Environment Protection Authority

Response to Questions from the Nuclear Fuel Cycle Royal Commission – Natural Attenuation and Groundwater Flow Rates

December 2015

EPA's Role Statement

The Environment Protection Authority (EPA) influences and regulates human activities to protect and restore the environment.

Introduction

The Nuclear Fuel Cycle Royal Commission wrote to the Environment Protection Authority (EPA) on 1 December 2015 seeking information with respect to evidence provided to the Commission's public session held on Wednesday 14 October 2015 regarding 'Expansion of Exploration and Mining Activities'. The further information requested relates to evidence of natural attenuation of groundwater at the Beverley in situ recovery uranium mine and the EPA's view of statements made by employees of Heathgate Resources about the movement of groundwater at the Beverley operation.

The EPA is responsible for administration of the *Environment Protection Act 1993* and *Radiation Protection and Control Act 1982*, both of which have a role in regulation of the industries identified in the letter.

The EPA works with a number of other government agencies in the assessment and regulation of uranium mining activities, in particular with the lead agency for mining in South Australia, the Department of State Development (DSD). Other agencies with roles in the assessment process include Aboriginal Affairs and Reconciliation, SafeWork SA, and the Department of Environment, Water and Natural Resources (DEWNR).

This report provides further information to support statements made by the EPA during the Commission's public sessions and the basis for the EPA's views with respect to statements made by Heathgate Resources.

The report also discusses the role of the EPA with respect to the function of DSD who are responsible for administration of the *Mining Act 1971*.

Q 1: Evidence that the acidic solution injected into the groundwater during in-situ recovery operations at Beverley is naturally attenuating over time.

BACKGROUND

Uranium mining activities in South Australia are authorised by the EPA through licences under the Radiation Protection and Control Act to carry out mining or mineral processing of a prescribed radioactive substance, and the Environment Protection Act to undertake prescribed activities of environmental significance.

In administration of its legislative function, the EPA works closely with DSD, which administers the Mining Act and is the lead regulatory agency for mining developments in South Australia. Through authorisations under the Mining Act, proponents develop documents that describe a mine proposal and operations, including a Program for Environment Protection and Rehabilitation. These documents are developed in close consultation with the EPA and other Government agencies to ensure agency requirements are adequately addressed.

Uranium mines also require Commonwealth approval under *Environment Protection and Biodiversity Conservation Act 1999*.

A key objective of State and Commonwealth authorisations with respect to groundwater is to ensure that risks to the environment and community are managed for present and future generations. Monitored natural attenuation is a key consideration in achieving this goal.

It is Commonwealth and State Government policy that any new uranium mining project must represent best practice. To this effect, Australia's In Situ Recovery Uranium Mining Best Practice Guide (Geoscience Australia, 2010) was published by the Australian Government in partnership with the South Australian Government. The Best Practice Guide details the principles of best practice, which uranium in situ recovery mines must meet.

The Best Practice Guide outlines the principles that:

- rehabilitated sites will not present any significant radiation exposure risks;
- impacts on groundwater quality will be within agreed parameters which reflect future land uses;
- there will not be impacts on any other aquifers at the mining lease or beyond; and
- the lease and surrounding area will be left in a state fit for agreed future land uses.

While there is an expectation that the above objectives will be met during operations, the Best Practice Guide supports an iterative approach that will enable continued assessment of groundwater impacts. This approach provides a basis for optimizing the planning of mine closure strategies and selecting the best techniques for remediation of groundwater.

DISCUSSION

Natural attenuation can be defined as the '*process occurring without the addition of amendments which over a period of time results in the composition of a liquid returning to or towards its pre-contaminated state. In this context, the process occurs with the aquifer'* (CSIRO 2004).

The EPA bases its view on monitored natural attenuation on several lines of evidence. These include published studies, modelling, laboratory studies and in field measurements.

<u>Published Studies</u>

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

The CSIRO published a 'Review of Environmental Impacts of the Acid In-situ Leach Uranium Mining Process' (CSIRO, 2004) that supports adoption of monitored natural attenuation as a management technique for uranium mine operations:

> *'Overseas operations show that natural attenuation will occur, and that natural attenuation has indeed reduced the impact from acid ISL on groundwaters and limited the seepage of leach solution from the well fields, with eventual return to pre-mining conditions.' And;*
>
> *'Overall, we consider that remediation of groundwaters already impacted by mining and re-injection appears unwarranted because of its perceived limited beneficial use and its expected natural attenuation.'*

International Atomic Energy Agency (IAEA)

The system of radiation protection adopted in South Australia is based around an international framework developed through international bodies, including the IAEA. The Manual of Acid In-situ Leach Uranium Mining Technology' (IAEA, 2001) (TECDOC 1239) acknowledges that natural attenuation occurs over extended periods via dilution and dispersion, with high salinity aquifers an appropriate option for disposal of in situ leach mineralized residual solutions.

A key focus of this paper is the Beverley uranium mining operations, which occurs principally within the Namba and Eyre Formation. Extensive testing has shown that the water quality of aquifers within the lease application areas have no potential beneficial use (as determined by the *ANZECC Guidelines for Fresh and Marine Water Quality 2004*) due to its inherent natural salinity, fluoride and radon concentrations.

<u>Laboratory Studies</u>

Pilot studies, typically conducted within a laboratory, utilise drill core sample material removed from an aquifer where a proposed mine is to occur. These studies confirm the acid consumption potential of an aquifer proposed for mining. The results of laboratory studies are also used as inputs for transport models.

A study was undertaken by the Australian Nuclear Science and Technology Organisation (ANSTO), 'Attenuation characteristics of Four Mile project area cores' (ANSTO Minerals, 2008), to determine the attenuation characteristics of drill core samples from the Four Mile deposit. This laboratory study assessed the impact of the various parameters of the core samples (clay, iron, calcite/calcium) on attenuation and allowed for modelling of mining fluid behaviour to determine aquifer/wellfield management strategies.

Laboratory test findings were confirmed during wellfield development. Acid added to mining fluid to maintain required pH corresponds to the natural attenuation processes identified during the studies.

Modelling

Complex models that incorporate site specific physical and chemical parameters are used to predict the transport of mining solutions within an aquifer. Models are utilized prior to mining and during operations to complement in-field measurements.

Hydrogeological modeling allows the development of a robust understanding of the geochemical processes that will occur when mining solutions flow downstream of the orebody through rock pores. Heathgate has undertaken natural attenuation geochemical studies as part of the Public Environment Report required under the Environment Protection and Biodiversity Conservation Act for government assessment. This work comprised laboratory testing of aquifer material undertaken by ANSTO, and development of a geochemical model calibrated to the laboratory test data undertaken by a consultancy, UIT.

For broad modelling purposes, an industry standard groundwater model, 'ModFlow', was adopted with 'Path-CAD' utilised for onsite localised wellfield management.

In 2008, UIT undertook a natural attenuation project, 'from lab tests to FME Aquifer – Geochemical Modelling', to predict attenuation in post-mining aquifers at Four Mile East (Umwelt und Ingenieurtechnik GmbH, 2008). The geochemical modelling performed by UIT is based on PhreeqC (an industry standard geochemical modelling package). It combines transport (advection and dispersion) with geochemistry (thermodynamics and kinetics). Real case and worst case scenarios were modelled with the report stating 'in all cases the acid front (pH<6) and uranium never leaves the Four Mile Embayment; their influence is confined within a maximum range of 3 to 4 km apart from the ore zone' (pg 56).

The models predicted that natural attenuation would occur and that water quality would return to within the range of pre-mining concentrations over a distance of approximately 5-6km. This would impact only those aquifers and water bodies with poor quality groundwater suitable only for mining and industrial uses. For the Four Mile assessment, the hydrochemistry and hydrogeological components of the modelling were reviewed and accepted by separate independent experts engaged by Government.

In terms of ensuring ongoing assessment of the hydrogeological models, Heathgate Resources has a program of model validation, implemented during the life of mine, which is set out in the Program for Environment Protection and Rehabilitation for both Four Mile (Section 6.10) and Beverley North (Section 7.10). In support of this, a report has been recently submitted to DSD, which uses 18 months of Four Mile wellfield data to validate the acid consumption parameters applied in the natural attenuation model (Ben Jeuken, Groundwater Science, 2015).

The report concludes that the acid consumption parameters used in the geochemical model are reasonable, though conservative for predicting the fate of acidic lixiviant used for leaching uranium at Four Mile East compared to all measured data for the Eyre Formation aquifer.

In Field Measurements

In addition to modelling and pilot studies, monitoring of acidity (pH), sulphate (SO_4) and uranium concentrations is conducted to support monitored natural attenuation. Monitoring undertaken by uranium mining operators in South Australia are reported quarterly to government agencies including the EPA, DSD and DEWNR. The data are subject to scrutiny as part of regulatory oversight, including scrutiny by hydrogeological experts.

While cessation of mining at selected wellfields across the Beverley operations is limited to recent times, data collected to date (Figures 1 and 2) demonstrates that following cessation of wellfield activity, natural attenuation is capable of neutralising acid within a mined aquifer. In addition, other in situ recovery operations in South Australia have demonstrated that monitored natural attenuation is able to occur following complete cessation of mining.

Figures 1 and 2 below indicate recovery of both pH and SO_4 initially following cessation of mining activities at particular Beverley wellfields (CSIRO, 2004), (source: Heathgate). The figures show an initial rapid decrease in concentration, followed by a slow to flat downward trend over a period of years. These trends are in line with publications which indicate monitored natural attenuation is a process that requires an extended period to occur.

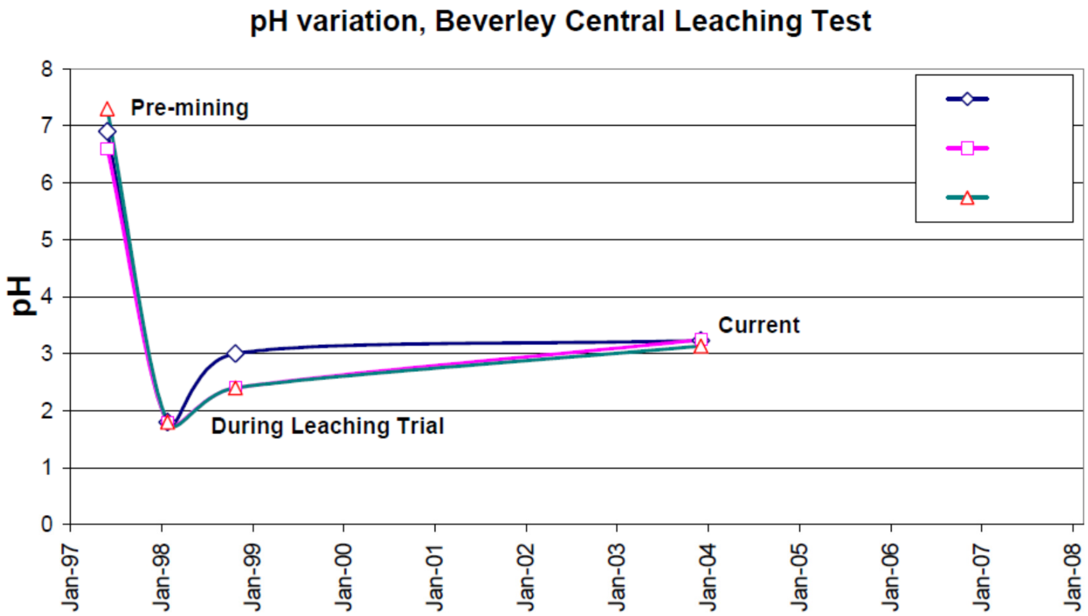

Figure 13 pH variation as measured at Beverley Central Leaching Test site before, during and after trial mining (Source: Heathgate Resources)

Figure 1: pH measurement following cessation of trial mining at Beverley Central Leaching Test site

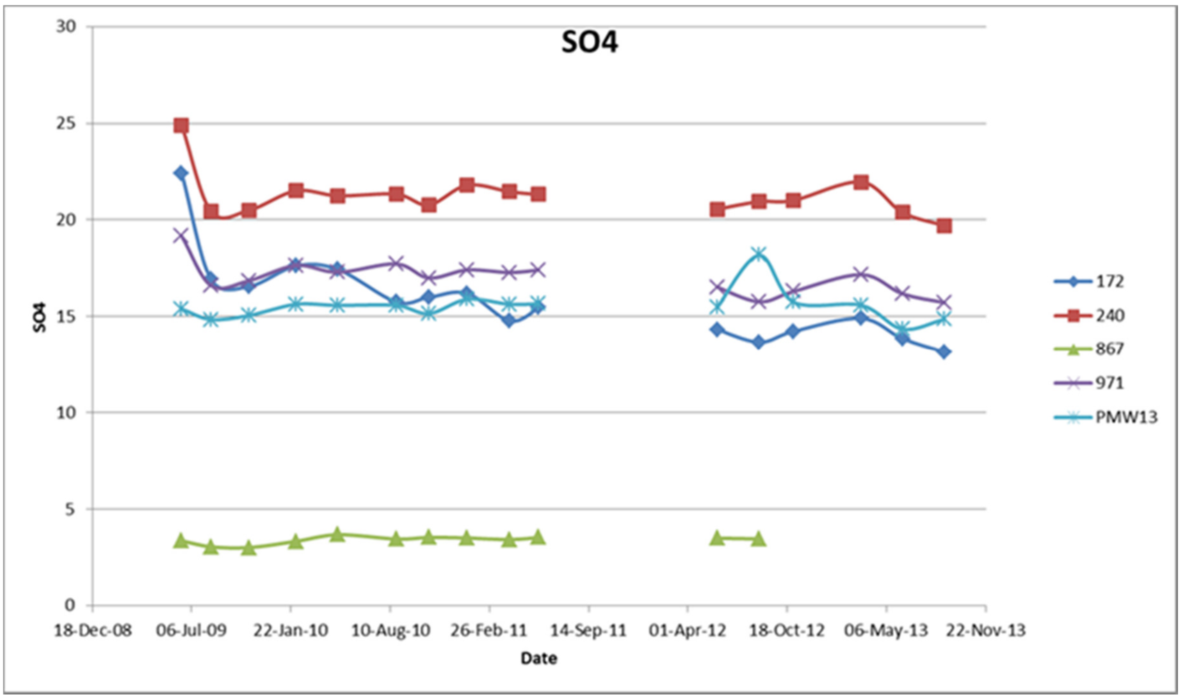

Figure 2: Sulphate (SO4) recovery following cessation of mining activities at selected Beverley wellfield

In addition to the Beverley operation, Oban Energy commenced a Field Leach Trial in 2010 as part of a proposed uranium mine operation. The trial involved approximately 10 tonnes of acid which was used to develop a trial wellfield.

Monitoring of the wellfields following cessation of the trial indicated that monitored natural attenuation objectives were able to be achieved for in situ recovery operations (Oban Energy Pty Ltd, 2015) (Figure 3). The relatively quicker recovery than that compared with an operational in situ recovery uranium mine may be due to there being a shorter wellfield development period, and that the trial involved considerably less acid.

These findings were supported in a third party assessment, Aldam Geoscience, who was engaged to conduct a hydrogeological review for Government. The findings stated that groundwater modelling conducted to support natural attenuation was valid, but conservative. The assessment indicated dispersion as an unlikely mechanism for attenuation of leach solutions at Oban, as the consumption of acid has been shown by the model to occur much more rapidly than previously modelled. It also indicated that pH will return to neutral within a few years and that, due to the relatively slow rates of water movement, there is no possibility of an acidified plume moving off site (Aldam 2014, p 3).

DSD, as lead regulator for closure of the Oban trial, engaged independent consultant Earth Systems (Jeff Taylor) to undertake a further review of the geochemistry of the Oban project's groundwater. The review found that following an additional round of groundwater monitoring in February 2015 it could be demonstrated that the pH of all trial groundwater wells had returned to between pH7-8, with dissolved uranium less than 1mg/L and acidity less than 50mg/L (Table 1).

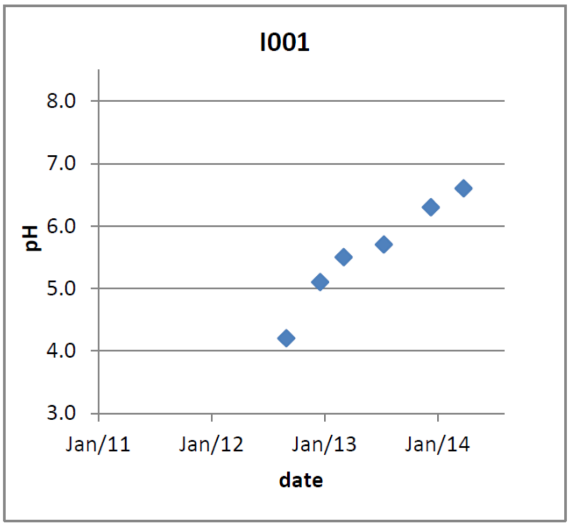

Figure 3: Oban pH monitored natural attenuation at the trial main injection well (I001) — Source: Aldam, R. (May 2014) *Review of Hydrogeological Conditions Oban ISR Site Havilah Resources NL*, Aldam Geoscience, pg. 41. (Note this report is also in Appendix D of the Final Compliance Report).

Page	: 4 of 5
Work Order	: EM1501373
Client	: HAVILAH RESOURCES NL
Project	: OBAN

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	OCM06	I001	I002	I003	I004
				Client sampling date / time	03-FEB-2015 15:00	03-FEB-2015 15:00	03-FEB-2015 15:00	03-FEB-2015 15:00	03-FEB-2015 15:00
Compound	CAS Number	LOR	Unit		EM1501373-006	EM1501373-007	EM1501373-008	EM1501373-009	EM1501373-010
EA005P: pH by PC Titrator									
pH Value	----	0.01	pH Unit		7.32	7.24	7.20	7.11	7.08

Table 1: Most recent pH results from the Oban trial, taken February 2015 (Appendix E, Final Groundwater Sampling) in the Final Compliance Report.

Source: Giles, C (August 2015), *Final Compliance Report For Rehabilitation and Closure of ISR Trials on Retention Lease 123 at Oban, South Australia*, Oban Energy Pty Ltd, pg. 175.

Monitored Natural Attenuation – Further Considerations

While there are lines of evidence that demonstrate monitored natural attenuation is a valid approach to management of aquifers at in situ recovery operations, ongoing monitoring is required to continually refine and verify these lines of evidence. This includes the development of contingency plans should the state of knowledge and evidence change such that the stated objectives of this process fail to be met.

The Four Mile Program for Environment Protection and Rehabilitation, as administered by the Mining Act schedules the revalidation and calibration of the model to occur 8 years after the commencement of mining. At Beverley North, this is scheduled to commence in year 5. Throughout this time, Heathgate Resources will continue to calibrate and refine natural attenuation models utilising wellfield monitoring data from closed wellfields.

Should natural attenuation monitoring and recalibrated modelling show that impacts on the aquifer could affect the groundwater use category beyond the attenuation as predicted by the current natural attenuation model, then Heathgate will be required to use further active remediation methods (such as further mixing or water treatment).

As the mine moves toward a closure phase, a similar process will occur to operational monitoring, where groundwater quality monitoring within old wellfields and in the near mining area will continue. If results are consistent with model predictions, then natural attenuation will be considered effective and monitoring will continue for the specified post-mining period. If results are inconsistent with model predictions, the geochemical model will be revised and recalibrated with the new data. If the refined model shows remediation outcomes will not be achieved through natural attenuation, then active remediation strategies will be implemented. This may include one or more of the following methods:

- Pump and treat;
- Mixing;

- The addition of remediation agents with a view of minimising the volumes of waste to be disposed at the surface; or
- Extending the groundwater attenuation zone by establishing that there is no compromise to environmental values of the Eyre Formation further downgradient.

DSD administers financial assurance in the form of rehabilitation bonds for both Beverley North and Four Mile which include a contingency for active remediation of wellfields in the unlikely event that this is required.

CONCLUSION

While monitored natural attenuation is regarded as a long term process, it is regarded as consistent with Government expectations with respect to management of wellfield mining solutions at in situ recovery uranium mines. There are multiple lines of evidence demonstrating that monitored natural attenuation will meet the operational and closure objectives of Government, including complex groundwater modelling, laboratory studies and in field monitoring data.

Government regulation of monitored natural attenuation will continue with ongoing monitoring and review of evidence gathered to date. In the event that monitored natural attenuation is not likely to achieve closure outcomes or expectations set by Government, additional contingency measures are planned and assured through financial bonds that will ensure closure outcomes, including protection of water resources for future land uses, are achieved.

While the discussion presented in this paper focuses on existing operations, the principles are relevant to any proposed operation. This means that each proposal will be assessed within this framework but the risks and control measures applied to any new proposal would consider and incorporate specific circumstances presented by each operation.

Q2: Does EPA (government) concur, and on what basis, with Dr Andrea Marsland-Smith from Heathgate Resources that the groundwater flow rate at Beverley is considered "slow".

DISCUSSION

The statements made by employees of Heathgate Resources during evidence provided to the Commission indicate a 'very, very slow' groundwater flow velocity (also called average linear velocity) at the Beverley mine lease.

There is no quantitative rating system for groundwater flow velocity; that is, there is no definition of 'slow'. Nevertheless, comparing the Beverley groundwater flow velocity to other gravel/sand aquifers, 1 meter per year (m/yr) would be considered at the lower end of the scale (Postma, 2010). 1 meter per year means that groundwater would take a great many years to reach any sensitive water body. Therefore, the EPA concurs on that basis that the groundwater flow can be considered 'slow'.

In-situ recovery operations in South Australia are generally within paleochannels containing rollfronts of uranium deposits within relatively porous sandy formations. At sections of the Beverley mine lease, a 'bathtub' or 'basin' scenario naturally exists where the original paleochannel is bound by clay aquitards that severely limit the natural flow in and out of natural groundwater, thus limiting lateral movement of groundwater. Beverley's operations mined in the Namba Formation which exhibit groundwater flow rates of approximately 1 m/yr, which is comparatively slower than the adjoining Four Mile operation, which is mined in the Eyre Formation with a groundwater flow rate of 10-20 m/yr. Other uranium in situ recovery operations are similarly diverse with the Honeymoon mine being 10-15 m/yr and the Oban mine being 1 m/yr. The disposal of process plant water from Beverley plant is to the Namba Formation aquifer (CSIRO, 2004) (IAEA, 2001) and is monitored for volume and quality as the Namba aquifer has naturally low recharge and low discharge rates.

The statements made by the Heathgate Resources employee are supported in the hydrogeological study report for Beverley (Flow Environmental Management, 2007). In this report, Heathgate Resources considers that the groundwater flow at Beverley is slow. The monitoring data presented in the report supports this groundwater conceptual model. The Flow Environmental Management (2007) report describes groundwater flow velocity as low by virtue of the Beverley channel aquifer being a bound hydraulic system in that there is neither significant recharge to, nor discharge from, the channel sands under natural conditions.

In addition, the flat hydraulic gradient, together with the low permeability of the aquitard between the Willawortina Formation above the Namba Formation (Beverley aquifer) and the underlying shales, further supports the statement that groundwater velocity is relatively slow. It is important to note that groundwater flow velocities of aquitards are several orders of magnitude lower than that encountered in aquifers.

The International Atomic Energy Agency (IAEA) Technical Document, chapter 11, considers 'slow' flow to be in range of 1-3 m/yr (IAEA, 2001). The CSIRO publication 'Review of Environmental Impacts of the Acid In-situ Leach Uranium Mining Process' (pg 21) describes the Beverley aquifer's undisturbed groundwater as 'essentially semi-stagnant (very slow lateral flow)' (CSIRO, 2004).

Regardless of groundwater flow rate, government has, through the licensing process, requirements on operators to ensure that impacted aquifers are monitored for natural attenuation, and if necessary there are other techniques available to ensure that there is evidence that the aquifer quality is improving prior to relinquishing the operator of licence responsibilities.

Note: Calculation of groundwater flow velocity (average linear velocity) -

$v_x = -k/n_e \, dh/dl$, where

k is hydraulic conductivity

n_e is the effective porosity

dh/dl is the hydraulic gradient

CONCLUSION

EPA and DEWNR concur with the description by Heathgate Resources that the groundwater flow rate in the Namba Formation aquifer at Beverley could be considered as 'slow'.

This opinion is based on recognition that classifying groundwater flow rates is a qualitative assessment, the Beverley aquifer groundwater movements are slower when compared with other aquifer systems in South Australia and published references in recognised national (CSIRO) and international (IAEA) literature indicate groundwater flow rates in the order of 1-3 m/yr are considered as 'slow'. In addition, the distance to the nearest sensitive water body is very large when compared to the aquifer flow rate of 1 m/year.

Irrespective of groundwater flows, assessment and control of risks at any existing or proposed uranium mine would be developed within a framework that ensures protection of groundwater for the continued and sustained beneficial use for existing and future generations.

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