Municipal Aquifer Conceptual Site Model
LANXESS Canada Co./Cie
Elmira, Ontario

Preamble

The American Society for Testing and Materials (ASTM) International (ASTM E1689-95, 2014) defines a conceptual site model (CSM) as "a written or pictorial representation of an environmental system and the biological, physical and chemical processes that determine the transport of contaminants from sources through environmental media to environmental receptors in the system". ASTM International also states that "a CSM should be used to enable experts from all disciplines to communicate effectively with one another, resolve issues concerning the site and facilitate the decision-making process".

The CSM described in this document will be used to support the ongoing off-site groundwater remediation and management strategies at the LANXESS Canada Co. (Site) located in Elmira, Ontario. In this regard, this CSM focuses on appropriate aspects related to hydrostratigraphy, contaminant sources and relevant history, contaminant fate and transport, past remediation efforts, and the present contaminant distribution. This factually-based CSM should be considered a "living document", and as additional Site information or data become available it should be updated as required. This CSM will provide the foundation for future discussions concerning data gaps, contaminant persistence or "hot spots", and to hypothesize about the nature of processes that may be occurring.

Previous iterations of the off-Site MA CSM have been completed, mostly in conjunction with the groundwater flow and contaminant transport model. A CSM that focused on the origin of ammonia contamination in the off-Site MA was also completed. Attachment A provides a list of reports with significant information or updates with respect to the Elmira MA CSM.

LANXESS provided a draft version of the CSM to stakeholders on April 13, 2017. Stakeholders provided comments and LANXESS responded to the comments and/or modified the CSM in response to these comments. The comment/response correspondence are included in Attachment A.

Hydrostratigraphy

The overburden deposits in the Township of Woolwich consist of a series of glacial till and related deposits overlying bedrock. The bedrock is found at depths that range from 30 to 60 metres (m) below ground surface (bgs). The glacial till deposits form a series of sheet-like layers of fine-grained materials, composed of silt and clay till with varying amounts of sand and gravel. Between the layers of glacial till are glaciofluvial outwash and glaciolacustrine deposits composed of varying amounts of sand, gravel, silt, and clay. The composition of these layers often varies spatially, and erosion and re-deposition of pre-existing glacial deposits occurred. Near the Site, these coarser grained glaciofluvial and glaciolacustrine sediments vary significantly in thickness, and are often discontinuous or interfingered with finer-grained glacial or glaciolacustrine deposits.

Approximately 200 stratigraphic logs from the more than 500 monitoring wells installed in the Elmira area form the basis for understanding the stratigraphy of the overburden. Based on the deep monitoring well nests shown on Figure 1, the following hydrostratigraphic units have been defined, in descending order:

1. The Surficial Aquifer (SA)
2. The Surficial Aquitard (SAT)
3. The Upper Aquifer (UA):
    a) The top beds of the Upper Aquifer (UA_1)
    b) The middle beds of the Upper Aquifer (UA2)
    c) The bottom beds of the Upper Aquifer (UA3)

4. The Upper Aquitard (UAT)
5. The Municipal Aquifer (MA):
    a) The Upper Municipal Aquifer (MU)
    b) The Municipal Aquitard (MAT), or its stratigraphic equivalent, the Low Gamma-Resistivity (LGR) zone
    c) The Lower Municipal Aquifer (ML)
6. The Lower Aquitard (LAT)
7. The Bedrock Aquifer (Bedrock)

Figure 2 provides a schematic of the hydrogeology of the Elmira area. This figure is a generalization of the most significant variations in the distribution of the aquifers and aquitards in Elmira and in particular, highlights the contrast in hydrogeologic conditions beneath the Site versus the rest of Elmira. The SA and the SAT, while locally important, do not play a significant role in the off-site remediation of the MA and are not discussed further.

The Ontario Geologic Survey has compiled a geologic model of the Quaternary geology of the Waterloo Region (AquaResource, 2012; Bajc, 2004). This model contains eight regionally significant stratigraphic units which are further subdivided resulting in 22 units. Many of these units are discontinuous or restricted to certain parts of the Waterloo Region. Relevant to this CSM are the following:

- The Catfish Creek Drift consists of the Catfish Creek Till and interbedded glaciofluvial sediments. The till has a highly variable texture and is described as clay-rich till, silt-rich till, sand-rich till or clay-rich silty sand. It is continuous with a maximum thickness >20 m. In the Elmira area, this till corresponds to the Upper Aquitard (UAT). Subsequent erosional processes have produced local windows in the Catfish Creek Till in the Elmira area. Local deposits of coarse-grained, moderately sorted sand and gravel occur within the Catfish Creek Till and these correspond to the Upper Aquifer (UA).
- The Pre-Catfish Creek outwash is coarse-grained, pebble to cobble gravel with a medium to very coarse-grained sand matrix and corresponds to the Upper Municipal Aquifer (MU).
- The Canning Drift consists of Canning Till and interbedded glaciolacustrine sediments that overlie the pre-Canning sediments. The Canning Drift is a relatively continuous aquitard unit that corresponds to the Municipal Aquitard (MAT). Erosion during subsequent ice advances and retreats has created local windows in this aquitard that connect the overlying Pre-Catfish Creek outwash aquifer to the underlying Pre-Canning outwash.
- The un-named pre-Canning till is a stony silt till that occurs as a discontinuous unit on top of the bedrock beneath Elmira. The Pre-Canning outwash overlies the pre-Canning till and tends to be preserved in bedrock depressions, notably the bedrock valley underlying the Elmira area where outwash is documented as a continuous unit that reaches local thicknesses in excess of 20 m. This Pre-Canning outwash makes up the Lower Municipal Aquifer (ML).

Upper Aquifer (UA)

The UA is not a single unified hydrogeologic unit. Rather, it is a number of different geologic units that have the common feature of being the first groundwater bearing zone encountered beneath the ground surface. The UA is typically unconfined, and composed primarily of sand or sand and gravel. The UA is either exposed at ground surface, overlain by fill, or overlain by the SAT. The UA is underlain by the UAT. The only exception is beneath the southwest portion of the Site where the UAT thins, and is locally absent so that the UA directly overlies the MU.

With the exception of the northeast corner of the Site, the UA is present beneath the Elmira area. In general, the off-Site UA is poorly characterized since the focus of the off-Site investigations has been the deeper strata. There are locations where the off-Site UA has been investigated; for example, the former Varnicolour site, and several retail gasoline stations. However, there has been no overall synthesis of UA characteristics. Beneath the Elmira area, the UA is separated from the underlying MA by a thick sequence of silt dominated till (UAT). During selected pumping tests for the off-Site CTS extraction wells, UA groundwater elevations were monitored and no response to pumping in the MA was observed. There is no direct connection between the off-Site UA and the MA. Beneath the Site, the UAT is thin, and as a result the MU was vulnerable to impact by former waste management practices.

The shallow stratigraphy (above the MU) beneath the Site is not representative of the shallow off-Site stratigraphy. In the northeast portion of the Site, where the ground surface rises above approximately 350 m above mean seal level (AMSL) the UA is replaced by a thick sequence of silt and clay till. There are sandy interbeds in this till sequence, but they do not appear to correspond with the UA. Stratigraphically, it appears that the hill in the northeast predated the deposition of the MA sands and gravel. The MA was deposited in a significant outwash event that draped the sands and gravel around the fringes of the silt till mound. In addition, the shallow glacial deposits in the Canagagigue Creek valley were reworked and redeposited by fluvial processes associated with Canagagigue Creek. Laterally extensive and thick glacial deposits dominate most of the remainder of Elmira outside the valley of the Canagagigue Creek floodplain.

Beneath the Canagagigue flood plain, the UA is divided into three local sub-units:

- UA_1 - Top beds of the Upper Aquifer (sand and gravel)
- UA_2 - Middle beds of the Upper Aquifer (silt)
- UA_3 - Bottom beds of the Upper Aquifer (sand and gravel)

The UA_1 is an unconfined aquifer that consists mainly of sand, and sand and gravel with lesser amounts of silty sand, and silty sand and gravel. West of Canagagigue Creek, fill material overlies the UA_1. The composition of this fill varies from silty sand and gravel to sand or sand and gravel. Refuse material such as glass, plastic, metal, wood and building materials are also present in the fill material beneath the southwest portion of the Site in the area shown on Figure 3 corresponding to the former M-2 municipal landfill. Figure 3 also shows the locations of former wastewater treatment ponds RPW-4, RPW-5, RPW-6, and RPW-8. Remnants of clay liner material from the former ponds are also locally present in the fill material. A former native soil horizon also occasionally underlies the fill. The UA_1 is thickest adjacent to Canagagigue Creek (typically 2 to 3 m), and becomes thinner and finer grained to the east and eventually pinches out against the topographic high in the northeast corner of the Site. To the west, as the ground surface rises up from the Canagagigue Creek flood plain, the UA_1 thins, becomes finer grained and eventually transitions into thin silty sand seams within the UAT. The hydraulic conductivity of the UA_1 typically ranges from 10^{-2} to 10^{-1} centimetres per second (cm/sec).

Prior to the installation of the Upper Aquifer Containment System (UA CS) in 1997, groundwater in the UA_1 flowed towards and discharged into Canagagigue Creek. The UA_1 is thin and discontinuous east of the Creek. Discharge of uncontaminated UA_1 groundwater from the east bank of Canagagigue Creek is seasonal. Beneath the northwest portion of the Site, the dam on the Creek raises surface water elevations so they are higher than the adjacent UA_1 groundwater elevations. This causes surface water to recharge UA_1, which then flows south around the dam and discharges into Canagagigue Creek. Since 1997, the UA CS captures UA_1 groundwater beneath the southwest portion of the Site, including the former wastewater retention ponds, and prevents the most heavily contaminated UA_1 groundwater from discharging into Canagagigue Creek. Significant improvements to Creek water quality have occurred since the UA CS was commissioned. The portion of the UA_1 south of the dam and north of Shirt factory Creek continues to discharge into the Creek but routine surface water and groundwater quality monitoring indicates this does not cause a significant deterioration of the Creek water quality.

The UA_2 is a discontinuous aquitard consisting primarily of silt, silty sand, or silty clay. The UA_2 is typically overlain by the UA_1. Locally, the UA_2 contains a closely spaced (~0.01 m) network of very small fractures and hence is considered a leaky aquitard.

The UA_3 is a semi-confined aquifer, and is typically composed of sand or sand and gravel. The UA_3 typically overlies the UAT, but where the UAT is absent, the UA_3 is in direct contact with the MU. This occurs beneath the southwest portion of the Site adjacent to Canagagigue Creek, where the UAT is thin (<1 m). The saturated thickness of UA_3 is typically 1 to 2 m. Beyond the Canagagigue Creek floodplain limits, the stratigraphic horizon corresponding to UA_3 is occupied by the UAT. The hydraulic conductivity of the UA_3

ranges from 10^{-3} to 10^{-2} cm/s with a geometric mean of 1.5×10^{-2} cm/s. Prior to 1997, the groundwater flow direction in the UA_3 beneath the Site was variable. Generally, flow was towards Canagagigue Creek. Groundwater flow between UA_1 and UA_3 was downward with the exception of an area of upward groundwater flow adjacent to the southern portion of Canagagigue Creek. Operation of the UA CS contains the flow of UA_3 groundwater beneath the southwest portion of the Site and has reversed the upward gradient near Canagagigue Creek.

Beneath the Elmira area and beneath the Site there is a downward gradient between the UA and the underlying MU. Both off-Site and on-Site groundwater extraction in the MA have lowered the MA groundwater elevations and increased the magnitude of the downward gradient.

Upper Aquitard (UAT)

The UAT underlies the UA and overlies the MU, and is composed of silt and/or clay, with various proportions of sand and gravel. Beneath most of the Elmira area, outside the valley of the Canagagigue Creek floodplain, the UAT is 5 to 10 m thick. Immediately west of the Site the UAT has significant zones of silty sand and silty sand and gravel, and seams of sand or sand and gravel up to 0.6 m thick. Beneath the area corresponding with the valley of the Canagagigue Creek floodplain and the western half of the Site, the UAT thins, particularly in the southwest portion of the Site. Here the UAT is thin (<1 m), or even absent at some locations (aka windows). On-Site stratigraphic logs have revealed the presence of at least two windows in the on-Site UAT and there may be others that have not been delineated. Beneath the eastern portion of the Site, the UAT thickens, particularly in the northeast where the UAT coalesces with the underlying MAT in a continuous till sequence >10 m thick.

One local area where the UAT has been well characterized is the Yara property, immediately west of the Site (see Figure 3). Thin interbeds of silty sand, sand, and sand and gravel were deposited within the till at the Yara property and may be locally connected to and be consistent with UA strata. Beneath the Yara property, the UAT is described as silt till with interbeds of silty sand and sandy silt. Layers of sand and gravel are also present. The hydraulic conductivity of the UAT beneath the Yara property ranges from 1.8×10^{-7} to 1.3×10^{-3} cm/sec, with a geometric mean of 3.6×10^{-5} cm/sec. The upper range of these hydraulic conductivity values correspond to the layers of sand and gravel. Beyond the Yara property, there are no UAT hydraulic conductivity data available.

Upper Municipal Aquifer (MU)

The MU extends beneath most of the Town of Elmira including the Site, and is a confined aquifer composed primarily of sand and gravel. The MU is typically overlain by the UAT. Beneath the Site, the MU overlies the MAT. West of the Site, beneath the Elmira area, the MU overlies the MAT, or its stratigraphic equivalent, the LGR. Further west and south, the MU and the ML thicken and where the MAT is absent, the MU and the ML coalesce to form a single aquifer, the MA. Beneath the Site the MU is typically between 5 and 10 m thick; however, it is absent at a few discrete locations. To the west, beneath north-central Elmira, the MU thickens to >10 m and further to the north it is between 15 and 20 m thick. To the south, in the vicinity of W3R[1] (Figure 1) the MU is thinner, typically 5 to 10 m thick. In the southern portion of Elmira, the MU thickness is more variable. The MU is locally absent northeast of containment wells E7/E9[2]. The area where the MU is absent is shown on Figures 5 and 7. Near E7/E9, the thickness of the MU ranges from approximately 5 m to more than15 m. The hydraulic conductivity of the MU ranges from 3.0×10^{-2} to 3.3×10^{-1} cm/s, with an average value of 1.7×10^{-1} cm/s. Based on the analysis of representative MU soil samples, the average fraction of organic carbon (f_{oc}) is 0.24 percent.

1 In 2016, LANXESS replaced off-Site extraction well W3 with replacement well W3R, located approximately 10 m south of the original well.

2 The South Well Field consisted of former municipal water supply wells E7 and E9. In 1990, E9 was converted to a containment well to prevent further southward migration of the NDMA plume. In 1999, LANXESS commissioned E7 as the containment well and E9 was converted to a backup well. The two wells are not permitted to operate simultaneously and are referred to as "E7/E9".

Municipal Aquitard (MAT) and the Low Gamma - Resistivity (LGR) Zone

The MAT is an aquitard that consists of silty clay with various proportions of sand and gravel. Where the ML is present beneath the Site, the MAT separates the MU from the ML. Where the ML is not present, the MAT overlies the LAT and these two units are difficult to differentiate. The MAT attains a maximum thickness of 15 m, but it typically ranges from 5 to 10 m in thickness. Based on the analysis of representative MAT soil samples, the average f_{oc} is 0.32 percent.

West and south of the Site the MAT thins, pinches out and is replaced by the LGR. The LGR is a zone of poorly graded sand within the MA characterized by a low gamma - low resistivity geophysical response that occupies a stratigraphic position equivalent to the MAT. The LGR is composed of fine to medium-grained poorly graded sand and is therefore part of the MA. It is not a confining layer or an aquitard. Where present, the LGR is typically 4 to 8 m thick. Pumping in either the MU or ML in areas where the LGR is present produces an equal response in both aquifers.

Lower Municipal Aquifer (ML)

The ML is a confined aquifer composed of sand and gravel, and is overlain by either the MAT or the LGR and underlain by either the LAT or Bedrock. At the Site, the ML is overlain by the MAT and underlain by the LAT. Beneath the northeast portion of Elmira the ML is typically 5 to 10 m thick. Further west, beneath the Elmira area, the ML thickens and can be more than 10 m thick. There is an increasing thickness trend to south where the ML attains its maximum thickness of 20 m southwest of E7/E9.

At the Site, the extent of the ML is limited and it is present only in the southeast corner of the Site and in a thin wedge along the central portion of the western Site boundary. The ML is also absent beneath part of southern Elmira area in the vicinity of off-Site extraction well W3R and northeast of off-Site containment wells E7/E9. The areas where the ML is absent are shown on Figures 6 and 8. The hydraulic conductivity of the ML ranges from 2.0×10^{-2} to 2.2×10^{-1} cm/s. Based on the analysis of representative ML soil samples, the average f_{oc} is 0.24 percent.

Lower Aquitard (LAT)

The LAT is an aquitard composed primarily of clay. Beneath the Site, where the ML is mostly absent, the MAT and LAT are in contact and are difficult to differentiate. Beneath the Elmira area, the LAT is absent at some locations and the ML and Bedrock are in direct contact. The thickness of the LAT beneath the Site ranges from approximately 1 to 14 m. Beneath the rest of Elmira, the thickness of the LAT ranges from non-existent to 14 m. Both of these maximum values represent combined MAT/LAT thickness. Based on the analysis of representative LAT soil samples, the average f_{oc} is 0.32 percent.

Bedrock Aquifer (Bedrock)

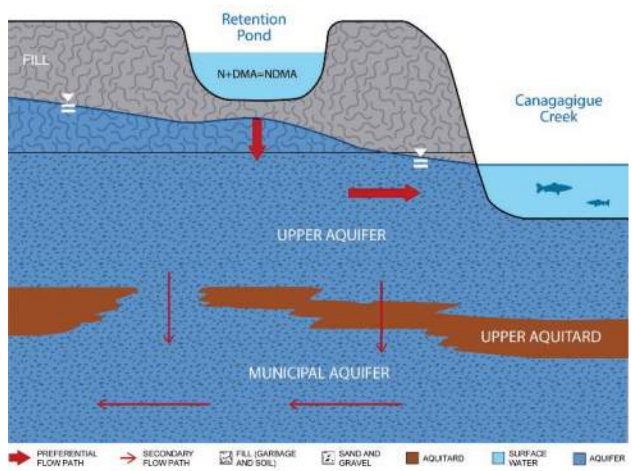
The Bedrock beneath the Elmira area consists of interbedded blue and gray shale and tan dolomite of the Salina Formation. The bedrock is weathered where it contacts the LAT or the ML, and below this zone, horizontal fractures are observed. Regionally, the top of the Bedrock slopes south and beneath the Site the top of Bedrock is approximately 320 m AMSL, which is the local high. West of the Site, there is a bedrock valley that trends southwest/northeast and the top of the Bedrock drops to approximately 305 m AMSL. East of W3 (Figure 1), the bedrock valley trend changes to southeast/northwest and extends to near E7/E9. The hydraulic conductivity of the competent Bedrock ranges from 10^{-3} to 10^{-2} cm/s, and it behaves like an equivalent porous media.

Contaminants, Sources and Relevant History

The buildings and infrastructure that comprise the LANXESS manufacturing facility were constructed on fill that was placed on the west side of the Canagagigue Creek flood plain. This infilling was gradual and generally proceeded from the west and north. Initially liquid wastes were discharged to Canagagigue Creek or piped to disposal pits on the east side of the Site. Eventually a series of waste water retention ponds (RPW-5, RPW-6, RPW-7, and RPW-8) were constructed west of Canagagigue Creek (Figure 3). A combination of solids separation, decanting, evaporation and infiltration occurred in the ponds before the remaining liquid was discharged to Canagagigue Creek. When the wastewater treatment system was constructed in the 1970s, RPW-5, RPW-6, and RPW-7 were decommissioned and then backfilled in the late 1980's. RPW-8 was converted into a storm water retention pond and is still in use.

N-nitrosodimethylamine (NDMA) and chlorobenzene are the two contaminants of concern (COC). NDMA is an industrial by-product or waste product of several industrial processes, and chlorobenzene is a colorless, flammable liquid used in chemical manufacturing. Table 1 lists the relevant physical and chemical properties for these COC. The Ontario Drinking Water Quality Standard (ODWQS) for NDMA is 0.009 micrograms per litre [μg/L], and for chlorobenzene is 80 μg/L) (MOECC, 2017).

NDMA Source



At LANXESS, NDMA was generated as a reaction by-product in the former west side wastewater retention ponds, shown on Figure 3, that were constructed in stages from 1943 (RPW-5) to 1966 (RPW-8). The pond bottoms were likely within a few metres of the water table, and dissolved NDMA migrated from the ponds into underlying groundwater in the UA_1. While groundwater flow in the UA_1 was horizontal and discharged to Canagagigue Creek, the elevated hydraulic head in the ponds presumably increased downward vertical hydraulic gradients that enhanced groundwater migration through the leaky UAT beneath the ponds and into the MU. Since NDMA is miscible in water, this leakage was entirely associated with the dissolved phase. From approximately 1945 to 1970 the LANXESS wastewater retention ponds were the source of NDMA entering the Elmira groundwater system. The ponds were lined in the 1970s to reduce discharge to groundwater, and decommissioned in 1989, eliminating this contaminant source.

Chlorobenzene Sources

Chlorobenzene was used primarily as a raw material for chemical manufacturing. The earliest waste management practices prior to approximately 1970 involved the burial of solid wastes, burial of drums of solid or liquid waste, disposal of liquid wastes in pits (some dug into the water table) and discharge of liquid waste into Canagagigue Creek. In the 1970s these practices were abandoned in favour of on-Site disposal of solid and drummed waste in lined pits and treating liquid waste in an on-Site treatment system prior to release. The presence of chlorobenzene in the UA_1 suggests that there were four main locations where chlorobenzene may have entered the groundwater beneath the Site. These are shown on Figure 3 and are:

- The RPW-1 and RPW-2 disposal ponds,
- Waste management units on the eastern portion of the Site,
- Waste water retention pond RPW-5 in the west central portion of the Site, and
- co-mingled with municipal waste in the M-2 landfill.

These locations all involved subsurface disposal of materials containing chlorobenzene as a separate dense non-aqueous phase liquid (DNAPL).

RPW-1 and RPW-2

The RPW-1 and RPW-2 disposal ponds were located in the northwest portion of the Site adjacent the former pilot plant. Liquid wastes that included DNAPL were placed in RPW-1 and suspended solids settled as the liquid was decanted into RPW-2. Because RPW-1 and RPW-2 were located upstream of the dam on Canagagigue Creek, and the water elevation of Canagagigue Creek was above the local UA_1 groundwater elevation, the contaminated UA_1 groundwater from beneath these disposal ponds flowed south around the dam before discharging into to Canagagigue Creek. The UAT is approximately 5 m thick in this area and it thus limited downward contaminant migration into the MU. RPW-1 and RPW-2 were abandoned and backfilled in 1969 and 1979, respectively.

East Side Waste Management Units

The extensive thickness of the tills (UAT, MAT, and LAT) beneath the eastern portion of the Site and the lack of aquifers (UA, MU, and ML), limited the extent that waste placed in these areas impacted the MU. Historic NDMA concentrations from the early 1990s were >100 μg/L but these have decreased to 3 μg/L in 2015 in the east side MU monitoring well OW43-11. Over the same period chlorobenzene concentration has persisted, typically in the range of 200 to 500 μg/L, suggesting there may be a local source near this well location.

RPW-5

Liquid wastes containing DNAPL were disposed of in retention pond RPW-5. In 1993, LANXESS excavated approximately 80 m^3 of fill/soil containing residual[3] DNAPL from beneath the RPW-5 liner. This DNAPL source impacted both UA and MU groundwater quality as evident by elevated historic chlorobenzene concentrations. Deceasing chlorobenzene concentrations in groundwater samples recently collected suggest residual DNAPL is not present near RPW-5.

M-2 Landfill

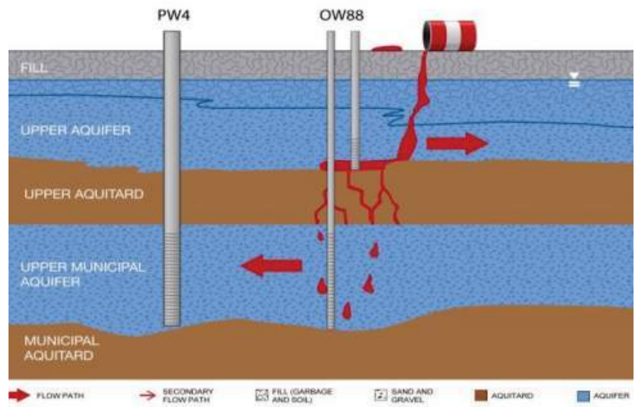
The M-2 landfill (Figure 3) received municipal waste from 1936 until it closed in 1962. Three distinct types of NAPLs have been observed within the M-2 landfill.

1. Dispersed within the fill are isolated blobs of solid, hard tar-like material. These NAPLs are highly viscous, and migration appears unlikely.
2. Drums have been observed buried in the M-2 landfill. Some of these drums contained solvents, or solvent residues that are NAPLs. During an excavation in 2012, crushed 55-gallon drum carcasses, portions of 55-gallon drum carcasses, crushed 5-gallon drum carcasses, glass bottles; process wastes including viscous tar-like NAPL, hardened tar NAPL with a shiny black appearance; municipal solid waste; and other waste, including tires and rubber hoses were observed. While a comprehensive remediation of the M-2 landfill has not been undertaken, LANXESS excavates and disposes of any drums, and any associated waste material encountered during construction or other subsurface activities. The NAPL dispersed within the M-2 waste material did not migrate from the landfill and it was not a significant contributor to off-Site groundwater contamination.

---

3 Residual NAPL is defined as NAPL that is hydraulically immobile.

3. Notwithstanding the M-2 landfill conditions described above, mobile[4] DNAPL was observed in the M-2 landfill material at monitoring well nest OW88. While installing the on-Site borehole for the UA_1 monitoring well OW88-8 (Figure 1) DNAPL was observed at the base of the UA. This well was installed at a depth of approximately 8 m bgs and DNAPL flowed into the well. OW88-8 was routinely purged and DNAPL has not been present in this well since 1995. The UAT at OW88 is interlayered clay/silt till and sandy gravelly silt, the latter being stained and odourous. Residual DNAPL is present near on-Site MU monitoring well OW88-19 at a depth of approximately 20 m bgs. Further downward migration was halted by a thick sequence of MAT and LAT silt tills (the ML is absent in this area). The chlorobenzene concentrations in groundwater samples from these wells range from 10,000 to 100,000 µg/L. The magnitude of these chlorobenzene concentrations has persisted for decades and thus indicates the presence of a DNAPL source. The core of the on-Site MU dissolved-phase chlorobenzene plume is located near OW88-19. On-Site MU containment well PW4 is located approximately 150 m away and has contained this on-Site MU chlorobenzene plume since 1993. Chlorobenzene concentrations in off-Site MU sentry wells CH-47A/E have decreased from >10,000 µg/L in the early 1990s to 130 µg/L in June 2017.



Therefore, while some residual NAPL exists in the M-2 landfill, groundwater contaminated by this residual NAPL is contained beneath the Site and does not contribute to off-Site groundwater contamination.

Groundwater Flow and Contaminant Distribution Prior to the 1998 Remediation Activities

Prior to the start-up of the off-Site Collection and Treatment System (CTS) in 1998, there were several different pumping regimes that shaped the distribution of the off-Site NDMA and chlorobenzene plumes. The relevant developments before 1998 were:

1945 to 1977 - North Well Field supplies municipal water

1977 to 1989 - South Well Field (E7 and E9) added to municipal water supply

1989 to 1994 - Interim pumping of E9 as containment well; north well field operated as municipal water supply

1992 to present - Hydraulic containment of the on-Site MU commences

1994 to present - Municipal water supply pipeline from Waterloo complete; North Well Field shut down

Prior to NDMA being detected in municipal water supply well E9 in November 1989, there was little off-Site groundwater data collected. In response to the NDMA discovery, the Regional Municipality of Waterloo (RMOW) completed a hydrogeologic investigation to determine the extent of the NDMA plume beneath Elmira and its source. Between December 1989 and August 1991, RMOW installed 158 monitoring wells mostly in the MU and ML in Elmira and the surrounding Township of Woolwich. Groundwater elevation data were collected in 1990 and 1991. Routine quarterly groundwater elevation monitoring of the entire Elmira MA began in 1995. Figure 5 through Figure 8 show the 1998 NDMA and chlorobenzene plumes in the MU and ML.

[4] Mobile NAPL is defined as NAPL that flows under a pressure gradient or gravitational body force.

From the time of the construction of RPW-5 in the 1950's, NDMA and chlorobenzene migrated downward into the MU beneath the Site. Vertical migration of NDMA and chlorobenzene through the thin or absent (aka windows) UAT occurred mainly beneath the southwest portion of the Site. Historic NDMA concentrations that were >200 μg/L defined the core of the on-Site MU NDMA plume that was centered beneath former wastewater ponds RPW-7 and RPW-8 in the south central portion of the Site. Further south, vertical migration of DNAPL through the UAT also occurred near monitoring well OW88-19, forming the core of the MU on-Site chlorobenzene plume under the M-2 landfill with historic chlorobenzene concentrations that were >50,000 μg/L in groundwater samples from OW88-19. The timing of the chlorobenzene release at OW88 is not known.

A number of contaminant transport processes control the migration of NDMA and chlorobenzene from the identified on-Site sources in this complex hydrogeologic setting. The primary transport process was advection where a dissolved contaminant moves with the direction of the bulk groundwater flow. The large-scale groundwater flow regime in the MA is defined by the influence of groundwater extraction systems on the natural horizontal and vertical groundwater hydraulic gradients. Superimposed on this bulk groundwater flow is the mechanical dispersion process which results from groundwater velocity variations at a range of spatial scales. This mechanical dispersion process gave rise to spreading of dissolved COC primarily in the direction of groundwater flow but also transverse. The history of the spatial and temporal variations of groundwater flow in the MA has thus controlled the distribution of the existing NDMA and chlorobenzene plumes. In addition, molecular diffusion which is caused by the presence of concentration gradients resulted in the transport of COC from areas of high to low dissolved concentrations. While the molecular diffusion process is insignificant when advective transport is dominant, it is a time dependent process and results in contaminant mass being transported into lower hydraulic conductivity zones where advection is minimal.

Two important attenuation processes affected the NDMA and chlorobenzene mass as it was being transported through this hydrogeologic system. First, sorption may cause dissolved COC molecules in the groundwater to attach preferentially to aquifer soils depending on the hydrophobicity of the contaminant and soil properties. The degree of hydrophobicity of an organic compound is represented by log K_{ow} or K_{oc} (Table 1), and if reversible organic-organic partitioning is assumed to control sorption then the f_{oc} represents the soil capacity. The organic carbon partition coefficient (K_{oc}) for NDMA and chlorobenzene is 25.7 and 224, respectively. Therefore, NDMA is less sorbed than chlorobenzene. The f_{oc} varies from 0.24% (MU and ML) to 0.32 percent (MAT and LAT) indicating a higher degree of sorption occurred in the aquitards compared to the aquifers. Sorption manifests as a retardation of advective transport and results in the transport velocity of a contaminant being less than the actual groundwater velocity. The second attenuation process is biological degradation where the indigenous occurring microorganisms degrade the contaminant. There is some literature evidence that suggests that native consortia can mineralize NDMA under both aerobic and anaerobic conditions (e.g., Gunnison et al., 2005; Bradley et al, 2005); however, no Site-specific data exist. The biodegradation of chlorobenzene by aerobic organisms (half-live of 69 to 150 days) or by facultative bacterial under anaerobic conditions (half-live of 280 to 580 days) has been observed (USGS, 2006). Chlorobenzene has been shown to undergo microbial-mediated reductive dechlorination under anaerobic conditions. Again, no Site-specific information has been collected to assess the biodegradation of chlorobenzene. The oxidation-reduction potential and dissolved oxygen measured in the MA indicates that reducing and anaerobic conditions are present in portions of the MA.

From the 1950s through to the late 1970s, NDMA and chlorobenzene impacted groundwater in the on-Site MU migrated off Site under the regional, southerly hydraulic gradient. The North Well Field created an east/west oriented groundwater flow divide beneath central Elmira that extended under the Site. As a result, NDMA impacted MU groundwater also migrated northwest towards the North Well Field. While the exact location of this former groundwater flow divide is unknown, it created a bifurcated NDMA plume, with a northwest and a southwest lobe, suggesting that the flow divide was located south of a portion of the on-Site NDMA source area. Off-Site chlorobenzene migration in the MU appears to have occurred primarily southwest from the southwest corner of the Site. Therefore, the location of the east/west groundwater flow divide was south of the NDMA source in the MU, and north of the chlorobenzene source.

The onset of groundwater extraction from the South Well Field in the late 1970s increased NDMA migration to the southwest and decreased migration to the northwest. Pumping from the South Well Field enhanced the natural hydraulic gradient to the south and forced the east/west oriented groundwater flow divide to shift north. If this divide shifted north of the on-Site NDMA source, then NDMA migration to the northwest ceased. This groundwater extraction regime remained in place until the North Well Field was shut down. Figure 4 shows the general groundwater flow direction and the east/west divide in the MA based on the 1991 groundwater elevation data. Both the South Well Field and the North Well Field were operating, and there were no on-Site containment wells pumping.

In addition to the changes in groundwater flow patterns, it is presumed that the strength of the NDMA source was not uniform. Figure 5 shows the highest NDMA concentrations (>100 μg/L) in 1998 were present in two distinct areas: beneath the on-Site source area, and approximately 1,300 m southwest of the Site beneath central Elmira. This suggests that the NDMA loading into the MA was temporally variable.

In combination with the horizontal groundwater flow and the contaminant migration described above, vertical contaminant migration occurred downward into the ML and the underlying Bedrock. The limited extent of the on-Site ML and the presence of a thick sequence of silt/clay till prevented the direct downward migration of NDMA into the on-Site ML.

NDMA and chlorobenzene impacted groundwater entered the ML west of the Site. The limit of where the ML is absent is near monitoring well nest CH-44, located approximately 150 m west of the western Site boundary, where the ML is <1 m thick. The MAT overlying the ML at this location is approximately 7 m thick and appears competent. NDMA and chlorobenzene are not detected in the overlying MU, so downward migration from directly above did not occur at CH-44. There is a window in the MAT at the OW58 monitoring well nest, but this is located upgradient (northeast) of CH-44 and similarly the MU is relatively uncontaminated at OW58. The migration pathway(s) through the MAT and into the ML is not known. As shown on Figures 6 and 8, the NDMA and chlorobenzenes plumes in this part of the ML are relatively small in aerial extent.

Separate lobes of the NDMA and chlorobenzene plumes in the ML are located beneath south-central Elmira (Figures 6 and 8). These lobes were created when the NDMA and chlorobenzene plumes in the MU were migrating southwest from the Site under the influence of the South Well Field and reached the area west of W4 where the MAT is replaced by the poorly graded sand LGR. The absence of the MAT allowed the NDMA and chlorobenzene plumes to migrate downward into the ML and then southwest and south towards wells E7/E9.

The distribution of NDMA in the Bedrock is further "offset" to the west, relative to the ML NDMA plume. NDMA is not present in the Bedrock beneath the Site or near CH-44. NDMA entered the Bedrock west of the Site, near the MOE1 and OW61 monitoring well nests, presumably through a window in the LAT. NDMA then spread southwest and west as it migrated towards wells E7/E9. It is possible that there are other LAT windows to the Bedrock beneath the central core of the off-Site ML NDMA plume. The footprint of the ML chlorobenzene plume near CH-44 is much smaller than the NDMA plume. The higher sorption of chlorobenzene relative to NDMA likely retarded the migration of chlorobenzene in the ML and hence it did not reach the window(s) in the LAT. As a result no chlorobenzene has been observed in the Bedrock.

Groundwater Contaminant/Collection Systems

Presently, LANXESS operates four separate groundwater containment/collection systems:

1. Upper Aquifer Containment System (UA CS)
2. On-Site Containment and Treatment System (OSCTS)
3. Off-Site CTS
4. E7/E9 AOP

The commissioning date and the target pumping rates are:

System	***Date Commissioned***	***Target Pumping Rate (L/s)***
E7/E9 AOP	1990	30.9
OSCTS	1991	5.0
UA CS	1997	0.8 to 1.2
Off-Site CTS	1998	34.7

The UA CS consists of ten containment wells and one groundwater collection trench completed in the UA_1 or the UA_3 beneath the Site. The UA CS intercepts shallow UA groundwater beneath the southwest portion of the Site and prevents it from discharging to Canagagigue Creek. LANXESS adjusts the UA CS pumping rates in response to seasonal changes in groundwater and surface water flow.

The OSCTS consists of four containment wells, PW1, PW3, PW4, and PW5, completed in the MU beneath the Site. LANXESS ceased routinely pumping PW1 and PW3 in 2008; however, LANXESS maintains them as backup wells to augment on-Site MU containment.

Off-Site CTS extraction wells W3R, W4, W5A, and W5B, and the off-Site containment well pair E7/E9 associated with the E7/E9 AOP extract groundwater from the MA. In March 2016, MOECC issued a new Environmental Compliance Approval that allowed LANXESS to construct a new groundwater treatment system to accommodate the increase in groundwater extraction from four new off-Site CTS wells. In 2017, LANXESS plans to shut down W4 and commission the four new off-Site CTS extraction wells. The combined target-pumping rate will be approximately 70 litres per second (L/s).

Groundwater Flow and Contaminant Distribution since the Start of the 1998 Remediation Activities

In 1998 and 1999 LANXESS commissioned the off-Site CTS extraction wells. Initially, ammonia dissolved in MA groundwater was treated in the Elmira Waste Water Treatment Plant (WWTP) prior to discharge to Canagagigue Creek. In 2000, the agreement with RMOW to treat groundwater containing ammonia at the Elmira WWTP expired. Off-Site pumping was maintained at target pumping rates during the winter months but as the surface water temperature increased, the assimilative capacity to the Creek decreased and the discharge of effluent containing ammonia was reduced by reducing the pumping rates of the off-Site CTS extraction wells.

The source of approximately 80 percent of the ammonia in the off-Site MA groundwater is from the former Yara[5] fertilizer blending facility located immediate west of the Site. Yara installed a water supply well in the MU in the 1970s but the groundwater quality was not suitable. The well was completed in an underground vault and subsequently a fertilizer storage facility was constructed on top of the vault. Sediment that was found in the bottom of the well when it was sealed and abandoned in 1991 had 3,690 milligrams per kilogram (mg/kg) or 0.37 percent ammonia. This is the highest concentration of ammonia ever detected in an Elmira well.

In 2006, Yara, the MOECC and LANXESS signed a settlement agreement with respect to the funding and operation of the Ammonia Treatment System (ATS). The ATS was commissioned in 2008 and year-round pumping of the off-Site CTS wells at target pumping rates resumed.

In 2000, the MOECC amended the requirements for on-Site hydraulic containment. The requirement for hydraulic containment of the MU beneath the entire Site was relaxed and only hydraulic containment of the contaminated portion of the MU beneath the southwest portion of the Site was required. PW1 and PW3 were shut down, PW5 was installed in 2005 and the pumping rate at PW4 was increased. This was required

[5] The former Nutrite Inc. facility was purchased by Yara Canada Inc.

because increased off-Site groundwater extraction was making it increasingly difficult to maintain on-Site MU containment.

Figure 9 shows the general groundwater flow directions in the MA based on the 2016 groundwater elevation data. These flow directions indicate that the MU is contained beneath the Site, preventing ongoing contaminant mass loading to the off-Site MA. The E7/E9 AOP contains the southern limit of the off-Site NDMA plume. The off-Site CTS extraction wells (W3, W4, W5A, and W5B) combine to remove contaminant mass from the off-Site MA and provide hydraulic containment of the off-Site plumes.

LANXESS has extracted more than 26 x 10^9 L of groundwater via the E7/E9 AOP and the off-Site CTS since 1998. Figures 5 and 7 show a comparison of the 1998 and 2016 NDMA and chlorobenzene concentration contours in the MU, and Figures 6 and 8 show a comparison of the 1998 and 2016 NDMA and chlorobenzene concentration contours in the ML. Figures 10 and 11 present a schematic of the MU and ML respectfully, and illustrate the spatial extents of the remaining NDMA (>0.009 μg/L) and chlorobenzene (>80 μg/L) plumes as of 2016.

In the early 1990s the core of the off-Site NDMA plume was defined by NDMA concentrations >100 μg/L. By the time the off-Site CTS was commissioned in 1998, the core of the NDMA plume had migrated south and was being extracted by E7/E9, particularly from the ML. From 1998 to 2016, the maximum concentration beneath central Elmira decreased from >100 μg/L to <10 μg/L.

The estimated dissolved phase mass of NDMA and chlorobenzene in-place for 1993 and 2016 is:

Dissolved Plume	*1993 Mass (kg)*	*2016 Mass (kg)*	*1993 – 2016 Mass Reduction*
NDMA	135	15.5	88 %
Chlorobenzene	577	79	86 %

These data show that the groundwater contaminant/collection systems have been effective in removing between 86 and 88 percent of the dissolved phase mass from the off-Site MA.

Concurrent with the plume mass removed, the area or footprint of the off-Site NDMA and chlorobenzene plumes (>OWDQS) since 1998 has also been reduced as given by:

Dissolved Plume	*1998 Area (m^2)*	*2015/2016 Area (m^2)*	*1998 – 2016 Reduction (m^2)*	*1998 – 2016 Reduction*
MU NDMA	3,117,500	1,821,200	1,296,300	41 %
ML NDMA	3,272,400	2,266,000	1,006,400	31 %
MU Chlorobenzene	213,300	105,100	108,200	51 %
ML Chlorobenzene	129,200	95,700	33,500	26 %

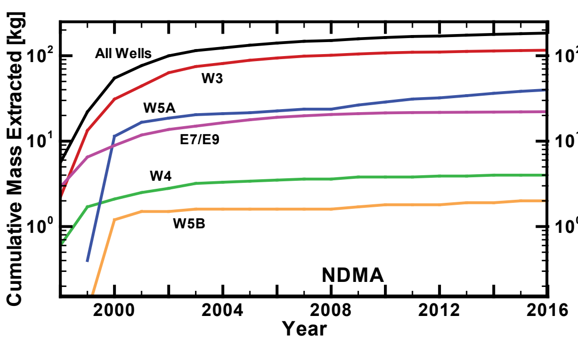
The northern or upgradient extent of the NDMA plumes have decreased the most, along with the plume extent near southern containment well E7/E9.

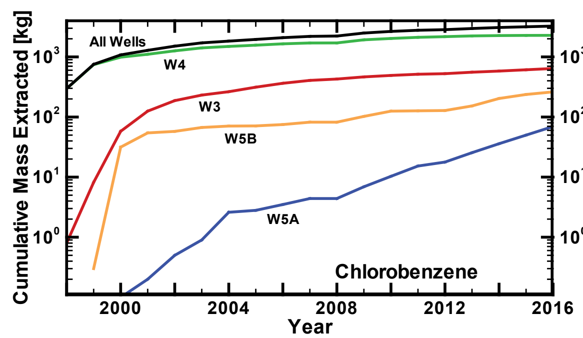
Extraction wells W3 and E7/E9 have reduced the core of the off-Site NDMA plume in the MU and the ML. At extraction well W3, concentrations of NDMA have decreased from >100 μg/L in 1998 to 1 μg/L in April 2017. Similarly, at E7/E9 the NDMA concentrations have decreased from concentrations >10 μg/L to approximately 0.03 μg/L. The mass of chlorobenzene and the area of the off-Site chlorobenzene plume have been reduced since 1998, and the portion of the off-Site chlorobenzene plume in the MU with concentrations >1,000 μg/L has been eliminated. As expected, the rate of COC mass extracted from the off-Site CTS has diminished over time to near asymptotic levels. The following are the mass removal rates for the off-Site CTS extraction wells in 2016:

Well	Aquifer	NDMA Removal Rate (kg/year)	Chlorobenzene Removal Rate (kg/year)
W3	MU	1.1	31.5
W4	ML	0.01	6.1
W5A	ML	1.6	19.6
W5B	MU	0.04	24.5
E7/E9	ML	0.1	-

The cumulative mass extracted from 1998 to 2016 for all off-Site CTS extraction wells is shown below for NDMA and chlorobenzene. The NDMA data indicate that extraction wells W4, W5B, and E7/E9 have reached asymptotic levels and contribute little to ongoing mass removal of NDMA from the MA. The average rate of NDMA mass extracted from W3 and W5A over the last five years has been relatively constant at 1.3 ± 0.3 and 1.8 ± 0.5 kg/year respectively. In contrast, extraction well W4 has reached asymptotic levels for chlorobenzene, while the annual rate of chlorobenzene mass extracted from W3, W5A and W5B over the last five years have been highly variable.

LANXESS plans to increase the W3R pumping rate when construction of the expanded treatment system is completed in 2017. While the mass removal rate at E7/E9 has substantially decreased, the NDMA concentrations are approaching the ODWQS of 0.009 μg/L.





Mass Remaining

The mass remaining in the MA is based on the current understanding of the off-Site hydrostratigraphy, and the observed distribution of dissolved phase NDMA and chlorobenzene in the MA. The estimated 2016 in-place dissolved mass of NDMA and chlorobenzene is ~16 and 80 kg, respectively. Despite the overall reduction in dissolved mass and plume areal extent of the COC, there are two areas of elevated NDMA concentration (>10 μg/L), and three areas of elevated chlorobenzene concentration (>100 μg/L) as noted in the following:

- Immediately west of the Site, NDMA concentrations >100 μg/L persist in the ML at monitoring wells CH-44D (147.5 μg/L) and OW61-34 (366.9 μg/L). This portion of the ML is distant from the off-Site CTS extraction wells and is in an area where the ML thins (to about 1 m) and eventually pinches out. This plume lobe has been stable since the early 1990s indicating that the groundwater in this area of the ML is not influenced by the groundwater contaminant/collection systems. New ML extraction wells W8 and W9 were installed near CH-44 and OW61-34, respectively and will be commissioned in 2017.
- The other area where elevated NDMA concentrations persist is in the northwest lobe of the MU plume near monitoring well OW60-26. From 1992 to 2002 NDMA concentrations at OW60-26 increased from 10.07 to 84.22 μg/L. Delineation completed in 2014 reduced the known extent of the northwest NDMA plume in the MU and indicated that elevated NDMA concentrations were limited to within approximately 10 m of monitoring well OW60-26. In 2015, LANXESS installed a temporary pump in OW60-26 and pumped approximately 8,000 L/day for approximately four months. NDMA concentrations in samples collected from OW60-26 decreased from 42.45 to 20.27 μg/L during this time. This portion of the MU

is remote from any extraction wells and the plume appears stagnant. The limited area of the elevated NDMA concentrations suggests that the NDMA mass in the vicinity of OW60-26 is relatively small (<100 g).

- The remaining off-Site chlorobenzene plume in the MU is between extraction wells W4 and W5B. This portion of the chlorobenzene plume has been relatively stable since about 2000 after W5B was commissioned. Groundwater in this area of the MU appears to be in a stagnation zone created by the competing capture zones generated by extraction wells W4 and W5B.
- Within the ML, there were two lobes of the chlorobenzene plumes in 1998; one immediately west of the Site and the other farther west, beneath central Elmira. Groundwater extraction since 1998 has reduced the southwest extent of the off-Site ML chlorobenzene plume. The area of the chlorobenzene plume represented by the 1,000 μg/L contour line has been reduced and has shifted eastward toward extraction well W5A. As with the MU chlorobenzene plume, the remaining portion of the central off-Site ML chlorobenzene plume is within the presumed stagnation zone between extraction wells W4 and W5A.
- As with NDMA, elevated chlorobenzene concentrations (>1,000 μg/L) persist immediately west of the Site in the ML. LANXESS plans to implement additional groundwater extraction in this area via new extraction well W8 in 2017.

Since the start of the off-Site CTS in 1998, approximately 180 kg of NDMA and 3,300 kg of chlorobenzene have been removed from the off-Site MA. This extracted mass of NDMA and chlorobenzene exceeds the 1998 estimate of dissolved phase mass in-place of approximately 120 kg of NDMA and 300 kg of chlorobenzene. Accounting for the sorbed NDMA mass present in the MA, the estimated total mass in-place in 1998 is approximately 170 kg which is consistent with the total mass of NDMA extracted to date (the error associated with these in-place mass estimates is likely ±20 percent). In contrast, the estimated total chlorobenzene mass in-place in 1998 is ~1,300 kg (dissolved and sorbed), which is significantly lower than the total mass of chlorobenzene extracted to date. The source of this ~2,000 kg of additional chlorobenzene mass extracted is unknown.

In 2014 and 2015, LANXESS included vertical aquifer sampling (VAS) in groundwater investigations at 12 locations to explore potential NDMA or chlorobenzene plume stratification within the MU and ML. At 10 locations the MU and ML were sampled, and at the remaining two locations the MAT was absent and the stratigraphic sequence sampled was MU/LGR/ML. Only 13 of 44 potential profiles (2 locations x 2 compounds) generated sufficient data to assess plume stratification (three or more COC detections). Of these 13 profiles, 11 profiles indicated that either the concentration of NDMA or chlorobenzene was increasing (>50 percent increase in concentration between the top and bottom of the profile) with depth. Only 5 of these 11 (~45 percent) profiles were associated with a coarse basal layer as determined from soil classification information. Based on these data, vertical plume stratification of NDMA or chlorobenzene because of the presence of a coarse basal layer is not a dominant feature within the MA.

Prior to 1998, it is likely that diffusion of both NDMA and chlorobenzene occurred from the ML and MU into adjacent lower hydraulic conductivity material. Once the off-Site CTS was commissioned in 1998 and the concentration gradients reversed, back diffusion occurred. Back-diffusion is likely to manifest in this MA system as a low-level persistent secondary source controlled locally by the mass of NDMA and chlorobenzene stored in the lower hydraulic conductivity material and the groundwater flow system. LANXESS has investigated the depth of penetration of COC into the aquitards by collecting soil samples at increasing depths from the aquifer/aquitard contact and analyzing them for NDMA and chlorobenzene. At one location, NDMA had penetrated more than 1.8 m into the surrounding aquitard and the maximum observed chlorobenzene penetration was 1.2 m into the surrounding aquitard. To date groundwater quality data have not provided any evidence of back diffusion of either NDMA or chlorobenzene.

Current Groundwater Receptors

Since 1997, the UA CS has prevented the core of the NDMA and chlorobenzene plumes in UA_1 groundwater beneath the southwest portion of the Site from discharging into Canagagigue Creek, and as a result, the water quality in the Creek has improved. Regional discharge of groundwater from the MA occurs beyond the limits of the NDMA and chlorobenzene plumes so discharge to surface water is not a complete exposure pathway. Since the early 1990s, exposure to the municipal water supply wells and residential water supply wells has been prevented by not pumping the municipal wells impacted by NDMA and replacing the groundwater supply with a pipeline source from Waterloo in 1994. The chlorobenzene plume did not extend as far as the municipal water supply wells. Currently there is no environmental or human exposure to NDMA or chlorobenzene in the off-Site UA and MA groundwater.

References

AquaResource Inc., 2012. Region of Waterloo Tier Three Water Budget and Local Area Risk Assessment Rural Well Fields Characterization Report.

ASTM E1689-95, 2014. Standard Guide for Developing Conceptual Site Models for Contaminated Sites, ASTM International, West Conshohocken, PA, 2014, www.astm.org.

Bajc, A.F., 2004. Three-dimensional mapping of Quaternary deposits in Waterloo Region, Southwestern Ontario; Ontario Geological Survey, Open File Report 6145.

Bradley, P.M., S.A. Carr, R.B. Baird, F.H. Chappelle, 2005. Biodegradation of Nitrosodimethylamine in soil from a water reclamation facility. Biorem. J., 9, 115-120

Gunnison, D., M.E. Zappi, C. Teeter, J.C. Pennington, R. Bajpai, 2000. Attenuation mechanisms of N-nitrosodimethylamine at an operating intercept and treat groundwater remediation system. J. Hazard. Mater., B73, 179-197.

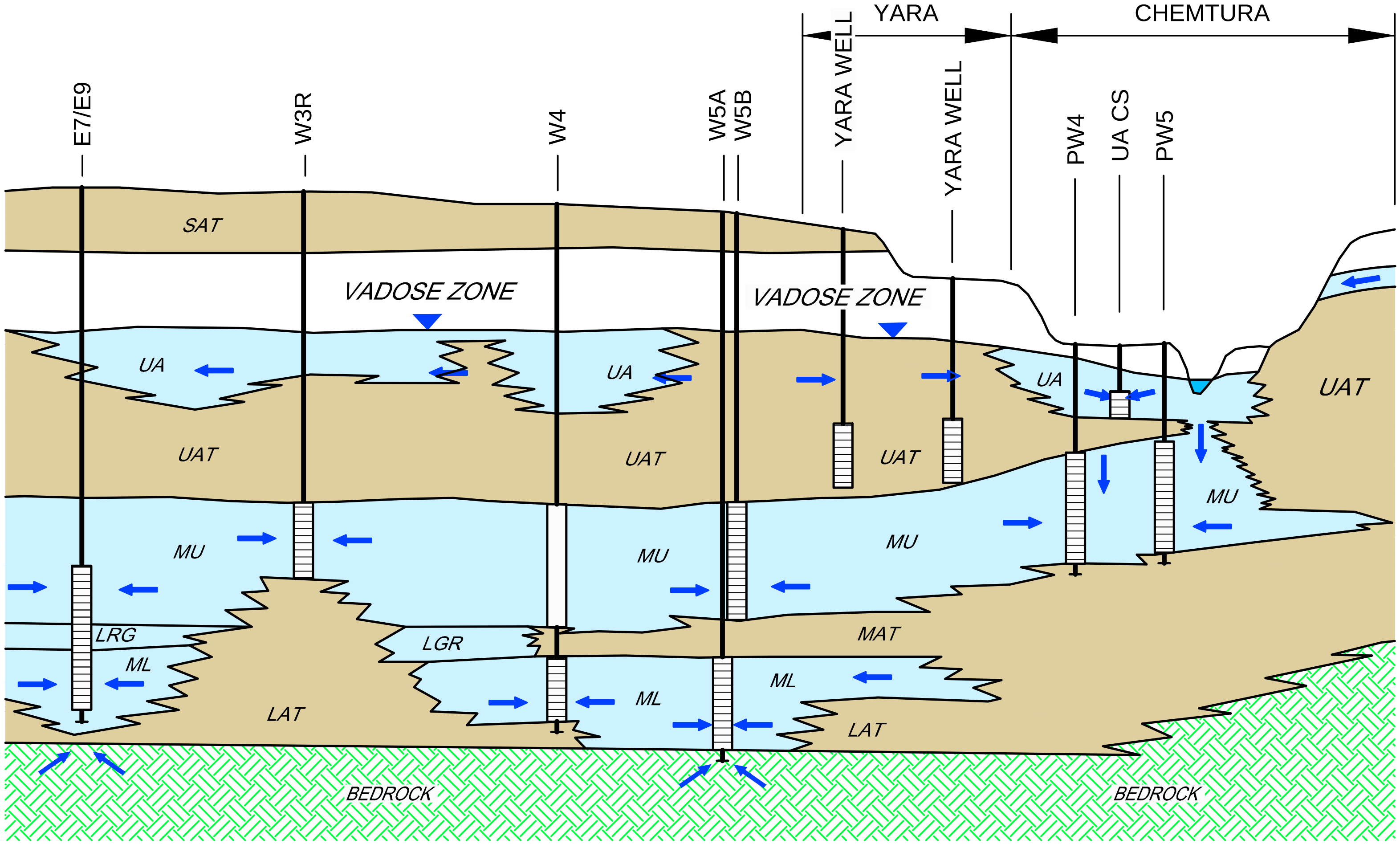
MOECC, 2017. Ontario Regulation 169/03, Ontario Drinking Water Quality Standards, January 2017.

United States Environmental Protection Agency, 2014. EPA 505-F-14-005, January 2014.Technical Fact Sheet – N-Nitrosodimethylamine (NDMA)

USGS, 2006. Description, Properties, and Degradation of Selected Volatile Organic Compounds Detected in Ground Water - A Review of Selected Literature. Open-File Report 2006-1338. www.pubs.usgs.gov/of/2006/1338/pdf/ofr2006-1338.pdf

Alan Deal, P.Geo.

04432-11(083)GN-WA024 JUN 19, 2017



HYDROGEOLOGICAL UNIT

SA	SURFICIAL AQUIFER	MAT	MUNICIPAL AQUITARD
SAT	SURFICIAL AQUITARD	LGR	LOW GAMMA-RESISTIVITY ZONE
UA	UPPER AQUIFER	ML	LOWER MUNICIPAL AQUIFER
UAT	UPPER AQUITARD	LAT	LOWER AQUITARD
MU	UPPER MUNICIPAL AQUIFER	BEDROCK	BEDROCK

LEGEND

- WELL SCREEN
- WELL SCREEN ISOLATED BY A PACKER
- GROUNDWATER FLOW DIRECTION

figure 2

SCHEMATIC OF HYDROGEOLOGIC UNITS
LANXESS CANADA CO./CIE
Elmira, Ontario

04432-11(083)GN-WA028 JUN 19, 2017

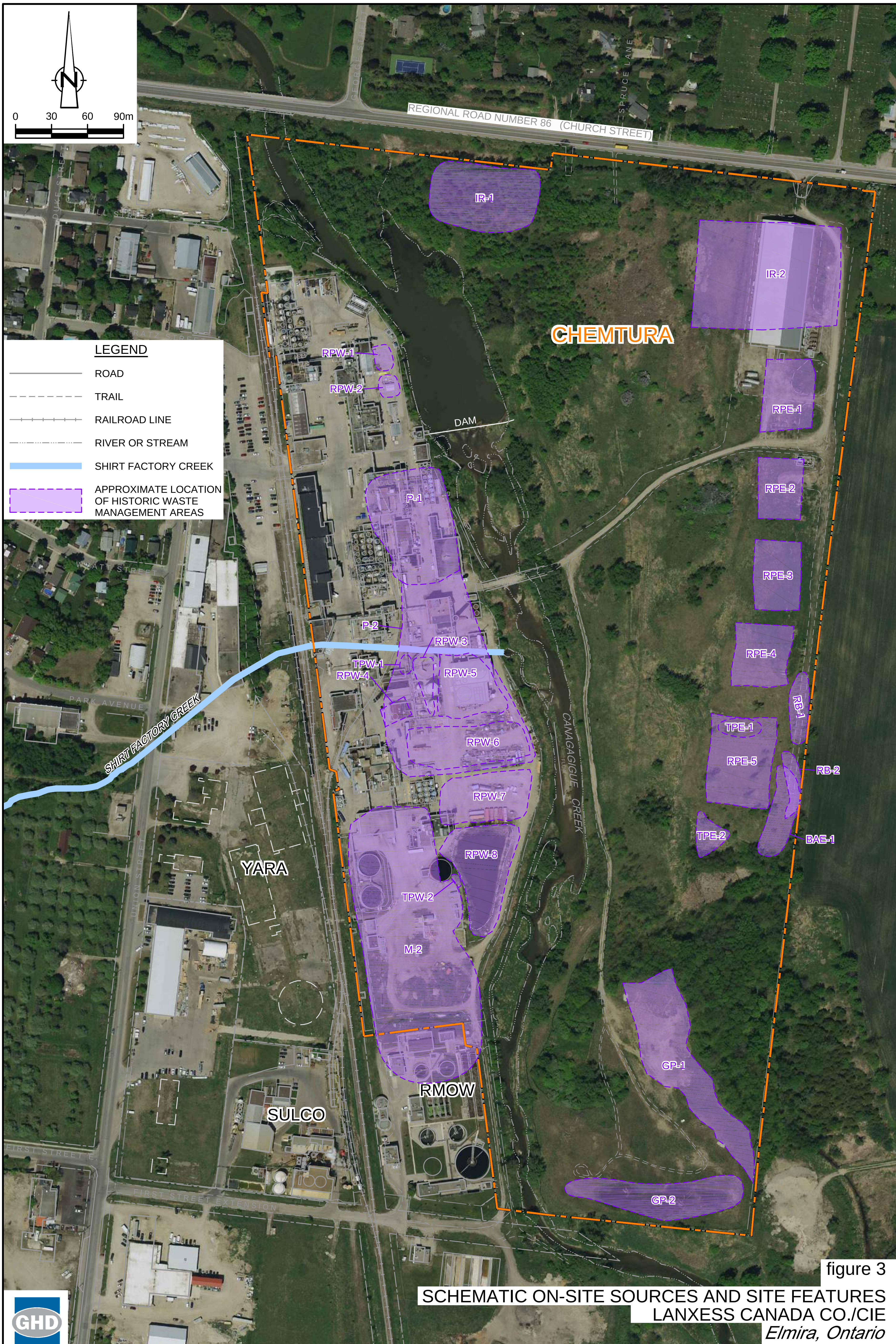


figure 3

SCHEMATIC ON-SITE SOURCES AND SITE FEATURES
LANXESS CANADA CO./CIE
Elmira, Ontario

04432-11(083)GN-WA027 JUN 19, 2017

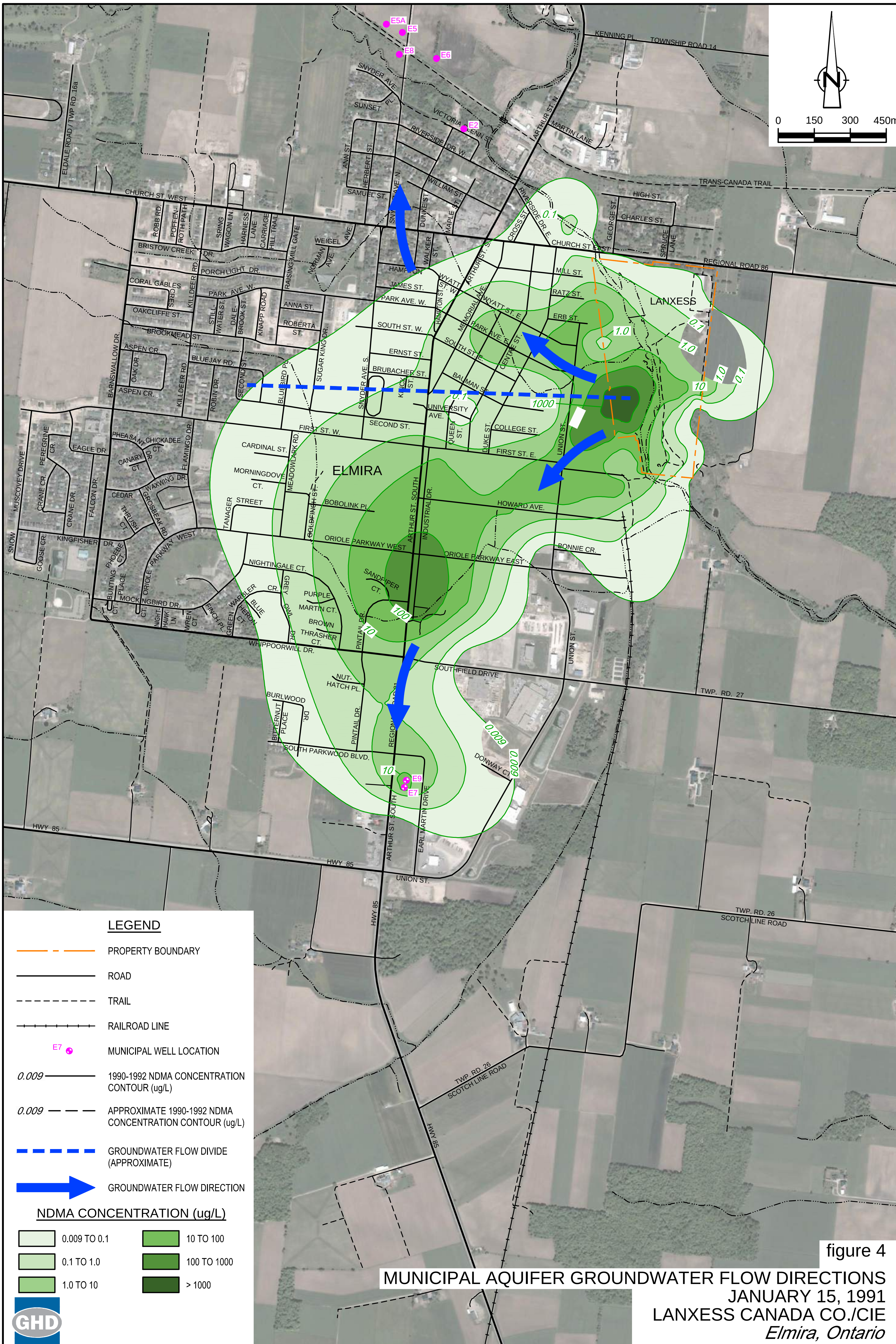
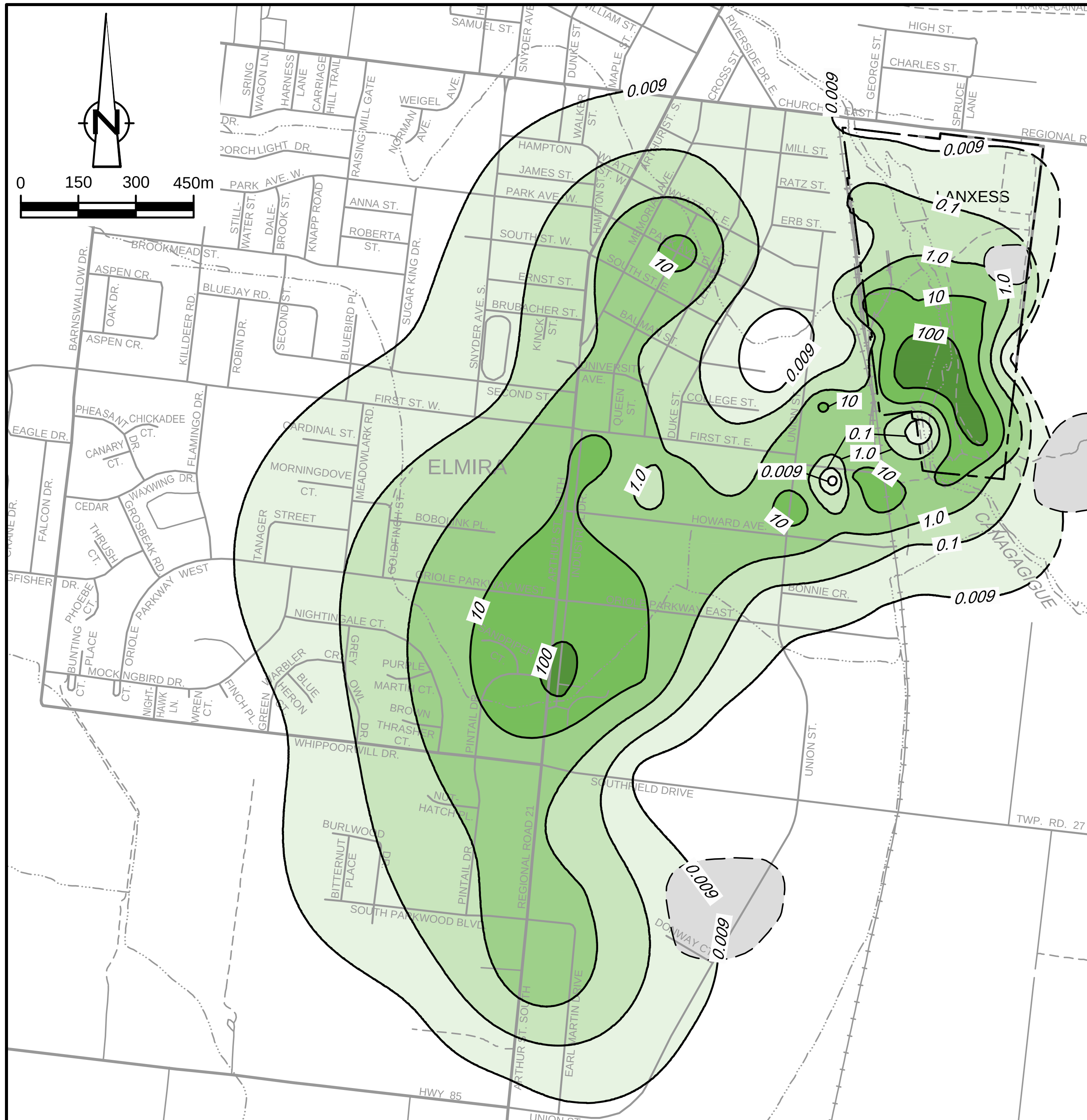


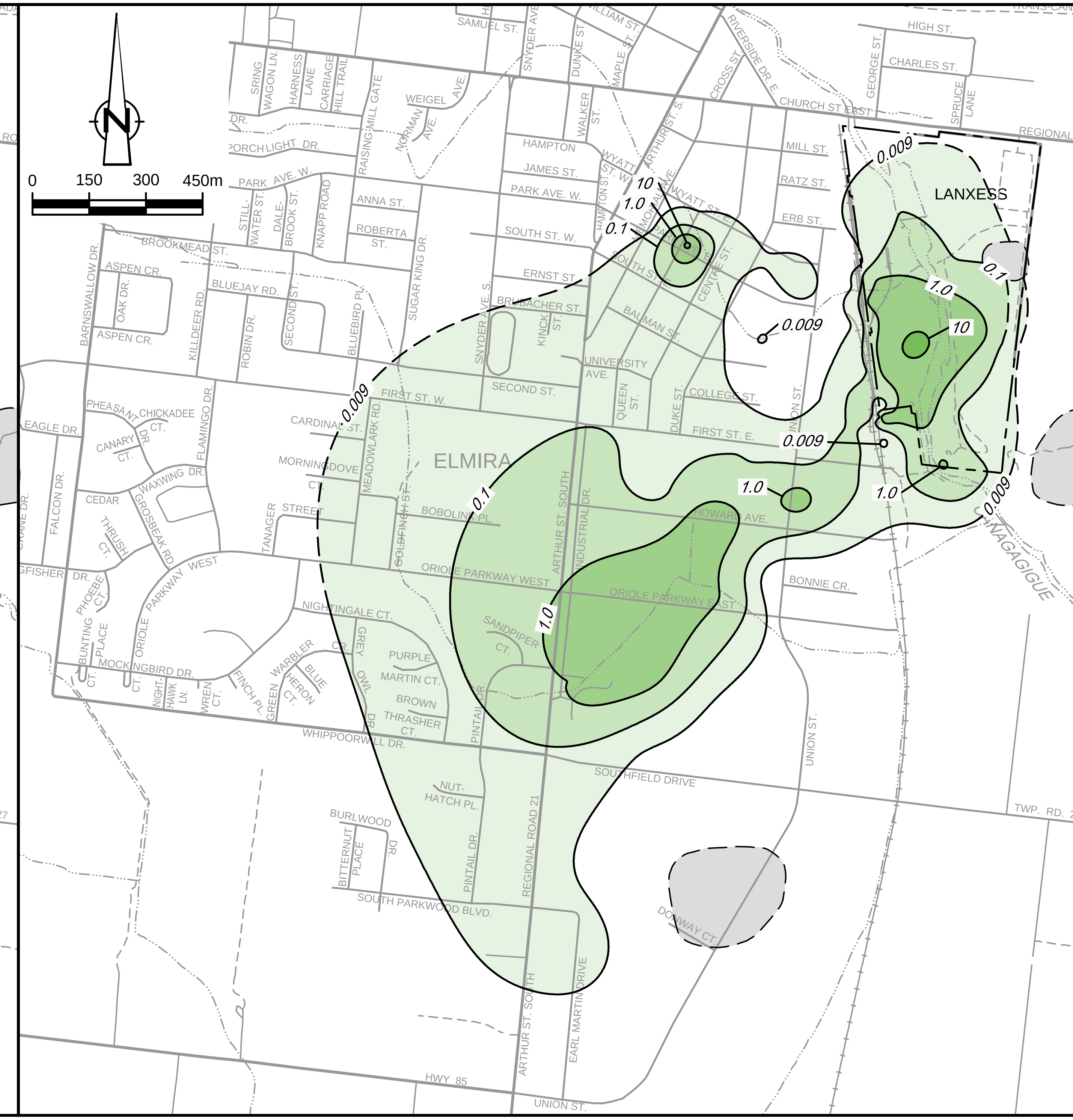
figure 4

MUNICIPAL AQUIFER GROUNDWATER FLOW DIRECTIONS
JANUARY 15, 1991
LANXESS CANADA CO./CIE
Elmira, Ontario

04432-11(083)GN-WA025 JUN 19, 2017



1998 NDMA CONCENTRATIONS



2015/2016 NDMA CONCENTRATIONS

LEGEND

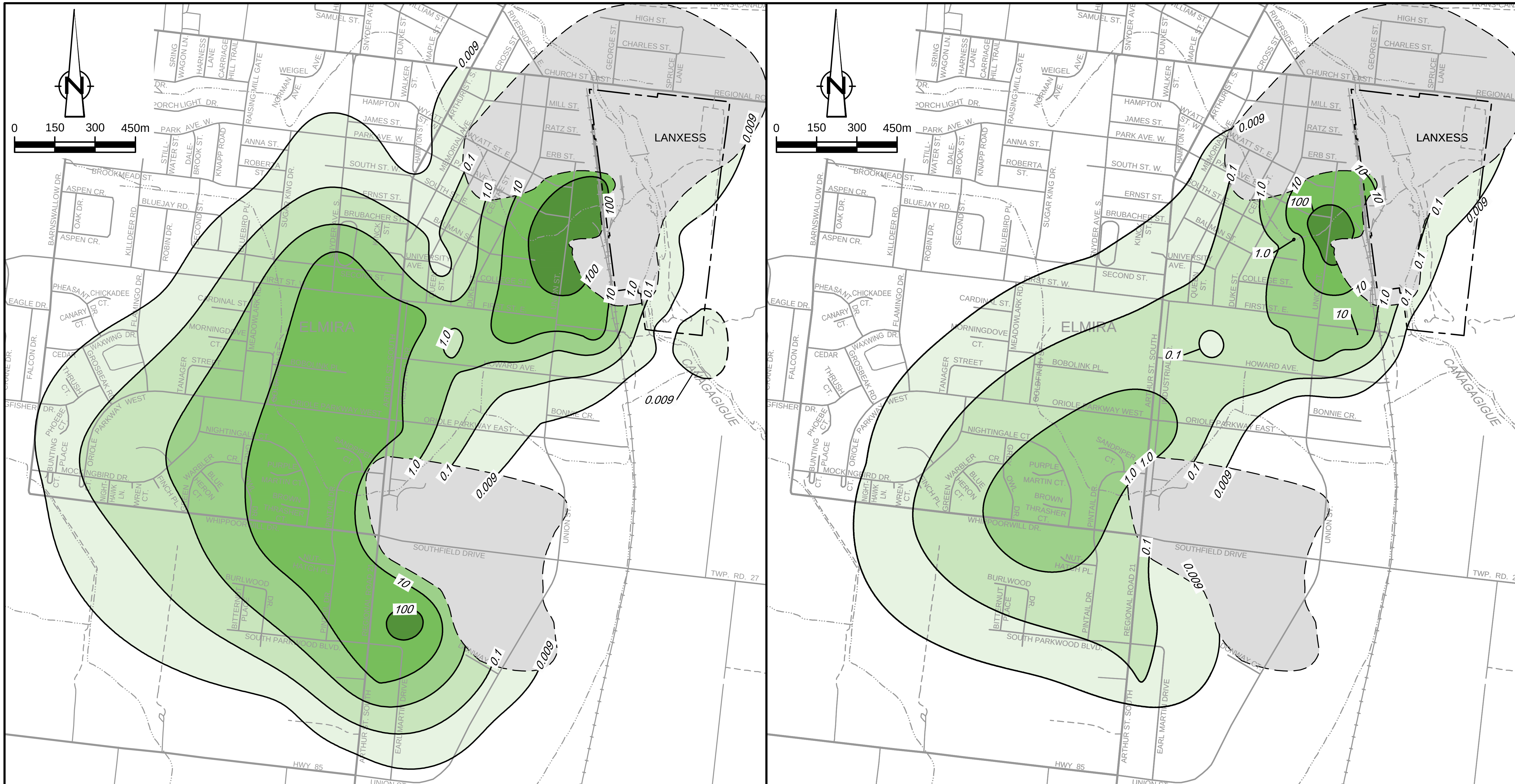
- ROAD
- TRAIL
- RAILROAD LINE
- RIVER OR STREAM
- APPROXIMATE AREA WHERE UPPER MUNICIPAL AQUIFER DOES NOT EXIST
- 0.009 — NDMA CONCENTRATION CONTOUR (ug/L)
- 0.009 — — APPROXIMATE NDMA CONCENTRATION CONTOUR (ug/L)

PARAMETER CONCENTRATION (ug/L)

- 0.009 TO 0.1
- 0.1 TO 1.0
- 1.0 TO 10
- 10 TO 100
- 100 TO 1000

figure 5

1998 AND 2015/2016 NDMA CONCENTRATIONS
UPPER MUNICIPAL AQUIFER
LANXESS CANADA CO./CIE
Elmira, Ontario



1998 NDMA CONCENTRATIONS

2015/2016 NDMA CONCENTRATIONS

LEGEND

- ROAD
- TRAIL
- RAILROAD LINE
- RIVER OR STREAM
- APPROXIMATE AREA WHERE LOWER MUNICIPAL AQUIFER DOES NOT EXIST
- 0.009 NDMA CONCENTRATION CONTOUR (ug/L)
- 0.009 APPROXIMATE NDMA CONCENTRATION CONTOUR (ug/L)

PARAMETER CONCENTRATION (ug/L)

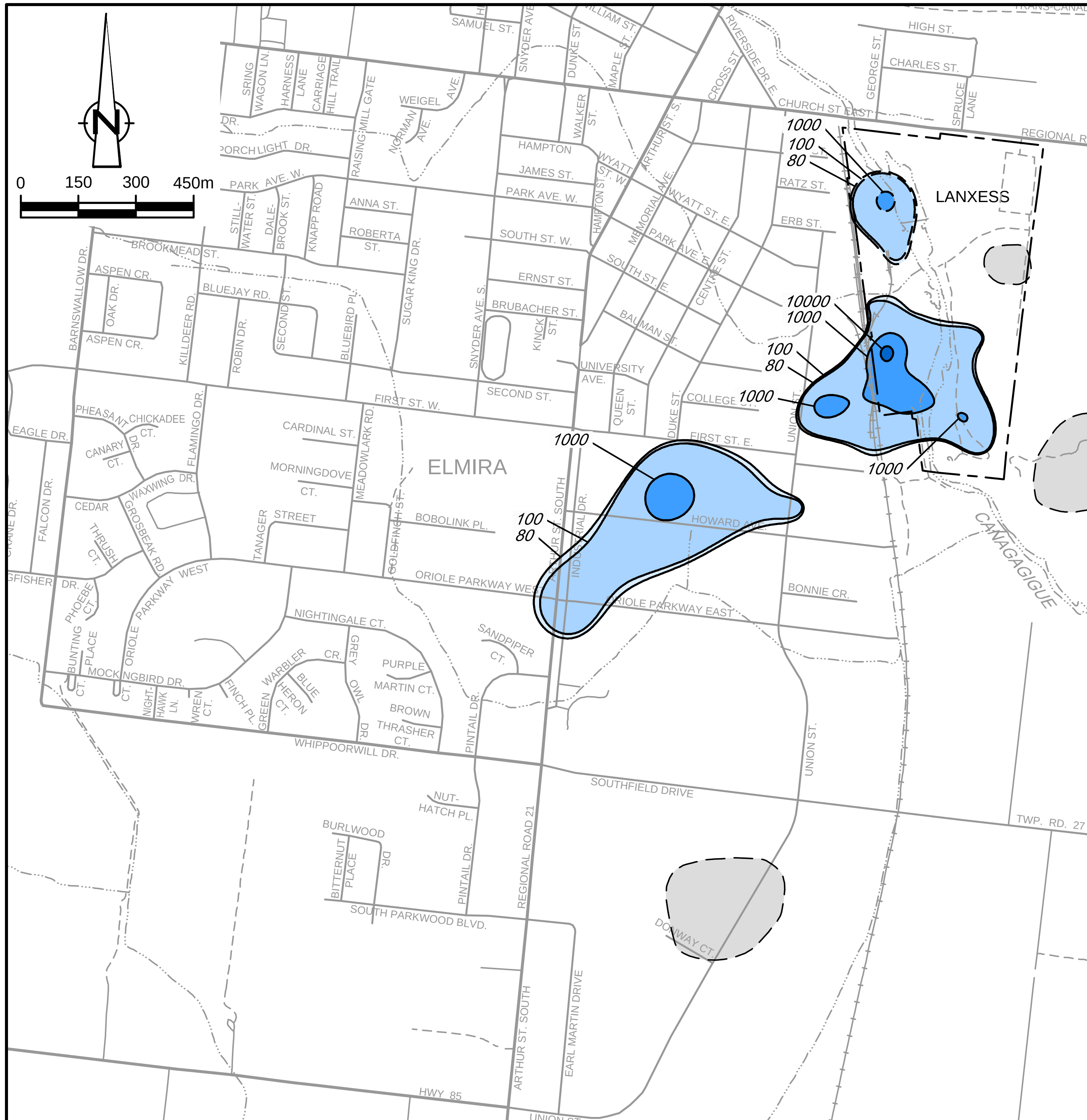
- 0.009 TO 0.1
- 0.1 TO 1.0
- 1.0 TO 10
- 10 TO 100
- 100 TO 1000
- >1000

figure 6

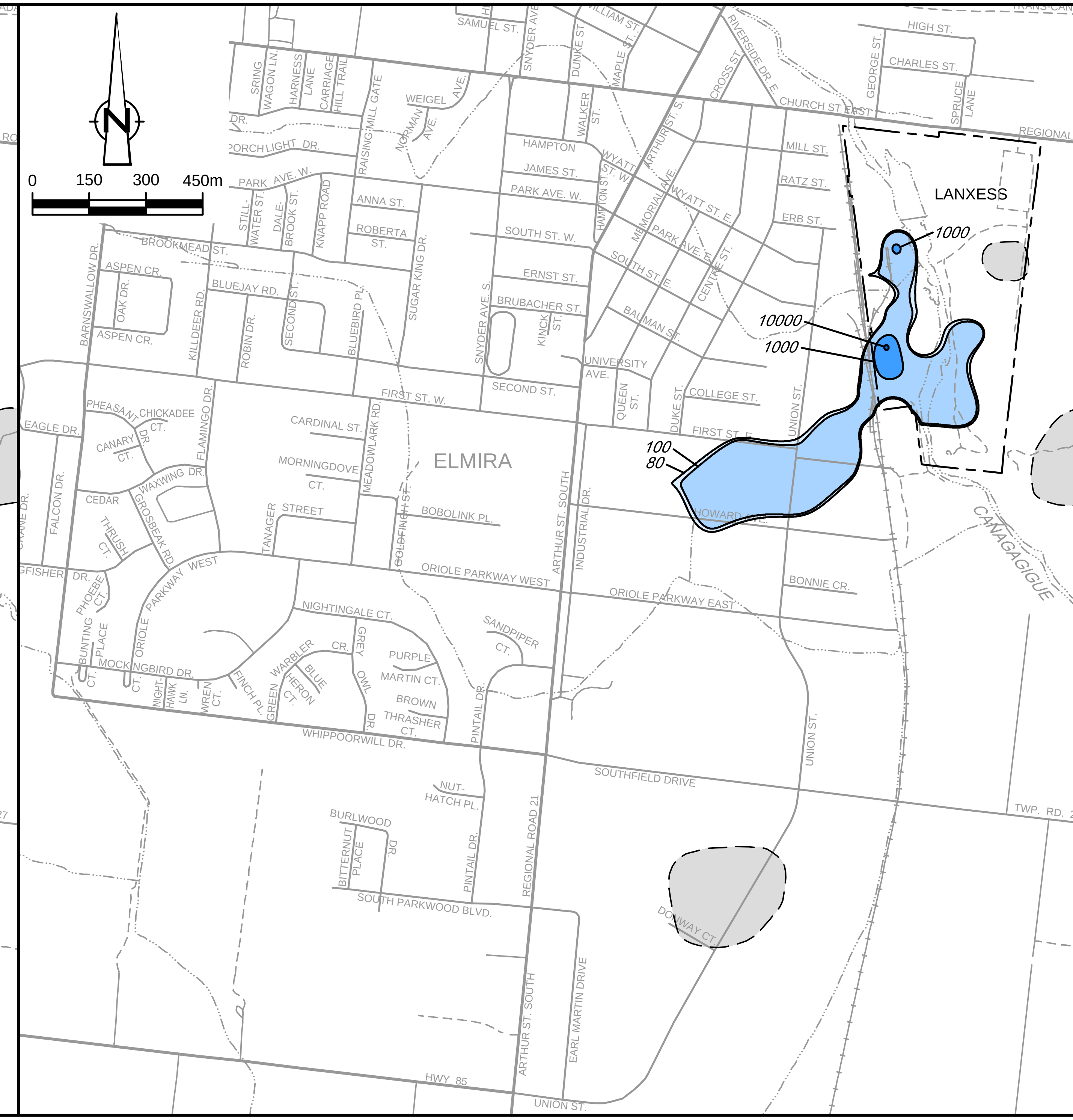
1998 AND 2015/2016 NDMA CONCENTRATIONS
LOWER MUNICIPAL AQUIFER
LANXESS CANADA CO./CIE
Elmira, Ontario

GHD

04432-11(083)GN-WA030 JUN 19, 2017



1998 CHLOROBENZENE CONCENTRATIONS



2015/2016 CHLOROBENZENE CONCENTRATIONS

LEGEND

- ROAD
- TRAIL
- RAILROAD LINE
- RIVER OR STREAM
- APPROXIMATE AREA WHERE UPPER MUNICIPAL AQUIFER DOES NOT EXIST
- 80 CHLOROBENZENE CONCENTRATION CONTOUR (ug/L)
- 80 APPROXIMATE CHLOROBENZENE CONCENTRATION CONTOUR (ug/L)

PARAMETER CONCENTRATION (ug/L)

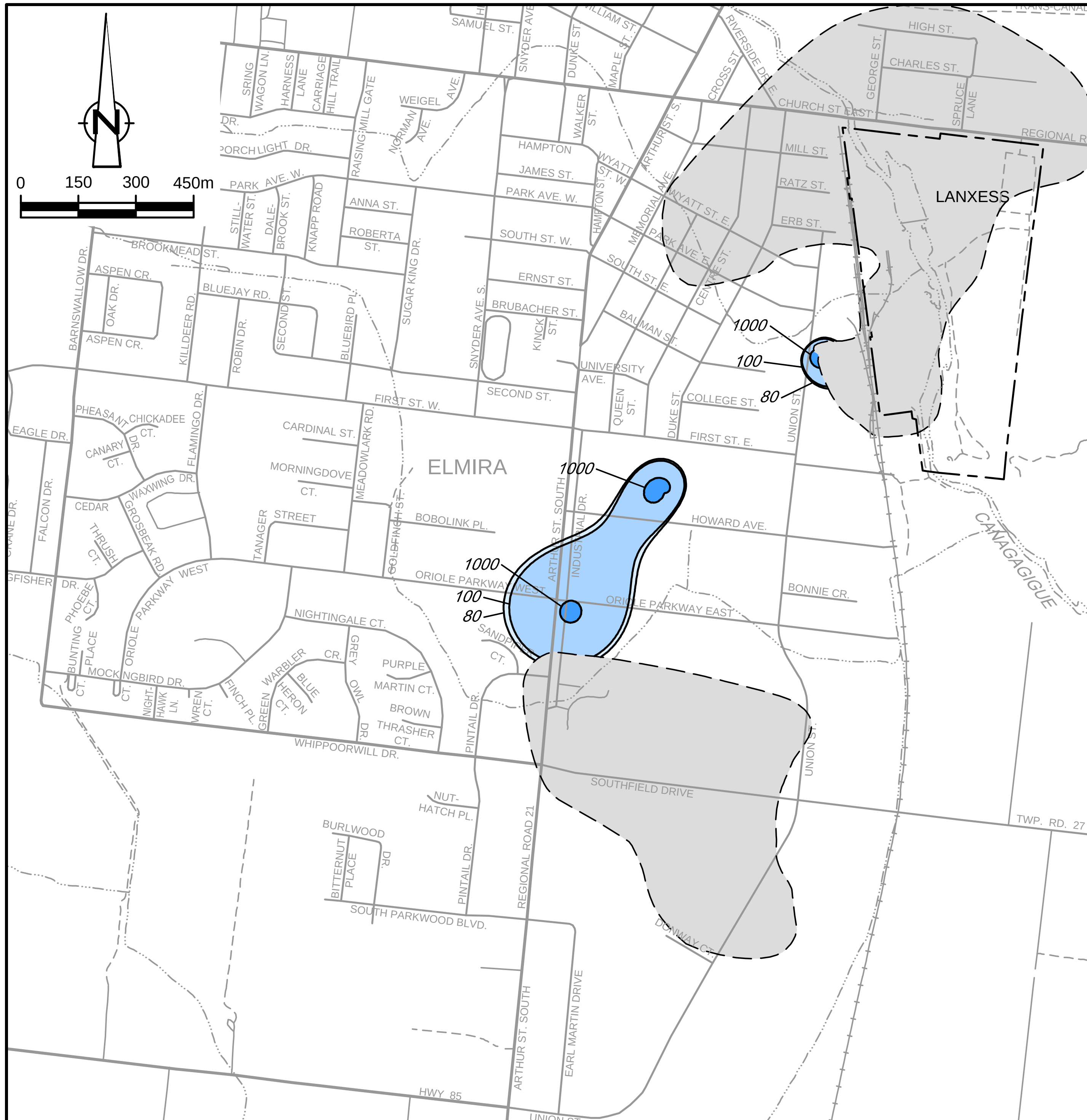
- 80 TO 100
- 100 TO 1,000
- 1,000-10,000
- >10,000

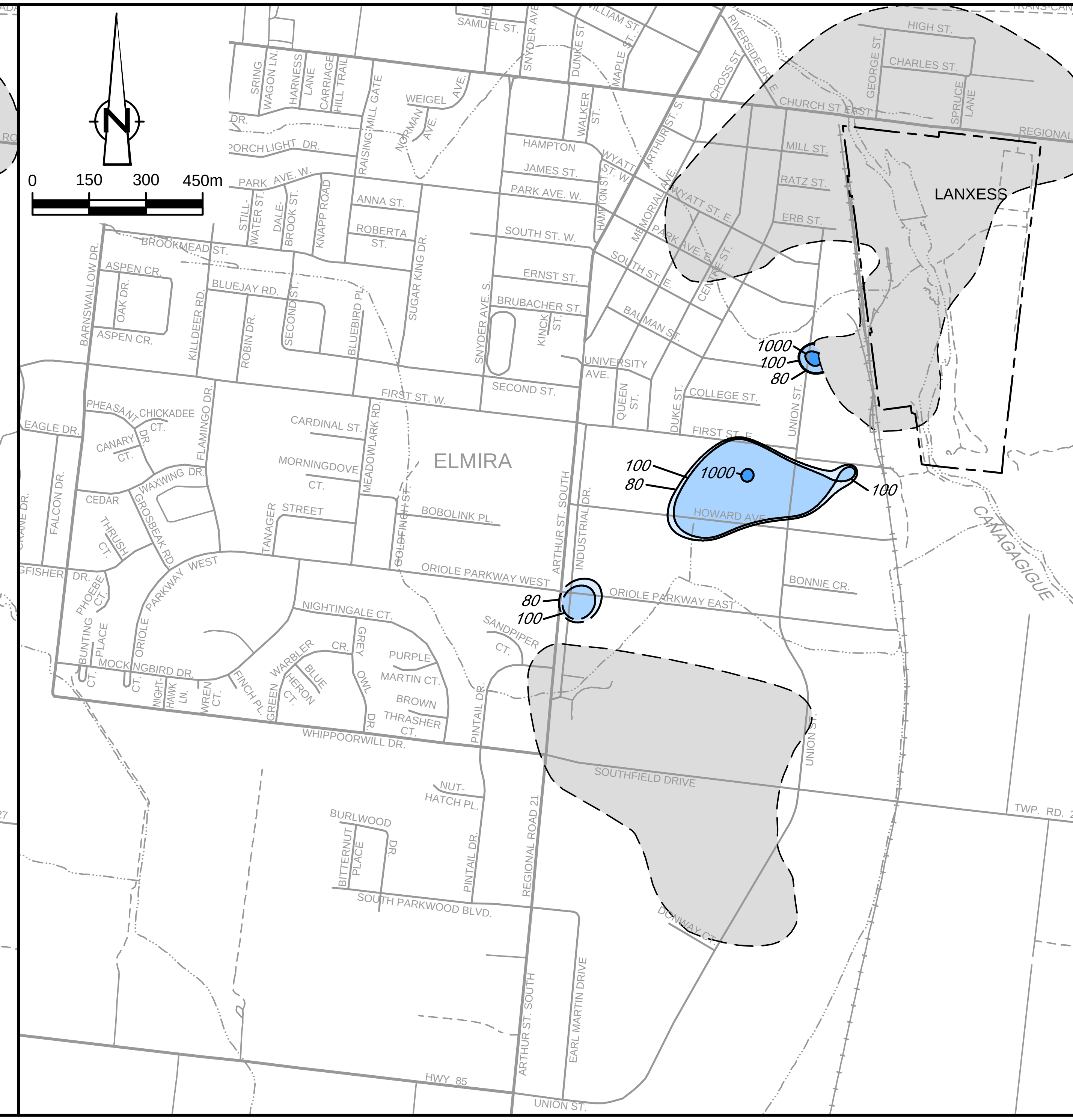
figure 7

1998 AND 2015/2016 CHLOROBENZENE CONCENTRATIONS
UPPER MUNICIPAL AQUIFER
LANXESS CANADA CO./CIE
Elmira, Ontario

GHD

04432-11(083)GN-WA031 JUN 19, 2017





1998 CHLOROBENZENE CONCENTRATIONS

2015/2016 CHLOROBENZENE CONCENTRATIONS

LEGEND

- ROAD
- TRAIL
- RAILROAD LINE
- RIVER OR STREAM
- APPROXIMATE AREA WHERE LOWER MUNICIPAL AQUIFER DOES NOT EXIST
- 80 — CHLOROBENZENE CONCENTRATION CONTOUR (ug/L)
- 80 - - APPROXIMATE CHLOROBENZENE CONCENTRATION CONTOUR (ug/L)

PARAMETER CONCENTRATION (ug/L)

- 80 TO 100
- 100 TO 1,000
- 1,000-10,000

figure 8

1998 AND 2015/2016 CHLOROBENZENE CONCENTRATIONS
LOWER MUNICIPAL AQUIFER
LANXESS CANADA CO./CIE
Elmira, Ontario

GHD

04432-11(083)GN-WA032 JUN 19, 2017

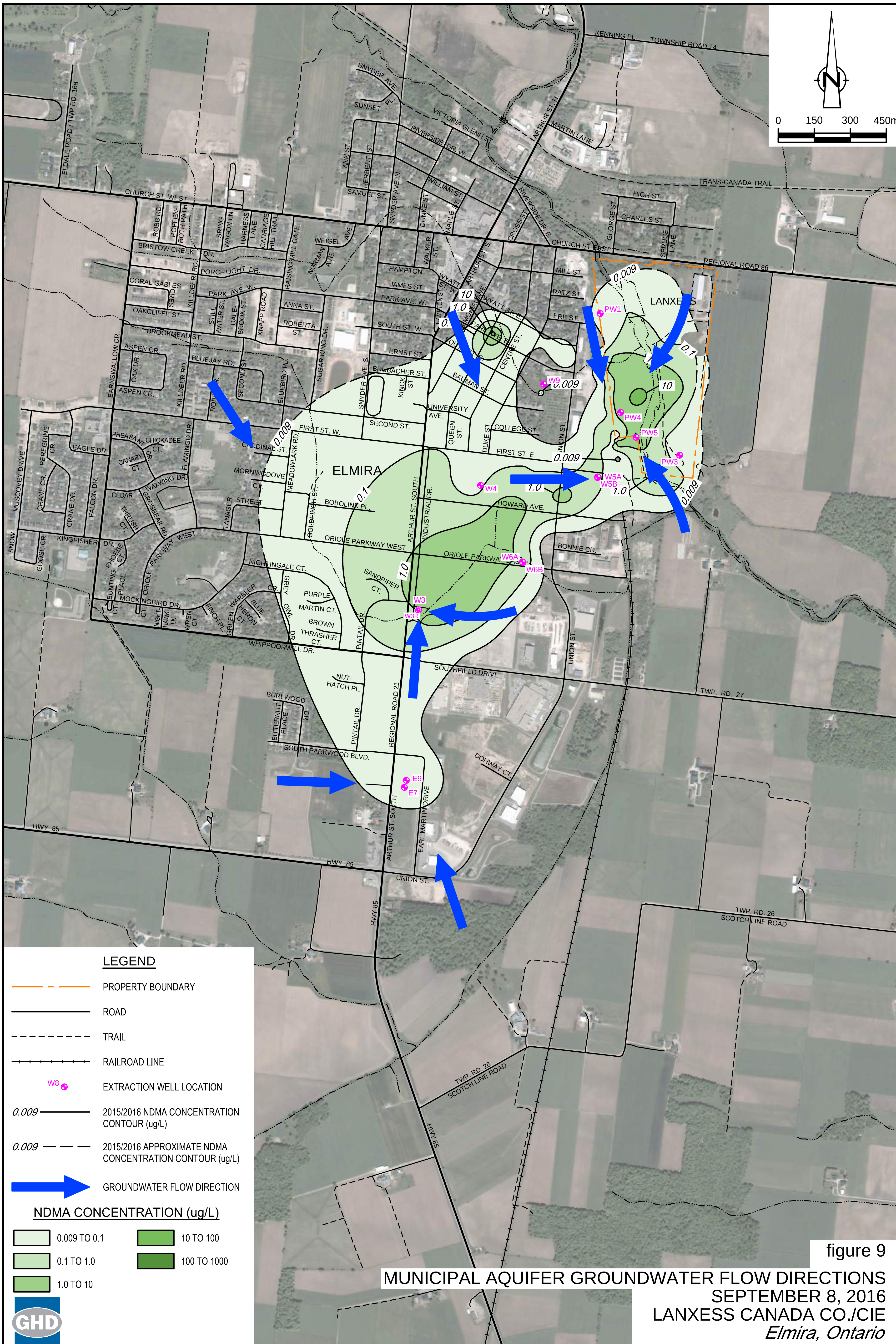


figure 9

MUNICIPAL AQUIFER GROUNDWATER FLOW DIRECTIONS
SEPTEMBER 8, 2016
LANXESS CANADA CO./CIE
Elmira, Ontario

04432-11(083)GN-WA026 JUN 19, 2017

Figure 10
Schematic of the Upper Municipal Aquifer showing the spatial extents of the 2015/2016 NDMA and Chlorobenzene Plumes.

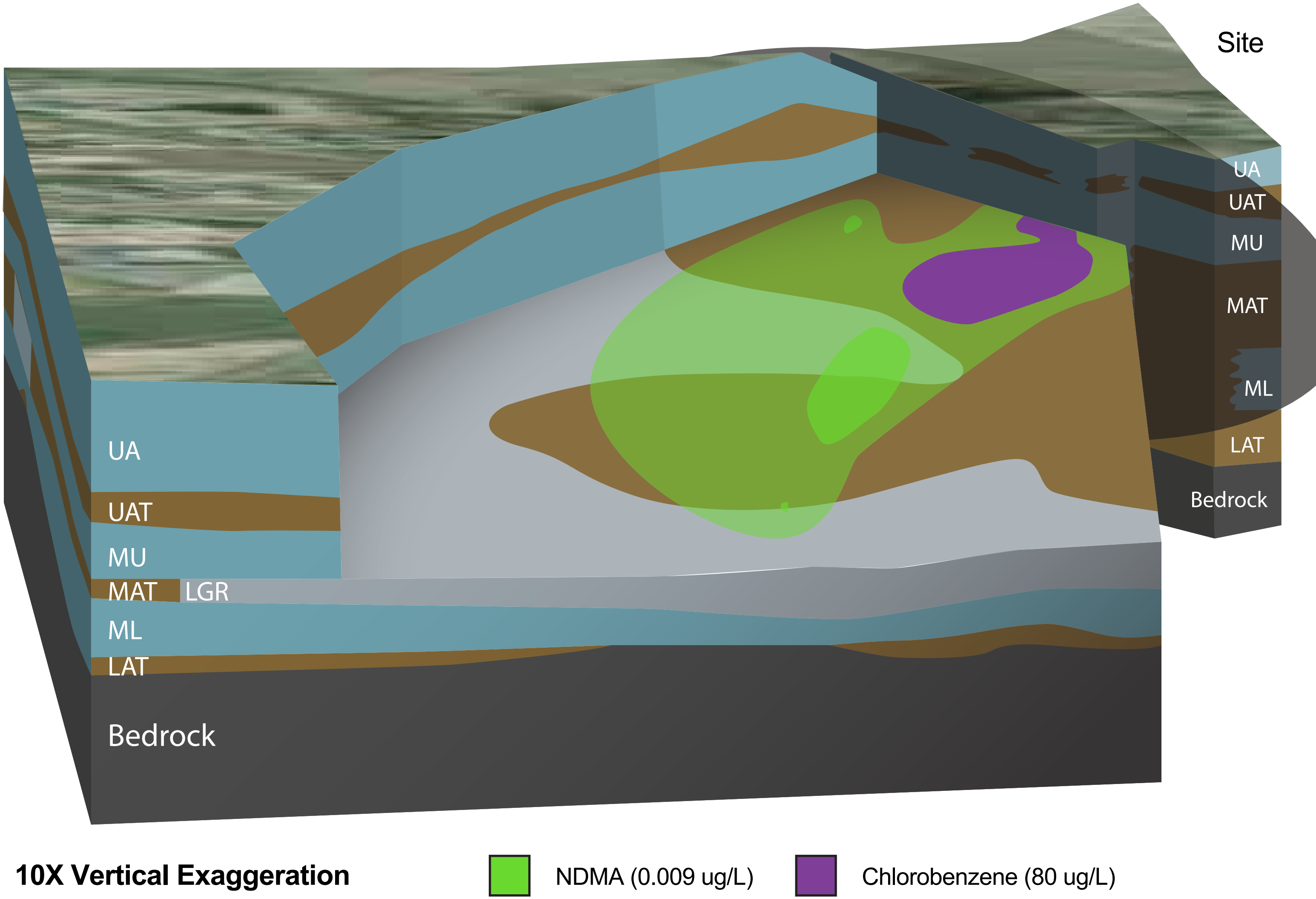


Figure 11
Schematic of the Lower Municipal Aquifer showing the spatial extents of the 2015/2016 NDMA and Chlorobenzene Plumes.

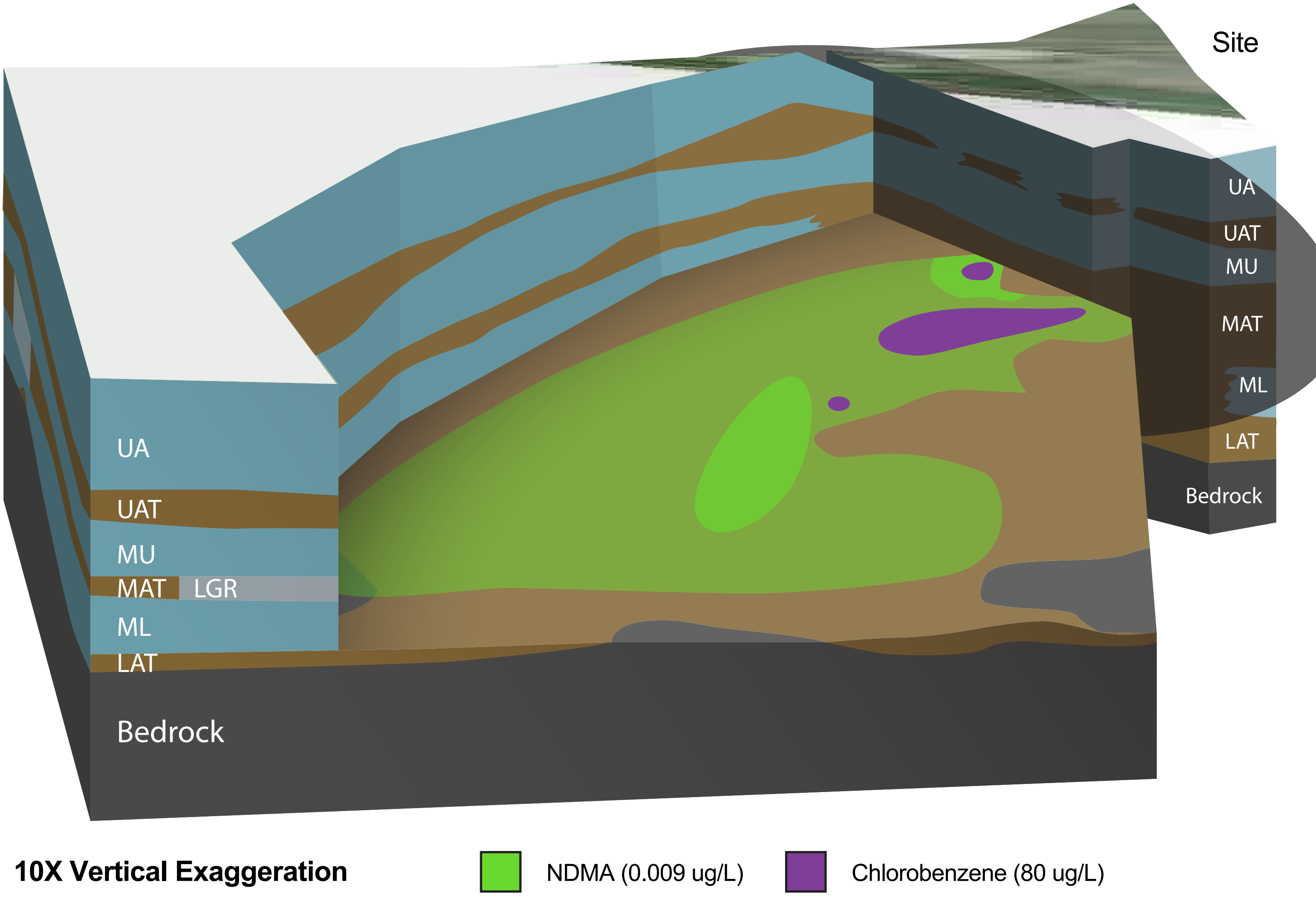


Table 1

Physical and Chemical Properties of the COC

Property	***NDMA***	***Chlorobenzene***
Formula	$C_2H_6N_2O$	C_6H_5Cl
CAS No.	62-75-9	108-90-7
MW (g/mol)	74.08(1)	112.56(2)
Density (g/mL)	1.0059(1)	1.1058(2)
Aqueous Solubility (mg/L)	1,000,000(1)	466.3(2)
Vapour Pressure (mm Hg)	2.7(1)	3.9(2)
log K_{ow}	-0.57(1)	2.84(2)
K_{oc}	25.7(3)	224(4)

Notes:

1. USEPA, January 2014. Technical Fact Sheet – N-Nitrosodimethylamine (NDMA).
2. USEPA, January 1995. Chlorobenzene Fact Sheet: Support Document, EPA 749-F-95-007a.
3. MOECC, January 2017. Ontario Regulation 169/03, Ontario Drinking Water Quality Standards.
4. USEPA, May 1996. Soil Screening Guidance: Technical Background Document, EPA/540/R-95/128, Office of Solid Waste and Emergency Response, United States Environmental Protection Agency, Washington, DC.

Attachment A

Attachment A Previous CSMs and Related Reports

CH_2M Hill, 1991. Elmira/St. Jacobs Water Supply Project, Volumes I to IV: Hydrogeological Evaluation of the Elmira Aquifer System.

CRA, 1993. Updated Remedial Action Plan Update (RAP) Long-Term Collection and Treatment System, Uniroyal Chemical Ltd., Elmira, Ontario.

CRA, 1997. Final Support Document, Application for Certificate of Approval, Off-Site Collection and Treatment System, Uniroyal Chemical Ltd., Elmira, Ontario.

CRA, 2001. Optimization Study Report, Crompton Co., Elmira, Ontario.

CRA, 2003. Revised Nitrogen Species Report Crompton Co., Elmira, Ontario.

CRA, 2012. Groundwater Flow and Contaminant Transport Model Update, Chemtura Canada Co./Cie, Elmira, Ontario.

GHD, 2016. 2015 Model Check Point Analysis, Chemtura Canada Co./Cie, Elmira, Ontario.

Xiang, Y., J.F. Sykes, and N.R. Thomson, 1996. Optimization of Remedial Pumping Schemes for a Ground-Water Site with Multiple Contaminants, Ground Water, Vol. 34, No. 1, pp. 2-11.