

GROUNDWATER AND SURFACE WATER IMPACT ASSESSMENT: AMMONIA PIPELINE

1. INTRODUCTION

Environmental Compliance Consultancy (Pty) Ltd are preparing the Environmental and Social Impact Assessment (ESIA) for CMB.TECH Namibia (Pty) Ltd's ammonia pipeline between Arandis and Farm 58, Walvis Bay, Erongo Region, Namibia. As part of the ESIA, a groundwater and surface water impact assessment were undertaken. The summarised site description forms the basis for understanding the hydrological and hydrogeological setting(s) that the pipeline traverses and should be referenced when considering the assessment of impacts. The impact assessment follows ECC's Impact Prediction and Evaluation Methodology and considers first principles of contamination impact assessments, namely the source, pathway and receptor approach.

2. SITE DESCRIPTION

2.1 Locality and Climate

The proposed ammonia pipeline (~112 km in length) occurs between the towns of Arandis and Walvis Bay (Farm 58) in the Erongo region of Namibia.



Figure 1 – Locality map of the proposed ammonia pipeline

The regional area is classified as a subtropical desert climate (BWh) as per the Köppen -Geiger classification system. The area experiences very low annual rainfall (<50 mm) and high temperatures year-round with the mean annual temperature (MAT) exceeding 34°C. Annual evaporation rates are high (> 1500 mm), leading to a significant water deficit and a water-stressed environment.

There is however a change in local weather conditions toward the coast, often as far reaching as Arandis, with frequent occurrence of cloud and fog, up to 125 days per annum. Wind speeds reach up to 19 km/h and are predominantly from the southwest, however, the region is frequently subject to dry, hot easterly winds.

2.2 Topography

From the inlet of the pipeline near Arandis, the first ~40 km of the pipeline follow an elevation profile decrease from ~590 metres above mean sea level (mamsl) in a south-westerly direction to the crossing of the Swakop River and its flood plain (~140 – 120 mamsl). After crossing the river (~1.2 km traversing the river) the pipeline continues southward with decreasing elevation to Farm 58 and the port at ~70 mamsl and ~5 mamsl, respectively.

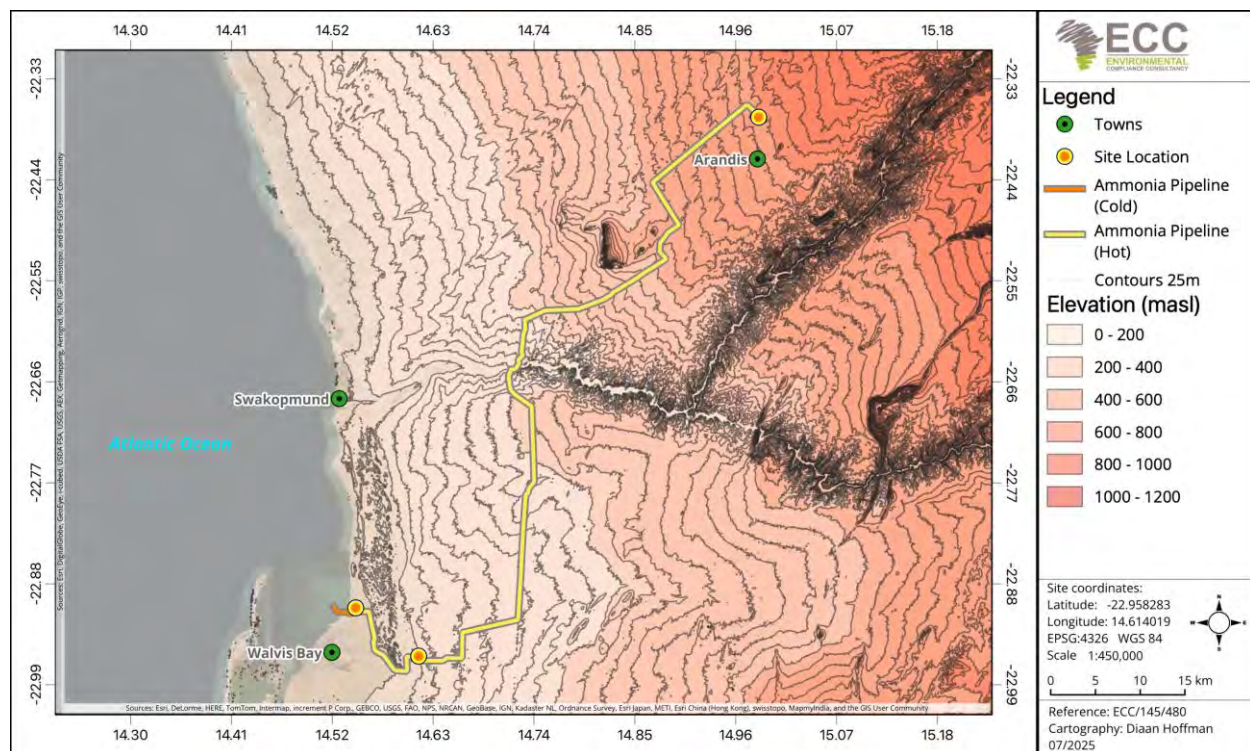


Figure 2 - Topographic map of the area for the proposed ammonia pipeline

2.3 Hydrology

The initial ~15 km of pipeline do not occur in a defined river catchment with the B2 road roughly aligning with the watershed for this stretch. The pipeline then crosses into the Swakop River

catchment a short distance north of northern most exit of the D1991 road. The pipeline crosses the southern watershed near the southern end of the D1991 road where it continues into an area without a defined catchment that is drained by the ephemeral Tumas River. The westward flowing Swakop river is ephemeral and seldom experiences flow in the southern reaches of the catchment where the pipeline crossing occurs (~20 km from the mouth to the Atlantic Ocean). However, this extent of the river is known to experience periodic flow associated with flash flooding every few years (flow experienced twice in the last ~6 years). The region east of the river crossing is a more incised and steeper sided valley as compared to the west, where it widens and the terrain flattens out into the dune field.

Run-off from rainfall in the areas north and south of the Swakop river catchment (including the area drained by the Tumas River) is expected to be limited and short lived; pooling in localised depressions and low points where evaporation and infiltration occur, especially when terminating into the dunes.

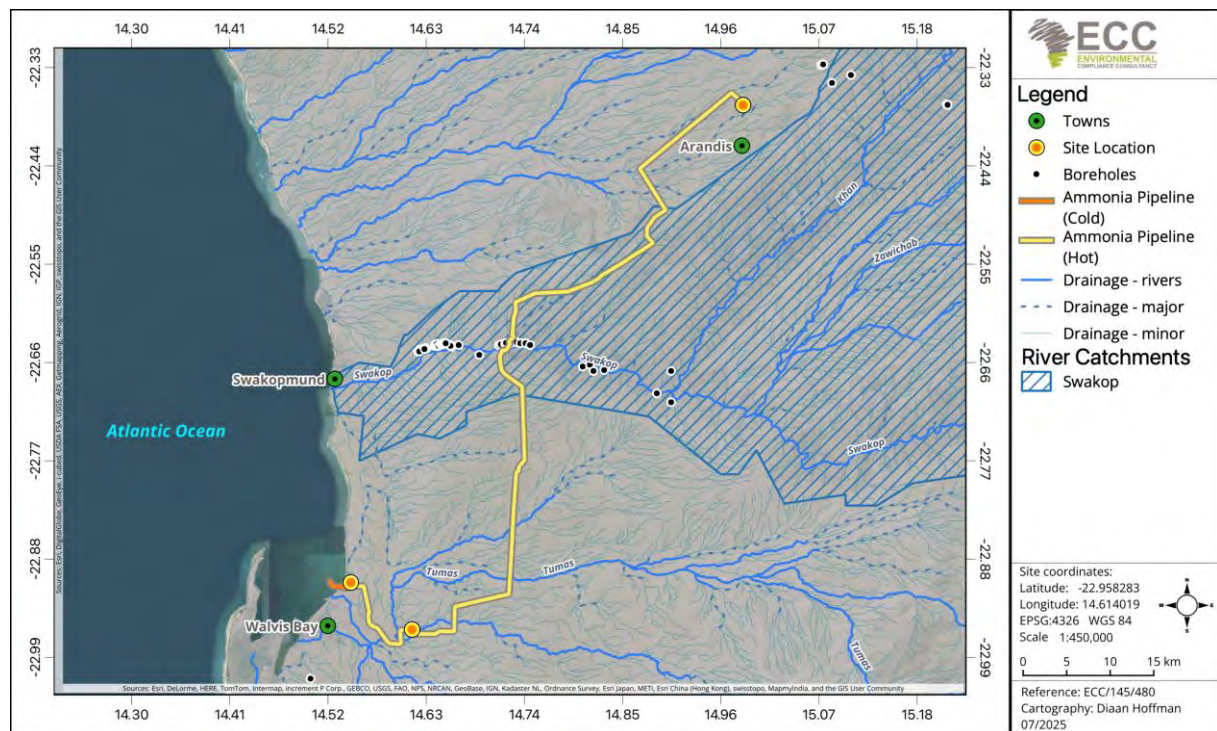


Figure 3 – River catchment map of the area for the proposed ammonia pipeline

2.4 Soils

The pipeline route occurs in the Namib Desert land division widely covered by unconsolidated colluvial material. The predominant soil type is classified as Petric Gypsisols. Aeolian gypsiferous deposits are widespread in the region, particularly near Walvis Bay. Petric Gypsisols are a subgroup of Gypsisols, characterised by a dense, hardened gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) accumulation

near or at the surface, forming an alkaline petrogypsic horizon. These soils are associated with arid and semi-arid environments, where evaporation exceeds precipitation, allowing for the concentration and precipitation of gypsum in the soil profile. The soils are typically strongly cemented restricting water infiltration, retention and root growth. This is supported by the large unvegetated areas observed in the region. Soil suitability for agricultural use is very limited due to the poor fertility and hardpan nature of the soils. There are however some agricultural operations located in the Swakop River's dry bed and floodplain ~10 km downstream of the pipeline crossing.

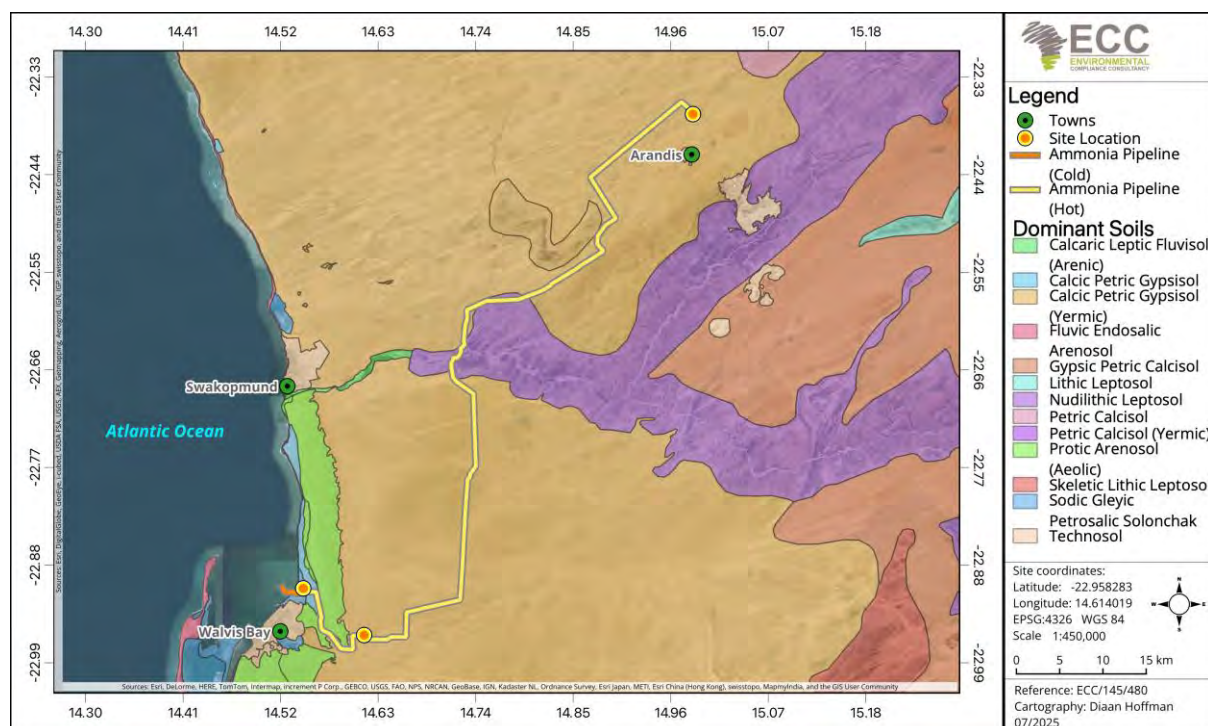


Figure 4 - Soil map of the area for the proposed ammonia pipeline

2.5 Geology and Hydrogeology

Due to its length and linearity, the pipeline crosses numerous lithologies of varied thickness. Generally, the region north of the crossing with the Swakop River has less or thinner Quaternary cover as compared to the pipeline route south of the river crossing toward Namib Coastal Plain.

The eastern segment of the pipeline (Arandis to D1991) is predominantly underlain by metasediments of the Damara Supergroup, Swakop Group and syntectonic Red Granites. Lithologies crossed variably include members of the Kuiseb, Karibib, Arandis and Chuos Formations as well as the Red Granites. It appears that the greater portion of the pipeline north of the Swakop River is underlain by the Kuiseb Formation comprising micaceous schist, minor calc silicates, arkosic quartzites and local marbles (and a portion over the Red Granites). South of the Swakop and beneath the Quaternary cover, outcrop of the Nosib Group, Khan and Etusis formations as well as Salem Granites are mapped on the 2214 Walvis Bay sheet. These lithologies vary in composition and are predominantly characterised by calc silicate rocks, mica schists, quartzite and metaconglomerate. The area directly around Walvis comprises dune sands of the Namib Group, Sossus Formation.

The Namibian Hydrogeological map classifies the area as a region with little or no groundwater potential. This is attributed to the predominant geology as well as the low recharge and poor water quality encountered in the region. The metasediments occurring in the region typically have low groundwater potential and are classified as aquitards, however increased potential may be associated with faults and fractures. Although the schists of this Kuiseb aquitard are folded and faulted, they respond in a ductile manner to stress and therefore have poorly developed secondary porosity and are hence less transmissive in terms of groundwater flow and may be deemed advantageous in that groundwater contamination risk is reduced due to the low transmissivity of the schists. Similar can be applied to the granites encountered. The alluvial sediments of the Swakop River are however, considered a porous aquifer.

Groundwater quality in the granites and schists is typically poor in this region due to rock-water interactions, low recharge rates, evaporation concentration and long residence times. This reduces the groundwater use potential of the region. EC values are expected to exceed 1000 mS/m as seen around Arandis.

When considering the porous aquifer associated with the Swakop River alluvium however, the groundwater quality may be improved as compared to the secondary fractured rocks in the region. This is evidenced by ~10 boreholes mapped on the national database occurring ~2 km downstream of the pipeline's river crossing, within the riverbed and >20 some 10 km further downstream where conductivities are lower but still exceed ~400 mS/m deeming the water

unsuitable for human consumption without prior treatment, but in some instances still sufficient to use for agriculture or livestock watering.

It is anticipated that the Quaternary sediments in the area east and north of Walvis are thin with limited groundwater potential, albeit shallow water levels and with poor water quality.

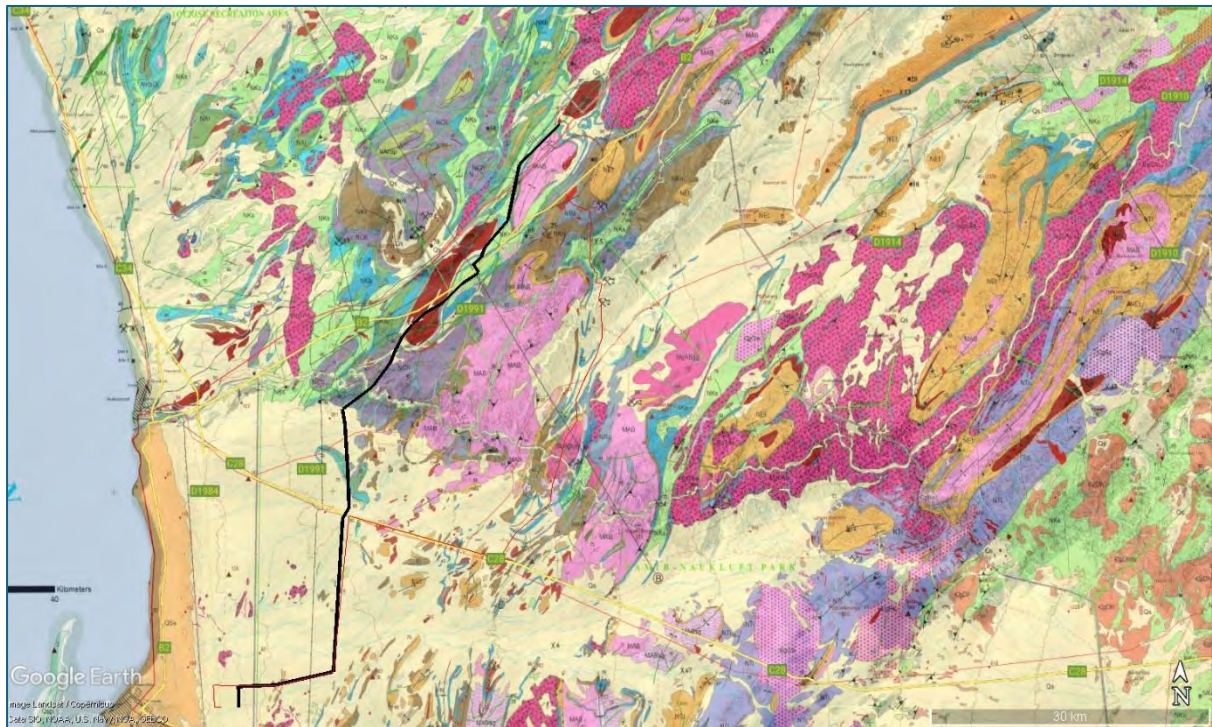


Figure 5 - 2214 Walvis Bay 1:250 000 geological map of the area for the proposed ammonia pipeline

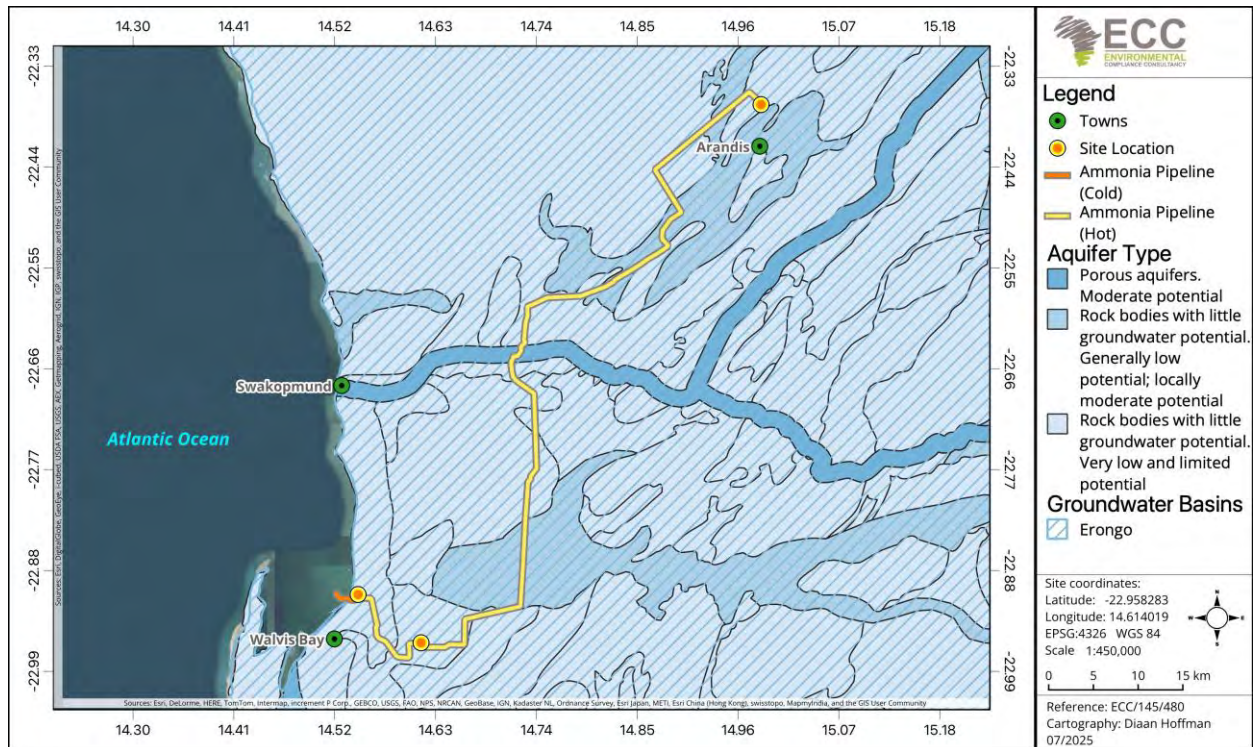


Figure 6 – Groundwater potential map of the area for the proposed ammonia pipeline

2.6 Hazard description

In general, spills of ammonia will result in both dissolution and vaporisation. The escaping plume from a pipeline leak will likely be made up of flashed off ammonia vapour, entrained droplets of liquid ammonia and entrained ambient air. The degree of vapour flash is dependent on the temperature and pressure of the liquid ammonia.

Pools of cold (-33°C) liquid ammonia on the ground can be formed either as a result of rainout from the release (especially in foggy or humid conditions) or from the continued spills from the line. Due to the low vapour point however, ammonia is expected to vaporise before infiltration can occur.

Ammonia is very soluble in water, meaning that when NH_3 gas encounters water (as fog, mist, soil moisture, flowing or standing water), it readily dissolves into the water. Once dissolved in water ammonia forms ammonium hydroxide ($\text{NH}_4^+ + \text{OH}^-$). The addition of OH^- may cause an increase the alkalinity and pH of water or soil. The presence of fog in the region can significantly increase ammonia's depositional potential – either to soil, water bodies or vegetation. Based on its properties, ammonia and the ammonium ion are not expected to significantly adsorb to soil, especially in an arid hot region where soil moisture is expected to be very low. If retained in soils,

surface runoff and flooding may mobilise ammonia and nitrates resulting in concentrated deposition elsewhere, infiltration to the groundwater environment or discharge to the ocean.

The reaction between ammonia and water is exothermic, leading to a localised temperature increase on the water surface and increase in pH. Although ammonia is considered non-persistent in the environment and does not accumulate in the tissues of organisms, it can be acutely toxic to aquatic organisms. Ammonia's breakdown into nitrates can lead to nutrient imbalances, causing eutrophic conditions resulting in algal blooms and hypoxic or anoxic conditions.

Potential Environmental Pathways

The table is compiled based on information of the hazard and various relevant properties of the environment discussed in the site description.

Pathway	Mechanism	Comment
Groundwater contamination	Infiltration of spilled liquid/gas through permeable soils, fractures, or sediment to groundwater	Limited by volatilisation
		Highly unlikely in arid climates
		Not readily adsorbed to soils for long
		Poor infiltration capacity of soils and geology
Surface water contamination	Spill into ephemeral riverbed, during or followed by flash flood	Limited by volatilisation
		Highly unlikely in arid climates
		Not readily adsorbed to soils
		Low frequency of flow
Air to surface transfer	Ammonia can dissolve into fog droplets and deposit onto soil or runoff surfaces	Limited by volatilisation
		No permanent surface water bodies in the region
Soil interactions	Ammonia can adsorb temporarily, but also mobilise nutrients/metals or alter Ph	Low productivity soils
		Limited by volatilisation

Vulnerability and Sensitivity of Receptors

Groundwater

- Low recharge rates due to arid climate, making dilution or flushing of contaminants very slow.
- Shallow aquifers in are particularly vulnerable.
- Calc-silicate rocks and marbles may buffer pH but do not prevent contamination from ammonium or nitrate transformation.

- Ammonia or ammonium may nitrify to nitrate, which is mobile and persistent in groundwater.

Surface Water

- Ephemeral rivers may appear low-risk, but spills during dry seasons can persist in sediments until mobilised by a flash flood, resulting in downstream contamination pulses.
- Aquatic life in ephemeral pools (e.g., dormant eggs, macroinvertebrates) may be highly sensitive to pH and ammonia spikes.

Risk Characterisation

Impacts to groundwater are evaluated for the secondary / fractured aquifer versus the porous (Swakop River alluvium) aquifer based on a set source of contamination i.e. ammonia pipeline leak. As described in the hydrogeological description, the impact to the fractured aquifer, and the subsequent impact(s) of the fractured aquifer becoming contaminated, is lower than that of the porous aquifer (based on source-pathway-receptor approach).

The fractured aquifer has a lower likelihood of contamination and associated impacts from a pipeline leak/ammonia release due to several hydro-physical and water resource potential factors (source, pathway and receptor), namely:

- low rainfall reducing likelihood of contaminant mobilisation (pathway);
- low infiltration rates reduce likelihood of contaminant transport (pathway);
- high evaporation rates reduce infiltration potential lowering the likelihood of contaminant transport (pathway);
- unproductive soils with limited beneficial land use (receptor);
- low transmissivity of the aquifer reducing spatial extent of impact (pathway);
- deeper water table – increased vadose zone providing additional treatment capacity (pathway);
- limited supply potential for groundwater use if not targeting faults/fractures (receptor);
- regionally poor water quality resulting in limited groundwater use (receptor);
- no groundwater dependent ecosystems identified (receptor).
- Accumulation of contaminant in soils – mobilised after wet period (pathway).

Some of the factors relating to the geographic location (e.g., low rainfall, high evaporation) listed above are applicable to the porous aquifer, however the following differences are noted:

- increased infiltration rates due to porous nature of aquifer (pathway);
- shallower water tables increasing the likelihood of contaminants reaching the water table (pathway);

-
- increased beneficial land use e.g., agriculture (receptor);
 - increased transmissivity of aquifer (pathway);
 - increased potential for groundwater use (receptor);
 - improved groundwater quality for groundwater use (receptor);
 - groundwater dependent ecosystems identified in river bed (receptor);

The points listed for the porous aquifer become applicable to the surface water impacts too, as the focal receptor is intermittent flow in the river; which is directly associated with the porous aquifer. Additional impacts for surface water not listed above include:

- Infrequent flow of the river (pathway)
- Accumulation of contaminant in soils/sediments with negative impact on riverine vegetation, reducing land use potential and causing nutrient spikes (receptor);
- Limited aquatic life in surface waters due to intermittent flow (receptor);
- Long term persistence and pulsed recurrence of contaminant due to periodic flushing (pathway);

It is noted that during normal pipeline operation, these risks and associated impacts are very low. This is based on the assumption of appropriate, compliant designs and materials used as well as sufficient safety features and leak detection being employed. The impact assessment is therefore tailored specifically to impacts if ammonia is released / spilled from the pipeline.

Activity/Risk	Receptor	Impact	Nature of impact	Value & sensitivity	Magnitude of change	Significance of impact
Pipeline operation	Secondary aquifer - groundwater	Groundwater contamination due to a leak in the pipeline resulting in a deterioration of water quality.	Adverse Direct Partly reversible Medium term Local Unlikely	Low	Minor	Low
Pipeline operation	Porous aquifer - groundwater	Groundwater contamination due to a leak in the pipeline resulting in a deterioration of water quality (and potential use of the water resource)	Adverse Cumulative Partly reversible Medium term Local Unlikely	Low	Moderate	Low
Pipeline leak	Surface water (Swakop river)	Surface water contamination resulting in degradation of water quality and aquifer characteristics	Adverse Direct Partly irreversible Medium term Local Rare	Low	Moderate	Low
Pipeline leak	Soil	Soil contamination resulting in groundwater / surface water contamination	Adverse Cumulative Partly reversible Short term On-site Unlikely	Low	Minor	Low

Conclusion and Recommendations

Although ammonia is a hazardous substance, the likelihood of significant groundwater or surface water contamination is low due to:

- The physical behaviour of ammonia (rapid volatilisation);

-
- The dry (low soil moisture, low infiltration, high evaporation) surface conditions;
 - The inherent physical characteristics of the secondary aquifer;
 - The limited exposure of the porous aquifer to the pipeline;
 - Poor water quality, and unused nature of the secondary aquifer;
 - The infrequent flow of surface water;
 - Robust designs (engineering controls), safety features, inspection protocols and leak detection monitoring.

It is recommended that baseline water quality be retrieved from at least four boreholes nearest the pipeline (downstream) within the Swakop River and at least two (2) baseline samples upstream. Annual monitoring of the groundwater quality is recommended, either from these same boreholes, or from dedicated monitoring boreholes installed in the river alluvium. It is however noted that these boreholes may be at risk during times of flood.

The use of water during emergencies and to manage vapour plumes should be done so with caution and avoided if possible to prevent water rich in absorbed ammonia from pooling, mixing or infiltrating.

Safety valves should be strategically placed allowing the river crossing segment to be isolated if needed, such as during flood events or leaks.

This assessment was prepared by L Towers, for Environmental Compliance Consultancy (Pty) Ltd.

L. Towers

MSc. Geohydrology, Pr.Sci.Nat