TECHNICAL NOTE

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SUBJECT: **Alternative Solution for Road Construction** –
James Bay Lithium Mine Project

PROJECT NO.: 201-12362-00

DATE: March 31, 2022

The purpose of this technical note is to present the proposed alternative for the construction of haul roads for the James Bay Lithium Mine Project following the information request received on March 3, 2022 and the supplementary information request dated March 23, 2022, from the Joint Assessment Committee.

Considering the concerns raised by federal and provincial experts regarding the proposed road design, the decision was made to install an impervious geomembrane to better protect surface water and groundwater from possible contamination that could be generated by the waste rock used as a rolling layer, in accordance with the applicable criteria.

Haul roads will have a total length of 6.5 km, of which 1.2 km will be built directly on the waste rock stockpiles and thus, will not require a liner. Map 1 shows the location of the roads.

The roads will be 25 m wide and will be constructed according to the cross-section shown on Figure 1, except for the segments located on the waste rock piles.

JUSTIFICATION OF THE CHOSEN SOLUTION AND ALTERNATIVE SOLUTION

The design presented in July 2021 was as follows:

- a foundation soil with a thickness of up to 1.5 m, compacted as backfill,
- a 450 mm layer of crushed stone of 0-56 mm caliber, compacted.

It was 5.3 km long with an average right-of-way width of 38 m for an estimated surface area of 150,000 m^2, therefore a need for 225,000 m^3 of borrow materials and 100,000 m^3 of crushed stone.

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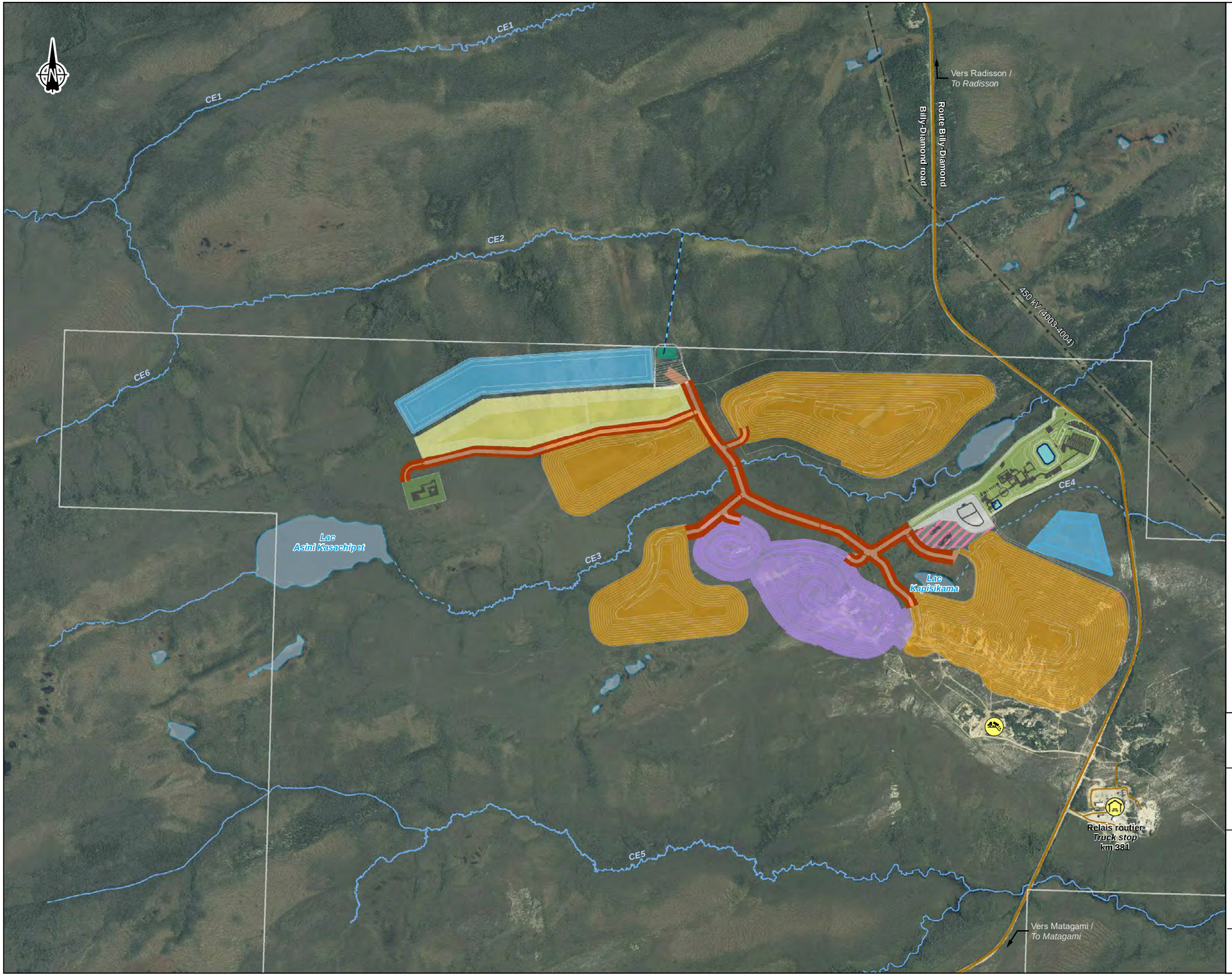

Limite de propriété / *Property limit*

Composantes du projet / *Project Component*

Route / *Road*

Effluent minier / *Mine effluent*

Usine de traitement de l'eau / *Water treatment plant*

Secteur administratif et industriel / *Administrative and industrial sector*

Fosse / *Pit*

Halde à minerai / *ROM pad*

Halde à stériles / *Waste rock stockpile*

Halde à matières organiques et dépôts meubles / *Overburden and peat storage facility*

Entrepôt à explosifs / *Explosives magazine*

Aire d'entreposage / *Dry storage area*

Usine à béton (temporaire) / *Concrete batch plant (temporary)*

Bassin de rétention d'eau / *Water retention basin*

Infrastructures / *Infrastructure*

Route principale / *Main road*

Route d'accès / *Access road*

Ligne de transport d'énergie / *Transmission line*

Relais routier / *Truck stop*

Lieu d'enfouissement technique isolé / *Isolated technical landfill*

Hydrographie / *Hydrography*

CE3 Numéro de cours d'eau / *Stream number*

Cours d'eau permanent / *Permanent stream*

Cours d'eau à écoulement diffus ou intermittent / *Intermittent or diffused flow stream*

Plan d'eau / *Waterbody*

GALAXY

Mine de lithium Baie-James / James Bay Lithium Mine

Carte / *Map* 1
Aménagement du site minier /
Mine Site General Arrangement

Sources :
Othoimage : Microsoft Bing (ESRI, 2017)
Gestim : MRNF Québec, 210315
Données du projet / Project data : Galaxy 2020

0 200 400 m
UTM, fuseau 18, NAD83

Mars / *March* 2022

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Approbation : C. Martineau
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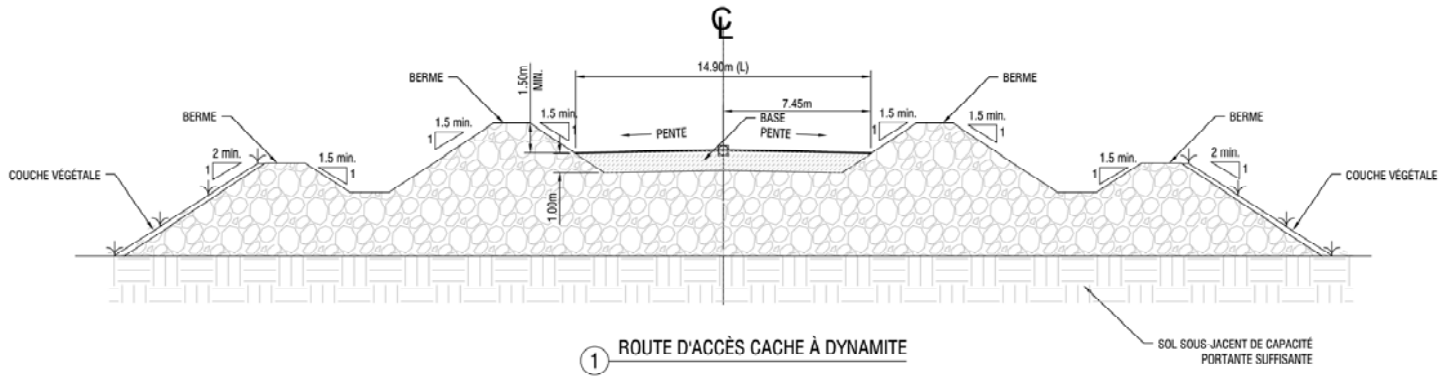
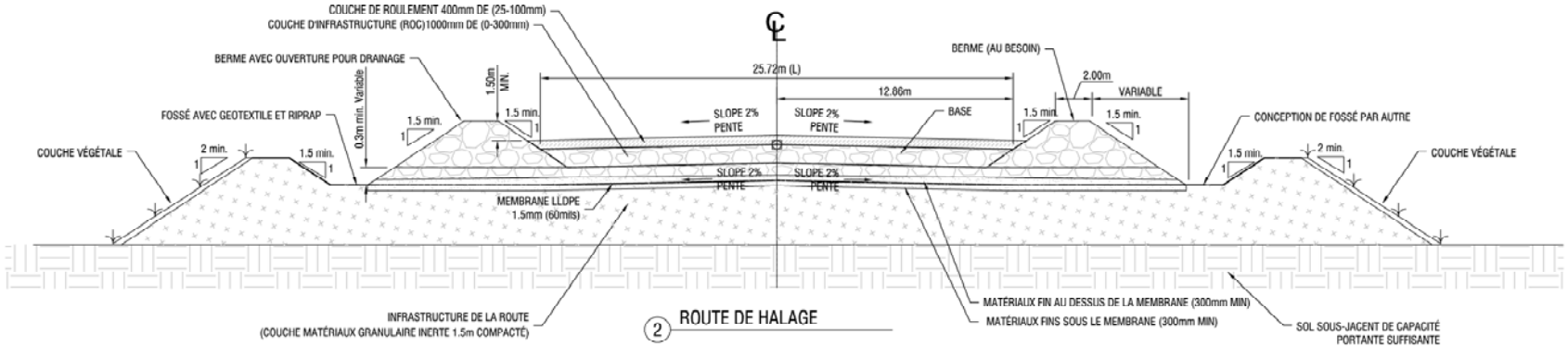




Source: GMining Services, 2022

Figure 1 Hauling Road Cross-Section

The materials were to come from the overburden present on the site, from the borrow pit located at km 381, behind the landfill site, as well as from a borrow pit to be opened and from a quarry developed on the site of the future pit. The quarry materials had to be temporarily stored on a platform after their crushing and periodically watered in order to leach the metals and have materials suitable for construction. The drainage water was all directed to the main collection basin, then monitored, treated if necessary and discharged at the final effluent point to CE2.

GLCI continued its search for materials as authorities continued their environmental analysis.

In September 2021, the water treatment plant that was to be built in year 9 was added right at the start of the project. It would be built in two phases, a first phase for the treatment of problematic elements (iron and arsenic) with a treatment capacity for leaching crushed materials and a second phase to meet the operating flow, the concentrations required by permits and to target EDOs.

On the one hand, with a water treatment plant, the idea came to replace the borrow materials of the foundation with a layer of waste rock of 0-300 mm caliber, i.e. straight from the blast, with no further crushing. Thus, all watering water for waste rock leaching as well as runoff water would be directed to the water treatment plant. Groundwater percolation was considered negligible. However, the volume of tailings to be washed was increased.

On the other hand, as part of the engineering process, following the results of geotechnical investigations, GLCI refined its road cross section and increased the thicknesses of materials to increase the resistance factor.

Then in January 2022, to respond to the concerns of the authorities regarding the protection of groundwater, the choice of a road design consisting of a base constructed with borrow materials covered with an impervious synthetic membrane and waste rock was proposed.

The cross-section has been reviewed accordingly. It is now constructed with:

- foundation of run material from overburden up to 1.5 m thick, clay-free and compacted;
- a layer of fine sand 300 mm thick to receive the geomembrane;
- the 1.5 mm (60 mils) thick LLDPE geomembrane;
- a layer of fine sand 300 mm thick to protect the membrane;
- a 1000 mm thick infrastructure layer of 0-300 mm caliber run-of-waste rock;
- a surface layer 450 mm thick in crushed waste rock 25-100 mm caliber.

The volumes of materials required are now around 425,000 m^3 of borrow materials and 375,000 m^3 of waste rock.

The choice of foundation material was made on the basis of the evaluation shown in Table 1; the choice of covering and rolling materials was made on the basis of the evaluation shown in Table 2.

Table 1 Considered alternatives for foundation material of haulage roads

Criterion	weight	Combination of sources for borrow material - from site and from external borrow pit	rating	Borrow material from site	rating	Crushed rock from site	rating	Crushed rock from SDBJ quarry at km 394	rating
Availability	15	100 000 m^3 from BNE 50701, 125 000 m^3 from a borrow pit to open and 200 000 m^3 from site	15	Yes, SNC-Lavalin report, August 2021	15	Yes, available waste rocks on surface	15	Yes but new area to open	15
Distance/Construction costs	10	70% less than 1 km, 30% at 2 km	7	100% less than 1 km	10	100% less than 1 km	10	12 km	5
Travel on BD road[5]	15	Yes for 30% of the material, i.e. those from the pit to open totalizing 200 000 tm. Transported by 30 t trucks = 6 666 roundtrips	10	No	15	No	15	Yes. On site crushed material totalizing 765 000 tm. Transported by 30 t trucks = 25 000 roundtrips	5
Opening of new land	10	Less than 3 ha	5	No	15	No	15	Less than 3 ha	5
Permitting duration	10	BNE and authorization 22, less than de 3 ha, minimum 1 year[1]	5	Surface Lease and Forest intervention permit, 6 months	10	BEX and authorization 22, 6 months	10	Extension of BEX open surface. i.e. authorization 22 by SDBJ, 6 months	10
GHG[3]	10	Additional emissions for 26 000 km	8	No additional emission	10	No additional emission	10	Additional emissions for 612 000 km	2
Protection of underground water	20	Borrow material are inert with respect to leaching	20	Borrow material are inert with respect to leaching	20	Leaching potential. Demonstration of seepage rate < 3,3 L/m^2/day on total road length difficult even impossible	0	Active authorization from MELCC[4] but no geochemical assay result available	15
Rehabilitation effort and costs	10	Material useful on site. Portion to eliminate according to final characterization	8	Material useful on site. Portion to eliminate according to final characterization	**8**	Transportation on waste piles of 425 000 m^3 and reprofiling of piles	0	According to their geochemical behavior during operation	?
Total	100		78		**98**		75		Max 62

Note 1: It is necessary to go through the COMEX exemption process, then to apply for a BNE at MERN and to an authorization according to EQA Section 22 at MELCC.
Note 2: Crushed metabasalt has a slightly higher density than sand.
Note 3: Additional emission from the present project GHG assessment.
Note 4: This material is the same as the site basalt; it was authorized by the MELCC in 2002 and in 2019. No geochemical characterization was presented as part of the 2019 authorization. The 2002 documents are not available.
Note 5: The increase in traffic on the Billy-Diamond road is a sensitive issue for the Cree communities.

Table 2 Considered alternatives for structural and surface material on haulage roads

Criterion	weight	Waste rock from site	rating	Synthetic impervious geomembrane and waste rock from site	rating	Crushed rock from km 394 quarry	rating	Crushed rock from another quarry	rating
Availability	10	Yes, available waste rocks on surface	10	Yes, available waste rocks on surface; membrane available in Southern Quebec	10	Yes, but new area to open	10	Beside diabase on site[2], no other quarry or potential quarry identified within 28 km[3].	5
Distance/Construction costs	10	Less than 1 km	10	Less than 1 km for waste rock, 320 000 m^2 of geomembrane to buy and have delivered on site	2	12 km	8	28 km	5
Travel on BD road[5]	15	No	15	Transport of geomembrane from km 0 to 382	10	Yes, On site crushed material totalizing 675 000 tm. Transported by 30 t trucks = 22 500 roundtrips	0	Yes, On site crushed material totalizing 765 000 tm. Transported by 30 t trucks = 25 000 roundtrips	0
Opening of new land	10	No	10	No	10	Less than 3 ha	5	Less than 3 ha	5
Permitting duration	5	BEX located on ESIA area report and authorization 22, 6 months	5	BEX on located ESIA area report and authorization 22, 6 months	5	Extension of BEX open surface, i.e. authorization 22 by SDBJ, minimum 1 year[1]	5	Extension of BEX open surface, i.e. authorization 22 by SDBJ, minimum 1 year[1]	5
GHG[2]	10	No additional emission	10	Additional indirect emission related to geomembrane transport	8	Additional emission for 540 000 km	5	Additional emission for 1 260 000 km	0
Protection of underground water	20	Leaching potential. Demonstration of seepage rate < 3,3 L/m^2/day on total road length difficult even impossible	0	Impervious membrane	20	Active authorization from MELCC[6] but no geochemical assay result available	15	Active authorization from MELCC[6] but no geochemical assay result available	15
Dispersion of crystalline silica[7]	10	Model conducted with gneiss and basalt mix	6	Model conducted with gneiss and basalt mix	6	Metabasalt with less than 3% SiO_2, SNC-Lavalin, July 2021	8	No geological data found	?
Rehabilitation effort and costs	10	Transportation on waste piles of 375 000m^3 and reprofiling of piles	2	Transportation on waste piles of 375 000m^3 and reprofiling of piles Membrane to dispose in authorized site	**0**	According to their geochemical behavior during operation	?	According to their geochemical behavior during operation	?
Total	100		68		**71**		Max 64		Max 53

Note 1: It is necessary to go through the COMEX exemption process, then to apply for a BNE at MERN and to an authorization according to EQA section 22 at MELCC.
Note 2: Additional emission from the present project GHG assessment.
Note 3: Diabase from site was geochemically tested and the results showed levels above the MELCC resurgence criteria for Ag, Cu, Hg and Fe during the first months of kinetic testing.
Note 4: An authorized quarry under the name of the SDBJ is open at km 10 of Opinaca Reservoir Road. The open mining area has an area of 2.6 ha. The working face is about 20 m high.
Note 5: The increase in traffic on the Billy-Diamond road is a sensitive issue for the Cree communities.
Note 6: This material is the same as the site basalt; it was authorized by the MELCC in 2002 and in 2019. No geochemical characterization was presented as part of the 2019 authorization. The 2002 documents are not available.
Note 7: The computer model with the gneiss-basalt mixture carried out made it possible to anticipate compliance with the hourly criterion at all sensitive receptors and a slight overrun of the annual criterion at the truckstop as well as at a campless bear and beaver hunting site. GLCI had a modeling done with the metabasalt of less than 3% in SiO2. The results are a little lower than those of the gneiss-basalt mixture but also exceed the annual criterion at the bear and beaver hunting site. The segregation of metabasalts at the GLCI site would be difficult because this lithology is mainly encountered there from a depth of 100 m.

The scenario using the site's borrow materials with the installation of a geomembrane and the site's waste rock was therefore retained.

By de facto eliminating scenarios in which leaching potential above metal resurgence criteria is demonstrated, the alternative for the foundation would be the combination of borrow pit materials and site materials and the alternative for the structuring and surface layers would be the transport of materials from the quarry at km 394. However, no geochemical result for leaching test is currently available for these materials.

ROAD DESIGN DESCRIPTION

The foundation of the 5.3 km of roads, to be built on natural soil, will be established in overburden from the stripping of the pit surface, the administrative and industrial sector as well as from the construction of the water retention basins, namely the north basin (main basin) and the east basin (Map 1). The overburden is composed of a mixture of sand, gravel and clay. Only sand, silt and gravel will be used as borrow material for roads; part of the clay will be used in the construction of the north basin (bottom layer and peripheral dikes), the rest will be stored on the overburden pile.

According to the SNC-Lavalin report, (August, 2021), the areas where the materials will be recovered are mainly composed of sand/gravel, till and silt. The only place where there is some clay is the northern basin sector where the clay is mixed with silt in the first meters on the surface. This layer has average of 3m in thickness, with a variability between 1.75 m and 10.2 m.

This material will be compacted to obtain a solid foundation to allow the passage of haul trucks. A total of approximately 425,000 m^3 of overburden will be needed to build the 5.3 km of roads.

The foundation will be covered with a 1.5 mm thick linear low density polyethylene geomembrane (LLDPE) inserted into 300 mm thick layers of sand to protect against punching. The geomembrane will also cover the side ditches of the road and will be anchored on the side slope.

CHOICE OF GEOMEMBRANE

This type of geomembrane offers superior elongation properties to HDPE, it is more flexible. It will be able to mold itself better to the movements of the ground and of the foundation of the road. It is resistant to water, cold temperatures and chemical attack. The 1.5 mm (60 mils) thickness is generally sturdy and flexible enough to allow installation that is fairly easy for a specialist crew. This thickness offers resistance to punching, settling and significant chemical attack. This thickness is that used in landfills or similar storage structures. The 1.5 mm geomembrane allows welds to be made well and verified with an industry standard QA/QC program.

In the mining sector, an evaluation of several types of construction of waterproofing barriers for different types of containment works has shown that the use of polyethylene geomembrane such as LLDPE makes it possible to contain water from acid mine drainage, particularly during containment of leach piles (Renken et al., 2006). Renken evaluated several cases before concluding that HDPE and LLDPE geomembranes can be excellent containment solutions to contain element-laden water.

In an arctic climate, Esford et al. (2010), demonstrates the successful installation of a 1.5-mm thick LLDPE geomembrane at temperatures between -15 and -25oC in the tailings pond (conventional type) of the Meadowbank mine located in Nunavut. He mentions that "LLDPE was selected due to its resistance to stress cracking, its multi-axial deformation and tolerance to strains, in recognition of the potential for differential settlement to occur in the foundation soils, by comparison with high density polyethylene (HDPE)."

In the industry, its qualities are sold as follows:

For its various properties, the use of LLDPE is vast and it is found in many objects such as plastic bags, toys, pipes, cable covers and geomembrane sheets. For containment structures, the LLDPE geomembrane is generally used in applications with large differential settlement or in areas of high risk of stress cracking. LLDPE makes it possible to contain or control fluids thanks to its multiaxial properties and resistance to stress cracking (www.solmax.com, March 2022).

LLDPE geomembranes have excellent resistance to multiaxial elongation and can deform without losing their properties. The civil engineering applications for which the LLDPE geomembrane is often used are as varied as technical landfills (LET), retention basins, contaminated soil treatment sites, waste snow dumps, waterproofing of ditches, light fills and others (www.innovex.ca, March 2022, www.geomembrane.com, March 2022).

The LLDPE geomembrane being inert in nature and resistant to low temperatures and to various chemical compounds, it will be able to collect and direct towards the main collecting basin, rainwater transiting through the layers of waste rock. This water will be much less aggressive in nature than solution from a heap leach or leachate from a domestic waste landfill.

As for the longevity of the geomembrane, it is currently being studied by several manufacturers as well as the Geosynthetic Institute (GSI, www.geosynthetic-institute.org). Longevity is difficult to predict since it depends on several factors (e.g. the type of stresses applied, the quality of the resin, the conditions of use, the protection against bad weather and UV rays, the preparation of the foundations and the layer protection, QA/QC program, etc.). The GSI conducts studies and proposes a methodology for conducting this type of test. For example, the durability of Solmax high-density polyethylene (HDPE) geomembranes in covered applications can be predicted by considering that the GRI-GM 13 standard is met. At 40°C, the predicted durability of the geomembrane is estimated at 69 years; i.e. that after age 69, its measured material properties will have decreased by 50%. At 20°C, the durability is 446 years. Note that even with a reduction in material properties, the geomembrane will still be usable to waterproof a surface. While complying with the GRI-GM17 standard, the durability results for a LLDPE geomembrane is expected to be less than that of HDPE, but it is realistic to expect a lifespan beyond the expected 19 years of the mine.

In his book entitled "Designing with Geosynthetics", Dr. Robert M. Koerner[1], after evaluating the properties of geomembranes, seems to be convinced that the polyethylene material of the geomembrane has demonstrated durability. As for him, the durability of the geomembrane is more related to the attention paid to the operations, during its installation and its protection against external factors, than to its intrinsic properties.

[1] The late Dr. Robert M. Koerner was a professor of civil engineering at Drexel University and founder and director of the Geosynthetic Institute. He has written numerous articles and reference books on the use of geosynthetics, including Designing with Geosynthetics, which has sold more than 40,000 copies. He has received several titles including Drexel University's Lindback Distinguished Teaching Award, was an honorary member of the American Society of Civil Engineers (ASCE) and was elected a Fellow of the National Academy of Engineering.

PROTECTION OF THE GEOMEMBRANE

To protect the geomembrane, it will be inserted between two layers of fine granular material, 300 mm thick. The laying of the geomembrane will be done by certified installers; a QA/QC program is integral part of their duties. They will check the installation surface as well as the integrity of the properties of the geomembrane, before delivery and during installation, and welding with, as reference, compliance with the GRI-GM17 standard of the Geosynthetic Institute (GSI) (presented in appendix) as well as the associated ASTM standards.

On the upper layer of fine granular material, minimum 300 mm thick, will be laid a layer of infrastructure 0-300 mm caliber with a thickness of 1000 mm and a surface layer of 450 mm of thickness 25-100 mm caliber.

This 1.45 m of additional equipment will cushion the weight of the towing trucks. Given the capacity of the haul trucks (100 mt) that will travel on these roads, it is important to have a certain thickness of rocky material and not only loose material for road construction. A thickness of 1 m of rock material was recommended by our engineers.

The infrastructure and bearing layers will be constructed of waste rock. These layers will be considered and managed as waste rock piles. It will take approximately 375,000 m^3 of waste rock to build these layers. The Revision C road plan is attached.

SOURCE OF MATERIALS

The volume of rock required includes road structural layer, surface and side berms. The hauling roads are two-way; they are 25 m wide and have side berms to meet the requirements of the Mining Health and Safety Regulations and contain snow cleared in winter. Indeed, the Regulation requires, for two-way roads, a width equivalent to three times the width of the trucks (a 777 is 5.2 m wide) as well as embankments or parapets when the vehicles are exposed to a fall of more than 3 m. The potential fall on the site will not reach 3 m but GLCI has made the decision to put these berms for safety. The berms will be equipped with openings for drainage, which will be able to evacuate the spring melt.

To extract these materials, GLCI will have to develop a quarry in the footprint of the deposit, since this work will be done before obtaining the mining lease. The opening of this quarry will require obtaining the BEX at the MERN and an authorization from the MELCC under Section 22 of the EQA.

The borrow materials will initially come from the south-west sector of the pit (green areas on the maps of months 1 and 6), then from the sector of the northern collection basin and, if necessary, from the sector of the water collection basin of the east dump. The SNC-Lavalin report (August 2021) presents the surveys carried out in these sectors.

PROTECTION OF GROUND AND SURFACE WATER

The geomembrane will act as a sealing measure for groundwater. The daily percolation rate below the threshold recommended by D019 of 3.3 L/m^2/day will be respected. A LLDPE geomembrane is said to be impervious, no infiltration rate is listed in the technical data sheets (see GRI-GM17 Standard Specification in appendix). In the literature, we found an equivalent hydraulic conductivity value of 3.5 x 10^{-15} m/s for a 0.75 mm thick LLDPE geomembrane (Giroud, 1989).

Surface water will be collected and directed by gravity and pumping (depending on the sector) to the northern water retention basin (the main basin), then to the WTP and controlled to ensure compliance with D019 criteria and standards of the MMDMER in addition to aiming towards the compliance of the EDOs before their discharge in CE2.

It should be noted that during the first month of construction, drainage water will be directed to the ditches under construction and a sediment barrier will be installed to protect CE3. At the end of the first month, there will be three water discharges on site, namely, the area of the water treatment plant, the west edge of the overburden pile and the north end of the basin of the industrial site. GLCI considers that these waters will not yet be a mining effluent; no blasting will have occurred, only movement of borrow material. The first month work is used to pave the way for the installation of the water treatment plant, which will be operational before the 6th month of construction and as soon as the site effluent reaches a flow rate of 50 m^3/day.

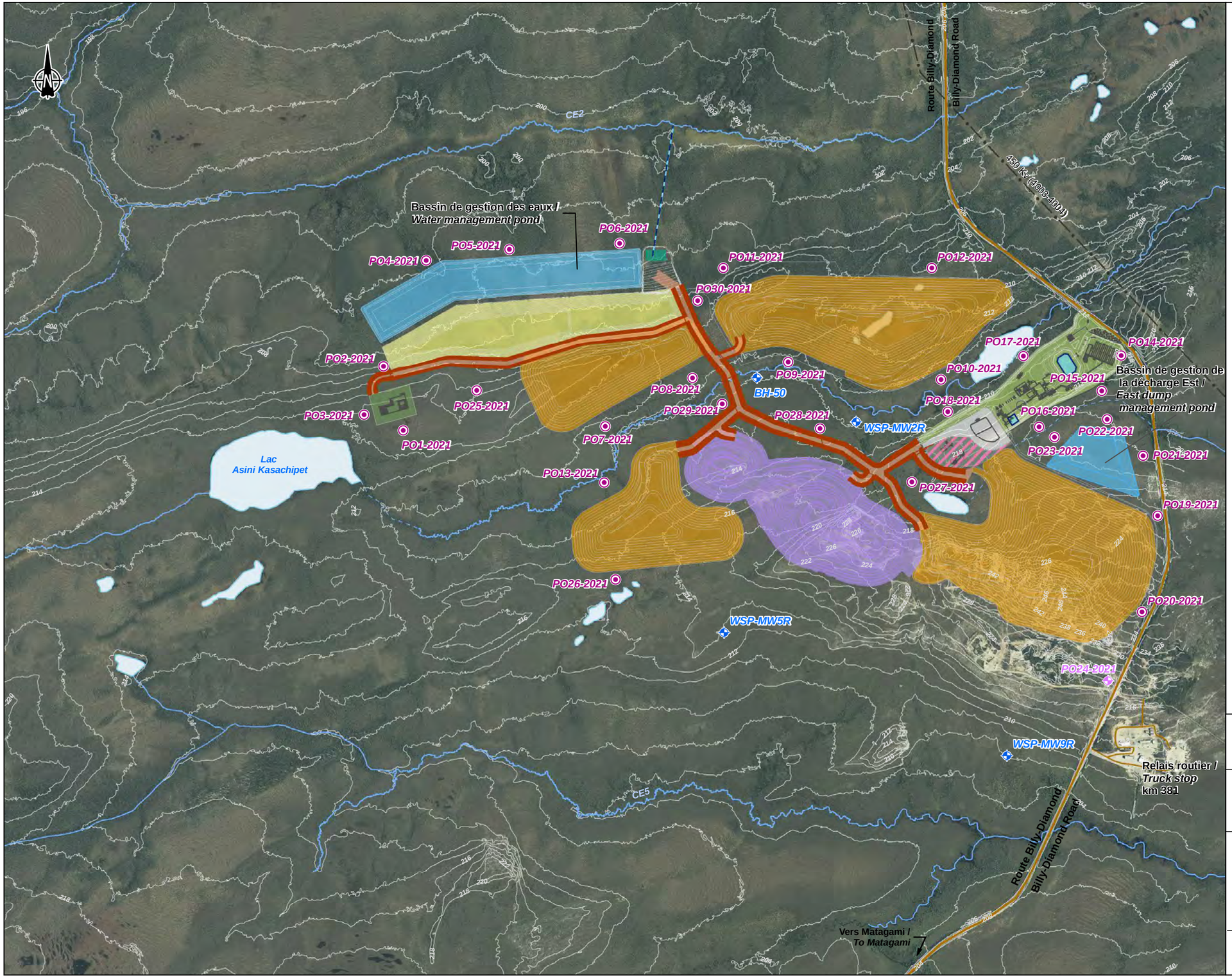
Sampling wells will be installed along the roads to monitor groundwater quality. Sampling of groundwater from areas at risk (Map 2) will be carried out as required by section 2.3 of D019 and compared to resurgence criteria.

It is likely that over time holes will appear in the geomembrane and that a certain amount of water could infiltrate (even landfills always assume a certain number of holes per hectare). On the other hand, the infiltration will be minimal since to have an infiltration there must be a difference in water head between the two sides of the geomembrane, which is unlikely in the case of these roads. In addition, the paths and ditches will be built with slopes of 2% from the center, which will promote the flow of water towards the ditches, then their direction towards the northern collection basin. With or without a geomembrane, the majority of precipitation will still run off into the side ditches and to pumping stations. In the event that part of the precipitation is not collected in the ditches and has infiltrated under the road, it will be controlled by the sampling wells. If the applicable criteria were to be exceeded in a well, the search for the cause could lead to repairs of the geomembrane or local pumping to the north retention basin for future treatment. From experience, geomembrane breaks are very local; the extent of the contamination is measured by rigorous monitoring of neighboring wells. Galaxy could pump in these monitoring wells in order to suck up the contamination until compliance with the environmental criteria returns. This scenario is comparable to cases of leakage around conventional tailings dams where local pumping is a proven effective method.

Rigorous monitoring is the best method of prevention, it makes possible the detection of unwanted situations before they become important.

IMPACTS ON THE PROJECT

The water balance already presented remains the same and does not need to be modified, as does the surface water modelling, which does not need to be modified. Indeed, in the previous design, the precipitation on the roads was already directed towards the ditches to reach the main collection basin and the WTP. The portion percolating into groundwater was deemed to be insignificant. The addition of the geomembrane is an additional protection; the percolation volume will remain insignificant.



Suivi des niveaux des eaux / *Water level monitoring*

- Puits existant / *Existing well*
- Puits proposé / *New well*

Suivi de la qualité de l'eau / *Water quality monitoring*

- Puits proposé / *New well*

Infrastructures / *Infrastructure*

- Route principale / *Main road*
- Route d'accès / *Access road*
- Ligne de transport d'énergie / *Transmission line*
- Relais routier / *Truck stop*

Hydrographie / *Hydrography*

- CE3 Numéro de cours d'eau / *Stream number*
- Cours d'eau / *Stream*
- Cours d'eau à écoulement diffus ou intermittent / *Intermittent or diffused flow stream*
- Plan d'eau / *Waterbody*

Composantes du projet / *Project Component*

- Effluent minier / *Mine effluent*
- Route / *Road*
- Usine de traitement de l'eau / *Water treatment plant*
- Secteur administratif et industriel / *Administrative and industrial sector*
- Fosse / *Pit*
- Halde à minerai / *ROM pad*
- Halde à stériles / *Waste rock stockpile*
- Halde à matières organiques et dépôts meubles / *Overburden and peat storage facility*
- Entrepôt à explosifs / *Explosives magazine*
- Cour d'entreposage / *Dry storage area*

GALAXY

Mine de lithium Baie-James / James Bay Lithium Mine

Carte / *Map* 2
Suivi des eaux souterraines / *Groundwater Monitoring*

Sources :
Orthoimage : Galaxy, août / august 2017
General Arrangement, 2020
Données du projet / Project data : Galaxy 2021

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UTM, fuseau 18, NAD83

Mars / *March* 2022

Dessin : A. Masson
Approbation : C. Martineau
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The overburden pile will have a volume of up to approximately 4.1 Mm^3, it will include peat (1.2 Mm^3), silt/sand/gravel (2.6 Mm^3) and clay (0.4 mm^3). The use of 425000 m^3 of silt/sand/gravel will effectively reduce the volume stored but this pile will keep the same footprint, only its configuration (slope and elevation) will be modified. It will gain stability even if the stability was not problematic.

The rehabilitation plan has been modified (version to be submitted to the MERN in early April 2022) in order to review the costs to bring the upper layers of the roads (infrastructure and surface layers) to the waste rock piles and allocation for the elimination of the geomembrane in an authorized landfill site. The borrow materials that were used for the foundation of roads will be characterized before their reuse for the restoration of the site. If a portion was found to be contaminated by waste rock leachate, it would be transported to the waste rock piles, if a portion was found to be contaminated by hydrocarbons, it would be transported to a site certified for this purpose.

The construction stages are modified as well as the water management during construction. The main activities are described below. Maps 4-8 to 4-10 of the EIA (WSP, 2021) have also been modified accordingly. They are presented in appendix.

Besides the indirect GHG emissions related to the transport of the membrane to the site, the evaluation of GHGs will not be modified, this calculation was made on the basis of fuel consumption which did not change.

It should be noted that the modification of the routes will not result in any modification to the 43-101 feasibility study.

CONSTRUCTION STAGES

- **First month (Map 4-8 revised):**
  - Build development roads with overburden from the mine pit area (green area).
  - Start the construction of the road foundation with overburden from mine pit area (green area).
  - Open the area that will be dedicated to the industrial site and begin levelling.
  - At the crossing of the CE-3, install the culvert and sediment barriers. The installation of the culvert will create kind of speed bump on the road.
- **Months 2 to 6 (Map 4-9 revised):**
  - Complete the levelling of the industrial site; the excess overburden will be kept to finalize the foundations of the roads.
  - Complete the construction of the foundation of the roads to be built on the natural soil. The overburden will come from the footprint of the mine pit, the industrial site, the footprint of the north water management pond and, if necessary, from the footprint of the east pond.
  - The membrane protection material will be a screened fine sand.

- Install the construction water treatment plant.
- Build the collection pond for the water to be controlled and treated before it is discharged to the CE2.
- Prepare the waste rock extraction site:
  - Install the side berms to direct the water to the collection basin.
  - Build the ponds to collect drainage water.
  - Install the pumps and pipes towards the north water management pond and WTP.
- Install the geomembrane on the foundation of the roads. This operation is hard to do in winter. Depending on the month in which the work begins, there may be a shutdown to ensure that the weather conditions are conducive to construction and geomembrane installation.

- **Months 7 to 12 (Map 4-10 revised):**
  - Install the temporary concrete batch plant.
  - Build the foundations on the industrial site.
  - On the haul roads, install the layer of fine materials on the geomembrane.
  - Blast the waste rock in the mine pit footprint authorized as quarry.
  - Put the infrastructure layer on the roads with the 0-300 mm caliber material that will have been sorted directly in the blasted area, without crushing.
  - Put the surface layer by crushing the waste rock on the road. The crusher will be moved as construction of the road progresses. Drainage water will be collected by ditches and directed to the WTP.

- **Months 12 to 18:**
  - Road construction will be completed.
  - There will be no changes in water management on the site.
  - Construction of buildings.

Map 4-7 of the Environmental Impact Assessment – Version 2 (WSP, 2021) showing the water management during the operation phase has also been revised and is presented in appendix.

Based on the information presented, the impact assessment for the construction, operation and rehabilitation phases described in the Environmental Impact Assessment – Version 2 (WSP, 2021) remains unchanged.

Prepared by:

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Encl. Appendix 1: Road plans
Appendix 2: Maps 4-7 to 4-10
Appendix 3: GRI-GM17 Standard

NOTE TO THE READER

This document was translated from the original French version. Therefore, the French version constitutes the official version. In case of conflict of interpretation between the English and French versions, the French version prevails.

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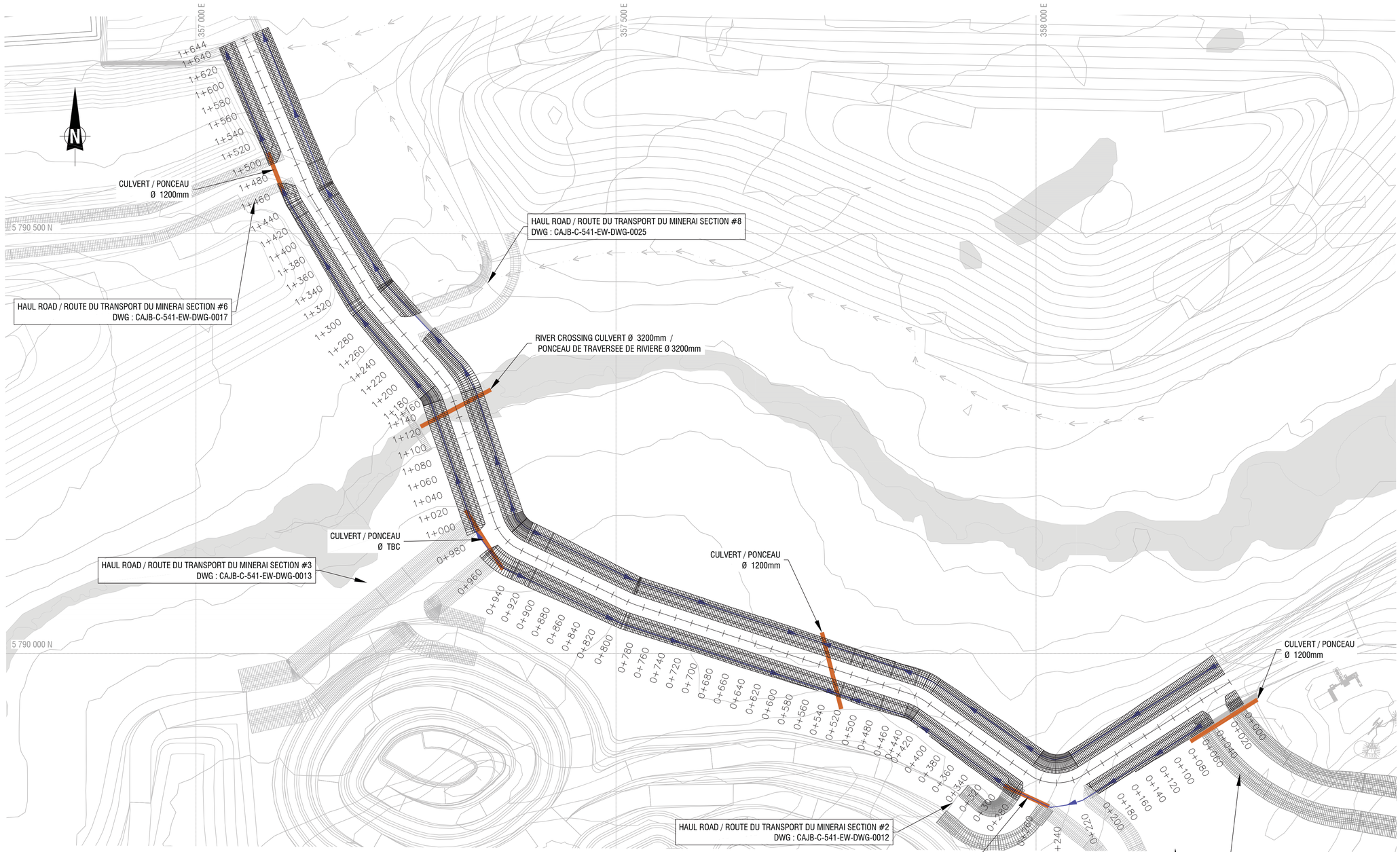
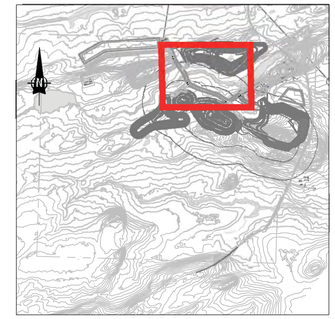
APPENDIX 1

ROAD PLANS



1 PLAN VIEW / VUE EN PLAN
1:2 500



KEY PLAN / PLAN PRINCIPAL

ISSUED FOR PERMITTING
ÉMIS POUR DEMANDE DE PERMIS

FEASIBILITY STUDY
ÉTUDE DE FAISABILITÉ

REV	DESCRIPTION	BY PAR	ENG ING	DATE
C1	ISSUED FOR PERMITTING ÉMIS POUR PERMIS	Y.B.	E.S.	21-11-17
C	FEASIBILITY STUDY ÉTUDE DE FAISABILITÉ	P.P.	E.S.	21-07-15
B	ISSUED FOR REVIEW POUR COMMENTAIRE	P.P.	E.S.	21-05-04
A	INTERNAL REVIEW REVISION INTERNE	P.P.	E.S.	21-04-13

GALAXY

Mining Services

DESIGN / CONCEPTEUR : P. GAUTHIER	21-07-28
DRAWN / DESSINATEUR: P. HERISSE	21-07-28
CHECKED / VÉRIFIÉ PAR : Y. BERGER	21-07-28
ENGINEER / INGÉNIEUR: E. SHAMMA	21-07-28
SCALE / ÉCHELLE: AS SHOWN	DATE

PROJECT/ PROJET:
BAIE-JAMES

PHASE:
FEASIBILITY STUDY
ÉTUDE DE FAISABILITÉ

TITLE:
HAUL ROAD
EARTHWORKS
PLAN VIEW
SECTION #1

TITRE:
ROUTE DU TRANSPORT DU MINERAI
TERRASSEMENT
VUE EN PLAN
SECTION #1

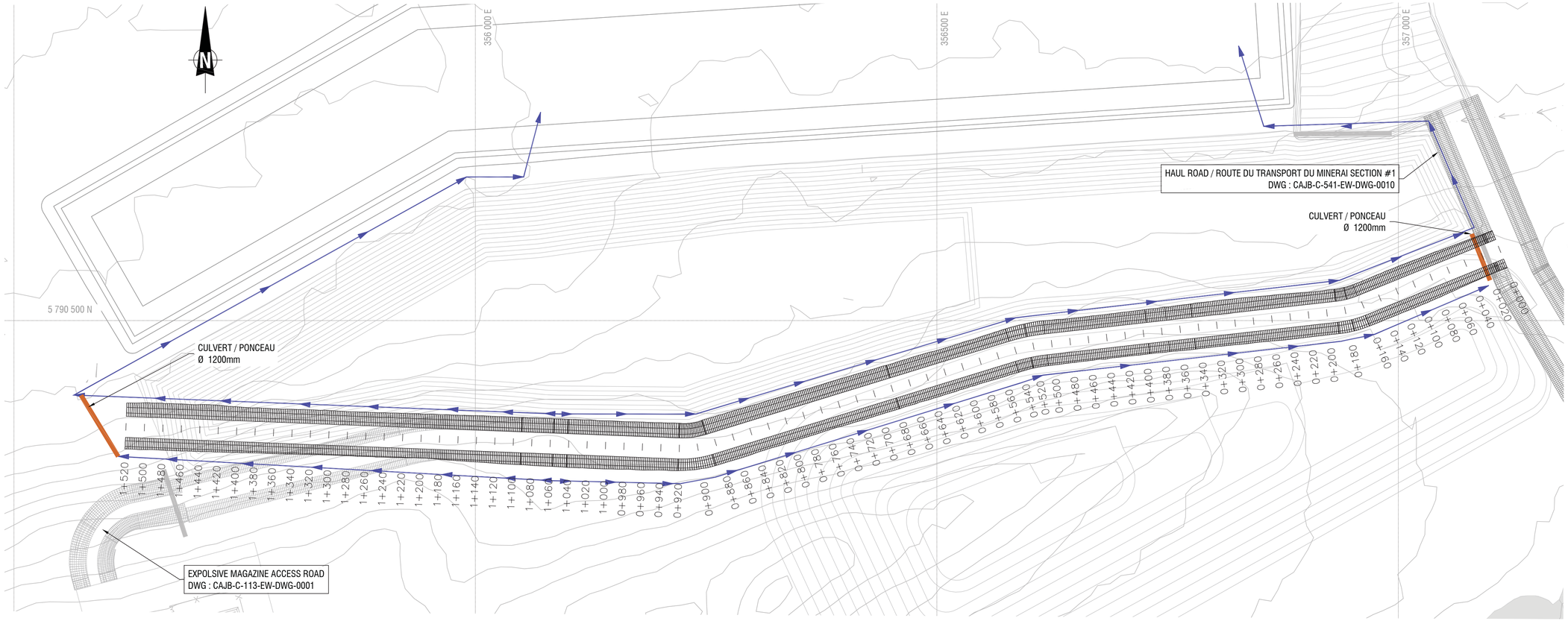
DRAWING NO.: CAJB - C -
DESSIN NUM.:

541	EW	DWG	0010	C1
AREA	DISC.	TYPE	SEQ. NO.	REV.

Eyad Shamma 131710 Québec

2021-11-24

PAPER SIZE FORMAT : A1

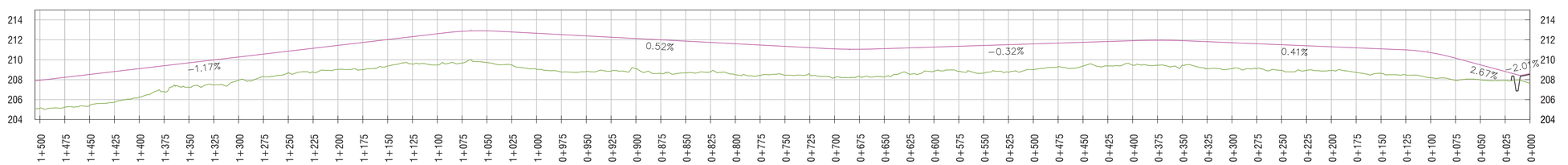


1 PLAN VIEW
1:2 500 VUE EN PLAN

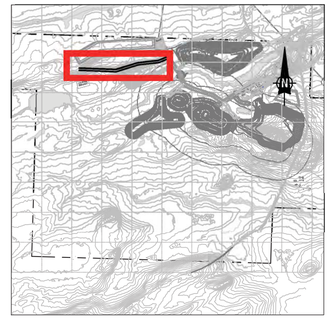
LEGEND / LEGENDE

NATIVE GROUND / TERRAIN NATUREL

ROAD INFRASTRUCTURE / INFRASTRUCTURE DE LA ROUTE



2 ROAD PROFILE
V=10 : H=1 PROFIL DE LA ROUTE



KEY PLAN / PLAN PRINCIPAL

ISSUED FOR PERMITTING
ÉMIS POUR DEMANDE DE PERMIS

FEASIBILITY STUDY
ÉTUDE DE FAISABILITÉ

REV	DESCRIPTION	BY PAR	ENG ING	DATE
C1	ISSUED FOR PERMITTING ÉMIS POUR PERMIS	Y.B.	E.S.	21-11-17
C	FEASIBILITY STUDY ÉTUDE DE FAISABILITÉ	P.P.	E.S.	21-07-15
B	ISSUED FOR REVIEW POUR COMMENTAIRE	P.P.	E.S.	21-05-04
A	INTERNAL REVIEW REVISION INTERNE	P.P.	E.S.	21-04-13

GALAXY

Mining Services

DESIGN / CONCEPTEUR : P. GAUTHIER	21-04-13
DRAWN / DESSINATEUR: P. PAQUETTE	21-04-13
CHECKED / VÉRIFIÉ PAR : Y. BERGER	21-04-13
ENGINEER / INGÉNIEUR: E. SHAMMA	21-04-13
SCALE / ÉCHELLE: AS SHOWN	DATE

PROJECT/ PROJET:
BAIE-JAMES

PHASE:
FEASIBILITY STUDY
ÉTUDE DE FAISABILITÉ

TITLE:
HAUL ROAD
EARTHWORKS
PLAN VIEW & ELEVATION
SECTION #6

TITRE:
ROUTE DU TRANSPORT DU MINERAI
TERRASSEMENT
VUE EN PLAN & ELEVATION
SECTION #6

DRAWING NO.: / DESSIN NUM.: CAJB - C -

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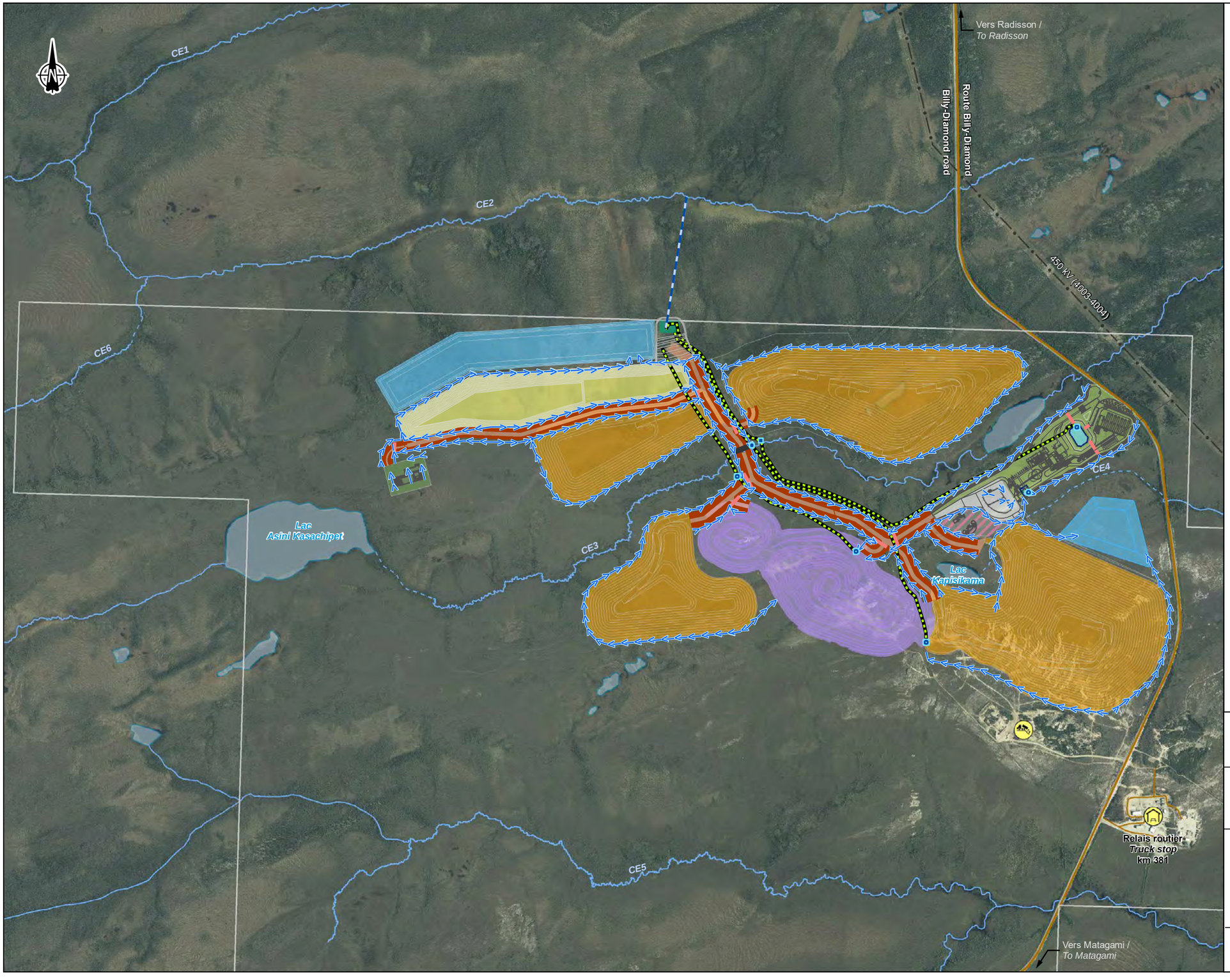
AREA	DISC.	TYPE	SEQ. NO.	REV.

APPENDIX 2

MAPS 4-7 TO 4-10



Limite de propriété / *Property limit*

Composantes du projet / *Project Component*

Route / *Road*

Effluent minier / *Mine effluent*

Usine de traitement de l'eau / *Water treatment plant*

Secteur administratif et industriel / *Administrative and industrial sector*

Fosse / *Pit*

Halde à minerai / *ROM pad*

Halde à stériles / *Waste rock stockpile*

Halde à matières organiques et dépôts meubles / *Overburden and peat storage facility*

Entrepôt à explosifs / *Explosives magazine*

Aire d'entreposage / *Dry storage area*

Usine à béton (temporaire) / *Concrete batch plant (temporary)*

Bassin de rétention d'eau / *Water retention basin*

Ponceau de drainage / *Drainage culvert*

Ponceau / *Culvert*

Tuyau de collecte des eaux de ruissellement / *Stormwater collection pipe*

Station de pompe temporaire / *Temporary pump station*

Sens d'écoulement des eaux / *Direction of water flow*

Infrastructures / *Infrastructure*

Route principale / *Main road*

Route d'accès / *Access road*

Ligne de transport d'énergie / *Transmission line*

Relais routier / *Truck stop*

Lieu d'enfouissement technique isolé / *Isolated technical landfill*

Hydrographie / *Hydrography*

CE3 Numéro de cours d'eau / *Stream number*

Cours d'eau permanent / *Permanent stream*

Cours d'eau à écoulement diffus ou intermittent / *Intermittent or diffused flow stream*

Plan d'eau / *Waterbody*

GALAXY

Mine de lithium Baie-James / James Bay Lithium Mine

Carte / *Map* 4-7 REV
Gestion des eaux en phase d'exploitation /
Water management during the operation phase

Sources :
Othoimage : Microsoft Bing (ESRI, 2017)
Gestim : MRNF Québec, 210315
Données du projet / Project data : Galaxy 2020

0 150 300 m
UTM, fuseau 18, NAD83

Mars / *March* 2022

Dessin : A. Masson
Approbation : D. Thiffault
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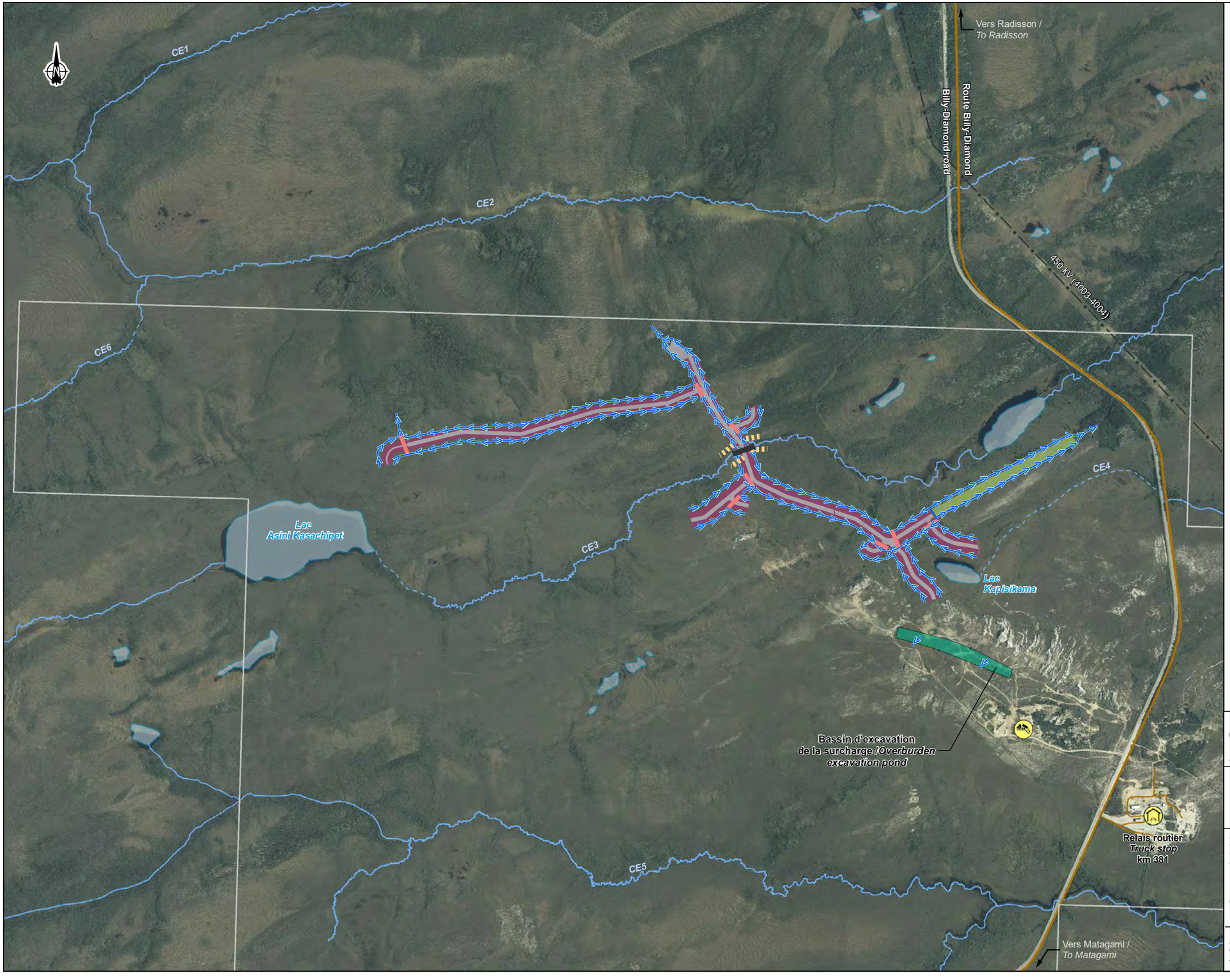

Limite de propriété / *Property limit*

Composantes du projet / *Project Component*

Assise de route / *Road foundation*

Secteur administratif et industriel /
Administrative and industrial sector

Ponceau de drainage / *Drainage culvert*

Ponceau / *Culvert*

Barrière à sédiments / *Sediment barrier*

Sens d'écoulement des eaux /
Direction of water flow

Infrastructures / *Infrastructure*

Route principale / *Main road*

Route d'accès / *Access road*

Ligne de transport d'énergie / *Transmission line*

Relais routier / *Truck stop*

Lieu d'enfouissement technique isolé /
Isolated technical landfill

Hydrographie / *Hydrography*

CE3 Numéro de cours d'eau / *Stream number*

Cours d'eau permanent / *Permanent stream*

Cours d'eau à écoulement diffus ou intermittent /
Intermittent or diffused flow stream

Plan d'eau / *Waterbody*

GALAXY

Mine de lithium Baie-James / James Bay Lithium Mine

Carte / *Map* 4-8 REV
Gestion des eaux en phase de construction – Mois 1 /
Water management during the construction phase – Month 1

Sources :
Othoimage : Microsoft Bing (ESRI, 2017)
Gestim : MRNF Québec, 210315
Données du projet / Project data : Galaxy 2021

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UTM, fuseau 18, NAD83

Mars / *March* 2022

Dessin : A. Masson
Approbation : D. Thiffault
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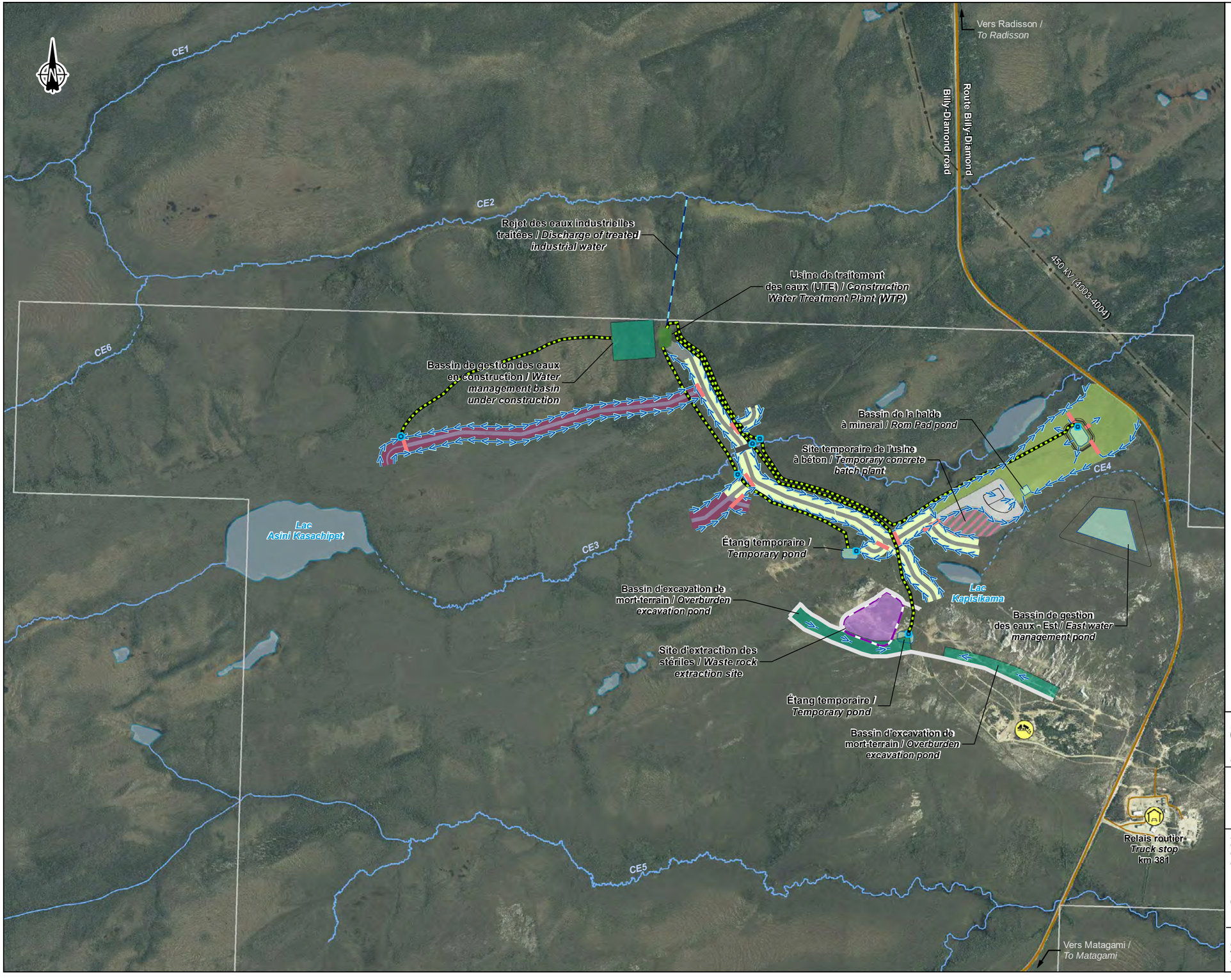

Limite de propriété / *Property limit*

Composantes du projet / *Project Component*

- Assise de route / *Road foundation*
- Route (membrane installée) / *Road (membrane installed)*
- Secteur administratif et industriel / *Administrative and industrial sector*
- Halde à minerai / *ROM pad*
- Aire d'entreposage / *Dry storage area*
- Bassin / *Basin*
- Ponceau / *Culvert*
- Effluent minier / *Mine effluent*
- Tuyau de collecte des eaux de ruissellement / *Stormwater collection pipe*
- Station de pompage temporaire / *Temporary pump station*
- Sens d'écoulement des eaux / *Direction of water flow*

Infrastructures / *Infrastructure*

- Route principale / *Main road*
- Route d'accès / *Access road*
- Ligne de transport d'énergie / *Transmission line*
- Relais routier / *Truck stop*
- Lieu d'enfouissement technique isolé / *Isolated technical landfill*

Hydrographie / *Hydrography*

- CE3 — Numéro de cours d'eau / *Stream number*
- Cours d'eau permanent / *Permanent stream*
- Cours d'eau à écoulement diffus ou intermittent / *Intermittent or diffused flow stream*
- Plan d'eau / *Waterbody*

GALAXY

Mine de lithium Baie-James / James Bay Lithium Mine

Carte / *Map* 4-9 REV
Gestion des eaux en phase de construction – Mois 6 / *Water management during the construction phase – Month 6*

Sources :
Othoimage : Galaxy, août 2017
Gestim : MRNF Québec, 210315
Données du projet / Project data : Galaxy 2021

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UTM, fuseau 18, NAD83

Mars / *March* 2022

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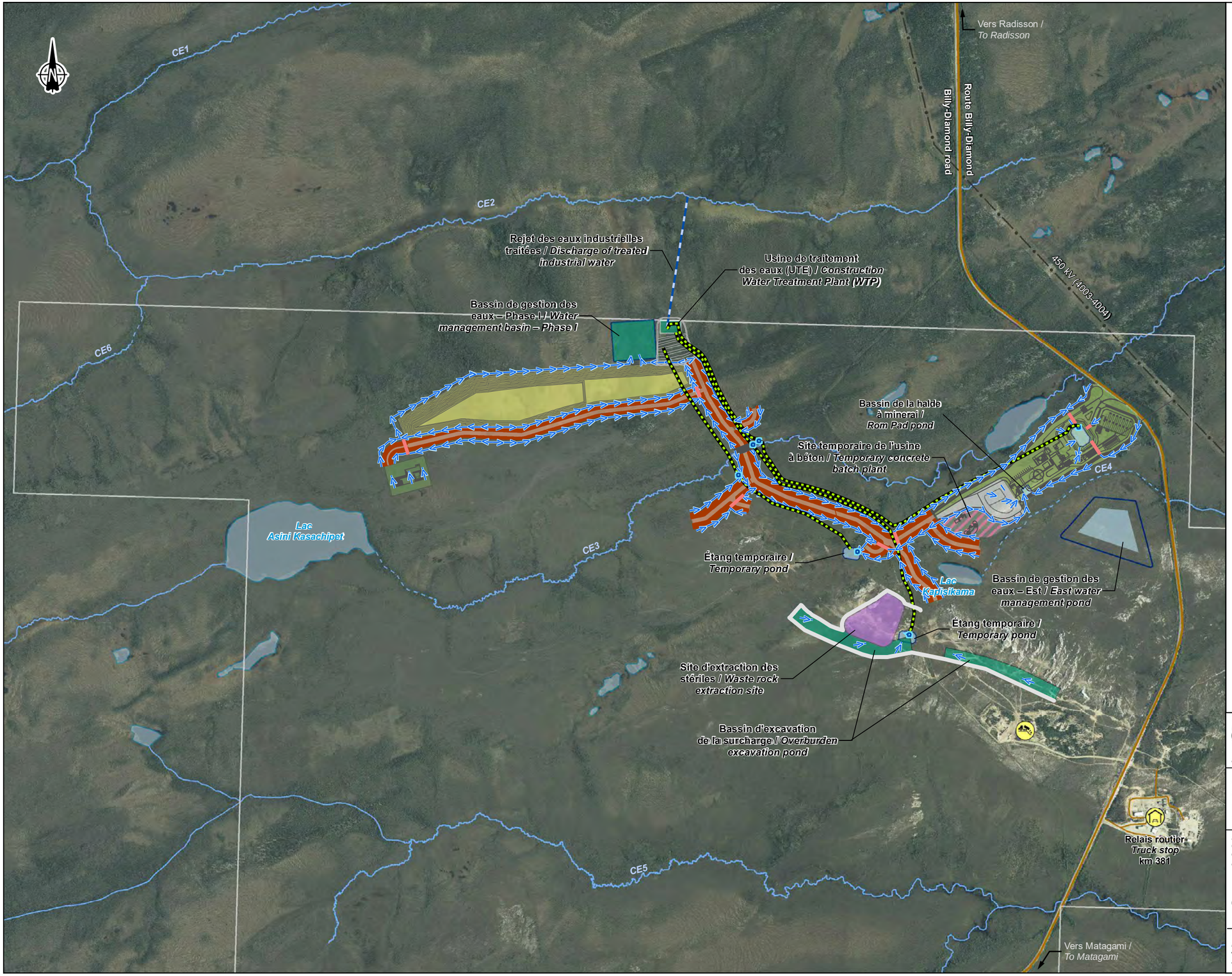

Limite de propriété / *Property limit*

Composantes du projet / *Project Component*

- Route complétée / *Completed road*
- Effluent minier / *Mine effluent*
- Usine de traitement de l'eau / *Water treatment plant*
- Secteur administratif et industriel / *Administrative and industrial sector*
- Fosse / *Pit*
- Entrepôt à explosifs / *Explosives magazine*
- Aire d'entreposage / *Dry storage area*
- Bassin / *Basin*
- Ponceau / *Culvert*
- Tuyau de collecte des eaux de ruissellement / *Stormwater collection pipe*
- Station de pompe temporaire / *Temporary pump station*
- Sens d'écoulement des eaux / *Direction of water flow*

Infrastructures / *Infrastructure*

- Route principale / *Main road*
- Route d'accès / *Access road*
- Ligne de transport d'énergie / *Transmission line*
- Relais routier / *Truck stop*
- Lieu d'enfouissement technique isolé / *Isolated technical landfill*

Hydrographie / *Hydrography*

- CE3 — Numéro de cours d'eau / *Stream number*
- Cours d'eau permanent / *Permanent stream*
- Cours d'eau à écoulement diffus ou intermittent / *Intermittent or diffused flow stream*
- Plan d'eau / *Waterbody*

GALAXY

Mine de lithium Baie-James / James Bay Lithium Mine

Carte / *Map* 4-10
Gestion des eaux en phase de construction – Mois 12 / *Water management during the construction phase – Month 12*

Sources :
Orthoimage : Galaxy, août 2017
Gestim : MRNF Québec, 210315
Données du projet / Project data : Galaxy 2021

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UTM, fuseau 18, NAD83

Mars / *March* 2022

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Approbation : D. Thiffault
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wsp

APPENDIX 3

GRI-GM17 STANDARD

Geosynthetic Institute
475 Kedron Avenue
Folsom, PA 19033-1208 USA
TEL (610) 522-8440
FAX (610) 522-8441

Revision 14: March 17, 2021
Revision schedule on pg. 12

GRI - GM17 Standard Specification*

Standard Specification for

"Test Methods, Test Properties and Testing Frequency for
Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes" SM

This specification was developed by the Geosynthetic Research Institute (GRI), with the cooperation of the member organizations for general use by the public. It is completely optional in this regard and can be superseded by other existing or new specifications on the subject matter in whole or in part. Neither GRI, the Geosynthetic Institute, nor any of its related institutes, warrant or indemnifies any materials produced according to this specification either at this time or in the future.

1. Scope

1.1 This specification covers linear low density polyethylene (LLDPE) geomembranes with a formulated sheet density of 0.939 g/ml, or lower, in the thickness range of 0.50 mm (20 mils) to 3.0 mm (120 mils). Both smooth and textured geomembrane surfaces are included.

1.2 This specification sets forth a set of minimum, maximum, or range of physical, mechanical and endurance properties that must be met, or exceeded by the geomembrane being manufactured.

1.3 In the context of quality systems and management, this specification represents manufacturing quality control (MQC).

Note 1: Manufacturing quality control represents those actions taken by a manufacturer to ensure that the product represents the stated objective and properties set forth in this specification.

*This GRI standard specification is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This specification will be reviewed at least every 2-years, or on an as-required basis. In this regard it is subject to change at any time. The most recent revision date is the effective version and it is kept current on the Institute's Website <<geosynthetic-institute.org>>.

1.4 This standard specification is intended to ensure good uniform quality LLDPE geomembranes for use in general applications.

Note 2: Additional tests, or more restrictive values for the tests indicated, may be necessary under conditions of a particular application. In this situation, interactions with the manufacturers are required.

Note 3: For information on installation techniques, users of this standard are referred to the geosynthetics literature, which is abundant on the subject.

2. Referenced Documents

2.1 ASTM Standards

D 792 Specific Gravity (Relative Density) and Density of Plastics by Displacement
D 1004 Test Method for Initial Tear Resistance of Plastics Film and Sheeting
D 1238 Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer
D 1505 Test Method for Density of Plastics by the Density-Gradient Technique
D 1603 Test Method for Carbon Black in Olefin Plastics
D 4218 Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
D 4833 Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products
D 5199 Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes
D 5323 Practice for Determination of 2% Secant Modulus for Polyethylene Geomembranes
D 5596 Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
D 5617 Test Method for Multi-Axial Tension Test for Geosynthetics
D 5721 Practice for Air-Oven Aging of Polyolefin Geomembranes
D 5885 Test method for Oxidative Induction Time of Polyolefin Geosynthetics by High Pressure Differential Scanning Calorimetry
D 5994 Test Method for Measuring the Core Thickness of Textured Geomembranes
D 6370 Standard Test Method for Rubber-Compositional Analysis by Thermogravimetry (TGA)
D 6693 Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes
D 7238 Test Method for Effect of Exposure of Unreinforced Polyolefin Geomembrane Using Fluorescent Condensation Device
D 7466 Test Method for Measuring the Asperity Height of Textured Geomembranes

D 8117 Standard Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by Differential Scanning Calorimetry

2.2 U. S. Environmental Protection Agency Technical Guidance Document "Quality Control Assurance and Quality Control for Waste Containment Facilities," EPA/600/R-93/182, September 1993, 305 pgs.

3. Definitions

Manufacturing Quality Control (MQC) - A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factory originated. MQC is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract specifications.
ref. EPA/600/R-93/182

Manufacturing Quality Assurance (MQA) - A planned system of activities that provides assurance that the materials were constructed as specified in the certification documents and contract specifications. MQA includes manufacturing facility inspections, verifications, audits and evaluation of the raw materials (resins and additives) and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if the manufacturer is in compliance with the product certification and contract specifications for the project.
ref. EPA/600/R-93/182

Linear Low Density Polyethylene (LLDPE), n – A ethylene/α-olefin copolymer having a linear molecular structure. The comonomers used to produce the resin can include 1-butene, 1-hexene, 1-octene or 4-methyl-1-pentene. LLDPE resins have a natural density in the range of 0.915 to 0.926 g/ml (ref. Pate, T. J. Chapter 29 in Handbook of Plastic Materials and Technology, I.I. Rubin Ed., Wiley, 1990).

Formulation - The mixture of a unique combination of ingredients identified by type, properties and quantity. For linear low density polyethylene geomembranes, a formulation is defined as the exact percentages and types of resin(s), additives and carbon black.

Nominal - Representative value of a measurable property determined under a set of conditions, by which a product may be described. Abbreviated as nom. in Tables 1 and 2.

4. Material Classification and Formulation

4.1 This specification covers linear low density polyethylene geomembranes with a formulated sheet density of 0.939 g/ml, or lower. Density can be measured by ASTM D1505 or ASTM D792. If the latter, Method B is recommended.

4.2 The polyethylene resin from which the geomembrane is made will generally be in the density range of 0.926 g/ml or lower, and have a melt index value per ASTM D1238 of less than 1.0 g/10 min. This refers to the natural, i.e., nonformulated, resin.

4.3 The resin shall be virgin material with no more than 10% rework. If rework is used, it must be of the same formulation (or other approved formulation) as the parent material.

4.4 No post consumer resin (PCR) of any type shall be added to the formulation.

5. Physical, Mechanical and Chemical Property Requirements

5.1 The geomembrane shall conform to the test property requirements prescribed in Tables 1 and 2. Table 1 is for smooth LLDPE geomembranes and Table 2 is for single and double sided textured LLDPE geomembranes. Each of the tables are given in English and SI (metric) units. The conversion from English to SI (metric) is "soft". It is to be understood that the tables refer to the latest revision of the referenced test methods and practices.

Note 4: The tensile strength properties in this specification were originally based on ASTM D 638 which uses a laboratory testing temperature of 23°C ± 2°C. Since ASTM Committee D35 on Geosynthetics adopted ASTM D 6693 (in place of D 638), this GRI Specification followed accordingly. The difference is that D 6693 uses a testing temperature of 21°C ± 2°C. The numeric values of strength and elongation were not changed in this specification. If a dispute arises in this regard, the original temperature of 23°C ± 2°C should be utilized for testing purposes.

Note 5: There are several tests sometimes included in other LLDPE geomembrane specifications which are omitted from this standard because they are outdated, irrelevant or generate information that is not necessary to evaluate on a routine MQC basis. The following tests have been purposely omitted:

- Volatile Loss
- Dimensional Stability
- Coeff. of Linear Expansion
- Resistance to Soil Burial
- Low Temperature Impact
- ESCR Test (D 1693 and D 5397)
- Wide Width Tensile
- Water Vapor Transmission
- Solvent Vapor Transmission
- Water Absorption
- Ozone Resistance
- Hydrostatic Resistance
- Tensile Impact
- Small Scale Burst
- Various Toxicity Tests
- Field Seam Strength

Note 6: There are several tests which are included in this standard (that are not customarily required in other LLDPE geomembrane specifications) because they are relevant and important in the context of current manufacturing processes. The following tests have been purposely added:

- Oxidative Induction Time
- Oven Aging
- Ultraviolet Resistance
- Asperity Height of Textured Sheet

Note 7: There are other tests in this standard, focused on a particular property, which are updated to current standards. The following are in this category:

- Thickness of Textured Sheet
- Tensile Properties, incl. 2% Secant Modulus
- Puncture Resistance
- Axi-Symmetric Break Resistance Strain
- Carbon Black Dispersion (In the viewing and subsequent quantitative interpretation of ASTM D 5596 only near spherical agglomerates shall be included in the assessment).

Note 8: The minimum average value of asperity height does not represent an expected value of interface shear strength. Shear strength associated with geomembranes is both site-specific and product-specific and should be determined by direct shear testing using ASTM D5321/ASTM D6243 as prescribed. This testing should be included in the particular site's CQA conformance testing protocol for the geosynthetic materials involved, or formally waived by the Design Engineer, with concurrence from the Owner prior to the deployment of the geosynthetic materials.

5.2 The values listed in the tables of this specification are to be interpreted according to the designated test method. In this respect they are neither minimum average roll values (MARV) nor maximum average roll values (MaxARV).

5.3 The various properties of the LLDPE geomembrane shall be tested at the minimum frequencies shown in Tables 1 and 2. If the specific manufacturer's quality control guide is more stringent, it must be followed in like manner.

Note 9: This specification is focused on manufacturing quality control (MQC). Conformance testing and manufacturing quality assurance (MQA) testing are at the discretion of the purchaser and/or quality

assurance engineer, respectively. Communication and interaction with the manufacturer is strongly suggested.

6. Workmanship and Appearance

6.1 Smooth geomembrane shall have good appearance qualities. It shall be free from such defects that would affect the specified properties and hydraulic integrity of the geomembrane.

6.2 Textured geomembrane shall generally have uniform texturing appearance. It shall be free from such defects that would affect the specified properties and hydraulic integrity of the geomembrane.

6.3 General manufacturing procedures shall be performed in accordance with the manufacturer's internal quality control guide and/or documents.

7. MQC Sampling

7.1 Sampling shall be in accordance with the specific test methods listed in Tables 1 and 2. If no sampling protocol is stipulated in the particular test method, then test specimens shall be taken evenly spaced across the entire roll width.

7.2 The number of tests shall be in accordance with the appropriate test methods listed in Tables 1 and 2.

7.3 The average of the test results should be calculated per the particular standard cited and compared to the minimum value listed in these tables, hence the values listed are the minimum average values and are designated as "min. ave."

8. MQC Retest and Rejection

8.1 If the results of any test do not conform to the requirements of this specification, retesting to determine conformance or rejection should be done in accordance with the manufacturing protocol as set forth in the manufacturer's quality manual.

9. Packaging and Marketing

9.1 The geomembrane shall be rolled onto a substantial core or core segments and held firm by dedicated straps/slings, or other suitable means. The rolls must be adequate for safe transportation to the point of delivery, unless otherwise specified in the contract or order.

9.2 Marking of the geomembrane rolls shall be done in accordance with the manufacturers accepted procedure as set forth in their quality manual.

10. Certification

10.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment.

English Units

Table 1(a) – Linear Low Density Polyethylene (LLDPE) Geomembrane (SMOOTH)

Properties	Test Method	Test Value								Testing Frequency (minimum)
		20 mils	30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness - (min. ave.) - mils • lowest individual of 10 values - %	D5199	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	per roll
Formulated Density (max.) - g/cc	D 1505/D 792	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	200,00 lb
Tensile Properties *(1)* (min. ave.) • break strength - lb/in. • break elongation - %	D 6693 Type IV	 76 800	 114 800	 152 800	 190 800	 228 800	 304 800	 380 800	 456 800	20,000 lb
2% Modulus (max.) - lb/in.	D 5323	1200	1800	2400	3000	3600	4800	6000	7200	per formulation
Tear Resistance (min. ave.) - lb	D 1004	11	16	22	27	33	44	55	66	45,000 lb
Puncture Resistance (min. ave.) - lb	D 4833	28	42	56	70	84	112	140	168	45,000 lb
Axi-Symmetric Break Resistance Strain (min.) - %	D 5617	30	30	30	30	30	30	30	30	per formulation
Carbon Black Content (range) - %	D 4218 *(2)*	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	45,000 lb
Carbon Black Dispersion	D 5596	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	45,000 lb
Oxidative Induction Time (OIT) (min. ave.) *(4)* (a) Standard OIT - min. — or — (b) High Pressure OIT - min.	 D 8117 D 5885	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	200,000 lb
Oven Aging at 85°C *(5)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 8117 D 5885	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	per formulation
UV Resistance *(6)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(8)*	D 7238 D 8117 D 5885	 N. R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	per formulation

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
- Break elongation is calculated using a gage length of 2.0 in. at 2.0 in./min.

(2) Other methods such as D 1603 (tube furnace) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (muffle furnace) can be established.

(3) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
- 9 in Categories 1 or 2 and 1 in Category 3

(4) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(5) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(6) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(7) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(8) UV resistance is based on percent retained value regardless of the original HP-OIT value.

SI (Metric) Units

Table 1(b) – Linear Low Density Polyethylene (LLDPE) Geomembrane (SMOOTH)

Properties	Test Method	Test Value 0.50 mm	0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	Testing Frequency (minimum)
Thickness - (min. ave.) - mm • lowest individual of 10 values - %	D5199	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	nom. -10	per roll
Formulated Density (max.) - g/cc	D 1505/D 792	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	90,000 kg
Tensile Properties *(1)* (min. ave.) • break strength - N/mm • break elongation - %	D 6693 Type IV	 13 800	 20 800	 27 800	 33 800	 40 800	 53 800	 66 800	 80 800	9,000 kg
2% Modulus (max.) - N/mm	D 5323	210	315	420	520	630	840	1050	1260	per formulation
Tear Resistance (min. ave.) - N	D 1004	50	70	100	120	150	200	250	300	20,000 kg
Puncture Resistance (min. ave.) - N	D 4833	120	190	250	310	370	500	620	750	20,000 kg
Axi-Symmetric Break Resistance Strain - % (min.)	D 5617	30	30	30	30	30	30	30	30	per formulation
Carbon Black Content (range) - %	D 4218 *(3)*	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	20,000 kg
Carbon Black Dispersion	D 5596	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	note *(3)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(4)* (c) Standard OIT - min. — or — (d) High Pressure OIT - min.	 D 8117 D 5885	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	90,000 kg
Oven Aging at 85°C *(5)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 8117 D 5885	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	per formulation
UV Resistance *(6)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(8)*	D 7238 D 8117 D 5885	 N. R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	 N.R. *(7)* 35	per formulation

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
- Break elongation is calculated using a gage length of 50 mm at 50 mm/min.

(2) Other methods such as D 1603 (tube furnace) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (muffle furnace) can be established.

(3) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
- 9 in Categories 1 or 2 and 1 in Category 3

(4) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(5) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(6) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(7) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(8) UV resistance is based on percent retained value regardless of the original HP-OIT value.

English Units

Table 2(a) – Linear Low Density Polyethylene (LLDPE) Geomembrane (TEXTURED)

Properties	Test Method	Test Value								Testing Frequency (minimum)
		20 mils	30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness (min. ave.) - mils • lowest individual for 8 out of 10 values - % • lowest individual for any of the 10 values - %	D 5994	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	per roll
Asperity Height (min. ave.) - mils	D 7466	16	16	16	16	16	16	16	16	Every 2nd roll *(1)*
Formulated Density (max.) - g/cc	D 1505/D 792	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	200,000 lb
Tensile Properties *(2)* (min. ave.) • break strength - lb/in. • break elongation - %	D 6693 Type IV	 30 250	 45 250	 60 250	 75 250	 90 250	 120 250	 150 250	 180 250	20,000 lb
2% Modulus – lb/in. (max.)	D 5323	1200	1800	2400	3000	3600	4800	6000	7200	per formulation
Tear Resistance (min. ave.) - lb	D 1004	11	16	22	27	33	44	55	66	45,000 lb
Puncture Resistance (min. ave.) - lb	D 4833	22	33	44	55	66	88	110	132	45,000 lb
Axi-Symmetric Break Resistance Strain (min.) - %	D 5617	30	30	30	30	30	30	30	30	per formulation
Carbon Black Content - %	D 4218 *(3)*	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	45,000 lb
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	45,000 lb
Oxidative Induction Time (OIT) (min. ave.) *(5)* (e) Standard OIT - min. — or — (f) High Pressure OIT - min.	 D 8117 D 5885	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	200,000 lb
Oven Aging at 85°C *(6)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 8117 D 5885	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	per formulation
UV Resistance *(7)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	D 7238 D 8117 D 5885	 N. R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	per formulation

(1) Alternate the measurement side for double sided textured sheet

(2) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
- Break elongation is calculated using a gage length of 2.0 in. at 2.0 in./min.

(3) Other methods such as D 1603 (tube furnace) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (muffle furnace) can be established.

(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
- 9 in Categories 1 or 2 and 1 in Category 3

(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

SI (Metric) Units

Table 2(b) – Linear Low Density Polyethylene (LLDPE) Geomembrane (TEXTURED)

Properties	Test Method	Test Value								Testing Frequency (minimum)
		0.50 mm	0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	
Thickness (min. ave.) - mm • lowest individual for 8 out of 10 values • lowest individual for any of the 10 values	D 5994	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. (5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	nom. -5% -10 -15	per roll
Asperity Height mm (min. ave.)	D 7466	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	Every 2nd roll *(1)*
Formulated Density (max.) - g/cc	D 1505/D 792	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	90,000 kg
Tensile Properties *(2)* (min. ave.) • break strength - N/mm • break elongation - %	D 6693 Type IV	 5 250	 9 250	 11 250	 13 250	 16 250	 21 250	 26 250	 31 250	9,000 kg
2% Modulus (max.) - N/mm	D 5323	210	315	420	520	630	840	1050	1260	per formulation
Tear Resistance (min. ave.) - N	D 1004	50	70	100	120	150	200	250	300	20,000 kg
Puncture Resistance – (min. ave.) - N	D 4833	100	150	200	250	300	400	500	600	20,000 kg
Axi-Symmetric Break Resistance Strain (min.) - %	D 5617	30	30	30	30	30	30	30	30	per formulation
Carbon Black Content (range) - %	D 4218 *(3)*	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	20,000 kg
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(5)* (g) Standard OIT - min. — or — (h) High Pressure OIT - min.	 D 8117 D 5885	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	 100 400	90,000 kg
Oven Aging at 85°C *(6)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 8117 D 5885	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	 35 60	per formulation
UV Resistance *(7)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	D 7238 D 8117 D 5885	 N. R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	 N.R. *(8)* 35	per formulation

(1) Alternate the measurement side for double sided textured sheet

(2) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
- Break elongation is calculated using a gage length of 50 mm at 50 mm/min.

(3) Other methods such as D 1603 (tube furnace) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (muffle furnace) can be established.

(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
- 9 in Categories 1 or 2 and 1 in Category 3

(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

Adoption and Revision Schedule
for
GRI Test Method GM17

"Test Methods, Test Properties and Testing Frequency for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes"

Adopted:	April 3, 2000
Revision 1:	June 28, 2000: added a new Section 5.2 that the numeric tables values are neither MARV nor MaxARV. They are to be interpreted per the designated test method. Also, corrected typographical error of textured sheet thickness test method designation from D5199 to D5994.
Revision 2:	December 13, 2000: added one Category 3 is allowed for carbon black dispersion. Also, unified terminology to "strength" and "elongation".
Revision 3:	June 23, 2003: Adopted ASTM D 6693, in place of ASTM D 638, for tensile strength testing. Also, added Note 4.
Revision 4:	February 20, 2006: Added Note 9 on Asperity Height clarification with respect to shear strength.
Revision 5:	Removed recommended warranty from specification.
Revision 6:	June 1, 2009: Replaced GRI-GM12 test method for asperity height of textured geomembranes with ASTM D 7466.
Revision 7:	April 11, 2011: Added alternative carbon black test methods.
Revision 8:	October 3, 2011: Expanded types of comonomers in the definition of LLDPE.
Revision 9:	December 14, 2012: Replaced GRI-GM12 with the equivalent ASTM D7238.
Revision 10:	November 14, 2014: Increased asperity height of textured sheet from 10 to 16 mils (0.25 to 0.40 mm).
Revision 11:	April 13, 2015: Unit conversion error was corrected for 0.75 mm (30 mil) thickness for the property of 2% modulus. The test value was changed from 370 N/mm to 315 N/mm in the SI (Metric) units tables to agree with the English units tables.
Revision 12:	November 4, 2015: Removed Footnote (1) on asperity height from tables.
Revision 13:	September 9, 2019: Editorial update to harmonize tables.
Revision 14:	March 17, 2021: Updated Standard OIT Test from ASTM D3895 to D8117.