OYU TOLGOI: HYDROGEOLOGICAL CONDITIONS NEAR THE MINESITE (SUMMARY DOCUMENT)
Oyu Tolgoi: Hydrogeological Conditions Near the Minesite
(Summary Document)

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Development of the Oyu Tolgoi mine requires the use of large volumes of water, with almost 3,500L/s required for operating the concentrator. Water will be produced from the Gunii Hooloi aquifer for operations at an average rate of approximately 700 l/s. Obviously the majority of the 3,500 l/s of water required for operation of the concentrator will be recycled from onsite use. Produced water will be stored in a large reservoir prior to distribution and use at the site. While up to 80% of the total water used onsite will be recycled or otherwise reused, significant volumes will be lost, primarily associated with the tailings that will be discarded following onsite processing (450 l/s), and through evaporation (100 l/s). As pointed out in the ESIA (http://ot.mn/en/about-us/environmental-social-impact-assessment/esia), water resources is clearly a sensitive environmental issue, especially as the site is located in a desert environment with very little precipitation and extremely high rates of evaporation. The sensitivities relating to water issues are discussed in detail in the project ESIA and assessed in terms of their impacts.

While the mine is located in an arid environment, there are several subsurface basins that contain large amounts of groundwater. In general, this groundwater is present from between 50 and 400 m below the ground surface and contains high levels of dissolved solids. While this water is not typically suitable for use by the local herders, or for agricultural use, it can be treated and used for industrial purposes, such as that of the industrial requirements for the Oyu Tolgoi (OT) Mine. It should also be noted that this water can be treated to drinking water quality, as is currently planned for the site.

Water is present in three different units in the vicinity of the site: shallow alluvial units present in the stream beds; weathered and fractured bedrock; and in the deeper sub surface basins filled with unconsolidated granular materials such as the Gunii Hooloi. The largest source of water in the region is present in the sub surface basins, and the Gunii Hooloi aquifer has more than enough water to provide site needs for the 100,000 tpd production rate planned for the 27 year life of mine. The Gunii Hooloi aquifer is currently under pressure, and it should be noted that the water use permit provided by the Government to use this water resource stipulates that exploitation of this aquifer must not cause a lowering of the potentiometric surface below the base of the confining layer (that is that the aquifer must be maintained under pressure). Detailed hydrogeological modelling of the aquifer shows that pumping at the average rate of 700 l/s for the period of 27 years will not result in lowering of the potentiometric surface below the base of the overlying confining layer, and further, that this use will only remove about 15-20% of the available water from this aquifer.

While the sub surface Gunii Hooloi basin is being exploited for Operational water needs, the intermediate weathered/fractured bedrock was targeted for construction water needs as this unit is present at the site and contains relatively fresh water. In the vicinity of the site this weathered/fractured bedrock can be overlain by clay or directly overlain by the alluvial sediments/aquifers.

A potential concern identified in the ESIA is that if the alluvial aquifer is situated directly on the weathered bedrock, then lowering of the water level in the bedrock (for example through pumping to provide mine water supply during construction or later through pit dewatering) could induce downward gradients, thereby causing a portion of the water in the alluvial aquifer to flow downwards recharging the weathered/fractured bedrock. This would result in less water being discharged downstream within the alluvium which could impact herder wells, vegetation or animals that rely on this shallow groundwater (and associated springs) downstream of the site.

Due to these concerns there are several commitments in the ESIA (Construction Environmental and Social Monitoring Plans) to closely monitor this situation, and to implement actions if impacts are identified. These commitments include WR05e, WR05g, WR21, WRM01, and WRM03 in Section D7 of the Environmental and Social Management Plan, Water Resources.
Information presented in the 2011 OT Annual Monitoring Report included the following statements:

There has been progressive water level drop observed at monitoring bores located in midstream of Undain river or at Oyu Tolgoi project lease. This is related to water use for project’s household and construction use. Starting from late September this year, water is also supplied for use at Gunii khoooloi camp. This means that there will less water taken from wells located within project lease and Undain (sic) river area underground water levels will be recharged.

When surveying bores located along Undain river and that are within the impact radius of water production well, water level dropped by 0.77-1.16m as of early September at the bore nearest to it and water level dropped by 0.14-0.27 m at the level furthest away from it. Water level drops, however were stabilized by late October and at some bores water was recharged (Graph 75). This drop in water level could be impacting Bor ovooni zadgai well, which is located south of project lease. Bor ovooni zadgai well had little water this year and has dried up since October. It continued to be dry even after rainfall events (Photo 27).

Information collected in the first two quarters of 2012 (including the fact that the Bor Ovoo spring remains dry) triggered a further examination of the situation, consistent with the commitments included in the ESIA.

A detailed assessment of the hydrogeological conditions around the minesite was commissioned in September 2012 to:

- Define baseline conditions and natural fluctuations in groundwater levels in the shallow alluvial sequence in and around the minesite area.
- Describe elements of mine development, especially groundwater abstraction, that have potential to impact on local groundwater levels.
- Assess any impacts on the shallow groundwater environment arising from such development.

The assessment, based on available data up to end-2012, was undertaken through the period October 2012 to June 2013 and included review of data related to rainfall, floods, springs and groundwater within the shallow alluvial aquifers associated with drainage courses and the underlying bedrock strata.

The study area enveloped the main Undai drainage system that passes through the mine site together with separate tributaries to the east and west which coalesce downstream and drain to the southeast. An unrelated distant catchment to the north was included to enable comparison of responses and trends.

A detailed technical report has been prepared that provides:

- An overview of the hydrogeological environment.
- Details of the monitoring network and available data.
- A description of the hydrological regime (from rainfall and streamflow monitoring records).
- A description of groundwater levels and quality in the alluvial and bedrock hydrogeological units.
- An assessment of flood occurrence and extent, recharge processes, natural groundwater level trends and the relationships between alluvial and bedrock flow systems.
- A description of mine development activities that have potential to impact on local groundwater systems with detail on groundwater abstraction and mining.
- An examination of water level responses to abstraction, open pit development and TSF construction.
- Discussion of impacts.

Summary findings are presented herein.
Monitoring

Responsible groundwater management has been a long-held commitment in the development of the Oyu Tolgoi (OT) project. OT has successively expanded their monitoring scope and capacity since project inception.

Four (4) catchments can be identified around the Project area – Western, Central, Eastern and Northern (Figure E-1). The largest catchment (Central) hosts the Undai River, which passes through the Mine Area toward the southeast.

A significant groundwater level monitoring data set has been established for the alluvial hydrogeological unit with monitoring of herder wells since 2004. Monitoring of bedrock water levels, rainfall, springs and streamflow has been included variously through 2007/2009. The locations of the herder wells and groundwater monitor bores are shown in Figures E-2 and E-3.
Figure E-2 Herder Well Locations

Figure E-3 Groundwater Monitoring Locations
The groundwater monitoring network has been augmented through 2011-2012 with installation of a series of multi-level piezometers equipped with data loggers that have already provided useful insights into hydrogeologic unit responses to floods, local hydraulic gradients and water level recession rates.

Through the monitoring effort and the findings of numerous investigations and studies undertaken (e.g. camp/construction water supply, open pit dewatering, geotechnical appraisals, foundation studies, TSF design, Undai stream diversion etc), reasonable definition of the general characteristics of the hydrological and hydrogeological regime has been established. Data is not yet available, however, to resolve the detail of all hydrogeological processes. Improvements and extension in some aspects of monitoring will be required.

**Rainfall and Runoff**

Mean annual rainfall at Khanbogd, located 35km northeast of the site, is 96mm.

Rainfall distribution in the project area is erratic; groundwater level responses demonstrate common occurrence of localised storm events and associated recharge. Runoff from rainfall is a common phenomenon in the headwaters of the catchments where most floods originate.

Climatic (rainfall) conditions experienced during the monitoring period are not wholly representative of the environment.

Since 2003 the area has experienced two of the highest rainfall years on record (2003 and 2010) and has only been subjected to a single 2-year period of below-average rainfall. Longer-term records from Khanbogd and other regional stations show longer (>2 years) and/or more frequent periods of below-average rainfall (Figure E-4).

![Figure E-4 Khanbogd Long Term Annual Rainfall Record](image)

Regular monitoring of rainfall at Oyu Tolgoi (OT) commenced May 2009.

**Floods**

The occurrence of floods is identified by photographic record at the minesite and by groundwater level hydrographs there and elsewhere.

Floods may occur at any time between May and September and are not consistent between catchments and not always consistent with rainfall records at OT and Khanbogd.

Small floods, as indicated by groundwater level hydrographs, are constrained to reaches of the upper catchment areas. The distance that any flood event extends downstream is controlled by the magnitude of the flood.

Large floods, generated in the headwaters of the Undai, that reached the minesite and further downstream, have occurred annually since 2008 with the exception of 2011.

Floods did occur in the upper Undai catchment mid-August 2011 and also on two separate occasions in the eastern catchment August-September 2011.

A discrete flood event in the eastern catchment, not seen elsewhere, has also been identified end-July 2012; this appears as a significant event in the monitoring record of all downstream sites and indicates that runoff from the massif plays an important role in maintaining water levels in downstream areas.

The largest Undai floods (September 2010 and August 2012) occurred late-season and are associated with widespread storms and significant antecedent rainfall (Figure E-5).
Floods provide the primary recharge, via infiltration, to the alluvial hydrogeological unit that underlies the streambeds.

Estimates of the volume infiltrating the Undai streambed from the two 2012 floods have been made; these show that individual floods may lose between 4,000 and 21,000 m³/km stream length to the underlying alluvial aquifer.

Figure E-5 Undai Flood - September 2010

Alluvial Hydrogeological Unit

The alluvial hydrogeological unit along the Undai is up to 400m wide and typically ~5m thick; as an aquifer it supports herder wells and springs.

Hydrographs for herder wells date back to 2004.

Water levels in wells in the upper catchment areas are relatively stable as these sites receive recharge from numerous runoff and flood events.

Wells in the lower catchments are only recharged during larger, less frequent flood events and therefore water levels here are subject to longer periods of recession.

Data from newly installed data loggers have provided detail on water level responses to individual floods in 2012. These confirm a general trend of reducing recharge response with distance along the drainage course.

The trend is not wholly consistent however; variations in the width of the aquifer and thus aquifer storage capacity may locally impart some control on response; this is supported by variations in hydraulic gradients.

Observed data confirms the conceptual model of water levels in shallow groundwater with natural throughflow in the order of 50 m³/d.
Alluvial water level rises of the order of 1m were observed near the minesite with passage of the August 2012 floods (Figure E-6). Only in sites in the upper catchment did the alluvial profile become fully saturated.

**Figure E-6 OTMB11-11 Hydrograph**

Hydrographs from herder wells in the downstream sections of the catchments show a general downward trend following the September 2010 flood up to July 2012. This regional trend – which is observed at sites both upstream and downstream of the minesite in the Undai catchment - is attributed to the absence of any floods of sufficient magnitude to reach the middle and lower catchment areas. The mean rates of recession (~1mm/d), as observed in the herder wells in the downstream sections of the catchments, are similar to an earlier recession through 2006-2008 associated with relatively low rainfall in 2007. (Figure E-7)

**Figure E-7 Hydrographs for selected Herder Wells**
The low water levels recorded in the middle and lower catchment areas end-2011 to mid-2012 are typically below the range observed during the alternating wet and dry years 2006-2010 and are similar to those recorded 2004-2005 during a 2-year period of below-average rainfall. They provide a base level for the climatic conditions experienced during the OT monitoring period.

The natural discharge processes from the shallow and permeable alluvial sediments are down-gradient throughflow within the alluvial units, lateral and vertical seepage to adjacent and underlying weathered bedrock strata, direct evaporation (from shallow groundwater and springs) under high summer demand and evapo-transpiration from limited, local phreatophytic vegetation that occurs along some streambeds.

Groundwater in the alluvial sediments is typically fresh (EC <1000 mS/m) and bicarbonate-dominant typical of a recharge environment. Seasonal variations in water quality are common and variations occur along the drainage course; the variations are considered to reflect evaporative processes and re-mobilisation of accumulated salts. Salinities in the eastern catchment tend to be higher than found in other catchments.

**Springs**

The location of springs monitored is shown in Figure E-8.

**Figure E-8 Spring Locations**

Monitoring data for springs is limited to an incomplete series of photographs dating back to 2008 and sporadic field EC measurements. The condition of springs varies seasonally; all display a drying trend following replenishment by floods in summer months commonly reaching dry conditions within the ensuing 3-6 months.
The salinity of water at the springs appears similar to that in the alluvium; marked reductions in salinity are associated with flood events but persist for only a few months.

Dry conditions were recorded at all upstream and downstream spring sites in 2010 which may be attributed to relatively low 2009 rainfall. Deterioration of conditions at all middle and lower catchment sites through 2011 is associated with the absence of floods and consequent natural alluvial water level recession. Differences in spring responses and characteristics have been noted.

The records within this monitoring period clearly show that the Bor Ovoo is first recorded as dry in July 2011 and has been recorded as dry since this time (Figure E-9)

![Figure E-9 Bor Ovoo – June 2010](image1.jpg) ![Bor Ovoo – June 2011](image2.jpg)

There are no springs down-gradient of Bor Ovoo that are solely dependent on the subsurface and surface water flow of the Undai channel. The next spring downstream of the mine lease is at Khukh Khad which is 6 km south of Bor Ovoo, at the confluence of the Western and Undai catchments.

Further downstream from Khukh Khad the Eastern catchment (which crosses the mine site and TSF) adds to the surface and subsurface flow.

**Bedrock Hydrogeological Unit**

The occurrence and movement of water within the bedrock is controlled by degree of weathering and presence of fractures and faults. Enhanced secondary permeability has been identified at a number of sites proximal to the Undai. Within the minesite area there are faults zones that have been identified around the perimeter of the open pit that impart major control on groundwater flow; this is supported by water quality data.

Groundwater in the bedrock units has similar characteristics to water in the alluvium in areas proximal to the drainage course. Within the pit area slight changes in chemistry occur and a wider range in salinity is observed; highly-mature waters are found to the north and south of bounding faults reflecting absence of recharge and or throughflow within these areas.

Hydrographs for most bedrock monitoring bores in the Mine License area date from about 2007 with use of bores installed as part of dewatering and camp supply investigations.

Regional water table contours developed for the bedrock demonstrate flow from elevated areas of outcrop that surround the mine area ultimately draining towards the southwest.

Hydraulic connection between the Undai alluvium and underlying bedrock has been demonstrated at many sites proximal to the Undai within the Mine Licence area. There, bedrock monitoring bores commonly show a response to floods and similar natural water level recessions.

Flow paths in the bedrock confirm recharge from the alluvium. The presence of a significant body of low salinity groundwater in the bedrock proximal to the Undai near the minesite and the observed response to Undai flooding testify to a high degree of inter-connection between the Undai alluvials and bedrock in that area.

Relatively stagnant groundwater conditions occur beneath the TSF reflecting infill and cover of low permeability Cretaceous strata.
Abstraction at the Minesite

Groundwater abstraction at the minesite has been entirely from bedrock bores with individual yields in range 1-5 L/s derived from weathered/fractured horizons that extend up to ~100m depth. Abstraction was minimal prior to commencement of construction. Two abstraction areas were established – one near the Undai on the northern boundary of the mine lease (Area A), the other within and around the open pit (Area B).

In Q2 2010 large-scale abstraction commenced from a total of 13 wells. Cumulative production steadily increased from April 2010 to 40,000 m$^3$/month in September 2010. Production rates were maintained at high levels, between 25,000 m$^3$/month and peak 44,000 m$^3$/month (April 2011), until September 2011 reducing dramatically thereafter as supplies from the remote, newly-commissioned Gunii Hooloi borefield became available. Total groundwater abstraction has been approximately 760,000 m$^3$ of which 530,000 m$^3$ (70%) has come from the mine block (Figure E-10).

![Figure E-10 Monthly Abstraction 2007-2010](image)

Through 2012, production at the minesite was limited to 600-2000 m$^3$/month provided by two (2) bores north of the pit and west of the Undai and two (2) bores within the mine area.
**Local Impacts from Abstraction**

The impacts of groundwater abstraction are clearly shown in many bedrock monitoring bores and/or derived water level contours. The water levels in bedrock production and monitoring bores show immediate response when abstraction is reduced (and ultimately terminated). Rapid recovery of water levels is evident through Q3 2011. A residual drawdown has been recorded at many sites indicating storage depletion. At sites close to drainage channels, the impacts of groundwater abstraction are superimposed on natural water declines similar to those observed in the alluvium (Figure E-11).

![Figure E-11 Natural and Induced Bedrock Water Level Variations](image-url)
In the northern area of abstraction, where production bores are in a line along and close to the Undai River, the potential area of impact extends along a 1,600m reach of the drainage course. In the southern area impacts are largely restricted to the mine area; minimal impacts occur across faults to the north, west and south (Figure E-12).

In the southwestern portion of the pit, however, permeable weathered bedrock extends beneath the Undai where bedrock water level drawdown has been recorded. This has created conditions for enhanced vertical leakage of groundwater from the Undai alluvium. Similar conditions may be assumed for the northern area where fractured bedrock strata outcrops near to the streambed.

There are no alluvial water level records through the abstraction period to confirm that such leakage has occurred. It can be inferred, however, that such leakage has occurred although it is not possible to quantify the resultant water level drawdown. The potential drawdown attributable to abstraction, as shown by a bedrock monitoring bore, located adjacent to the streambed near the south-western pit area also open to the overlying alluvial sediments, exceeds 0.25m (eg OTRC-1204 as shown in Figure E-11).

Records of saturated alluvial thicknesses >2m near the potential area of impact, prior to replenishment from the August 2012 floods, suggest vertical flux is limited.

Although storage depletion from the bedrock could, with adoption of reasonable aquifer parameters, account for the total volume of water abstracted it is considered that some contribution has been derived by leakage from the Undai alluvium both in the area southwest of the pit and in the northern area where fractured bedrock strata occurs in proximity to the alluvial aquifer.

Zones of potential impact on the alluvial aquifer, where a depression in the water table likely occurred during the period of peak abstraction, extend over a reach of ~1,000m near the southwest corner of the pit and ~1,600m near the northern boundary of the mine lease. The northern extremity of the zone near the pit is ~1,000m downstream of the planned Undai Diversion and cut-off wall.
Estimates of the potential loss of alluvial water storage to abstraction through the period of peak abstraction (post-September 2010 flood) have been made assuming a maximum alluvial water level decline, attributable to abstraction, of 1m.

Potential storage loss in the north is ~30,000m$^3$ and ~20,000m$^3$ in the south with the sum ~7% of the total abstraction. The cumulative contribution from the alluvium throughout the entire abstraction period, however, will be greater with the storage loss supplemented by additional, indeterminate contributions from throughflow interception and intermittent recharge volumes from floods.

**Local Impacts from Mining**

Open cut excavation for the open pit extended below the water table in Q1 2012. Mine inflows recorded to date have been <3L/s; limited field water quality measurements indicate a bedrock source. The impact of mine dewatering has been observed in some monitor bores around the pit (eg OTRC-1204 shown in Figure E-11).

**Impacts at Bor Ovoo**

Bor Ovoo spring has had a different response to other springs. It became dry in July 2011 during a period of peak abstraction from bedrock in Areas A and B upstream and during a period when no floods were recorded in the Undai. The loss of the spring and its failure to recover after major flood events in 2012 (when additionally exposed to impacts arising from mine inflows) can be attributed to dewatering of the underlying and adjacent bedrock (particularly in Area B directly upstream) and the natural groundwater recession in groundwater levels in the downstream areas of the catchments but it is not possible to quantify the relative contribution from the two processes.

**Water Level Recovery with Floods of August 2012**

Water level rises up to 1.3m occurred in the Undai alluvium within the mine lease in response to the 2012 floods.

Bedrock water levels in the north appear to have been fully restored whereas residuals remain in the south-western corner of the pit (refer Figure E-11).

The floods did not fully saturate the alluvial profile within the Mine Licence area. This can be attributed to the increase in alluvium storage capacity within the zones of potential impact (where water levels locally depressed as a result of enhanced vertical leakage) and that resulting from the preceding extended period of natural water level recession.

Data is not available to confirm whether recovery to mid-2009 water levels was achieved in the alluvium within the Mine License area.

Estimates of natural water level declines between mid-2009 and mid-2012, in range 0.75-1.5m, suggest that full recovery, at least in some reaches, has not been achieved. This is supported by the noted failure of Bor Ovoo spring to recover and observations of depths to water >2m during a drive-point piezometer survey conducted end-November 2011.

The condition of all spring sites downstream of the mine lease (Khukh Khad, Buural and Maanit) was restored by the 2012 Undai floods that supplemented impact from earlier, discrete floods emanating from the western and eastern catchments.

**Downstream Impacts**

Hydraulic gradients and recession rates observed within the alluvium in 2011 and 2012 generally fall within the natural range; variations do exist but may be related to natural features.

There are no data that suggest reduced throughflow in the Undai alluvium (upstream of Bor Ovoo) has had any impact on any other features further downstream.

The first long term data points downstream of the Bor Ovoo spring are the Khukh Khad herder well and the Khukh Khad spring.

The data and observations for the herder well are consistent with the regional trend and recession curves observed in downstream herder wells observed in other catchments through 2010-2012 (Figure E-7).
This has been confirmed by the drive-point piezometer survey which demonstrates depths to water and hydraulic gradients consistent with regional data (Figure E-13).

Figure E-13 Longitudinal Profile: Undai River November 2012

There are no data to indicate any groundwater impacts arising from TSF construction. It has been noted however that the August 2012 surface flow events, observed upstream at Dugtherder well, were not demonstrated at the first site downstream. It cannot be established whether this relates to the magnitude of the event, local impedance by mine infrastructure or the incomplete status of the surface water diversion channel at this time. Works have been initiated to complete the diversion channel.

Road construction across some natural drainage courses has created potential for impedance of surface water flows. Whilst no significant impacts have been identified further assessment is warranted (and is in progress).

**Future Potential Impacts**

Pumping mine water supply from the bedrock in the vicinity of the open pit has reduced the storage and throughflow of water in the alluvial aquifer. While the pumping of this water has ceased, ongoing pit dewatering is shown to continue; this issue and therefore this risk (to reduce water in the Undai) will continue for the life of the mine, and beyond.

It should be noted that the Undai diversion has been installed, and therefore surface and subsurface water is diverted at a point upstream of the former Bor Ovoo spring. The location of this diversion is to the northwest of the former spring, and across the western (West BAT) boundary fault of Area B (Figure E-12). No impacts of pumping from Area B to date have been observed across this fault. Therefore, the diversion is located in an area beyond any observed impacts to date. In addition to being located beyond this boundary fault, the location of the diversion is in an area where the alluvial sediments are underlain by clay, not weathered or fractured bedrock. These two features (that is locating the diversion upstream of the boundary fault at a location underlain by clay) significantly reduce the potential for lower water levels in the fractured bedrock to impact water in the Undai alluvials at or upstream of the diversion. Therefore, installation of the diversion is an engineered mitigation against possible future impacts to the water in the Undai alluvials.
While considered as an unlikely impact, this cannot be ruled out, and therefore detailed monitoring will continue to be conducted on multi-level piezometers between the former spring, the diversion and the open pit.

If results of this monitoring detect any potential impact to the water in the Undai alluvials, further mitigation measures will be considered, as required in the Water Resources Management Plan for Operations.

Mitigation of risks associated with leakage from the TSF has been accommodated within the design. Monitoring of the dedicated environmental monitoring bores around, and piezometers downstream of, the TSF will be able to provide early identification of any potential leakage and effectiveness of the surface (and groundwater) re-direction.

No significant impact on groundwater or surface water flows are anticipated from development of the underground mine. Bunding and surface water diversions are planned to limit potential inflows from rainfall/runoff that would report to the anticipated area of subsidence above the block-cave.

**Recommendations**

A number of recommendations have been made that seek to:

- Address the basin by basin variability of rainfall and therefore recharge to the alluvial hydrogeologic unit.
- Provide a quantitative understanding of future water availability in the environment of the operations.
- Augment QA/QC and reporting procedures.

Specifically, the recommendations include:

- Augmentation of rainfall, flood and spring monitoring.
- Further analysis of the data logger installations and data to further improve understanding of recharge to, and flow processes within, the alluvial hydrogeological unit and enable progressive calibration with rainfall and flood events.

All recommendations have been included within the monitoring programmes of the Water Resources Management Plan.