

SCS ENGINEERS



**Corrective Action Measures
Inert Gas Injection Work Plan
for Hot Spot Remediation**

Presented to:

Bridgeton Landfill, LLC

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Bridgeton, Missouri 63044
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September 9, 2015
File No. 23211003.04

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Superfund

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Appendices

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1.0 INTRODUCTION

In their letter dated August 10, 2015, the Missouri Department of Natural Resources (DNR) requested that Bridgeton Landfill, LLC prepare a Corrective Measures Work Plan that includes:

"...a corrective action measure using inert gas injection as a "hot spot" treatment."

This report presents the specifically requested Corrective Measures Work Plan.

Appendix D of the November 2014 Corrective Action Plan describes the identification of and remedial actions for local subsurface oxidation (SSO). As described in Appendix D:

"Subsurface Oxidation Events (SSO) are common events that occur at many landfills that have active gas collection systems. These are local subsurface fires that are caused by a combination of subsurface conditions and well management. Unlike large subsurface reactions (which are extremely rare, do not require oxygen to propagate, and are quite different in nature), SSOs usually only involve a small area and a minimal number of gas wells."

If the actions described in Appendix D of the November 2014 Corrective Action Plan are unsuccessful in controlling the SSO, inert gas injection may be implemented to remediate the SSO event.

2.0 INERT GAS INJECTION BACKGROUND

Carbon dioxide and nitrogen have been used to combat typical subsurface landfill fires. When the gas is introduced into the subsurface under pressure, it cools the fuel and displaces the oxygen that is supporting combustion. Inert gases can be injected in a gaseous or liquid state. Injection of the gas as a liquid allows the material to transform from liquid to gas in the subsurface, providing additional cooling and driving force beyond the injection pressure as the liquid "boils" and the gas expands.

Liquid carbon dioxide (CO₂) is the preferred inert gas for subsurface injection. Liquid CO₂ is easier to work with than liquid nitrogen (N₂) because of the extreme temperatures of liquid nitrogen, which boils at -321 °F. Additionally, nitrogen is a typical parameter monitored to evaluate the presence of potential air intrusion at adjacent monitoring points. A gram-mole of liquid CO₂ at 25 degrees Celsius (°C) and 300 pounds per square inch (psi) will expand to 22.4 liters at standard temperature and pressure (STP) conditions (0 °C and 1 atmosphere). This is equivalent to about 8.2 cubic feet (ft³) per pound or 16,433 ft³ per ton of liquid CO₂.

The injection of inert gas has been successful in extinguishing subsurface oxidation (SSO) events, but it has not been successful in all cases. The challenge for the injection of inert gas is how to ensure that it is introduced into the landfill in such a manner so that it is uniformly distributed throughout the impacted materials. Municipal solid waste in a landfill is a non-heterogeneous material. Depending on the specific items and materials that make up the waste

and the variability of the compaction effort, some denser areas may remain isolated from the gas. In these instances, the SSO event may rebound and, in the worst case scenario, continue to expand. In these cases, a repeat of the inert gas injection program or the application of other control measures may be required to remediate the SSO event.

The injection of inert gas may have a negative impact on the gas collection and control system. Typically, the landfill gas (LFG) collection system would be turned off in the immediate vicinity of the injection activity. Alternatively, the landfill gas collection system will be turned off in a wider area extending beyond the impacted area during treatment. If part of the landfill gas collection system remains active, gas extraction wells near the injection area might be able to be used to "steer" the migration of the treatment gas. The downside of leaving the landfill gas collection system active near the treatment area would be the capture of a significant amount of the treatment gas. If the methane (and/or hydrogen and carbon monoxide) content is sufficiently reduced, the flare(s) could require supplemental fuel to burn. Bridgeton Landfill has a natural gas line connected to the flares that can be used to supplement the landfill gas and keep the flares operating if inert gas is drawn into the collection and control system.

Inert gas injection is not a recommended remedial strategy for the subsurface event (SSE) reaction that exists in the South Quarry portion of the landfill. The SSE is not fire and does not require oxygen to support the chemical reactions that are occurring. The injection of inert gas would not interrupt these chemical reactions. Other than a potential slowing of the reactions due to the temporary cooling effect of the gas, the injection of inert gas will not end the SSE. Even if the inert gas could have an impact on the chemical reaction driving the SSE, the waste at depth is denser, increasing the difficulty of ensuring the gas is in direct contact with all the waste.

Therefore, inert gas injection technology is not appropriate for large, deep, area-wide reactions nor for conventional landfill fires (or SSOs) deeper than 30 feet

3.0 INERT GAS INJECTION FIELD PROGRAM

The following sections describe in general terms a program of inert gas injection. A program specific to the conditions encountered for an individual SSO event should be developed.

3.1 IDENTIFICATION OF AFFECTED AREA

The affected area must be delineated in order to design an effective injection plan. The Bridgeton Landfill, LLC Environmental Manager and the MDNR will actively collaborate to verify and classify the SSO event. Such determination will be made within four weeks of the Initial Notification. The event will be classified as a local SSO if monitoring indicates that combustion is constrained to one gas well and that there is no evidence that the SSO is enlarging. The Bridgeton Landfill will begin to implement their standard procedures to remediate an SSO as described in the Corrective Action Plan Appendix D, Local Subsurface Oxidation (SSP – Potential Landfill Fire), attached to this document as Appendix A. The Environmental Manager and the MDNR will actively collaborate to determine if and when inert gas injection should be performed.

3.1.1 Surface Observations

As described in Appendix D of the November 2014 Corrective Action Plan, typical symptoms of a SSO event include:

- Dramatic localized landfill settlement.
- Charred or cracked surface cover.
- Stressed or dead vegetation in an area that is otherwise properly vegetated.
- Smoke or smoky odor emanating from the landfill surface or wellhead.
- Drastic or unusual increase in flowing gas temperature.
- Abnormal discoloration of wellhead/riser assembly.
- Abnormally high carbon monoxide (CO) concentration in LFG.
- Deformed riser pipes.

To further define the area of the SSO event, a ground-based infrared (IR) thermometer survey should be performed. Use a hand-held IR laser thermometer (or equivalent device) to measure the temperature of the ground surface in area where an SSO event is suspected. Shallow fires or fires that have consumed large amounts of refuse will produce elevated surface temperatures. Extreme caution must be taken in these areas due to the possibility of the ground giving way. The area should be marked with caution tape to prevent individuals from walking or driving in the area of concern.

3.1.2 Subsurface Investigation

In order to design the injection point array to maximize the effect of the inert gas, the vertical location and extent of the SSO event should be defined. Given that the gas will tend to flow towards the lower atmospheric pressure at the ground surface, the injection points should be located at or just below the base of the SSO event area. The following methods can be used to evaluate the vertical extent of the SSO event.

3.1.2.1 Downhole temperature monitoring

If one or more gas extraction wells are present in the SSO event area, downhole temperature measurements can be made in these wells.

It should be noted that the procedures below may expose the observer to significant risks, including but not limited to:

- Explosive concentrations of methane.
- High concentrations of volatile organic compounds (VOCs).
- High temperature gas.
- High temperature well components.

The vacuum to the well should be shut off or reduced significantly to prevent the introduction of large quantities of air into the collection system. Depending on the well head construction, open an access port or remove the well head. Lower a thermocouple into the well and record the temperature at 5-foot intervals below the surface. SSO events are typically shallow, so the measurements should not extend below 50 ft and should not be performed below the liquid level in the well.

3.1.2.2 Thermocouple Array Installation

In situ subsurface temperature measurements can be made by installing arrays of thermocouples at regular depth intervals below the surface. The thermocouple arrays cannot be installed within the actual area of combustion of the SSO event, but can be installed outside the area of combustion to evaluate the vertical distribution of heat from the combustion. The arrays will be installed using Direct Push Technology (DPT) drilling methods. The DPT drill pipe will be advanced to the target depth with a disposable point. The arrays will consist of thermocouples attached to a solid spine of plastic or fiberglass rod. The thermocouples will be attached to the spine at 5-foot intervals with electrical tape. The wires will be secured to the spine above each of the thermocouples. The wire leads will be clearly labelled to identify the depth of burial of each of the thermocouples. The spine and thermocouple array will be placed in the drill rod. The drill rod will be withdrawn and the annulus between the borehole and the array will be filled with bentonite grout. The grout is intended to isolate the thermocouples by preventing hot gases from moving within the annulus. The surface at each array will be completed with an 18-inch thick concrete surface seal.

A vertical support will be placed into the surface seal. A weather proof box will be attached to the vertical support. The thermocouple wire terminals will be accessed inside the box. The spine and thermocouple wires have been known to act as a preferred pathway for landfill gas. Gas leaking around the wires may have to be addressed with additional bentonite and/or soil.

3.2 GAS INJECTION POINT INSTALLATION

Gas injection points (GIPs) will be installed using DPT drilling techniques. The injection points will be installed at standard 25 foot depth below the surface, unless investigations have been performed to determine the vertical extent. The gas injection points will consist of a dedicated 2-inch diameter DPT drill tooling (pipe) with ¼-inch holes drilled around the bottom two feet of the pipe. The holes will be spaced at approximately 2 inches apart in order to not overly weaken the pipe prior to installation. The surface at each injection point will be completed with an 18-inch thick concrete surface seal. For injection and pre-injection gas sampling the points will be fitted with a conversion from A-P drill thread to national pipe thread (NPT).

The top of the injection point will be fitted with a 90-degree elbow and a stainless steel, quarter turn ball valve. In addition, the top of the injection point will be fitted with either a pressure gage and/or a self-sealing quick connect to allow a pressure measurements (and gas measurements) to be made using a GEM or similar instrument. Coordinate with the CO₂ supplier to determine what the final connection should be to be compatible with the tanker truck delivery hoses.

For conservativeness, the radius of influence of each point has been estimated to be approximately 15 feet. Therefore, an array of injection points on a roughly 25-foot grid should be installed over the identified SSO event area. The grid should extend beyond the SSO event area, with a minimum of one injection point located outside the identified SSO event area on all sides.

3.3 INJECTION OF INERT GAS

As described above, it is estimated that each well will have a radius of influence of approximately 15 feet. Each injection point will consist of a 2-foot long perforated section of pipe and is estimated to influence approximately 5 feet vertically. An assumption of approximately 25 percent void space in the refuse mass was used to determine the volume of liquid CO₂ needed for a single well. The estimated liquid CO₂ utilized per injection point is 884 ft³, or 108 pounds of liquid CO₂.

Liquid CO₂ injection will be performed over a one-day period. Liquid CO₂ will be delivered to the Site via tanker truck. Access to the SSO area suitable for the tanker truck must be prepared. At each well location, the liquefied CO₂ supplier will connect directly to the gas injection point, and deliver approximately 108 pounds of liquefied CO₂. Note that it will be difficult to determine the exact amount of liquid CO₂ injected into each point due to the nature of the liquid CO₂ delivery (via tanker truck), therefore close attention will be paid to back pressure on the injection point, CO₂ and pressure influence on adjacent monitoring locations, and temperature fluctuations at the temperature monitoring points (if installed). The liquid CO₂ will be targeted for injection at pressures between 200 and 300 psi. This range has been selected due to higher pressures having the potential for causing ground upheaval and because, at pressures lower than approximately 75 psi, CO₂ will become a solid.

The injection will begin at the outer gas injection points and work inward to the center of the suspected combustion zone. This will minimize the potential for forcing heat outward from the combustion zone into adjacent areas. A Health and Safety Plan will be prepared to cover the inert gas injection activities and will be attached to this work plan prior to implementation. Special hazards include the risk of suffocation due to the displacement of oxygen and the risk of frostbite from super cooled gas, hoses, and piping.

Up to four rounds of injections are anticipated under the following scenario:

- Initial injection and monitoring overnight to determine the need for additional injection based on real-time monitoring of subsurface temperatures at the thermocouple locations.
- Additional injection on the second day, as needed.
- Temperature monitoring for one week and evaluation of need for additional injection (this may include evaluation of the need for additional injection points).
- Third injection within 24-72 hours, if needed.
- Weekly temperature monitoring for up to four weeks.

- If rebounding occurs after the third injection, a fourth injection will be implemented within 24-72 hours.
- Weekly temperature monitoring for up to four weeks.

Subsequent injections following the first day may be targeted at specific GIP locations rather than repeated injections at all GIP locations.

3.4 MONITORING

Monitoring must be performed during injection. Monitoring must also be performed after the injection has been completed to evaluate long term effect of the gas injection.

3.4.1 Injection Monitoring

The observer will look for any visual or audible signs of short circuiting; including surface cracking, gas release indicated by the discharge of soil particles or plumes of condensation from cold gas, or hissing noises. Potential leakage around the edges of the temporary cover and near thermocouple and injection points completed through the cover will also be monitored for VOCs using a hand-held FID and for CO₂ using a GEM 5000 (or equivalent).

Unused injection points will be monitored to ascertain if CO₂ gas has extended to the adjacent points as well as to monitor the gas within the zone of concern.

If they have been installed, temperature probes will be monitored prior to, during, and after each liquid CO₂ injection.

3.4.2 Performance Monitoring

After liquid CO₂ injection, the temperature points will be monitored for rebound of temperatures above 170 °F that may occur over the following month to determine the effectiveness of the liquid CO₂ injection at suppressing the elevated temperatures at the site. Generally, temperatures are expected to either rebound to former higher levels or stabilize at the lower temperatures within several days after injection. Temperature readings will be recorded continuously at 1-hour intervals throughout and after the gas injection by the existing thermocouple array. The thermocouple data will be read continuously until a few hours after injection, at least once on the following day, and on a weekly basis thereafter until it has been determined that temperatures have stabilized and there is little potential for re-ignition of the prior combustion.

In the event that elevated temperatures are not abated, a re-injection and/or expansion of the liquid CO₂ injection area may be required as discussed above.

If rebounding does not occur within four weeks following the second, third or fourth injections, the fire will be considered to be extinguished. If rebound occurs after the fourth injection, additional work will be warranted.

4.0 SCHEDULE

The schedule discussed within does not include the time to initially identify the SSO or the initial remedial efforts consistent with the oxygen deprivation approach described in Appendix D of the Corrective Action Plan. This schedule begins when the decision has been made that the initial oxygen deprivation remediation program has not adequately addressed the SSO.

During month one, any additional effort to verify the areal and/or vertical extent of the SSO will be performed. During this time, the array of GIPs will be designed and installed. Also a supplier of inert gas will be identified and placed under contract. During month two, the gas injection(s) will be performed. Month three will consist of performance monitoring to verify that the SSO has been successfully remediated.

5.0 REPORTING

Weekly Status Updates will be provided via email throughout the period for implementation of this work plan. Status Updates will include discussion of on-Site activities during the previous week, summary of data and findings, and planned activities for the following week. The Status Updates will be provided by close of business on Monday of the following week.

Appendix A

Corrective Action Plan Appendix D, Local Subsurface
Oxidation (SSO – Potential Landfill Fire)

APPENDIX D

LOCAL SUBSURFACE OXIDATION PROCEDURE

Appendix D

Local Subsurface Oxidation (SSO – Potential Landfill Fires)

Subsurface Oxidation Events (SSO) are common events that occur at many landfills that have active gas collection systems. These are local subsurface fires that are caused by a combination of subsurface conditions and well management. Unlike large subsurface reactions (which are extremely rare, do not require oxygen to propagate, and are quite different in nature), SSOs usually only involve a small area and a minimal number of gas wells.

In the North Quarry of the Bridgeton Landfill, it is important to distinguish between an isolated, readily-contained and easily-extinguished SSO from the advancement or initiation of a large subsurface reaction.

Typical Symptoms

- Dramatic localized landfill settlement.
- Charred or cracked surface cover.
- Stressed or dead vegetation in an area that is otherwise properly vegetated.
- Smoke or smoky odor emanating from the landfill surface or wellhead.
- Drastic or unusual increase in flowing gas temperature.
- Abnormal discoloration of wellhead/riser assembly.
- Abnormally high CO concentration in LFG.
- Deformed riser pipes.

Initial Notification and Investigation

Notify Environmental Manager immediately after visually identifying any potential SSO. An initial investigation shall be started within 12 hours after visual identification of a potential SSO.

- 1) Do not change the condition of the well during the initial investigation.
- 2) Health and Safety Considerations
 - Consult HASP for procedures related to landfill fires.
 - Under no circumstances shall an initial investigation be conducted without first consulting the HASP and implementing appropriate controls and procedures.
 - Do not breathe landfill gas or smoke. Stand upwind of emissions.
 - Wear appropriate PPE. Burns may be caused by hot PVC / HDPE / steel.
 - Do not drive heavy equipment / vehicles near well or depression until ground stability has been verified. *The burned waste mass may give way and equipment/personnel may fall into sinkhole.*
- 3) Conduct physical inspection
 - a) Inspect the nearest extraction well to the potential SSO location.
 - b) Inspect all wells within 500 feet of nearest extraction well to the potential SSO location.
 - c) Inspect the landfill surface within 500 feet of nearest extraction well to the potential SSO location.

d) Visibly inspect for large localized settlement, cracks, holes, collapse, missing components, and areas that could be sources of air intrusion into the waste mass including:

- Monitoring ports
- Well casing
- Hoses
- Erosion ruts
- Dry soil cracks
- Manways
- Lift stations
- Sumps
- Leachate cleanout risers

4) Measure gas quality, pressure and temperature, at all wells within 500 feet of nearest extraction well to the potential SSO location. *Special precautions may be necessary to address high gas temperatures.*

5) Measure CO concentrations with colorimetric tubes (Draeger tubes) at all wells within 500 feet of nearest extraction well to the potential fire location, and obtain summa canister samples for laboratory CO analyses at all wells that indicate CO detections >500 ppm by colorimetric tube. *Gas temperature and other interference gasses can affect the accuracy of the measurement; therefore, the results of any CO field monitoring should be expressed qualitatively only.*

6) Infrared Thermometer Survey

- Use an IR laser thermometer to measure the temperature of the ground surface in the area of the suspected SSO. *Shallow fires or fires that have consumed large amounts of refuse will produce elevated surface temperatures. Extreme caution must be taken in these areas due to the possibility of the ground giving way.*

SSOs are often caused by “overpulling” a gas well or wells in a certain area. Oxygen is drawn into the waste mass which can generate heat and provide the necessary oxygen for combustion. Since oxygen readings are collected as part of normal Title V, New Source Performance Standards (NSPS) monitoring, a review of the collected historical data from surrounding wells should be made. The data review should trend oxygen readings in from the wells in the general area of the SSO to determine if there was an overpull situation. Temperature should also be historically trended as heat; along with CO data (see below) is a good indicator of an SSO in the area.

Gas quality in wells adjacent to the SSO *may* be affected. In particular, carbon monoxide levels could elevate based on wellfield operation issues and preferred pathways within the waste mass. It is important to determine if the SSO is constrained to a single gas well and / or a single isolated area. Therefore, laboratory CO analyses will be expedited with results received within seven days of detection by colorimetric tube.

If the above investigation suggests that more than one gas well may be actively involved in an SSO area, then the investigation shall be expanded to include the wells within 500 feet of the SSO area.

Formal Notifications

The Environmental Manager shall notify the MDNR (SWMP Engineering Section Chief or Program Director at (573) 751-5401) within one business day of determination. The notification will include the gas well identification, date of initial detection, approximate area of the SSO, and results of initial investigation. The MDNR may observe or conduct confirmatory sampling.

Data Analysis

Determine the state of the SSO

- Analyze temperature gradient between monitored wells.
- Analyze oxygen gradient between monitored wells.
- Analyze nitrogen to oxygen ratio gradient between monitored wells. *If nitrogen is not measured directly, assume balance gas of nitrogen.*
- Analyze pressure gradient between monitored wells.
- Analyze methane to CO₂ ratio gradient between monitored wells.

Removing the Oxygen from the Fire

The key to stopping a SSO once it has begun is to completely restrict oxygen from entering the smoldering waste mass (snuff out the fire). Once the initial investigation has been performed and a general sense of the extent of the SSO has been determined, safely begin to restrict further oxygen intrusion using the following method:

- 1) Shutdown well(s) that is believed to have been the cause of the SSO.
- 2) Shutdown all wells in surrounding area (within the approximately 300 feet of suspect well(s)).
- 3) Cap or repair any item identified during the physical inspection that may be contributing to oxygen intrusion.
- 4) Carefully add additional cover to areas that show cap integrity issues if necessary. Work slowly and pay special attention to the ground surface as material placement commences.
 - During cover placement activities, there should be a minimum of two people available; the equipment operator, and a line-of-sight person on the ground that is responsible for watching the ground surface as the equipment operator places the soil.
 - Use a low ground pressure (LGP) machine, if available. If LGP machine is not available, use the lightest machine with the widest tracks available. Do not use rubber tired machine to place cover material.
 - Slowly push soil into the area and compact with the bucket or tracks of the equipment.

Note: Closing wellhead valves to minimize vacuum in the area of concern may cause vacuum levels to increase within the main header. This will redistribute the overall vacuum applied to the wellfield and may cause higher vacuums to other wells in the GCCS. Carefully watch for redistribution of vacuum, and adjust prime mover vacuum set-point accordingly. If greater than 10 percent of the total wells in the wellfield are closed to remediate the SSO, a complete retune of the wellfield may be warranted.

Things to Avoid

- Flushing the well with water – Flushing the well with water can potentially clog the well.
- Excavating soil in the SSO area – Do not excavate in the SSO area. Excavation will allow additional oxygen to enter the already smoldering waste mass and can potentially auto-ignite.
- Venting – Do not remove the wellhead to vent the well. Wellfields are typically under negative pressure. Residual vacuum exists in the waste mass for a period of time when wells are closed. If the wellhead is removed to vent, it is highly possible that the residual vacuum in the area will pull ambient air into the waste mass adding oxygen to the SSO.
- Introduction of water into open cap fissures – Applying water to open fissures in the cap where an SSO exists can create a plume of highly odorous stream. It is also dangerous to bring a heavy, rubber tired water truck to the area to apply water. The steam created can be dangerous to workers in the immediate area. If an open cap fissure exists in an SSO area, it shall be safely filled with soil. Removing the pathway for oxygen intrusion is the most effective way to put out the SSO.

Continued Monitoring

Monitor the wells closest to the suspected SSO area and adjacent wells at least once a day for at least two weeks.

- Monitor for gas quality, temperature, and CO. *As the SSO subsides, residual CO will remain in the waste mass for weeks and possibly months. Elevated CO levels are not a reliable indicator that an SSO is still in progress. However, CO levels should generally decline with time if the fire has been extinguished.*
- Once SSO indicators are no longer noted, monitor the well and adjacent wells once a week for at least 4 months before returning to normal monitoring schedule.

It is important that during these monitoring events the valve on the wellhead is opened for a prescribed time at a prescribed vacuum. This must be performed consistently from event to event to pull stagnant LFG from the well and fill the casing with fresh LFG from the Landfill formation. Analysis of this fresh LFG will provide the most realistic picture of the status of the SSO. Once readings are collected, the well must be returned to its closed position.

Repairs

Repairs should be made to the SSO area, as necessary

- Visual Inspection
- O&M Provider shall visually inspect the following:
 - Wellheads and lateral piping,
 - Cover soil and geosynthetics, and
 - Other items within SSO area.
- Provide findings to, and generate repair options for OM&M Manager.
- OM&M Manager shall facilitate repairs, as required.

Timeline for Local SSO Resolution

It is important that a structured SSO monitoring plan and diligent adherence to the plan be carried out to return the wellfield to normal operation as soon as possible. However, it is advisable to take time and slowly ensure the SSO is fully extinguished and that the bacteria population in the area has recovered and is consistently producing gas.

The severity of the SSO, the age of the waste, moisture content, and a number of other variables will all determine how long it takes the wellfield to regain compliance with NSPS. Experience has shown that the timeline from the point when the SSO is identified and extinguished to the point when the wellfield resumes normal operation can vary from 2 to 3 weeks up to (in some serious SSO situations) 1 year or more.

Classification of the Event

The Environmental Manager and the MDNR will actively collaborate to verify and classify the SSO event. Such determination will be made within four weeks of the Initial Notification.

The event will be classified as a local SSO if monitoring indicates that combustion is constrained to one gas well and that there is no evidence that the SSO is enlarging.

If the event is not classified as a local SSO and may, instead, be considered a triggerable action per the North Quarry Contingency Plan, then Bridgeton Landfill and the MDNR will discuss and reach agreement on the appropriate action which may include further monitoring or entering into the path of actions provided in Table 1 of the North Quarry Contingency Plan – Part 1.

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COST

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