meet RO (67 ug/L)	Distance to Peak	Peak Concentration
5	nd	450	near source	515
10	nd	765	flat to 459'	250
20	nd	1130	1017	72
21	nd	1000	1000	67
22	nd	Meets RO	1080	62
25	nd	Meets RO	1260	54

nd = less than 0.1 ug/L





MODEL OUTPUT: Midco II South after 22 years

DISSOLVED CONCENTRATIONS IN PLUME (mg/L at Z=0)

Source Midco II South - 1,000 microgram per liter

Target Concentration - 67 microgram per liter

Distance from Source (ft)

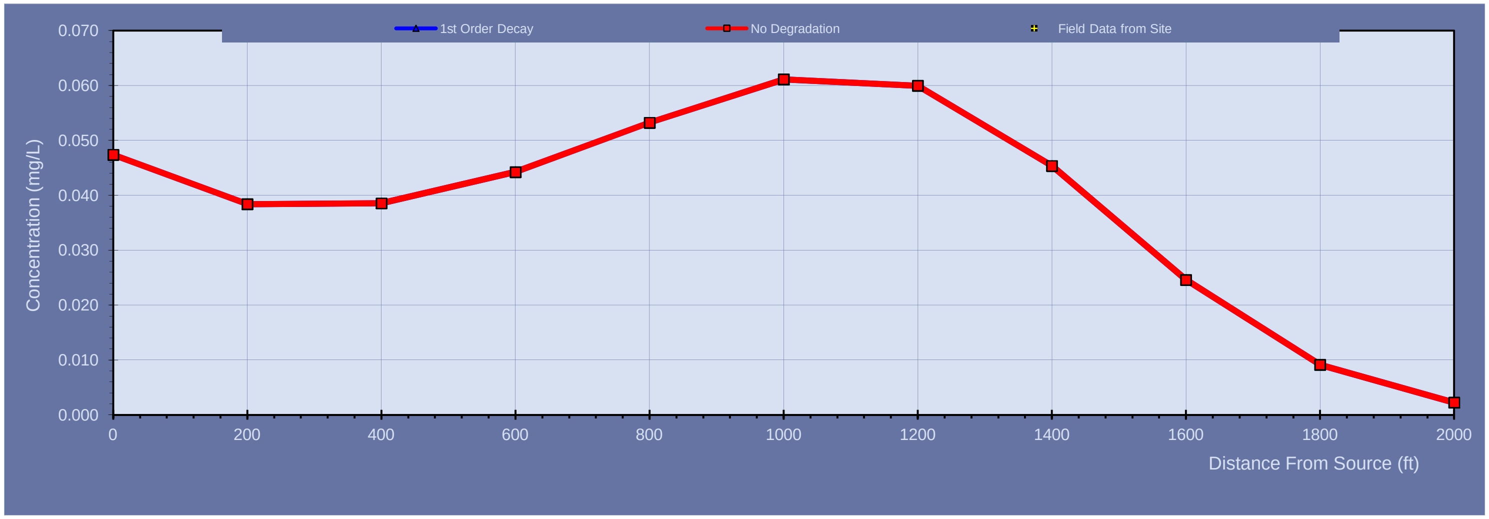
	0	200	400	600	800	1000	1200	1400	1600	1800	2000
No Degradation	4.74E-02	3.84E-02	3.85E-02	4.42E-02	5.32E-02	6.11E-02	5.99E-02	4.54E-02	2.46E-02	9.13E-03	2.26E-03
1st Order Decay	4.74E-02	3.84E-02	3.85E-02	4.42E-02	5.32E-02	6.11E-02	5.99E-02	4.54E-02	2.46E-02	9.13E-03	2.26E-03
Field Data from Site											

# of TimeSteps **50**

Displayed Time=22 years

Return to Input

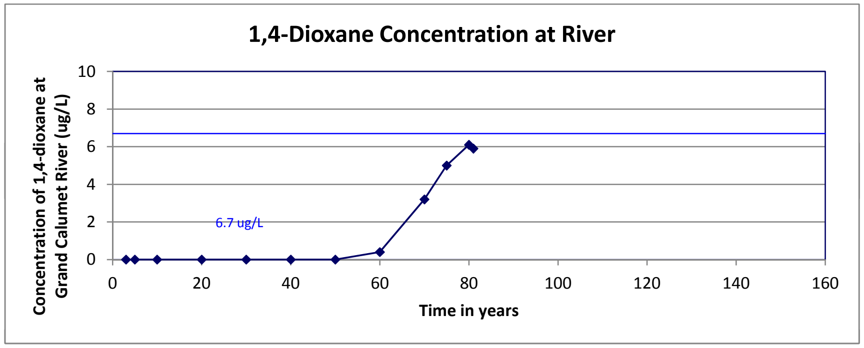
View Plume Output

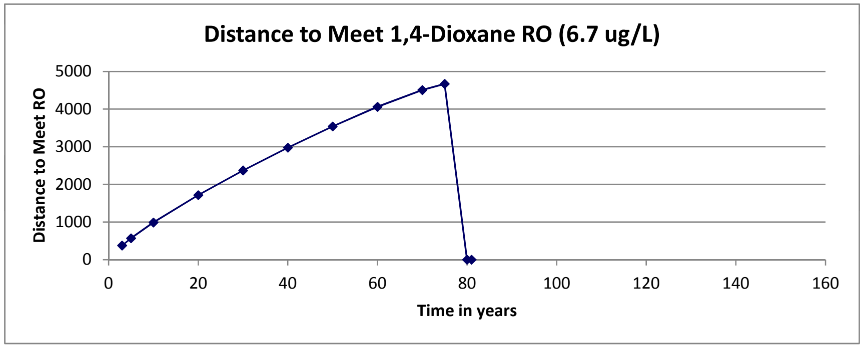


Midco II South Sensitivity Evaluation
5 Year Half Life - 10-5 cancer risk (6.7 ug/L criteria)

Time	Concentration at Grand Calumet River at 5000' (ug/L)	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration
3	nd	377	near source	690
5	nd	569	near source	515
10	nd	988	near source	250
20	nd	1715	1030	72
30	nd	2370	1670	36
40	nd	2975	2080	21
50	nd	3540	2830	15
60	0.4	4060	3500	10
70	3.2	4507	4050	8.1
75	5	4670	4200	7
80	6.1	Meets RO	4600	6.5
81	5.9	Meets RO	5000	5.9

nd = less than 0.1 ug/L

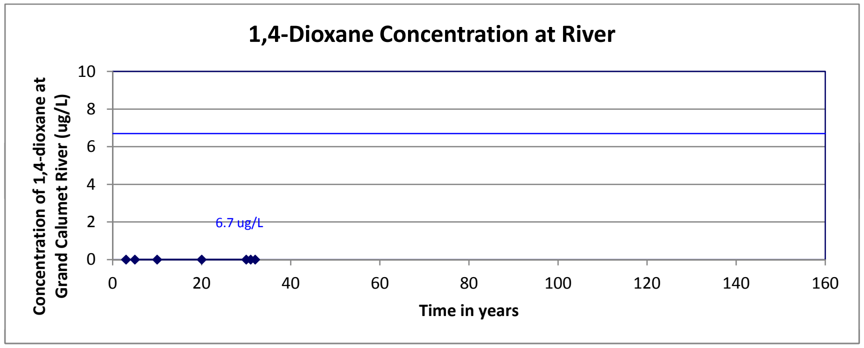


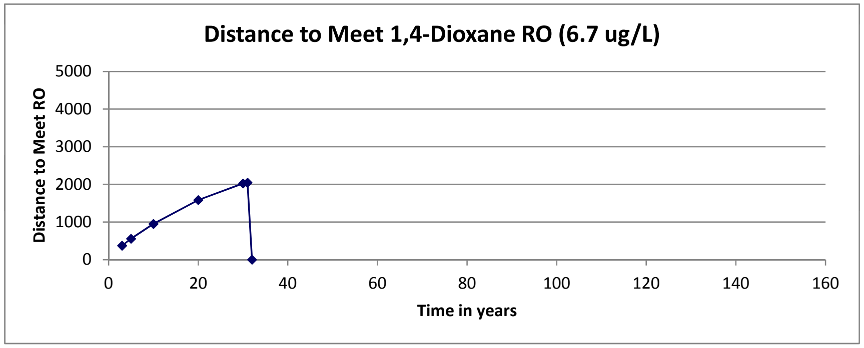


Midco II South Sensitivity Evaluation
0.8 Year Half Life - 10-5 cancer risk (6.7 ug/L criteria)

Time	Concentration at Grand Calumet River at 5000' (ug/L)	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration
3	nd	372	149	266
5	nd	557	279	147
10	nd	950	570	51
20	nd	1583	1266	15
30	nd	2025	1822	7.3
31	nd	2045	1840	6.8
32	nd	Meets RO	1935	6.4

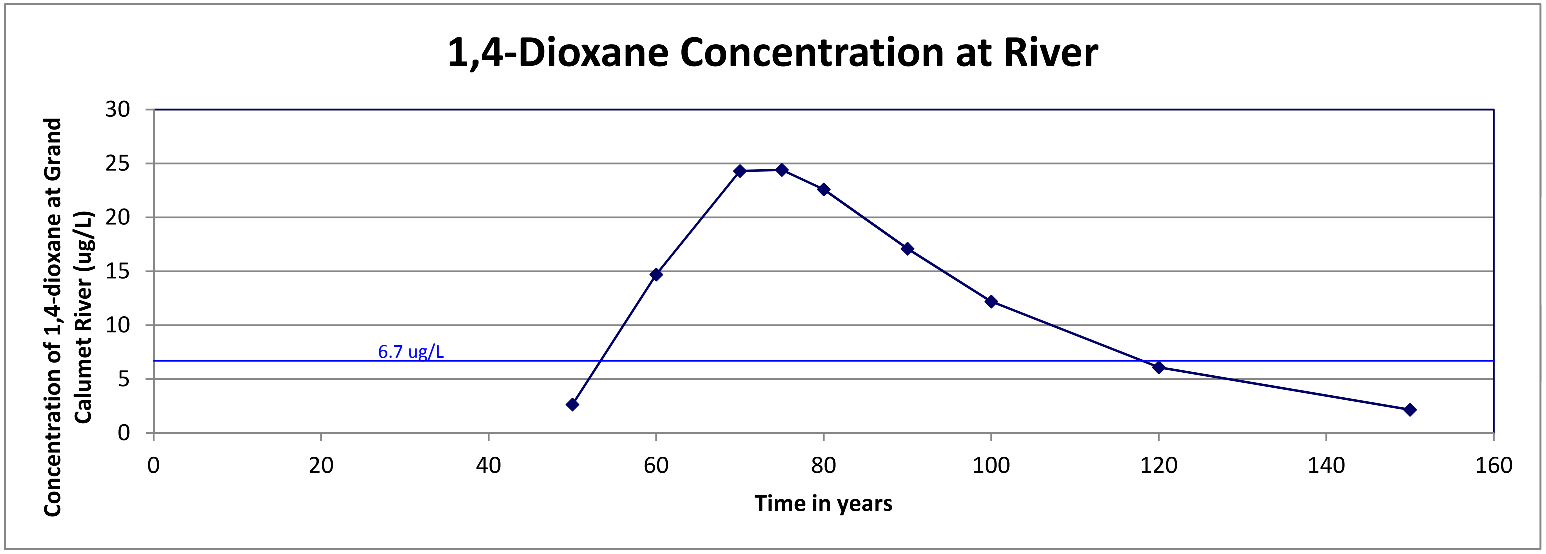
nd = less than 0.1 ug/L





Midco II South Sensitivity Evaluation
20 Year Half Life - 10-5 cancer risk (6.7 ug/L criteria)

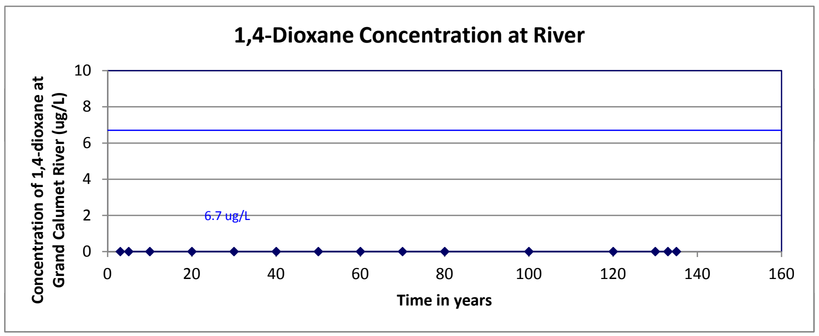
Time	Concentration at Grand Calumet River (ug/L)
50	2.65
60	14.7
70	24.3
75	24.4
80	22.6
90	17.1
100	12.2
120	6.1
150	2.16

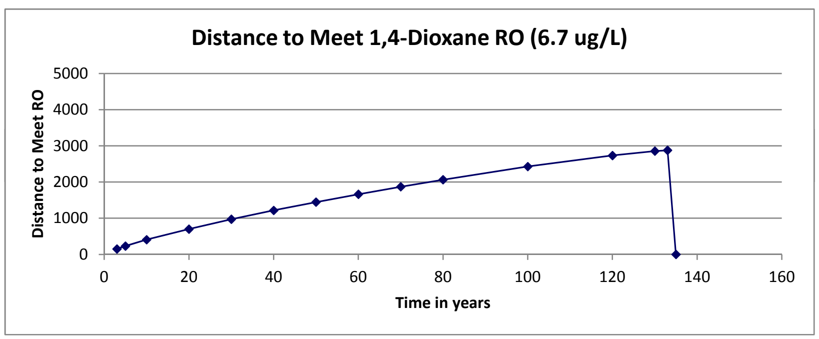


Midco II South Sensitivity Evaluation
Reduce K - 10-5 cancer risk (6.7 ug/L criteria)

Time	Concentration at Grand Calumet River at 5000' (ug/L)	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration
3	nd	152	near source	711
5	nd	232	46	607
10	nd	408	122	391
20	nd	700	350	179
30	nd	973	486	97
40	nd	1217	730	62
50	nd	1445	1011	41
60	nd	1662	1160	30
70	nd	1870	1309	23
80	nd	2065	1652	18
100	nd	2430	1944	12
120	nd	2735	2462	8.6
130	nd	2855	2570	7.4
133	nd	2878	2590	7
135	nd	Meets RO	2887	6.7

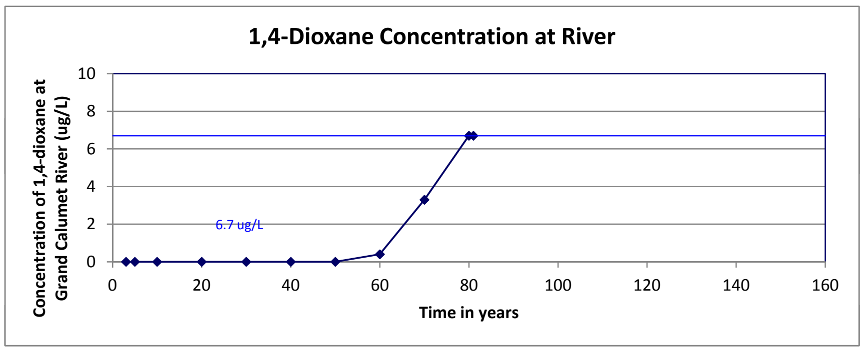
nd = less than 0.1 ug/L

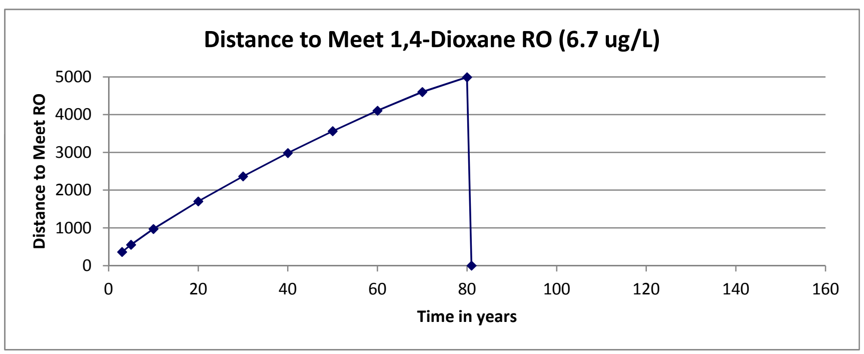




Midco II South Sensitivity Evaluation
Reduce Plume Length - 10-5 cancer risk (6.7 ug/L criteria)

Time	Concentration at Grand Calumet River at 5000' (ug/L)	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration	
3	nd	363	73	700	0
5	nd	553	55	526	160
10	nd	971	flat to 388'	240	
20	nd	1702	1021	82	
30	nd	2364	1655	41	
40	nd	2982	2087	24	
50	nd	3563	2850	17	
60	0.4	4105	3284	12	
70	3.3	4600	4140	9.1	
80	6.7	4990	4491	6.9	
81	6.7	Meets RO	5000	6.7	
	nd = less than 0.1 ug/L	exceeds at river			





Midco II South Sensitivity Evaluation
Increase Plume Length - 10-5 cancer risk (6.7 ug/L criteria)

Time	Concentration at Grand Calumet River at 5000' (ug/L)	Distance to Meet RO (6.7 ug/L)	Distance to Peak	Peak Concentration
3	nd	388	39	680
5	nd	582	58	506
10	nd	1001	near source	250
20	nd	1724	1034	66
30	nd	2370	1659	33
40	nd	2965	2076	19
50	nd	3516	2813	13
60	0.5	4010	3609	9.4
70	3.1	4400	3960	7.3
73	4.1	4450	4450	6.8
75	4.6	Meets RO	4185	6.3

nd = less than 0.1 ug/L