Armidale Regional Landfill
Armidale Dumaresq Council
19 February 2010

AECOM

Literature Review

Landfill Liners

Literature Review

Landfill Liners

Prepared for

Armidale Dumaresq Council

Prepared by

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1.0 Composite Landfill Liner Performance

Waste containment systems for landfills consist of liner systems below and around the sides of landfilled waste and final cover (capping) systems constructed over landfilled waste. In order to provide greater certainty in the containment of leachate within a landfill cell, a combination of liners and drainage layers performing complementary functions is usually employed. The purpose of constructing liner system is to eliminate or minimize, to the extent achievable, the migration of waste constituents out of a landfill. The goal of a final cover system is to cap and contain the wastes, minimize to the extent achievable the infiltration of water into the landfill and to control the emission of landfill gas.

The leachate barrier system to be installed at the proposed landfill will conform to the Benchmark Technique Number 1 of the *Environmental Guidelines: Solid Waste Landfills* (EPA, 1996). It is currently envisaged that this would consist of a 900 mm thick layer of recompacted clay with a permeability of less than 10^{-9} metres per second (m/s), as a minimum requirement. The leachate barrier system constructed for the landfill may also exceed these minimum permeability criteria, in order to create further surety of the ongoing integrity of the barrier.

If there is insufficient volume of appropriate clay material available from site excavation works to construct the required recompacted clay liner (to be determined during the detailed design phase), then an alternative composite clay / synthetic barrier system would need to be installed such as a landfill liner compromising a clay layer in combination with an artificial liner such as a Geosynthetic Clay Liner (GCL) or a High Density Polyethylene (HDPE) layer or an approved equivalent, would be used. Any such composite barrier system would also be subject to approval by DECCW and would need to meet or exceed the minimum Benchmark Technique requirements.

If required, it is anticipated that any such composite barrier design would consist of the following:

- A clay bedding layer with minimum thickness of 300 mm and permeability of less than 10^{-9}m/s;
- A 1.5 mm thick HDPE with a permeability of less than 10^{-11}m/s would overlay the clay bedding layer.

In conjunction with the barrier system the leachate level within the landfill is designed to be maintained not to exceed 300 mm above the base of the liner by a leachate collection system. The leachate barrier system would contain leachate over the period of time that the waste poses a potential environmental risk, that is, the time until Final Storage Quality is achieved. When final storage quality has been achieved, the waste is deemed to be acceptable in the surrounding environment, allowing the site to be safely closed (Hjelmar and Hansen, 2005). Therefore, ‘leakage’ at this time from landfill is considered to have negligible impact on the surrounding environment.

It is necessary to consider the potential, albeit limited, for defects to occur during the construction of a composite liner. It must be taken into account that components of the system may fail, with the leachate collection and conveyance system (LCCS) and geomembrane liner being the most vulnerable because they are subjected to severe chemical and biological conditions. Each component of the barrier system is not expected to function completely for the entire lifespan (which, for a large landfill, may be hundreds of years; Rowe et al., 2004). However, the system as a whole will provide the long-term environmental protection that is required.

A study of available literature on the efficiency of different landfill linings was undertaken to review typical liner life and performance and to establish the foreseeable life and performance for the proposed Armidale Regional Landfill, for which the findings are summarised in the sections below.

2.0 Leachate Generation and Quality Over Time

The proposed Armidale Regional Landfill would be used for disposal of General Solid Waste (Putrescible), which is typically classified as municipal solid waste (MSW). Published leachate chemistry data show that leachate from MSW landfills is a mineralized, biologically-active liquid containing trace concentrations of heavy metals and synthetic organic chemicals. During the active life of a MSW landfill which goes through various stages, waste decomposition takes place primarily in the acid stage. In this stage, the ratio of biochemical oxygen demand (BOD) to chemical oxygen demand (COD) is relatively high and pH is relatively low. As waste placement ceases, BOD to COD ratio decreases and pH increases. Trace chemicals are generally found to occur at significantly lower frequencies and concentrations in MSW leachate than in hazardous waste leachate (Bonaparte *et al,* 2002).

The concentrations of pollutants are mainly controlled by physico-chemical and biochemical processes, such as solubilisation, sorption, ion-exchange or biological degradation. Physico-chemical processes act as sinks for pollutants, resulting in a substantial decrease in pollutant mobility. The apparent effect of this phenomenon is to lower concentrations of pollutants in the leachate. Leachate quality in sanitary landfills is closely associated with biological degradation. Biological degradation will control the BOD and COD of the leachate as well as metal and sulphate concentrations. Any landfill containing biodegradable material will undergo separate degradation phases, although the necessary time might differ substantially from one case to another. As the waste passes through these phases, the leachate quality changes from a high pollution level to a rather low pollution level (Sven-Olof Ryding, 1992).

Bonaparte *et al* (2002) drew the following conclusions from various studies of landfill leachate generation rates in humid and arid regions:

- Open landfills (i.e., landfills without a final cover system) located in relatively humid regions have average leachate generation rates that are typically below 20,000 lphd.
- Average reported leachate generation rates for open landfills located in relatively humid regions can be up to 90% of precipitation that occurs at the landfill sites. This ratio is related to: (i) the type of waste and its initial moisture content; and (ii) waste placement and covering practices. The ratio is lower for MSW landfills than for hazardous waste or industrial solid waste landfills and for wastes with low hydraulic conductivity daily and intermediate covers than for uncovered wastes.
- Open landfill cells located in arid regions have average leachate generation rates that are much lower (i.e., less than 100 lphd) than cells in humid regions.
- Leachate generation rates decrease significantly after cell closure (i.e., after a final cover system is placed on the waste). From the published studies, Leachate Collection and Removal System (LCRS) flow rates decrease by approximately one to three orders of magnitude within one year after closure, and by up to two orders of magnitude after ten years of closure.

It is expected that a landfill operator can minimize leachate generation rates by using a small active disposal area and implementing effective measures to minimize infiltration of rainwater into the waste and to divert surface water away from the landfill. These measures are detailed in a Water and Leachate Management Plan which forms Appendix B of the Landfill Environmental Management Plan for the proposed Armidale Regional Landfill (refer to Appendix B of the EA) .

Based on these outcomes, we can conclude the following for the proposed Armidale Regional Landfill:

- Leachate quality and quantity would be dictated by the type of waste received, the design of the landfill and how the landfill is to be constructed and operated;
- Leachate chemistry and the naturally occurring processes within the landfill would act to degrade the pollutants over time; and
- While studies, such as the work by Hjelmar and Hansen (2005), discuss what constitutes final storage quality, there is acceptance that the naturally occurring degradation processes would eventually result in the leachate that has a low pollution level.

3.0 Performance and Degradation of Liners Using Geomembranes

A well-designed and installed intact geomembrane liner may be expected to experience some degradation or aging with time that will lead eventually to localised failure. The aging process of HDPE geomembranes is a simultaneous combination of physical aging and chemical aging. From an application perspective, chemical aging is the most important degradation mechanism and therefore requires particular attention (Rowe & Sangam, 2002). Degradation mechanisms include swelling, ultraviolet (UV) degradation, temperature, environmental stress cracking, degradation by extraction, biological degradation and oxidative degradation. These mechanisms are described as follows:

- Hsuan *et al* (1991), cited in Rowe and Sangam (2002), conducted a study of the performance of an HDPE geomembrane after 7year use for solid-waste leachate storage in a surface impoundment. The results indicated:
  - no substantial macroscopic change in the geomembrane sheets or seams after 7 year exposure;

  - no substantial changes in the internal structure of the material due to constant outdoor exposure; and
  - no affect on the engineering/hydraulic containment properties of the geomembranes.
- Eith and Koerner (1997), cited in Rowe and Sangam (2002), described a case in which an HDPE geomembrane was used as part of a double liner system for a landfill. During the eight years of service, the geomembrane had been exposed to various concentrations of leachate constituents. The physical, mechanical and endurance test results indicated no apparent degradation of the HDPE geomembrane properties since they were still within the range of data generated for the original material at the time of installation.
- Environmental stress cracking - An important consideration regarding the use of HDPE geomembranes is their susceptibility to stress cracking which, in turn, is a consequence of their highly crystalline structure (typically about 40–50%). Several investigators have reported field evidence of the vulnerability of HDPE geomembranes to stress cracking. With appropriate design, testing, specification, installation, seaming, and operational procedures, the potential for stress cracking failures can be significantly reduced.
- Koch et al. (1988) cited in Rowe and Sangam (2002), applied their pipe research expertise to the geomembrane area and concluded that the interaction with leachate is a primary issue in the service life of geomembranes. Although the stress fields in a HDPE pipe are different to those in a geomembrane liner, they conclude that considering all of the other factors (leachate interaction), the service life of HDPE geomembranes could be expected to be considerably greater than 100 years.
- Sangam (2001), cited in Rowe and Sangam (2002), examined the service lives of HDPE geomembranes under various exposure condition scenarios where geomembranes were used as bottom liners for MSW landfills. It was estimated that the primary geomembrane would last at least 200 years, when the landfill is well maintained and the temperature at the membrane is not higher than 151°C. For the conditions where the temperature is at 331°C, the service life is estimated to be about 70 years. For the typical groundwater temperature range of 7–101°C, it is estimated that the geomembrane used as a secondary liner will last at least 400 years, provided that it has a suitable antioxidant component, is not subjected to significant tensile stress and is covered by an adequate protection layer.
- The key findings of the work reported by Sangam (2001) and by Hsuan and Koerner (1995, 1998), cited in Rowe and Sangam (2002), are that the service lives of HDPE geomembranes are essentially controlled by the antioxidants in the liner material and the service temperature. However, there is a debate regarding the properties to be assessed with respect to the degree of polymer breakdown and the level used as the failure threshold. In landfill base liner applications, the real service life depends on the hydraulic and diffusive properties of the geomembranes and hence a geomembrane may lose strength while still performing satisfactorily as a barrier. Therefore, the ‘‘hydraulic and diffusive service life’’ of a geomembrane may exceed the service life as determined by the degradation of physical and mechanical properties, especially if tensile stresses are minimal.
- Bonaparte et al (2002) cite Bonaparte and Gross who concluded “the double-liner systems evaluated ... performed well. Leakage rates through the primary liners have been low or negligible in most cases”.

Based on these outcomes, the following can be concluded for the proposed Armidale Regional Landfill:

- HPDE is subject to a number of degradation mechanism;
- A typical HPDE liner should have an operational life of approximately 200 years if appropriately maintained; and
- HPDE liner elements need to be maintained during both construction and filling to maximise their operational life and performance.

4.0 Potential Leakage Rate Through Composite Liners

Leakage through a liner can be estimated by assuming a given number of defects occurring during liner construction/installation. While a good Construction Quality Control/Construction Quality Assurance (CQC/CQA) will minimise the number of defects, they cannot be completely eliminated.

Available field data suggests that given typical numbers of wrinkles and holes in a GCL, based on a per hectare surface area, for landfills with good CQC/CQA and where there is no damage to the liner during landfilling activities, post-closure leakages are very small and contaminant transport is likely to be controlled by diffusion through the liner system for contaminants that can readily diffuse through a geomembrane (Rowe (2007)).

Bonaparte *et al* (2002) drew the following conclusions regarding the hydraulic performance of composite liners:

- Leak Detection Systems (LDSs) underlying a geomembrane/recompacted clay liner composite liners almost always exhibit flow due to consolidation water. Measured LDS flow rates attributable to consolidation water are in the range of 0 to 1,000 litres/hectare/day (lphd), with most values being less than 200 lphd. LDS flow rates attributable to consolidation water are a function of the characteristics of the recompacted clay liner and the rate of waste placement in the overlying cell. Typically, the rate of flow decreases with time during the later portion of the active period of operation and the post-closure period. LDS flow rates in the range of 0 to 100 lphd have been reported within one to two years of the completion of active filling of a cell.
- Flow rates from the LDSs of cells with geomembrane/GCL composite primary liners are usually very low. LDS flow rates attributable to leakage through this type of primary liner typically varied from 0 to 50 lphd, with most values being less than about 2 lphd. The true hydraulic efficiency of geomembrane/GCL composite liners may often exceed 99.9%.
- Average LDS flow rates may increase by an order of magnitude, or more, due to liner system damage induced by heavy equipment operations in the cell. Engineering and operational measures should be used to prevent this type of occurrence.

In the event that defects are present in the HDPE membrane, AECOM has calculated a migration rate of leachate through the clay barrier layer at an estimated rate of 6.7 L/ha/day at discrete locations associated with the defects within the liner (AECOM, 2010). As these locations are considered to be discrete, discharges would, in effect, be a series of small point sources rather than the landfill being one large source area.

5.0 Recommendations for Improving Liner Performance

From the literature review, it can be concluded that many issues identified in the studies could be prevented or managed using robust design approaches, construction materials and procedures, and operation practices (Sangam and Rowe, 2001).

From these studies, the following recommendations would be considered for the detailed design and construction of the proposed Armidale Regional Landfill

a) Needlepunched nonwoven geotextiles can provide adequate protection of geomembranes against puncture by adjacent granular soils.

b) Temperature-induced waves (wrinkles) in geomembranes do not disappear when the geomembrane is subjected to overburden stress (i.e., when the geomembrane is covered with soil), rather the wave height decreases somewhat, the width of the wave decreases even more (i.e., the height-to-width ratio (H/W) of the wave increases), and the void space beneath the wave becomes smaller. Residual stresses in HDPE geomembranes installed in the field may be on the order of about 1% to 22% of the geomembrane's short-term yield strength in the vicinity of geomembrane waves, with higher residual stresses associated with higher H/W values. Significant residual stresses can reduce the geomembrane service life. The relationship between geomembrane type, magnitude of residual stress and service life requires further investigation.

c) If geomembrane waves after backfilling are to be avoided, light-coloured (e.g., white) geomembranes can be used, geomembranes can be deployed and seamed without intentional slack, geomembranes can be covered with an overlying light coloured temporary geotextile until backfilling occurs, and backfilling can be performed only in the coolest part of the day or even at night.

d) Polypropylene (PP) geotextiles are slightly more susceptible to UV degradation than polyester (PET geotextiles, and lighter weight geotextiles degrade faster than heavier geotextiles.

e) Geotextiles that are partially degraded by UV light do not continue to degrade when covered with soil, i.e., the degradation process is not auto-catalytic. Nonetheless, good practice dictates that geotextiles be covered with overlying protective materials in a timely manner to minimize exposure. Also, geotextiles should be protected from exposure prior to installation (i.e., by keeping the geotextile rolls in the shade or in opaque bags).

f) Buried HDPE geomembranes have an estimated service life that is measured in terms of at least hundreds of years. The three stages of degradation and approximate associated times for each as obtained from the laboratory testing program are:

  - antioxidant depletion (≈ 200 years),
  - induction (≈ 20 years) (the induction time represents a time period required to initiate a measurable amount of oxidation-induced chain splitting of the polymer structure), and
  - half-life (50% degradation) of an engineering property (≈ 750 years).

6.0 Conclusions

In conclusion, a number of studies of the long-term performance of composite liner systems suggest that geosynthetic clay liners (GCLs) and geomembranes can play a fundamental, and beneficial, role in providing environmental protection. Like all engineering materials they must be used appropriately and in accordance with site specific design and in strict adherence to construction specifications including Construction Quality Assurance or Construction Quality Control (CQC/CQA) programmes, and appropriate protection of the geosynthetics after construction/installation. In particular, given the diversity of available GCLs and their different engineering characteristics, GCLs should be selected based on the required engineering properties.

The three main findings that can be applied to the proposed Armidale Regional Landfill are:

- Composite liner systems must be used appropriately and in accordance with site specific design and in strict adherence to construction specifications including Construction Quality Assurance or Construction Quality Control (CQC/CQA) programmes, and appropriate protection of the geosynthetics after construction. In particular, GCLs should be selected based on the required engineering properties.
- The available laboratory and field evidence, combined with modelling, indicates that primary LCCSs in Municipal Solid Waste (MSW) landfills have a finite service life, which could range from less than 70 years to more than a century depending on the design, waste characteristics and mode of operation.
- Examination of both laboratory and field data indicates that the projected service lives of HDPE geomembranes may range from 70 years to many centuries depending on the material and exposure conditions.

7.0 References

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Armidale Regional Landfill
Armidale Dumaresq Council
12 February 2010

Hydrogeological (Leachate) Assessment

Hydrogeological (Leachate) Assessment

Prepared for

Armidale Dumaresq Council

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1.0 Introduction and Approach

In relation to the proposed Armidale Dumaresq Landfill the Department of Planning requires that:

> *"Risk of Migration of Leachate*
>
> *The quantified impact of leachate seepage on the national park should be included based on the potential risk and timeframe of seepage, and the amount and concentration of leachate that would reach the national park".*

In order to make an assessment of potential 'impact' AECOM has built a conceptual model that describes our understanding of the proposed landfill, existing site investigation data and standardised published assumptions about landfill design and leakage rates. In order to provide a quantitative assessment of the potential impact of the landfill this hydrogeological assessment requires conservative assumptions to be made based on our understanding of the design of the landfill and local geological and hydrogeological conditions. The nature of this process means that assumptions are made to be conservative i.e. to over predict impact in order to develop a worse case understanding of impact. However, this assessment assumes that the landfill may leak from day one of operation and that leaked leachate migrates in an unimpeded fashion toward the national park. In reality natural conditions are more complex than this simplified assessment allows and if the landfill is constructed as designed then there should be no demonstrable impact to the Gara River or Oxley Wild Rivers National Park.

1.1 Conceptual Model

The Armidale Dumaresq Council proposed landfill is located approximately 12 km east of Armidale in the New England region NSW. The site is located approximately 1000 m west of the Gara River, which flows into the Oxley Wild Rivers National Park.

The landfill is proposed to comprise a series of cells constructed in a staged approach, beginning with Cell 1 to the south of the site. The facility is also planned to include a sedimentation basin, leachate storage pond and a dry basin.

It is understood that the landfill cells are proposed to have the following design surface area of the cap:

- Cell 1 33 403 m^2
- Cell 2 24 237 m^2
- Cell 3 24 017 m^2
- Cell 4 25 163 m^2
- Cell 5 35 889 m^2
- Total 142 700 m^2
- Total 14.2 ha

Site investigation data relating to the physical/hydrogeological nature of the area proposed for the landfill that was used to develop the conceptual model is taken from:

> *Hydrogeological Assessment, Proposed Armidale Landfill, RCA Australia RCA ref 5929-004/2, August 2007. (RCA 2007)*

This reported the geology of the site from the Dorrigo – Coffs Harbour 1:250000 Geological Series Sheet SH 56-10 and 11 as comprising:

- Greywacke, slate, siliceous argillite, pebbly mudstone containing bands of Conglomerate, greybilly, sandstone and claystone in the northern part of the site.

Gauging of the standing groundwater levels within monitoring wells established on the site found the depth to groundwater to be highly variable ranging from 5 to almost 50 m below ground level at relative elevations above Australian Height Datum (m AHD) of 948 m to 967 m. RCA (2007) estimated groundwater flow direction to be generally toward the north-north east, towards the Gara River.

The Gara River is located within the Macleay River Catchment Area. The Department of Natural Resources rates the water source and cumulative stress as high within the river, with summer extraction demand regularly exceeding available flows in November (RCA 2007).

Geochemical testing of groundwater quality conducted by RCA (2007) found it to be '…*predominantly a chloride water type*.' Groundwater flow was presumed to have a longer residence time because of lower permeability of the rock, with slower groundwater velocity allowing longer contact with soluble minerals.

The relatively high concentration of both chloride and sulphate ions detected in groundwater on the site was considered by RCA (2007) to be as a result of the long residence time of the groundwater within the predominantly argillite bedrock and the solubility of the chemical constituents of the rock.

AECOM has adopted a simplified approach, using screening level equations that cannot account for heterogeneity and made the following assumptions about the hydrogeology of the environment in the landfill area in order the estimate possible impacts from leachate on the National Park.

Table 1: Assumptions Relating to the Environment

Assumption	Units	Value	Notes
Distance from Site to Gara River.	m	1000	Approximate distance from the facility to the River.
Hydraulic Conductivity	m/s	3.8E-06	Conductivity reported during Site investigation works. Value for BH11 (RCA 2007).
Vadose Zone thickness	m	21.3	Depth to groundwater in BH 12 in RCA (2007).
Sat zone thickness	m	25	Assumed
Hydraulic Gradient to River Gara	m/m	1.51E-03	Reported hydraulic gradient 1.51×10^{-3} between BH12 and BH04 which is likely to be representative of conditions below proposed landfill.
Effective porosity - Sandstone Bedrock		0.21	Specific Yield value for Sandstone, estimation of effective porosity. Zheng and Bennett 2002. *Applied Contaminant Transport Modeling 2nd ed.*Wiley.

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2.0 Landfill Leakage

The landfill is designed to minimise the potential for leachate leakage by utilising the multi-barrier design and a leachate collection system. The multi-barrier system comprises a layer of 2 mm HDPE liner overlying 900 mm of compacted clay liner (CCL) with a design permeability of 10^{-9} m/s. In conjunction with the barrier system the leachate level within the landfill is designed to be maintained not to exceed 300 mm above the base of the liner by a leachate collection system. Therefore, 'leakage' from the base of the landfill is considered to be negligible in practice. However, it is necessary to assess the potential impact of leakage on the basis that there is potential, albeit limited, for defects in construction of the HDPE liner. Leakages from the liner would then enter the environment, migrate downwards through the vadose zone, until the saturated zone is reached and then migrate laterally toward the Gara River. The potential impact is assessed as follows:

Leakage through the liner can be estimated using Giroud (1994)[1]

$$Q = 0.21 * iavg * a^{0.1} * h^{0.9} * k^{0.74}$$ Equation 1

Where:

Q	=	Volume of leakage though a liner (m^3/s)
iavg	=	Unitless factor based on h/D
a	=	Area of defect (m^2)
h	=	Hydraulic head on the liner (m)
k	=	Permeability of the liner (m/s)
D	=	Thickness of the liner (m)

Table 2: Calculations to Estimate the Landfill Leakage

Assumption	Value	Notes
Defects in the HDPE Liner.	1/4000 m^2	Typical for liner performance evaluation one defect per acre (4000 m^2) (Giroud et al., 1994)
Area of defect	1E-05 m^2	Diameter of 3.5 mm (Giroud et al., 1994)
Head on liner	0.3 m	Design maximum depth of leachate on liner.
Clay Permeability	1E-09 m/s	Design maximum permeability specification.
Clay thickness	0.9 m	Design minimum thickness of clay barrier.
iavg	5	Per Giroud (1994)
Leakage	3.09E-08 m^3/s	As per Equation 1
Leakage	6.7 L / ha / day	(unit conversion)
Leakage from landfill	95 L/day	6.7 * Landfill area (14.2 ha).

[1] Giroud, J.P., Badu-Tweneboah, K., and Soderman, K.L., 1994, "Evaluation of Landfill Liners", Proceedings of the FifthInternational Conference on Geotextiles, Geomembranes and Related Products, Singapore, September 1994, Vol. 3, pp.981-986.

The worse case value for leakage has been be estimated using the assumptions in Table 2 above. In order to model a worse case scenario this assessment makes no assumptions about the length of time required for defects in the liner to appear. Instead the model considers that leakage can occur once operation commences and the time taken for infiltration through the clay is driven by 300mm of leachate being present above the liner.

The time taken for leachate to traverse the clay barrier layer can be estimated using Darcy's Law:

$$v = \frac{q}{\eta}$$ Equation 2

Where:

v = Average linear/vertical velocity (m/s)

q = Darcy flux m/s

n = Porosity

Where:

$$q = k * \frac{dh}{dx}$$ Equation 3

Where:

k = Hydraulic conductivity

dh/dx = Hydraulic gradient assumed to be unitary for vertical flow.

Table 3: Estimation of Leachate Travel Time Across the Liner System

Assumption	Value	Notes
Hydraulic conductivity	1E-09 m/s	Design maximum permeability of the clay layer
Hydraulic gradient	1	Unitary value for a vertical flow path
Darcy flux	1E-09 m/s per m^2	As per equation 3
Porosity	0.6	Domenico and Schwartz (1990)[2]
Groundwater velocity	1.7E-09 m/s	As per equation 3
Time (Seconds)	5.4E08	
Time (Years)	17.12	

[2] Domenico, P. A. & Schwartz, F. W., (1990). Physical and Chemical Hydrogeology, John Wiley and Sons, Toronto.

3.0 Leachate Migration through the Vadose Zone

In the event that defects are present in the HDPE membrane, leachate has been assumed to migrate through the clay barrier layer at discrete locations associated with the defects at an estimated rate of 6.7 L/ha/day. As these locations are considered to be discrete, discharges will, in effect, be a series of small point sources rather than the landfill being one large source area.

Leachate will then enter the vadose zone and move down under the influence of gravity to groundwater. Typical subsurface geology found at the site comprises (RCA, 2007):

TOPSOIL:

Sandy gravely silt, dry, brown to depths between 0.15 and 0.2m, overlying

RESIDUAL CLAY:

Sandy silty clay/Sandy gravelly clay, variable colour including orange, yellow and grey, dry, typically stiff or better, overlying

ROCK:

Rock observed at the site includes greywacke, argillite and mudstone. Depth to rock is typically in the range 0.75-1.5 m, with the depth to groundwater of 21.3 m.

This type of strata is more complex than can be described by simple Darcy's Law equations and the use of Darcy's Flux is likely to considerably under estimate the length of time required for leachate to traverse the unsaturated zone. However, an estimation likely to represent a worse case scenario for vadose zone travel time has been made and this is described in Table 4 below. This calculation also does not account for interaction between the leachate and soil, which would tend to attenuate (reduce) contaminant concentrations.

Table 4: Estimation of Leachate Travel Time through the Vadose Zone

Assumption	Value	Notes
Hydraulic conductivity	3.8E-06 m/s	Saturated value for horizontal flow (RCA ,2007)), assumed conservatively to apply vertically for vadose zone
Hydraulic gradient	1	Unitary value for a vertical flow path
Darcy flux	3.8E-06 m/s	As per equation 3
Porosity	0.21	Domenico and Schwartz (1990)
Groundwater velocity	1.8E-05 m/s	As per equation 2
Flow path	21.3 m	
Time (Seconds)	1.2E06	
Time (Days)	13.62	

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4.0 Mixing in the Saturated Zone

Once leachate has traversed across the vadose zone it will cross the capillary zone and eventually enter the saturated zone. There will then be a degree of mixing and dilution with within the saturated zone. It is possible to estimate the mixing depth of leachate in the saturated zone (Equation 4)[3] and the resultant potential dilution factor (Equation 5)[3].

$$d = (0.0112L^2)^{0.5} + d_a\{1 - \exp[(-LI)/Kid_a)]\}$$ Equation 4

$$dilutionfactor = 1 + \frac{Kid}{IL}$$ Equation 5

Where

d	=	Mixing zone depth (m)
d_a	=	Aquifer thickness (m)
L	=	Source length parallel to groundwater flow (m)
I	=	Infiltration rate (m/yr)
K	=	Aquifer hydraulic conductivity (m/yr)
i	=	Hydraulic gradient (unitless)

Table 5: Estimation of Aquifer Mixing Zone Depth and Dilution Factor

Assumption	Value	Notes
Aquifer thickness	25 m	Assumed value.
Source length parallel to groundwater flow	10 m	Assumed value as a result of discrete point source discharges
Infiltration rate	2.4E-04 m/yr	6.7 L/ha/day *365 days/yr / 1000 L/m^3 /10000 m^2/ha
Hydraulic conductivity	1.2E02 m/yr	3.8E-06 m/s Conductivity reported during Site investigation works. Value for BH11, RCA (2007).
Hydraulic gradient	1.51E-03	Hydraulic gradient reported between BH12 and BH04.
Mixing zone depth	1.07 m	As per equation 4
Dilution factor	78.6	As per equation 5

4.1 Migration through the Saturated Zone

Once leachate has been mixed into the saturated zone it will migrate with the groundwater flow down gradient and attenuate and disperse as it does so. There are no site-specific data for leachate constituent concentrations as the landfill is a proposed facility, therefore, representative concentrations were selected from leachate concentration data from the Long Swamp Landfill. This landfill is understood to be representative of the proposed Armidale landfill. These were used to estimate saturated zone solute concentrations that could be used as inputs to a groundwater model to calculate lateral groundwater solute transport over a distance of 1 000 m, approximately the distance from the site to the Gara River.

[3] US EPA 1996 *Soil Screening Guidance: Users Guide 2nd ed,* reference 9355.4-23

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5.0 Methodology

A three dimensional analytical solute transport model (Domenico, P. 1987)[4] was then used to simulate transport with groundwater of representative source zone solute concentrations.

Bioscreen Version 1.4 is a software package produced by the USEPA that implements the Domenico analytical model to simulate advective transport and three-dimensional dispersion of source zone solute concentrations in groundwater (USEPA 1996 *BIOSCREEN Natural Attenuation Decision Support System User's Manual Version 1.3*, reference EPA/600/R-96/087).

Solute degradation and adsorption (retardation) in the natural environment were not included in the simulations. AECOM's adopted approach is considered appropriate for landfill leachate species that are unlikely to significantly degrade in the environment such as ammonia and chloride and is conservative for other species.

Solute transport was simulated over a 1000 metre distance for time periods ranging from 100 years to 10,000 years.

Table 6: Dilution Factor Mixing Zone Leachate Migration Model

Parameter	Symbol	Units	Value	Notes
Dilution Factor	DAF	-	78.6	Calculated in Table 4 above using equations 4 and 5

[4] Domenico, P. 1987 *An analytical model for multidimensional transport of a decaying contaminant species, Journal of Hydrology 91, pp 49*-58

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6.0 Bioscreen Input Parameters

Input parameters used in the model are summarised in the table below, hydrogeological parameters were taken from RCA (2007) where applicable.

Table 7: Bioscreen Input Parameters

Parameter	Symbol	Units	Value	Notes
Hydraulic Conductivity	K	cm/sec	3.8E-04	See Table 1
Hydraulic Gradient	i	-	1.51E-03	See Table 1
Porosity	n	-	0.21	See Table 1
Longitudinal Dispersivity	alpha x	ft	37.4	Calculated by Bioscreen.
Transverse Dispersivity	alpha y	ft	3.7	Calculated in Bioscreen (10% of alpha x)
Vertical Dispersivity	alpha z	ft	0.0	Conservative assumption
Retardation Factor	R	-	1.0	Assumes no retardation.
Modelled Area Length	-	ft	3000	Distance from source to receptor
Modelled Area Width	-	ft	1000	
Source Zone Width	-	ft	32	10 m See table 5
Source Thickness in Saturated Zone	-	ft	3.6	Mixing zone thickness of 1.09 metres (approx 3.57 feet) calculated for mixing zone model of leachate migration to groundwater.
Soluble Mass	-	kg	Infinite	
Time Period 1	-	yrs	100	
Time Period 2	-	yrs	500	
Time Period 3	-	yrs	1000	
Time Period 4	-	yrs	10,000	
Note: values given in imperial measures as a US EPA model was used that has these as inputs.				

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7.0 Results

The results of the assessment of leachate migration through the saturated zone are shown in Table 8 and Figures 1 to 4 below.

Leachate migration was modelled as a two-part process, comprising dilution of leachate as it moves vertically downwards to groundwater, followed by lateral transport of diluted leachate dissolved in groundwater. Modelling was based on representative leachate concentrations sourced from the Long Swamp Landfill.

Initial vertical leachate migration and concentration dilution model results are presented in column four of Table 8.

Subsequent lateral transport of dissolved leachate in groundwater model results are presented in columns five to eight of Table 8.

Conservatively assuming that no degradation and no retardation of solutes occurs, Figures 1 through 4 indicate that the first arrival of solutes at a distance of 300 metres (conservatively assumed to be the site boundary) is approximately 300 years and at 1,000 metres (i.e. the Gara River) would be between 700 and 800 years after generation of dissolved source zone concentrations.

This worse case assessment estimates that concentrations of solutes derived from leachate considered typical for the local area are predicted to be approximately 0.1% of the assumed original leachate concentration at the Gara River after a period of 10,000 years. The concentration of ammoniacal nitrogen was estimated to reduce from 132 mg/L to 0.13 mg/L and arsenic from 0.048 mg/L to 0.000051 mg/L after 10 000 years of continuous leakage. Furthermore, this model does not account for degradation or retardation of solutes and in reality these factors are likely to reduce the concentrations of solutes at the Gara River still further.

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8.0 Conclusions

An assessment has been made of the potential impact of the proposed Armidale landfill on the groundwater at the national park by undertaking simplistic quantified hydrogeological modelling. Estimates have been made of possible leakage from the landfill and the timescales over which leakage and subsequent transport of leachate in groundwater to the Gara River may take place. These estimates are largely based on assumed and uniform conditions and are considered likely to represent conservative estimates.

Potential leakage from the landfill was estimated as approximately 100 L/day.

The time taken for leachate to escape from potential defects in the liner and traverse the clay layer was calculated as approximately 17 years.

Travel time from there to the saturated zone was calculated as 13 days. Upon mixing with the underlying groundwater, leachate is calculated to be significantly diluted (80 times) over a depth of approximately 1 m in the groundwater.

Leachate contaminants would then take approximately 1000 years to reach the Gara River. After 10 000 years of consistent operation in this fashion leachate-related parameters are calculated to reach a concentration at the Gara River of approximately 0.1% of its input concentration.

Leachate concentration data from the Long Swamp Landfill were used as input concentrations to assess attenuation down gradient. The estimated down gradient concentrations were then compared to ANZECC (2000) 95% Trigger values for freshwater at 95% level of protection of species, it can be seen that results compare favourably with the exception of chloride, which is already acknowledged by RCA (2007) to be an issue in groundwater locally.

Therefore, in summary, this assessment of the hydrogeological impact of the Arimdale landfill on the national park indicates that impact will be negligible to indistinguishable from the existing groundwater quality.

Notwithstanding the simplifying assumptions made in the assessment, a groundwater model is a simplified approximation of a heterogeneous and highly complex physical system. As such, whilst models may be used to assess and predict aquifer behaviour and responses to a range of stresses, a degree of uncertainty is inherent in all models.

The report has been prepared by AECOM, and has been requested by our Client, Armidale Dumaresq Council. It is not to provide seepage migration time frames but to quantify impact of leachate seepage using a risk assessment model.

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Tables

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Table T1: Dilution Factor Mixing Zone Calculation and Solute Transport Simulation Results

Compound	Units	Initial Concentration (mg/L) - Long Swamp Road Landfill Data December 2009 (Cody Hart Environmental, Ref: 09.243.5)	Leachate Dilution to Groundwater (DAF=78.6)	100 year Model 1 km (3000 feet). Final Concentration $C_{final} / C_{initial}$= 0%	500 year Model 1 km (3000 feet). Final Concentration $C_{final} / C_{initial}$= 0%	1000 year Model 1 km (3000 feet). Final Concentration $C_{final} / C_{initial}$ = 3%	10, 000 year Model 1 km (3000 feet). Final Concentration $C_{final} / C_{initial}$= 8.5%	ANZECC (2000) 95% Freshwater
Chloride	mg/L	556	7.1	0	0	0.21	0.60	0.003
Arsenic	mg/L	0.048	0.0006	0	0	0.000018	0.000051	0.013
Ammonia-Nitrogen	mg/L	132	1.58	0	0	0.04	0.13	0.9
Nitrate-Nitrogen	mg/L	18.5	0.24	0	0	0.0071	0.020	0.7
Zinc	mg/L	4.5	0.054	0	0	0.00135	0.0045	0.008

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Figures

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Figure F1: Solute Transport – 100 Year Scenario

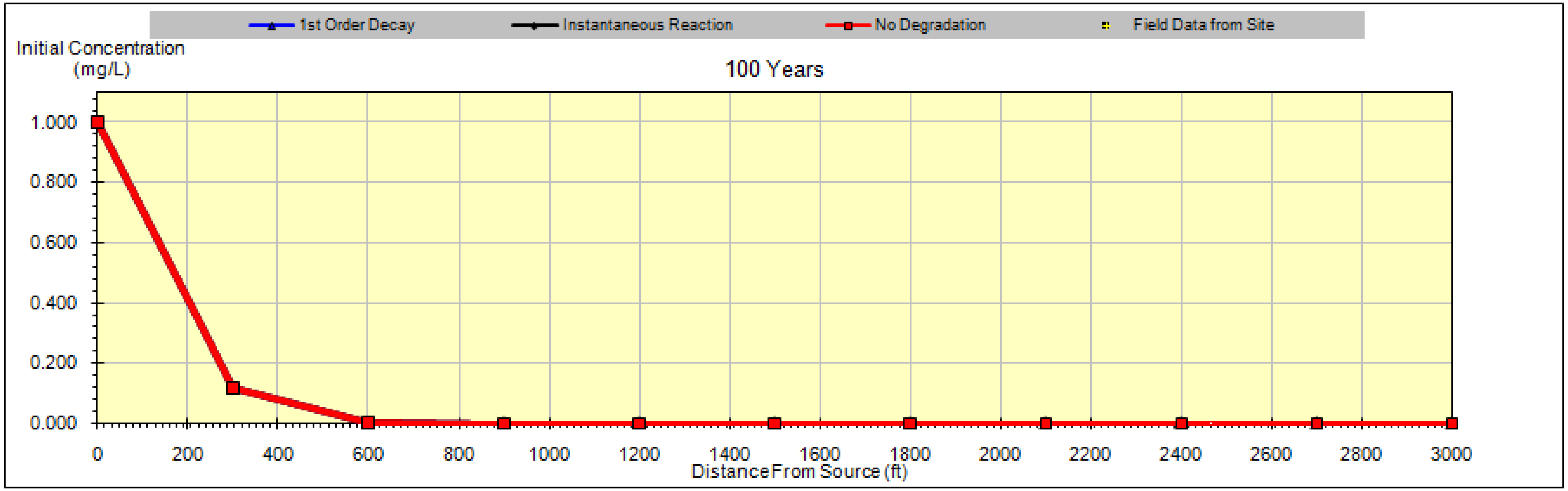


Figure F2: Solute Transport – 500 Year Scenario

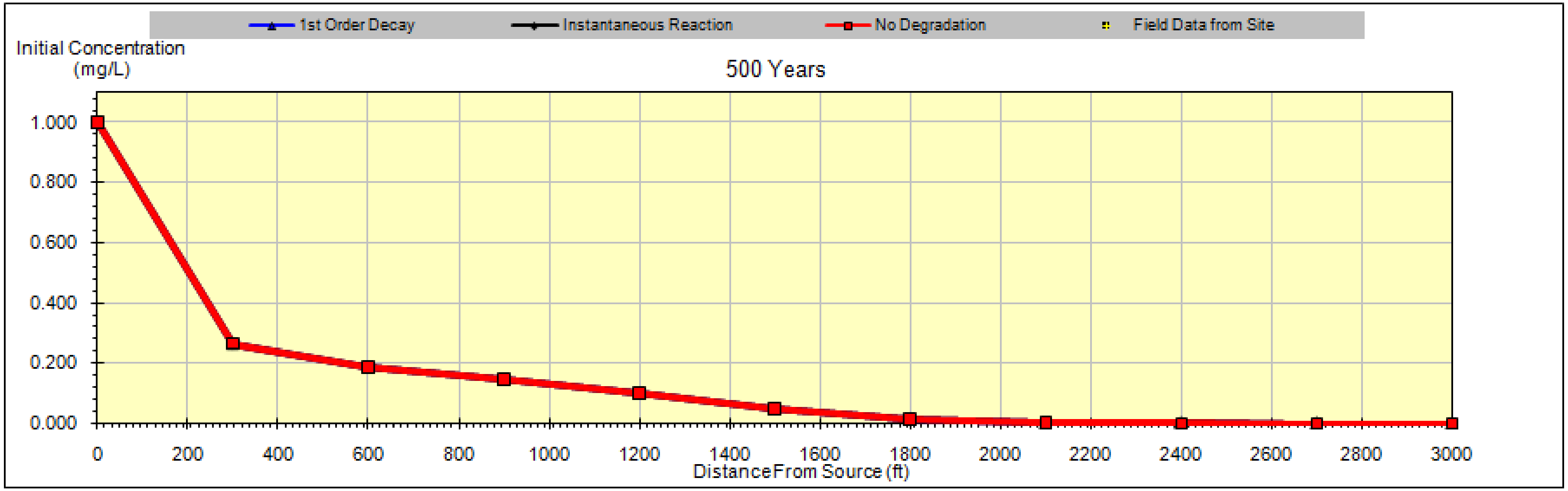


Figure F3: Solute Transport – 1,000 Year Scenario

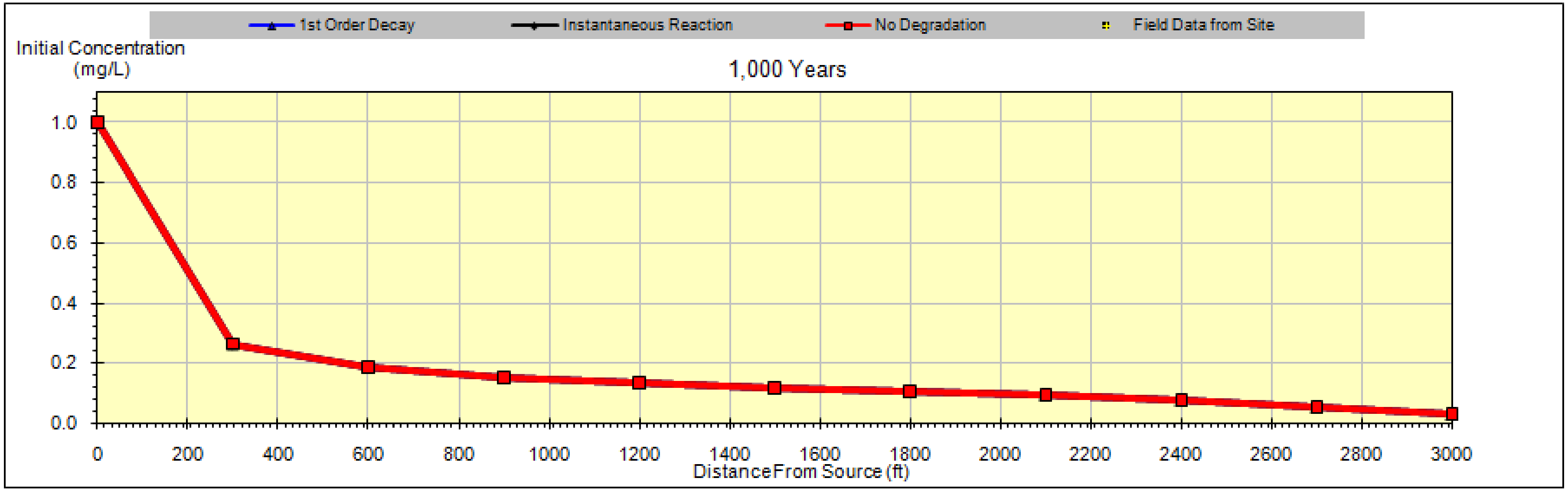
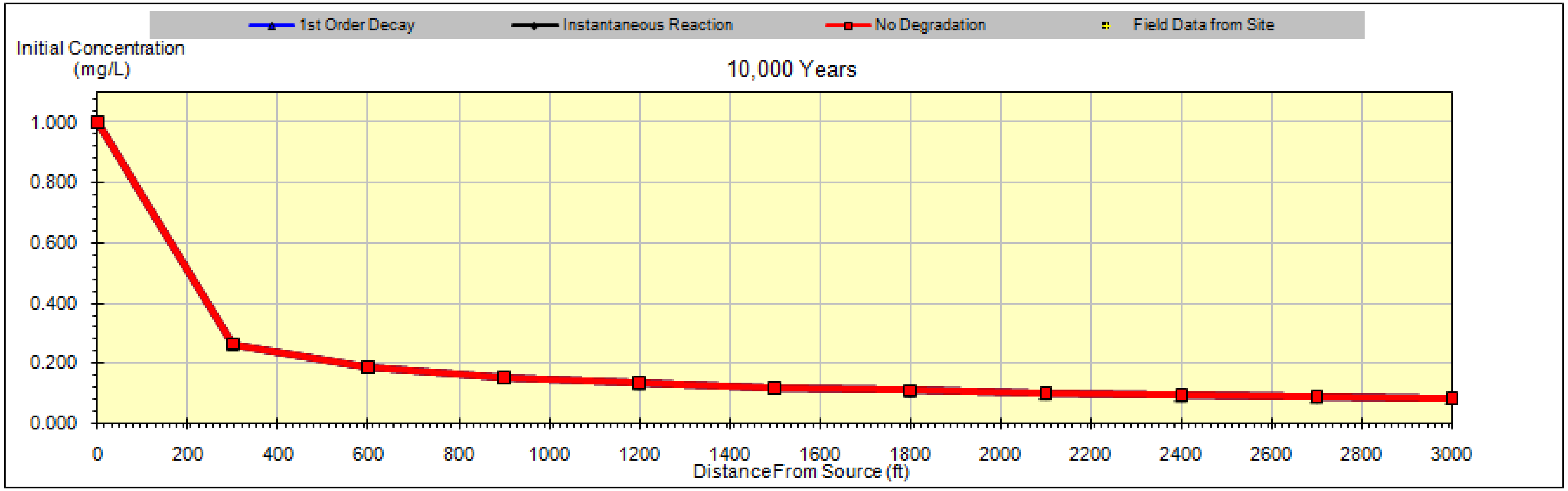


Figure F4: Solute Transport – 10,000 Year Scenario



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