

## SECTION B: BASELINE ASSESSMENT

### CHAPTER B6: WATER RESOURCES

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## 6 WATER RESOURCES

### 6.1 INTRODUCTION

This Chapter describes the baseline conditions for water resources in the Project Area of Influence. Water resources include surface water features such as ephemeral watercourses, the shallow groundwater aquifers used by the local communities and herders (and which sustain the springs that are also important to wildlife), and deep aquifers which will be utilised by the Project.

The aquifers in the Project area comprise shallow, locally important surficial aquifers which are up to 5 m below the surface and deeper aquifers typically over 50 m below the surface. The surficial aquifers are associated with ephemeral watercourses, and are critical for sustaining the springs and hand-dug wells used by herders throughout the year. The deeper clastic<sup>1</sup> aquifers, which are located away from the Mine Licence Area, contain the water resources which the Project will exploit for its operational water supply. In addition to these, during construction Oyu Tolgoi is exploiting the weathered/fractured bedrock aquifer present within the Mine Licence Area for its construction phase water supply.

This Chapter considers the general scarcity of water in the Gobi, and discusses this in a regional context. It describes the characteristics of surface water resources across the Project area, the surficial aquifers and their relationship with surface waters, herder wells and springs. It presents the approach Oyu Tolgoi has taken to assess the potential water resources available in the immediate area and how the Gunii Hooloi basin was chosen as the preferred water supply for the Project. It then describes the deep Gunii Hooloi aquifer which Oyu Tolgoi will exploit for its operational water supply, the relationship of this aquifer with aquifers at shallower levels and the herders and plants that rely on these aquifers. The Chapter also presents the initial results from the exploration of the Khanbogd groundwater supply and the existing groundwater supply for the *soum* centre. The impacts of Oyu Tolgoi's operations on the local surface water and groundwater are described in *Chapter C5*.

### 6.2 SOURCES OF DATA

Baseline data for this chapter has been obtained from a wide range of sources. The general data on surface water and groundwater in the Project area has been sourced from the DEIAs undertaken for the Oyu Tolgoi Project between 2004 and 2007. These include:

- Eco-Trade (2004), Oyu Tolgoi Project Environmental Impact Assessment, Volume I Report of Oyu Tolgoi to Gashuun Sukhait Road and Infrastructure Corridor, Environmental Protection Plan and Environmental Monitoring Plan, Eco-Trade LLC, 2004;
- ESIC (2007), Environmental Impact Assessment Report for the Oyu Tolgoi Project Domestic Airstrip Relocation, Environmental Study & Information Centre OC MT LLC, 2007;
- Eco-Trade (2005), Oyu Tolgoi Project Groundwater Resource Use from the Gunii Hooloi and Galbyn Gobi Regional Aquifers, Eco-Trade LLC, 2005; and
- Eco-Trade (2006), Oyu Tolgoi Project Environmental Impact Assessment, Volume 3 Mining and Processing, Eco-Trade LLC 2006.

The hydrogeological environment of the Project area has been subject to a number of complementary and evolving studies by Oyu Tolgoi. These studies have involved both the physical measurement and assessment of the aquifer characteristics and also gaining an appreciation of herders' knowledge and perceptions of aquifers in the area. Oyu Tolgoi's knowledge and understanding of the aquifers, such as the Gunii Hooloi Cretaceous Aquifer and the shallow aquifers within the Mine Licence Area, has increased steadily. Each additional investigation has built on the information presented in the initial DEIAs.

Groundwater modelling of both the Gunii Hooloi and the Mine Licence Area is on-going as Oyu Tolgoi continues to refine the models based on the new data being gathered. This ESIA has drawn on the

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<sup>1</sup> Clastic rocks are composed of fragments, or clasts, of pre-existing rock. Geologists use the term clastic with reference to sedimentary rocks as well as to particles in sediment transport whether in suspension or as bed load, and in sediment deposits.

published studies and the latest data on groundwater modelling to present the most up-to-date assessment of the water resources baseline in the Project area. Key sources of documentation on the major aquifers (borehole logs, pumping tests and modelling) include:

- Aquaterra (2004), Feasibility Study, Oyu Tolgoi Dewatering Investigation – Open Pit and Block Caving, Aquaterra Consulting Pty Ltd, 18 October 2004;
- Aquaterra (2004), Groundwater Exploration Investigation, Oyu Tolgoi Process Water Supply, Volumes 1-5, Aquaterra Consulting Pty Ltd, October 2004;
- Aquaterra (2006), Model Set Up and Calibration Report, Appendix 1.1, Revised February 2006;
- Aquaterra (2008), Gunii Hooloi Aquifer, Groundwater Investigation and Resource Assessment – 2007 (Revised Water Demand), Aquaterra Consulting Pty Ltd, March 2008;
- Aquaterra (2008), Gunii Hooloi Aquifer, Detailed Design, Bore Design (Revised Water Demand), Aquaterra Consulting Pty Ltd, February 2008;
- Sustainability (2008), Addendum to the Oyu Tolgoi Project Environmental Impact Assessment for the Water within the Gunii Hooloi Groundwater Resource Area, Sustainability Pty Ltd, May 2008; and
- Aquaterra (2010), Oyu Tolgoi Mine Site Hydrogeological Site Assessment, Aquaterra Consulting Pty Ltd, 9th December 2010.

The current investigation work being undertaken by Oyu Tolgoi is focused on the groundwater models for Gunii Hooloi and the Mine Licence Area. The objective is to refine these, with the use of additional data, and to examine in further detail some of the assumptions used in mine planning and impact assessment (including Gunii Hooloi abstraction and impact assessment). This ESIA places greater reliance on the later studies as these are based on the greatest depth of information. Reference, however, is also made to the earlier work where borehole data or geophysical modelling is provided that is relied upon but not reproduced in later documents.

The modelling undertaken by Oyu Tolgoi and engineering design for the water supply system has been peer-reviewed by independent third parties, with a focus on the reliability and sensitivity of the conclusions and assessment of risks and fatal flaws. The results of the peer reviews have been used to amend the model and/or the scope of further investigation of the aquifers. The key peer reviews undertaken are:

- Golder Associates: review of hydrogeology & modelling, August 2003;
- Water Management Consultants (Shrewsbury, England) review of hydrogeology & modelling, February 2006;
- Black & Veatch: engineering review of overall water supply system, April 2008; and
- Maison Worley Parsons pipeline and borefield design review, 2010.

A recent review of the hydrogeological models and concepts for both the Gunii Hooloi and Mine Licence Area by Aquaterra included a detailed discussion of the future changes to the model planned in order to further improve the confidence in both the baseline data assumptions and the modelled aquifer behaviour and potential impacts. The models and their assumptions are further discussed in *Chapter C5* where the potential impacts of the water abstraction on the Cretaceous aquifer and shallower aquifer systems are considered. Monitoring data and related reports from Oyu Tolgoi's environment department have been used to add to the data presented in the above report. This includes a recent water monitoring report produced for the Water Authority in the Ministry of Nature Environment and Tourism:

- Oyu Tolgoi (2010), OT Project Water Monitoring Report (translation), December 2010.

For information on the regional water context and scarcity the following reference has been used:

- World Bank (2009) Groundwater Assessment in the Gobi Region.

Other references used in the preparation of this Chapter are given in the text or as footnotes in the Chapter.

### 6.3 WATER SCARCITY IN THE SOUTH GOBI

Surface water is scarce in the arid South Gobi region, an area of about 350,000 km<sup>2</sup> extending across the *aimags* of Dornnogovi, Dundgovi and Omnogovi. The traditional herder way of life has evolved over time to be in balance with the region's resources although, in recent years, overgrazing has created a number of on-going environmental and economic problems. Overgrazing due to increased stock densities rather than water availability have been the constraining factor on the local herders to date; if there are significant climatic changes in the region (see *Chapter B2: Climate and Climate Change*) water scarcity may become a more critical factor.

Surface water in the South Gobi is limited in extent and, outside of the flow events in the ephemeral rivers following a significant storm, is restricted to isolated springs. Shallow groundwater within 2 m of the surface has traditionally been the main source of water for the herders and their animals and, where shallow enough, can also be exploited by the larger wildlife. This shallow groundwater also locally supports small stands of groundwater dependant vegetation such as the distinctive Siberian Elms.

Oyu Tolgoi recognises that water is a scarce commodity in the South Gobi region of Mongolia, an area of about 350,000 km<sup>2</sup> extending across the *aimags* of Dornnogovi, Dundgovi and Omnogovi, which have a combined population of approximately 150,000. The area's increasing industrial and urban development will inevitably place strains on this desert area's water resources given its low rainfall. The traditional herder's lifestyle has been generally in balance with the region's resources and is typically viewed as sustainable, although in recent years overgrazing in some areas has created a number of on-going environmental and economic problems.

Mining (principally coal and copper/gold) is the main focus of the industrial development in the region which is resulting in increasing populations in towns such as Dalanzadgad (the *aimag* capital) and Khanbogd, the *soum* centre and nearest community to Oyu Tolgoi. A 2009 World Bank study<sup>2</sup> has estimated that by 2020 water demand by the region's mines may reach approximately 300,000 m<sup>3</sup>/day and urban centres with a predicted population of around 200,000, will require approximately 25,000 m<sup>3</sup>/day. In addition to these demands, other developments, such as more intensive agriculture (to supply the local population) and tourism will add to the increasing water demands on the South Gobi's water resources. Although difficult to estimate, the World Bank study estimates the total water demand in the region by 2020 will be in the range of 400,000 to 450,000 m<sup>3</sup>/day, with the majority of this required by the mining projects in the region.

#### **Water Sources**

To support this economic development and associated water demand the only immediately available water resource are the deep, typically more saline, aquifers in the region. These aquifers have little or no recharge with the water they contain likely to date to an ancient period when there was more plentiful surface water in the region (hence this groundwater is often termed '*fossil groundwater*'). The aquifers can provide the vast majority of the water needed for urban and industrial growth in the South Gobi, although many urban centres can also be supplied to a degree from groundwater that is recharged on an annual basis. These deep aquifers generally contain water that is non-potable and in parts not suitable for livestock use without treatment, furthermore the water is beyond the reach of local herders (due to its depth). The study commissioned by the World Bank estimates that the groundwater potential of these deep aquifers in the South Gobi region varies from 200 to 500 million m<sup>3</sup>/year, assuming a 25 to 40 year period and allowing for a lowering of the groundwater of 50 m to 100 m. The lower range of the groundwater potential of 200 million m<sup>3</sup>/year, is equal to 550,000 m<sup>3</sup>/day (Oyu Tolgoi is currently permitted by the Government of Mongolia to take approximately 70,000 m<sup>3</sup>/day of water from the Gunii Hooloi deep aquifer). The World Bank study therefore concludes that the groundwater potential for the South Gobi region as a whole is sufficient to cover the projected water demands of the next 10 to 12 years (i.e. to 2023).

These fossil waters are not replaceable on any realistic timescale therefore their use needs to be justified on robust economic and social grounds, and any use of the water must meet the highest level of

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<sup>2</sup> World Bank (2009) Groundwater Assessment in the Gobi Region, Background document for the preparation of a Regional Environmental Assessment (REA) for the Gobi region to support the development of a Regional Development Strategy by the Government of Mongolia Final Draft Report 25/01/2009

management so the maximum benefit is attained for the water and minimal water is lost. Such an approach will require a very active water management programme that matches long-term supply with long-term need and demand. This will require a mix of instruments and actions (both public and private) including an improved and complete understanding of many of the aquifers and the water resources of the area, improved water permitting and pricing of the resource, water use efficiency, and developments that focus on the best use of this limited resource (taking account of economics and social needs). This strategy will also need to consider realistic alternative water supply options which are economically, socially and environmentally justifiable (the current speculative proposal for the use of pipelines for inter-basin water transfers within Mongolia is not considered to fulfil these criteria).

In summary based on conservative assumptions and the currently available information, there is considered to be enough groundwater to sustain the projected regional development until at least 2020<sup>3</sup>. However it should be noted that the current data available have limitations and are focused on the water resources which have been delineated by the mining companies active in the region and the Government of Mongolia. There are therefore basins which are known to contain water resources that are poorly defined and potentially other basins yet to be discovered. To provide a more accurate assessment of the regional water resources a more robust assessment is required combined with detailed regional planning at an *aimag* and/or National level.

## 6.4 SURFACE WATER

The Oyu Tolgoi Project Area of Influence is located within the southern part of the Central Asian Internal Drainage basin. This is a closed basin in the largest drainage basin in Mongolia<sup>4</sup> and has no outflow to the ocean; it includes the Great Lakes Depression in north-western Mongolia, while in the area of Oyu Tolgoi, surface water flows are to playa lakes located in Southern Mongolia and Northern China. Almost all water courses in the southern part of this basin are ephemeral in nature and remain dry for the majority of the year. The 120 km long Undai is one of the most significant hydrological feature in the Project Area of Influence, with a catchment covering an area of approximately 1,080 km<sup>2</sup> with its many ephemeral tributaries. The Undai passes south-eastwards through the western part of the Oyu Tolgoi mining license (see *Figure 6.2*) and terminates in the playa lakes of the Galbyn Gobi approximately 60 km south of the Oyu Tolgoi site.

The average annual precipitation in the Project area is 80 mm, 90% of which falls as rain during storm events in the warm summer season. Run-off from bedrock outcrops and surface water flows are only likely to occur following a significant rainfall event of approximately 20 mm or more. (The amount of rainfall required to generate surface flows will depend on the intensity of the rainfall, duration, slope and surface runoff coefficient.)

As these surface flows are short-lived and unpredictable, the flows are of limited use to the local population. Depending on the topography, these flash floods (locally called “Gobi wild floods”) often have a heavy sediment load, and can travel at relatively high speeds down the valleys from the area of rainfall into downstream areas which have not experienced any rain. Their potentially unexpected nature can make them a hazard, trapping domestic stock and wildlife and posing a danger to people and infrastructure.

The playa areas found to the south of the Mine Licence Area in the vicinity of the infrastructure corridor, flood following rain events and provide temporary standing water features which herders can use for their livestock. The flooding of these playas also impacts local transport as the subsequent soft mud of the playa make them largely impassable to traffic.

### 6.4.1 Surface Water Features in Mine Licence Area

The Mine Licence Area and surrounding area lie within the Undai catchment, with the Undai flowing through the western part of the Mine Licence Area. Majority significant part of the Undai’s catchment

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<sup>3</sup> Acacia Water, 2009. Referenced in Tuinhof, A. and Buyanhisnig, N. 2010. *Groundwater Assessment of the Southern Gobi Region*. Mongolia Discussion Papers, East Asia and Pacific Sustainable Development Department. Washington, D.C.: World Bank.

<sup>4</sup> WWF 2004, Freshwater Issues in Mongolia by Batnasan N, WWF Mongolia Programme Office.

(460 km<sup>2</sup>)<sup>5</sup> is upstream of the Mine Licence Area and given the size of this, heavy rainfall events in any part of this catchment can result in substantial flows in the lower sections of the Undai which passes through the Oyu Tolgoi Mine Licence Area (*Figure 6.1*). Flood estimation studies for the Undai basin demonstrate that, depending on the areal extent of a rainfall event, slope and other related parameters, the maximum flood discharge in the Undai may reach 130 m<sup>3</sup>/sec.

**Figure 6.1: Undai Flowing at Bor Ovoo location following Rainfall Higher up the Catchment**



Based on Oyu Tolgoi's observations of the Undai where it flows through the Mine Licence Area, the Undai typically flows 4-6 times per year (see *Figure 6.1*). The climatic records of the Omnogovi area indicate that an average year would include between 2 and 5 periods of significant flow; i.e. when the Undai is impassable for a period of time. During a very wet year the number of episodes may increase to nine flow events, whilst in a dry year there may only be one event. Approximately 70% to 80% of these flow events occur during the months of July and August and typically have a duration of a day at most.

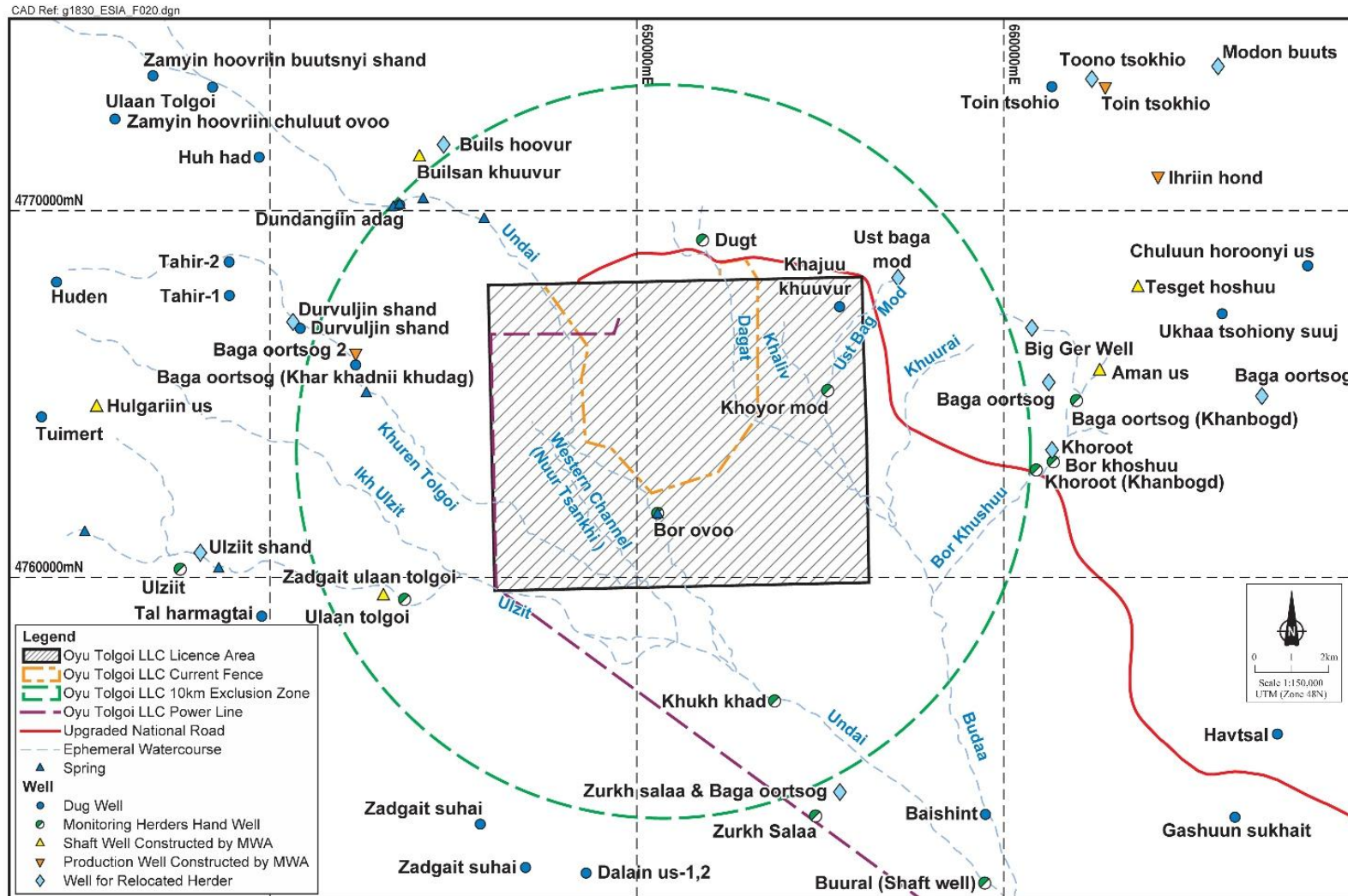
The main tributaries of the Undai in the vicinity of the Project (see *Figure 6.2*) are:

- Khuran Tolgoi which joins the Undai within the mining licence;
- Ulziit which joins the Undai immediately south of the licence boundary; and
- Budaa and Bor Khoshuu which originate from the west of Khanbogd Mountain and join the Undai near the Bural spring approximately 12 km southeast of the licence boundary.

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<sup>5</sup> SMEC, 2011: Oyu Tolgoi Project: River Diversion Detailed Engineering Detailed Design Report – Final, Ref: A2MW-90-K487, 5<sup>th</sup> September 2011

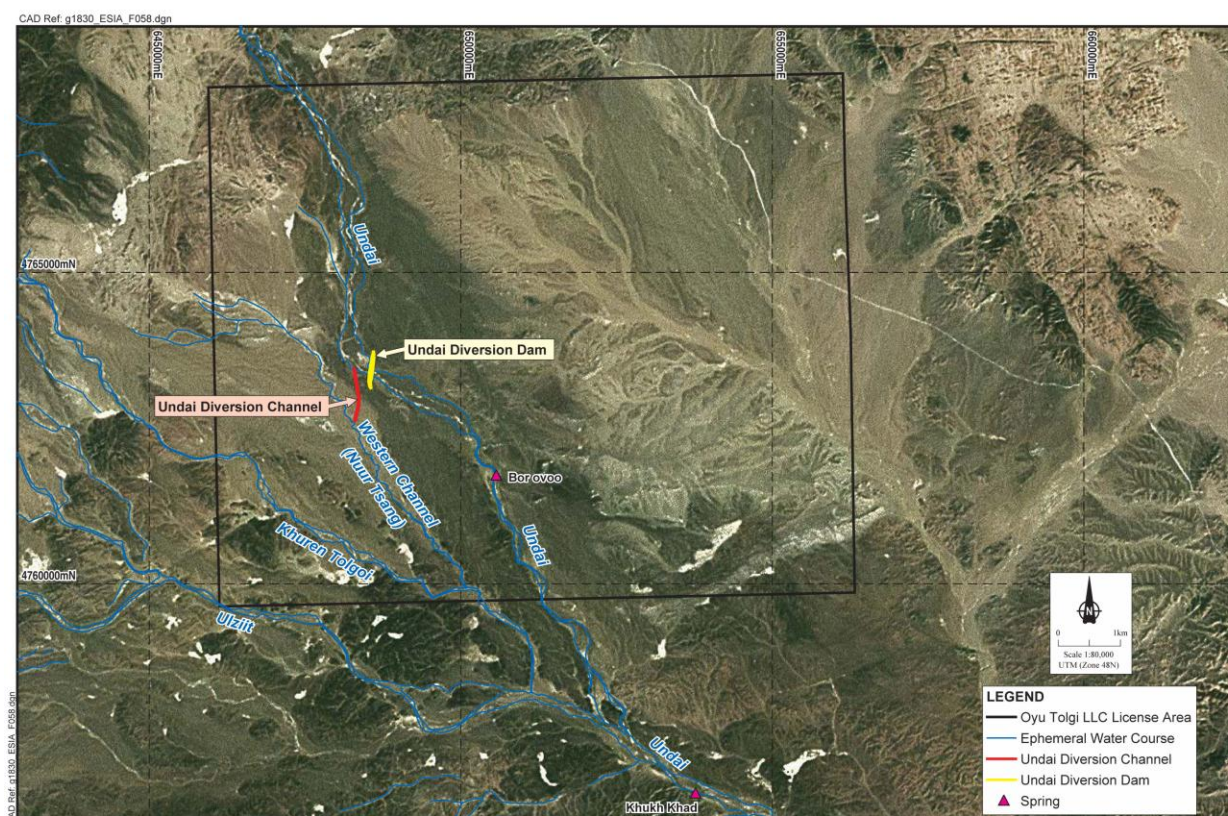
**Figure 6.2: Ephemeral Watercourses, Springs and Wells around the Oyu Tolgoi Licence Area**



Note: Watercourses are illustrative, for the majority of the year these are dry with no flow. The map shows a selection of the monitoring well used by Oyu Tolgoi as part of its monthly monitoring programme. Figure includes herder wells which have been subject to herder relocation e.g. Dugat and Khaliv (see Figure 6.15)

In addition to the tributaries of the Undai, the upper tributaries of the Budaa ephemeral watercourse flow through the north-eastern parts of the Mine Licence Area. The Nuur Tsangi (or Western Channel), which is the ephemeral water course immediately to the west of the Undai joining the Undai south of the Mine Licence Area, is the watercourse which will be used by Oyu Tolgoi for the diversion of the Undai. The relationship of these ephemeral watercourses is shown in *Figure 6.3*.

**Figure 6.3: Ephemeral Water Courses around the Undai associated with the Undai diversion**



The diverted Undai will flow south, through an engineered channel into the Western Channel. The Western Channel is a relatively straight (possibly fault controlled) ephemeral watercourse with a central 20 m wide channel within a broad (over 500 m wide), low relief valley which narrows at its southern extent to approximately 100 m. The Western Channel joins the Khuren Tolgoi ephemeral water course, which has a 150 m wide channel, approximately 900 m east of the confluence of Khuren Tolgoi with the Undai. The width of the braided Undai channel ranges from 20 m (350 m south of the Bor Ovoo spring) to approximately 200 m (adjacent to the planned Southern Pit). The meandering channel of the Undai and its tributaries are controlled by the broad shape of the valleys in which they sit and also the outcrops of harder bedrock.

#### 6.4.2 Surface Water Features in Gunii Hooloi

The broad Gunii Hooloi drainage basin or catchment (see *Figure 6.4*) within which the new Temporary Domestic Airport is located and from which the Project's water supply will be drawn, lies to the northeast of the mine and is within a separate catchment to the Undai.

Surface water in the Gunii Hooloi basin drains toward the east-northeast and ultimately discharges via the Galbyn Gobi to the larger internally draining Duut Toirim basin, which is a low point or depression located approximately 60 km east of the Gunii Hooloi borefield (see *Figure 6.4*). The surface water draining from the Gunii Hooloi sub-basin (*Figure 6.4*) makes up approximately 16% of the Duut Toirim basin catchment. In addition to the playa area associated with the Duut Toirim depression, there is a small playa depression at the eastern end of the Gunii Hooloi basin which collects some of the run-off from the basin and supports shallow rooted vegetation.

**Figure 6.4: Gunii Hooloi Sub-Catchment and Duut Toirim Catchment with the main drainage features**

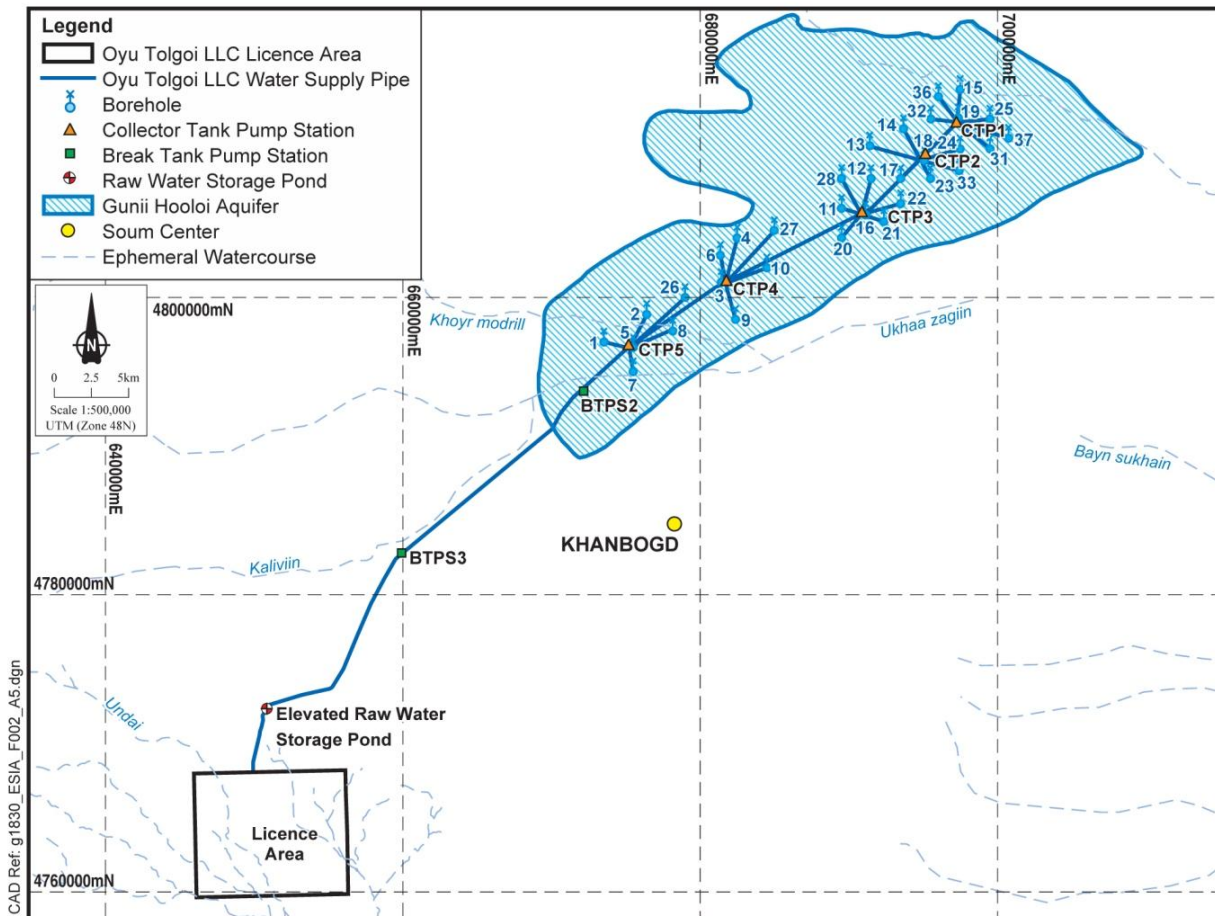


Source: Based on Aquaterra (2008), *Gunii Hooloi Aquifer, Groundwater Investigation and Resource Assessment – 2007 (Revised Water Demand)*, March 2008

In the Gunii Hooloi area, flows along the main ephemeral water courses are due to rainfall in the immediate area or in the hinterland of the catchments, such as on the Khanbogd Massif. The effect of these flow events on the shallow aquifers situated along the ephemeral water courses is discussed in *Section C6.5*. Although there is no flow monitoring in the Gunii Hooloi area, the reaction of the shallow aquifers (see *Figure 6.13*) indicates seasonal replenishment due to infiltration of surface water flows following significant rainfall events (inferred to be greater than 20 mm).

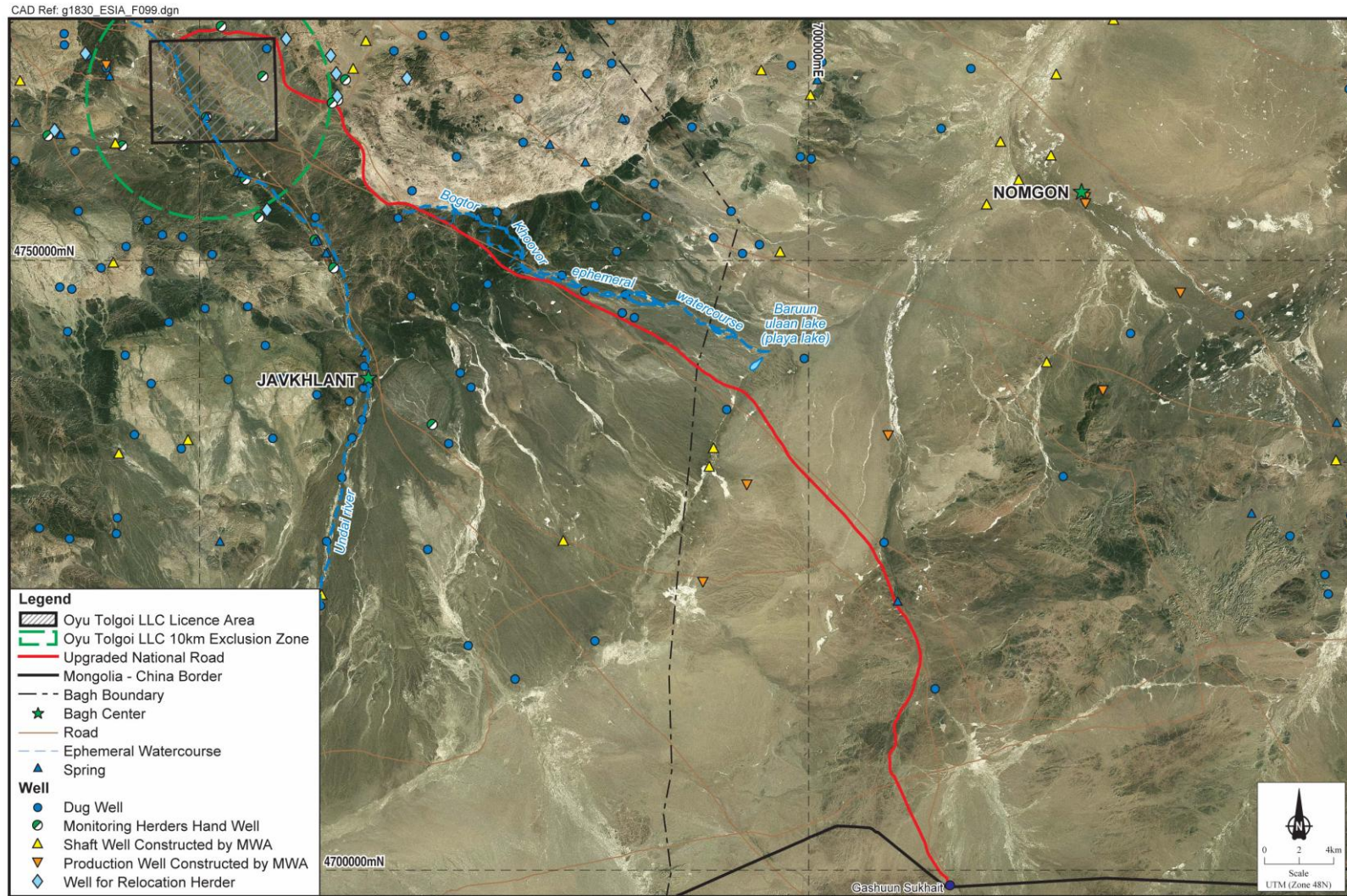
The ephemeral water courses in Gunii Hooloi which are illustrated in *Figure 6.4* are the most substantial and therefore the ones which have sufficient thickness of associated alluvium to be exploited by the herders. The area of the borefield itself is on a slightly elevated area which has no significant ephemeral watercourses and no alluvium capable of supporting sufficient water for herder wells. This explains the absence of herder wells in this area and it being locally referred to as “camel pasture” (i.e. only camels graze the area as it is too distant from any herder wells for goats and sheep to access). The pipeline connecting the borefield and the water lagoon and ultimately the Oyu Tolgoi process plant, will cross a number of ephemeral watercourses along its route (Khoыр modrill, Ukhaа zaglin and Kaliviin being the main ones, see *Figure 6.5*). The pipeline will be installed at depth of approximately 2 m depth (i.e. below the freezing zone) and backfilled with alluvial materials which have the similar hydraulic properties to the original stream bed materials.

**Figure 6.5: Ephemeral Watercourses in the vicinity of the Borehole Field and Pipeline**



The Temporary and Permanent Airports are located at the western end of the Gunii Hooloi catchment and comprises very gently undulating land varying between 1,190 and 1,205 m in altitude. There are no hydrological features on the site, although the area could be prone, as could any flat area, to short term inundation during a significant rainfall event. During such an event, sheet run-off would flow in an easterly direction.

**Figure 6.6: Map of Wells and Ephemeral Watercourses along the Road Route**



Source: Eco-Trade 2006: Supplementary Environmental Impact Assessment Report for Oyu Tolgoi- Gashuun Sukhait Infrastructure Corridor

### 6.4.3 Surface Water Features in the Infrastructure Corridor

The Infrastructure Corridor comprises the study area from the Mine Licence Area to Gashuun Sukhait, through which the road and electricity power lines to the border are being constructed. The hydrology and hydrogeology of this Infrastructure Corridor are similar to those around the Oyu Tolgoi Mine Licence Area, in that the area contains ephemeral watercourses which only flow for short periods after significant rainfall events. The key difference with the Infrastructure Corridor is that the catchments of these ephemeral watercourses along the route are small (see *Figure 6.6*). However, although limited recharge along the stream can be sufficient to maintain shallow wells used by herders for watering of livestock, and also to support local groundwater-dependent vegetation such as the Siberian Elm.

The route chosen for the road has been designed to minimise watercourses crossing and to avoid soft (when wet) playa areas, and runs parallel to the south-easterly orientation of the stream beds. As a consequence, the road crosses no major watercourses and there are few ephemeral watercourses or ravines near the road route. There are no substantial surface water features in the immediate environs around the road; of those in the area the largest (in terms of length and continuity) is the Bogtor Khoovor ephemeral watercourse, which discharges to the Baruun Ulaan Nuur playa lake (see *Figure 6.6*). In addition there are a number of shallow wells and occasional dense bushes of *Nitraria*, and elm tree communities where shallow groundwater is very close to the surface, adjacent to the route.

## 6.5 GROUNDWATER

The aquifers in the Project Area of Influence have been subject to a number of studies by Oyu Tolgoi with the main exploration drilling work having been done between 2004 and 2008. Oyu Tolgoi continues to refine the groundwater models, including planning the next stage of the Gunii Hooloi aquifer delineation studies. Based on the baseline data, the main aquifers in the Project area can be separated into three main hydrogeological units, which have varying degrees of hydraulic connectivity in the different parts of the Project area:

- **Alluvial aquifers:** These are linear aquifers associated with the major ephemeral watercourses, such as the Undai. These aquifers are Quaternary to Recent in age and tend to thin away from the main ephemeral watercourse and are hydraulically contiguous with the alluvial/colluvial sediments of the steppe. The main flow path in the aquifer is parallel to the main river bed following the more permeable and thicker sediment associated with the watercourse. They are typically exploited by herders for drinking water and animal water with the groundwater being accessed using shallow hand-dug wells and manual pumps. These aquifers occur on and around the Mine Licence Area, where the road to Gashuun Sukhait crosses the ephemeral water courses, and around the margins of the Gunii Hooloi Basin. They are absent or very poorly developed away from the ephemeral water courses and are absent from the area around the airport. Groundwater flows in these aquifers typically support the springs in the main ephemeral watercourses. Aquifers in these formations are currently exploited by the herders and the Khanbogd community.

There are sands outside of these linear alluvial features such as the Khaliv Sand Deposit which is located on the eastern side of the Mine Licence Area. These sands are typically dry and are not relied on for groundwater resources.

- **Cretaceous clastic aquifers:** These aquifers comprise thick Late Cretaceous sediments deposited in fault defined rift basins. They comprise a fining upwards sequence i.e. coarsest sediments are at the base of the sequence and are topped by low permeability or impermeable sediments which abut the basin edges. They receive little or no recharge from annual rainfall with the groundwater being considered fossil water (i.e. ancient), although data has not yet been obtained to confirm how old the waters are. They are generally separated from the shallow aquifers by the low/impermeable sediments and can be artesian (i.e. free flowing to the surface as found in some areas of the Galbyn Gobi) when penetrated by a borehole. They are developed in the Galbyn Gobi and Gunii Hooloi areas, including the area of the Galbyn Gobi traversed by the road to Gashuun Sukhait. These aquifers will be exploited by Oyu Tolgoi for the Project's process water supply in Gunii Hooloi and the Galbyn Gobi aquifer will be used for a few months during the construction phase to provide water for road construction through the Galbyn Gobi. These aquifers are also present in the Khanbogd sub-basin and are currently the subject of

exploration drilling and testing which has the aims of identifying a resource which can be used for the future Khanbogd municipal potable water supply (see Section B6.5.10).

- **Bedrock aquifers:** These are aquifers in the Palaeozoic (Silurian-Devonian) bedrock which comprises igneous and inter-bedded deformed and metamorphosed sedimentary rocks. Groundwater flow in these rocks is dominantly within the weathered bedrock which can be up to 30 m or more thick, or fractures in the bedrock which are influenced by the local faulting and competency of the bedrock. Locally, fracture zones associated with intrusions and dykes can be associated with permeable units. Where present, the overlying Late Cretaceous to Palaeozoic sediments, where clay dominated, will act as an aquiclude separating the bedrock from the shallow overlying alluvial and alluvial/colluvial aquifers. Recharge to this aquifer occurs where the clay is absent and there is hydraulic connectivity between the bedrock and alluvial aquifers, or where the bedrock outcrops such as on the Khanbogd Massif. The open pit mine will encounter this bedrock groundwater as it extends down through the weathered bedrock zone. As the underground block caving will be below this weathered zone it therefore will not interact with this aquifer unless the fractures associated with the block caving create a pathway up to groundwater in this weathered zone. These bedrock aquifers are being used by Oyu Tolgoi for camp/construction water supplies. They are only exploited by the local herders where the fracture system feeds a spring, such as on and around the Khanbogd massif to the east of the Mine Licence Area.

These aquifers and their relationships are discussed in the following sections.

### 6.5.1 Oyu Tolgoi Mine Licence Area Alluvial Aquifers & Bedrock Aquifers

The main groundwater resources within and immediately surrounding the Oyu Tolgoi Mine Licence Area are alluvial aquifers and shallow weathered bedrock. The shallow alluvial aquifers occur in alluvial outwash plains and in the beds of the ephemeral watercourses. Although thin aeolian and alluvial deposits cover approximately 70% of the Oyu Tolgoi Mine Licence Area, these are thin and clay rich and the only exploitable aquifers are linked to the alluvium in the beds of existing ephemeral watercourses. These alluvial aquifers are best developed in the Undai and Khuren Tolgoi (or Red Hill River) which converges with the Undai to the south of the Mine Licence Area, while in other watercourses are less well developed and are often discontinuous.

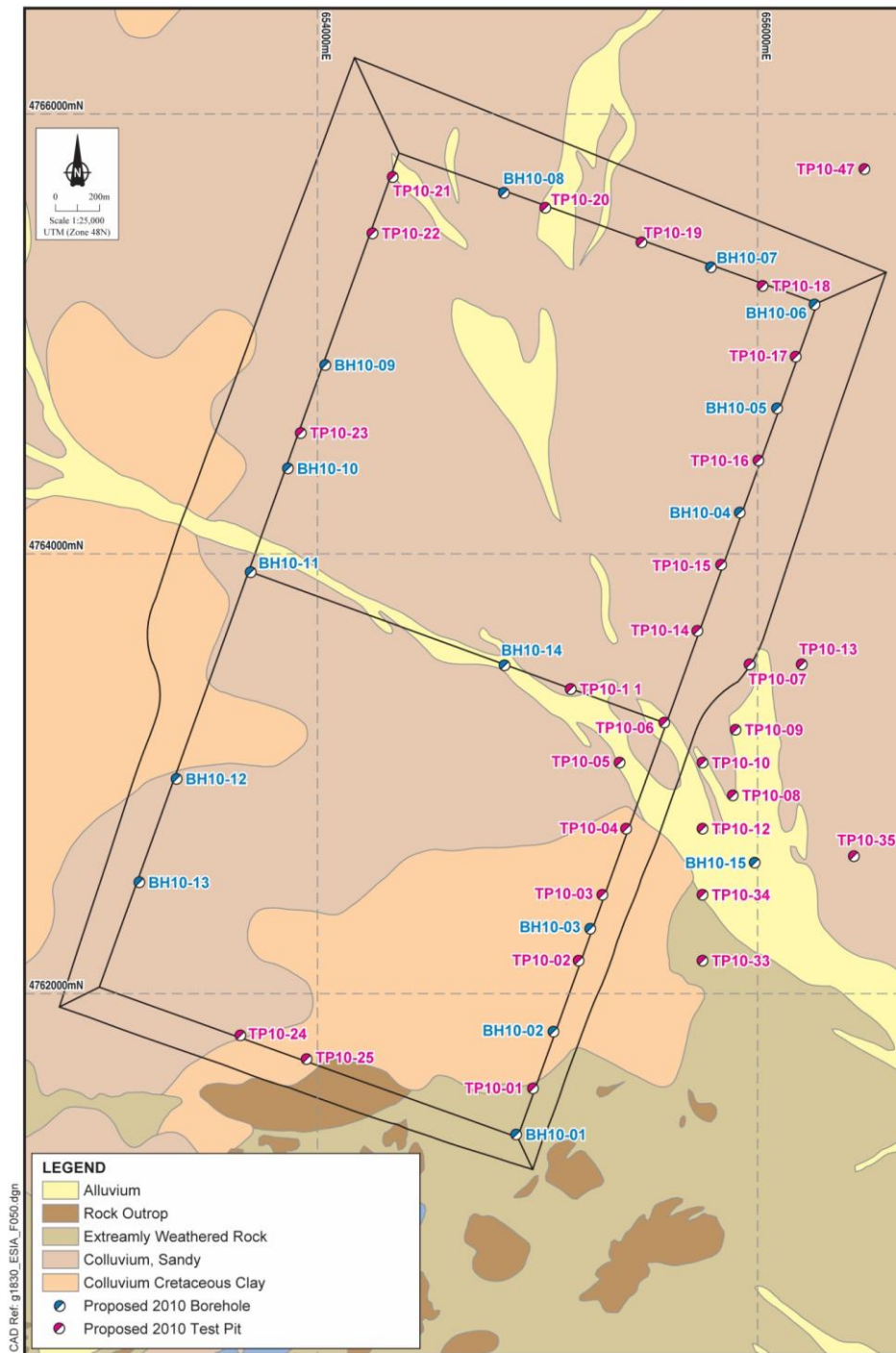
The exploration work undertaken as part of the Undai diversion design works indicates that the Undai alluvium in the vicinity of the proposed dam is up to 6 m thick. It is uniform in nature and consists of unconsolidated, loose silty sandy gravel to silty gravelly sand which is angular to sub rounded and poorly sorted. The contact between the alluvium and the weathered bedrock is sharp and the bedrock is only moderately to weakly weathered in the top 1 m. The groundwater gradient in the area of the proposed dam is approximately 0.0045 with a permeability of 226 m/day, and the flow rate is estimated to be 5 l/s. This flow rate will vary along the Undai and will vary seasonally depending on the level of the water within the alluvium, thickness of alluvium etc. (i.e. if the saturated thickness increases (the water level is at surface) thereby increasing the cross sectional area then assuming the same gradient the flow could be as much as 8 L/sec).

The majority of the north western part of the Mine Licence Area is underlain by clay rich Cretaceous with some shallow Cretaceous clay residual soils and clayey sands and clayey gravel and residual soils along the southern part of the Mine Licence Area. Where present, the Cretaceous Clay typically forms an aquiclude, although it does have sand and, towards the base, gravel units which can form discontinuous aquifers. These Cretaceous and overlying alluvial and windblown deposits have been mapped in detail to understand their implications for the mine infrastructure such as the Tailings Storage Facility (TSF) which is illustrated in *Figure 6.7* and *Figure 6.8*. The features of the TSF and waste rock dump and the implications of the shallow hydrogeology are discussed further in the impact assessment *Chapter C4 Topography Geology and Soils*.

Recharge to these shallow alluvial aquifers occurs via direct infiltration of rainfall, seasonal surface water flows along the ephemeral watercourse which can carry water into an area which has not experienced direct rainfall. Similarly there is recharge and along bedrock/alluvium contacts where runoff from the bedrock is likely to be enhanced, such as along the edges of the Khanbogd massif. The shallow aquifers located along with ephemeral watercourse in the surrounding area are the typical water sources used by local herders for their domestic and stock water supplies.

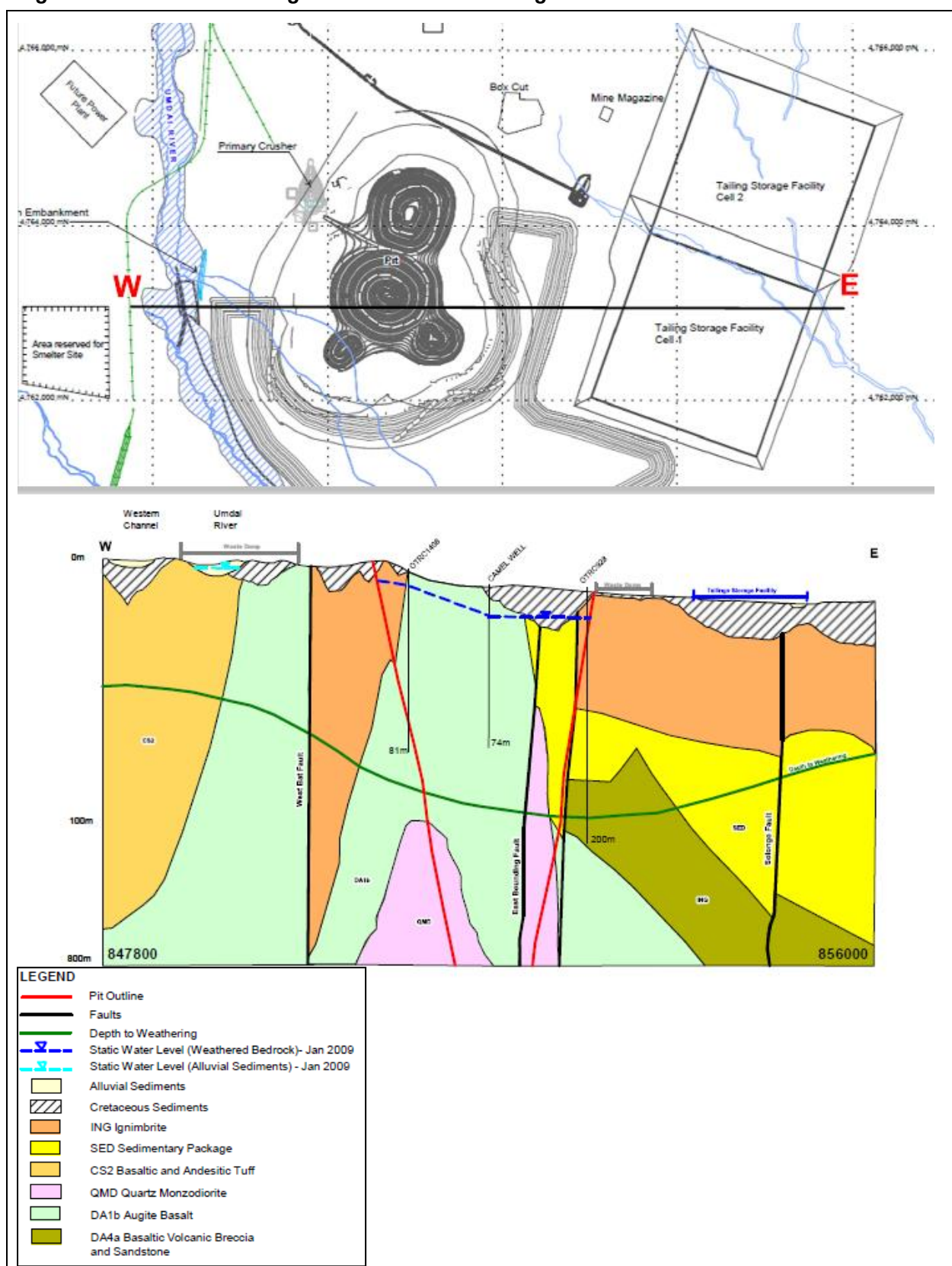
The underlying bedrock lithologies within the Project area typically have very low intrinsic permeability; however secondary permeability resulting from fracturing and weathering is relatively common in the area around the proposed Southwest and Central pits to depths up to 120 m (see *Figure 6.8*). Exploration (reverse circulation or 'RC') drilling in these two areas has intersected a limited number of water strikes, the highest resulting in an airlift yield of 8 L/s, predominantly from the transition zone of weathered to fresh bedrock at depths between 20 and 100 m. Other than some isolated occurrences, this drilling has encountered very few water-bearing fractures below 120 m depth, indicating very low bedrock permeability. This assessment has been reinforced by the almost total lack of water encountered during the sinking of Shaft No.1 and the driving of the underground levels. The geochemical testing of the waste rock (WRD) which will be produced from the open pit indicates that this rock could be potentially acid forming (see Section C5.4.10); there is, however, no evidence to indicate that the baseline groundwater conditions are acidic, with groundwater monitoring showing waters across the area to have weakly alkaline pHs.

**Figure 6.7: Shallow Geology Map of TSF and Groundwater Monitoring Wells**



Source: Data from Klohn Crippen Berger (2010), Oyu Tolgoi Tailings Storage Facility (alluvial deposits not shown)

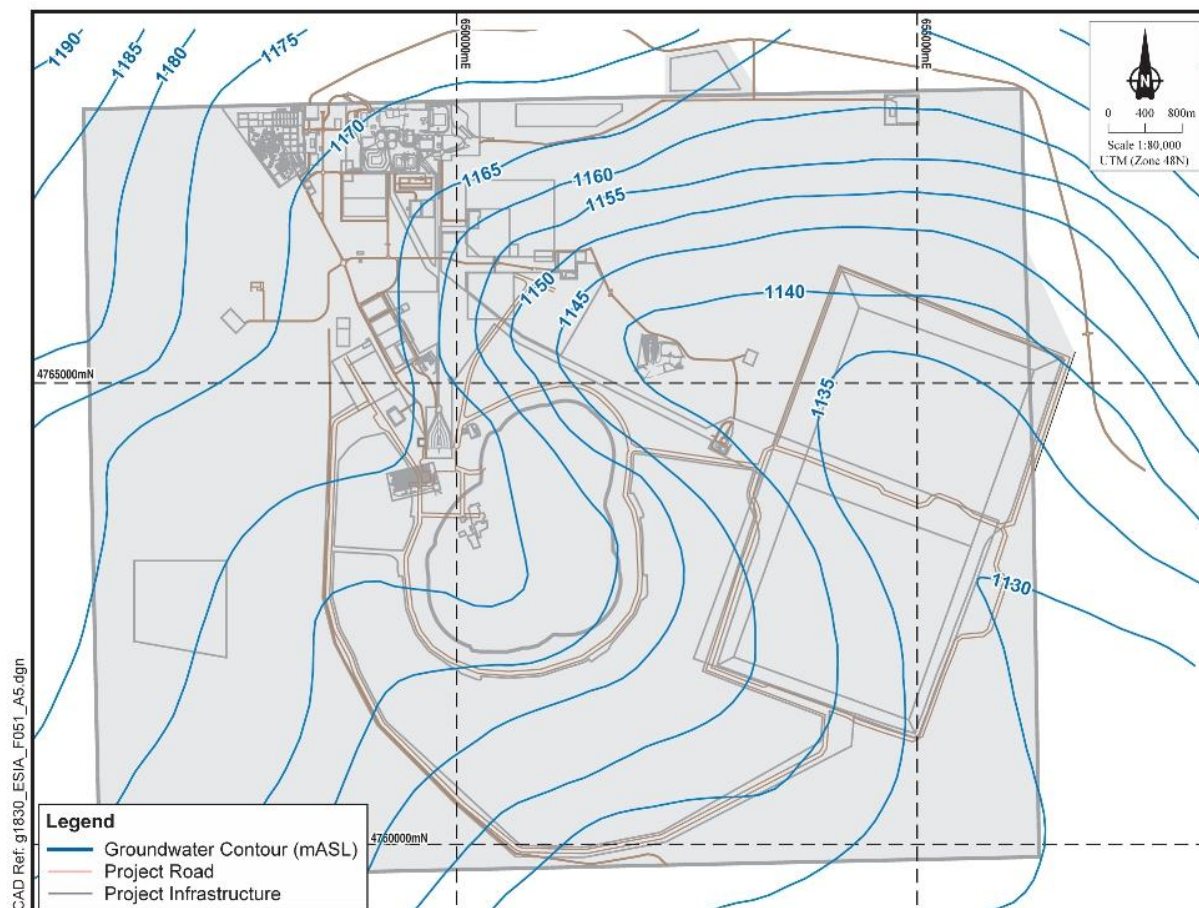
**Figure 6.8: West-East Geological Cross-Section through Mine Licence Area**



During the permeability testing undertaken by Aquaterra in 2004 as part of the mine dewatering study, known major fault zones were drilled to test whether these faults could form conduits for groundwater flow. The results of this drilling however showed these faults to be closed and filled with clayey

weathering products. The permeabilities determined from the packer tests undertaken indicated permeabilities of between  $9 \times 10^{-2}$  m/s in the weathered upper bedrock to  $8 \times 10^{-8}$  m/s in the competent rock sections with typical permeabilities of  $1 \times 10^{-4}$  m/s.

**Figure 6.9: Baseline Groundwater Contours (2004)**

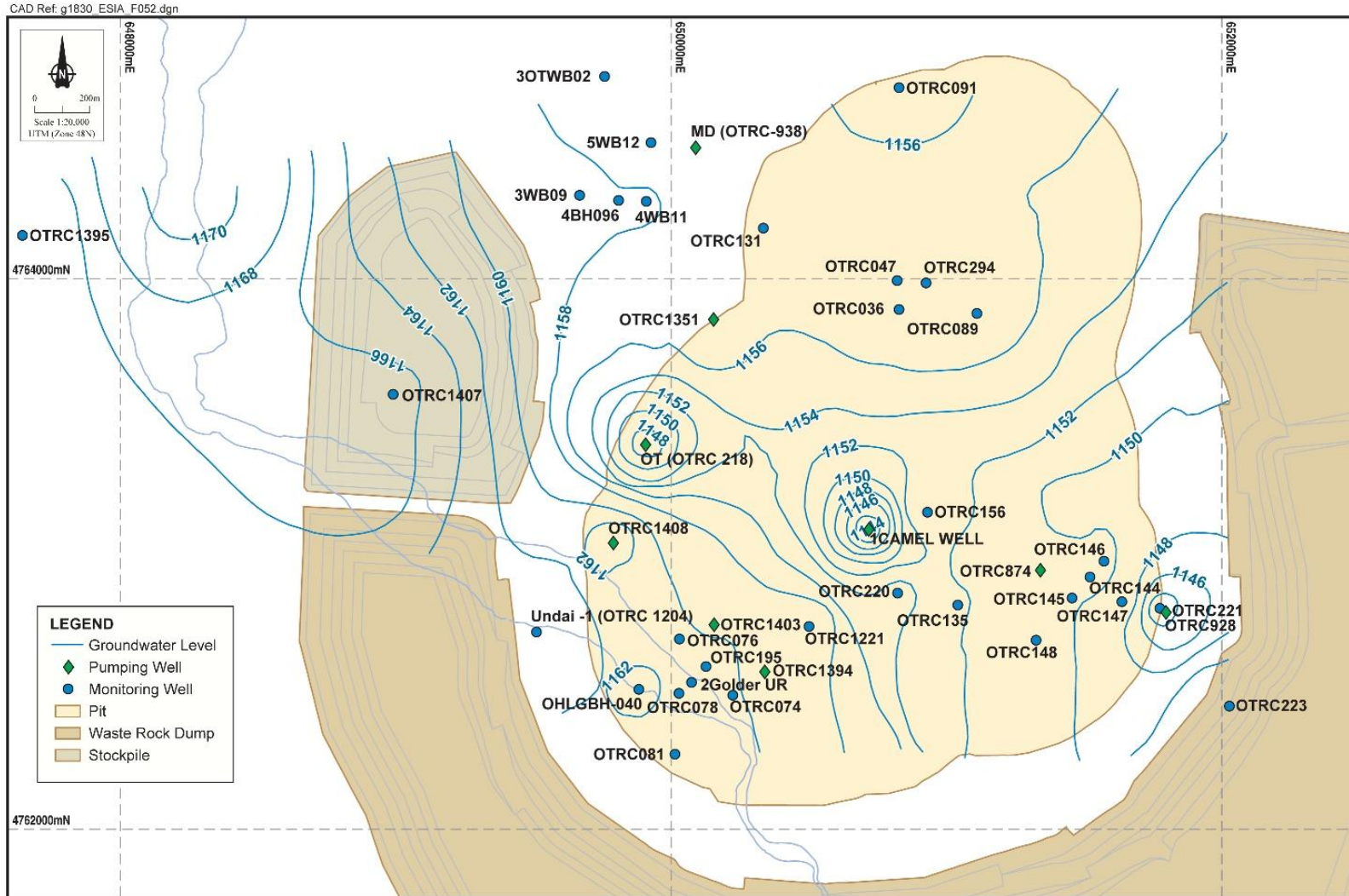


Source: Contours based on Eco-Trade (2006), Oyu Tolgoi Project Environmental Impact Assessment, Volume 3 Mining and Processing

A contour map of ground water levels in the Oyu Tolgoi Mine Licence Area, based on the water level measurements conducted by Aquaterra in 2004, is presented in *Figure 6.9* which is overlain on the future mine infrastructure and the approximate course of the Undai. This utilised the available groundwater monitoring points in 2004, and consequently is a generalised map of the groundwater levels through different, hydraulically linked, aquifer and low permeability units. As such it presents an approximation of the groundwater contours present in 2004; however the contours do correlate with the local gradient and the ephemeral watercourse and are considered to be representative of pre-construction water abstraction groundwater levels. Since 2004 a significant number of additional monitoring locations have been installed to assess the water level and behaviour at key locations (such as the WRD and TSF). In addition there has been abstraction for the construction water supply from the weather bedrock aquifer, which has altered the local groundwater gradient around the future open pit area.

The degree of influence of the drawdown in the boreholes on the Mine Licence Area, which exploit the weathered bedrock, and the adjacent Undai alluvial aquifers is inferred to be low. However the level of data is currently insufficient to ascertain with confidence the level of connectivity between the alluvial strata and adjacent hydrogeological units and thereby enable predictions of likely, long-term drawdown impacts. To address this Oyu Tolgoi has commissioned an assessment of the Undai channel architecture (using surface geophysics) and the installation of additional nested piezometers targeted at the most sensitive areas

**Figure 6.10: Water Levels in Southern Pit Location**



Source: Data from Oyu Tolgoi (2010), OT Project Water Monitoring Report (translation).

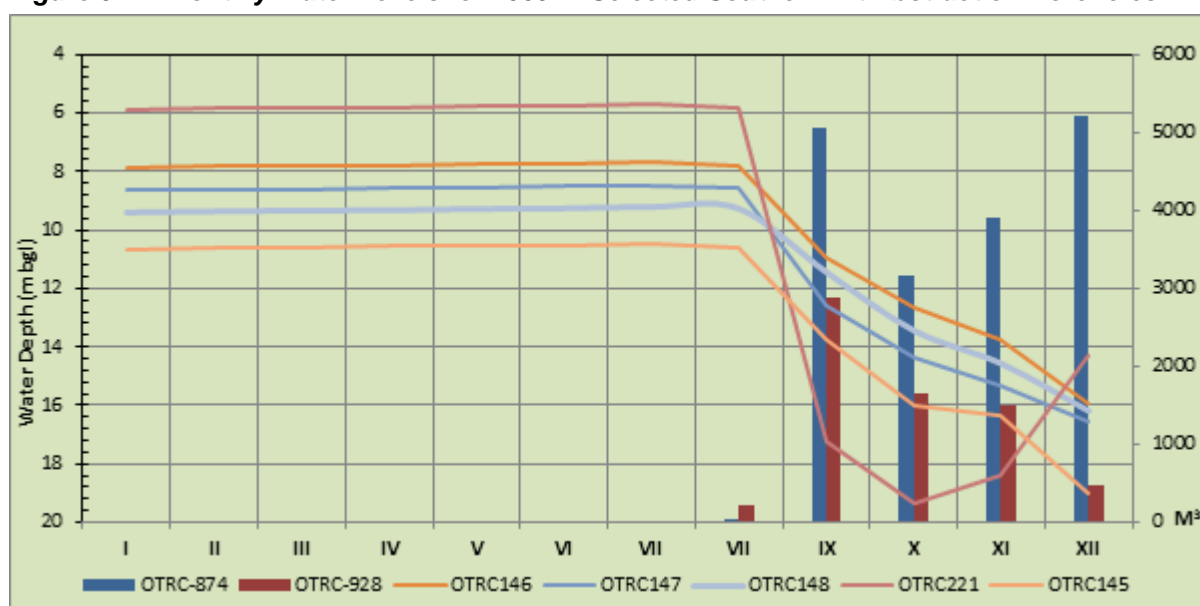
These nested piezometers are to comprise an installation in the alluvium and a nested completion in the weathered bedrock and bedrock strata. This data will be used to inform the current revision of the groundwater model for the Mine Licence Area. This model is being developed using the latest baseline data complemented by specific aquifer testing to develop a groundwater model which better represents the distribution of the various aquifers and aquicludes in the area. The model will enable Oyu Tolgoi to understand how the aquifer units will respond to the dewatering caused by the open pit mining that is due to commence in 2012.

The original water table across the Mine Licence Area was generally shallow, ranging between 5 and 15 m below ground level in the areas of Central and South West pits, but dropping to 20-30 m below surface for the Hugo South and Hugo North areas. It is at its shallowest along the watercourses (particularly the Undai) where it occasionally manifests as springs.

The water table followed the topography and slopes generally to the southeast with a hydraulic gradient of approximately 0.4 percent. A mound of groundwater trended NW-SE through the area and was generally controlled by the topography and the main surface drainage through the area.

The current pumping regime has resulted in groundwater levels decreasing in the southern area of the open pits around the pumping boreholes as illustrated in *Figure 6.10*. This figure illustrates the dynamic water levels during pumping when the abstraction boreholes are reducing the water levels/piezometric heads in the weathered bedrock (the source of the water). The drawdown observed is inferred to be very localised and focused to the immediate area around the boreholes, which reflects the low transmissivities in this weathered bedrock.

**Figure 6.11: Monthly Water Levels for 2009 in Selected Southern Pit Abstraction Boreholes**



Source: Oyu Tolgoi (2010), OT Project Water Monitoring Report (translation).

At a borehole level, groundwater level decreases of up to 14 m are recorded as illustrated by the hydrographs shown in *These nested* piezometers are to comprise an installation in the alluvium and a nested completion in the weathered bedrock and bedrock strata. This data will be used to inform the current revision of the groundwater model for the Mine Licence Area. This model is being developed using the latest baseline data complemented by specific aquifer testing to develop a groundwater model which better represents the distribution of the various aquifers and aquicludes in the area. The model will enable Oyu Tolgoi to understand how the aquifer units will respond to the dewatering caused by the open pit mining that is due to commence in 2012.

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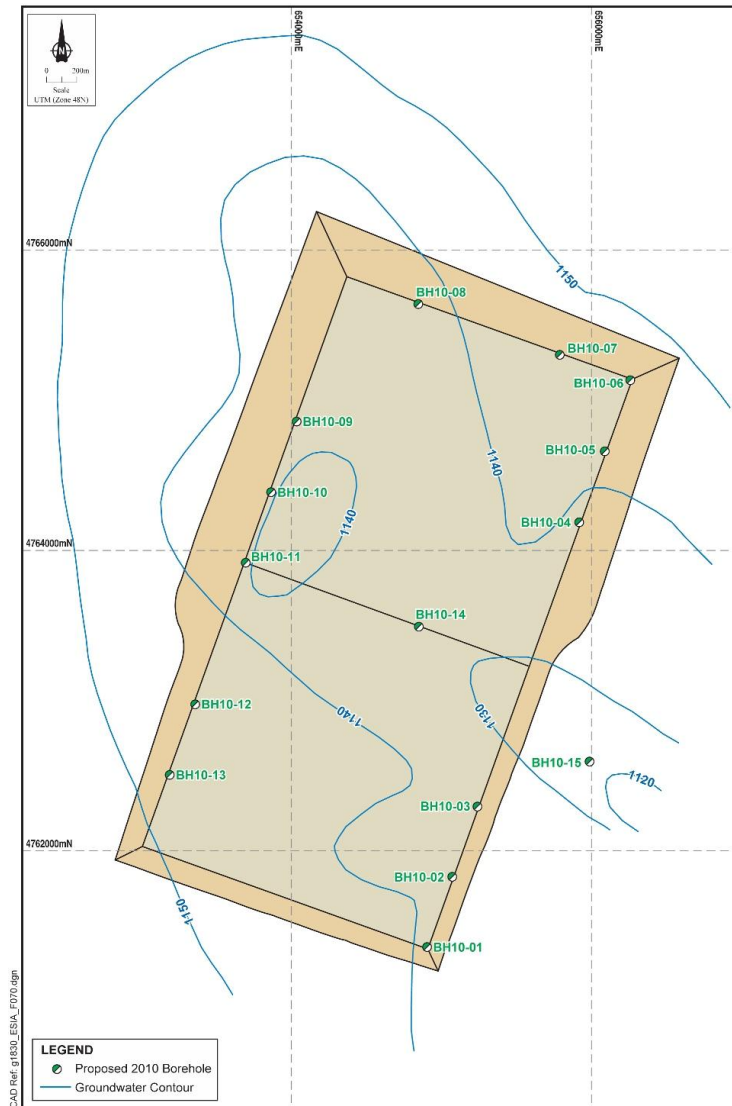
Figure 6.11, which shows the response of pumping from OTRC-874 and OTRC-928 on the groundwater levels in the pumping wells and the nearby observation wells. The pumping of OTRC-928 was considered not sustainable and therefore the pumping rate was reduced from approximately 2,900 m<sup>3</sup>/month to 500 m<sup>3</sup>/month, which resulted in a recovery in the groundwater level in monitoring well OTRC-221.

#### *Groundwater beneath the Tailings Storage Facility*

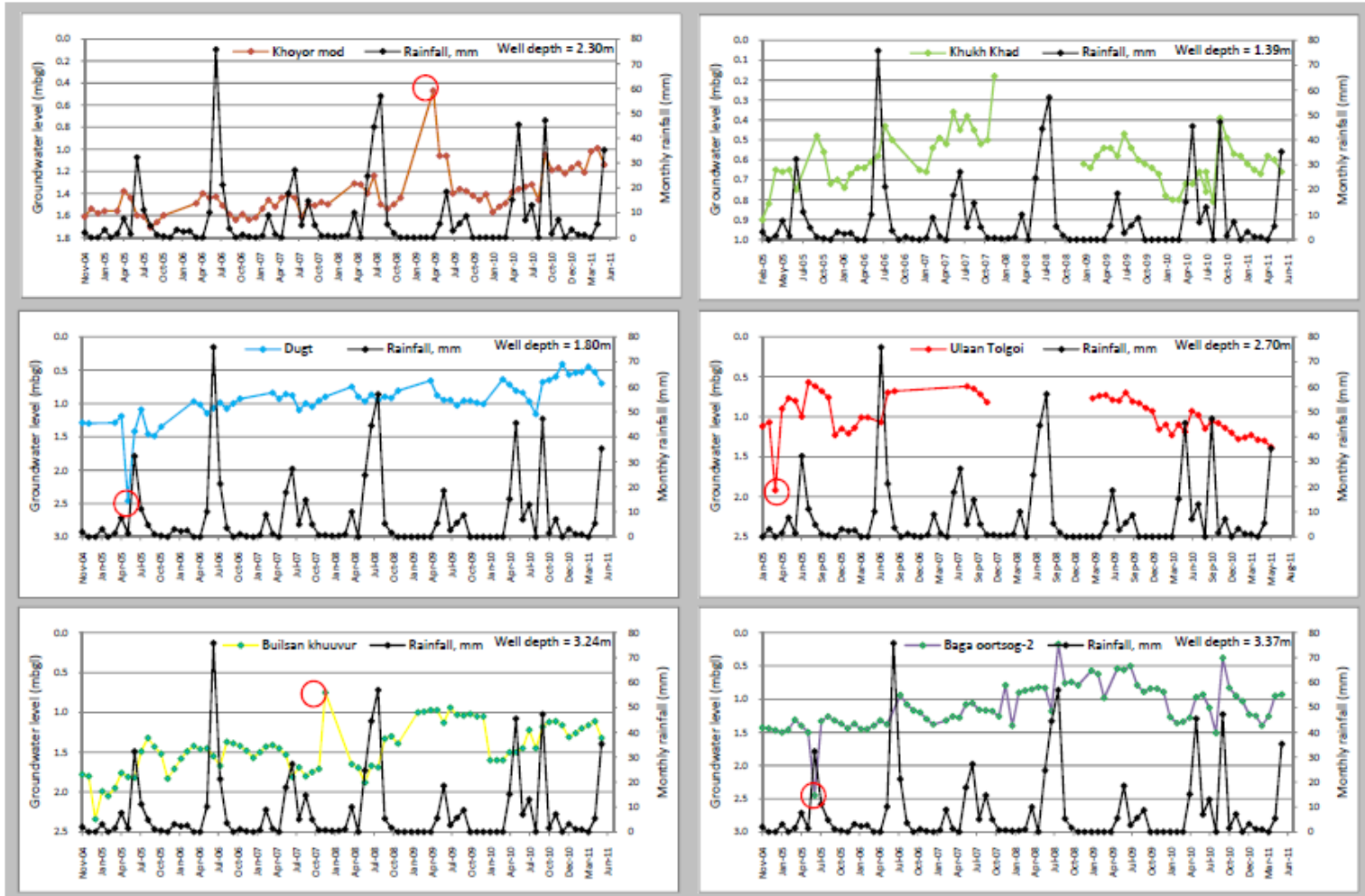
The initial assessment of groundwater levels in the Mine Licence Area (see *Figure 6.8*) showed groundwater beneath the TSF to have an easterly flow and be influenced by the local topography. Subsequent infill drilling in the TSF area has resulted in an increased monitoring well density, enabling the current water levels to be defined in greater detail (see *Figure 6.12*). This data confirms the earlier assessment that the general groundwater flow in this area is towards the east along the tributary to the Budaa with a fall from 1,150 m above sea level to less than 1,130 m across the area of the TSF. The groundwater in the area is typically 5 to 15 m below the surface and associated with more permeable sediments below the Cretaceous Clay and/or the top of the weathered bedrock, with a subtle hydraulic gradient (<1%) towards the southeast. Similarities in standing water levels in all nested and staggered standpipes installed in various formations and at various depths suggest groundwater in the vicinity of the TSF is largely unconfined. This is supported by groundwater chemistry results which do not indicate significant differences in water quality between the various shallow formations and intact bedrock. Generally groundwater is brackish (average 6,293 mg/L) compared to the near surface groundwater (319 mg/L). These results potentially suggest groundwater in deeper formations has relatively long residence times (possibly connate) and is subject to a higher degree of water-rock interaction and lower recharge when compared to the surficial formations. Shallow groundwater was typically bicarbonate dominated whilst groundwater from deeper formations was of sodium chloride type, and all water had a basic pH (i.e. greater than 7).

The investigation also identified that any very shallow groundwater associated with the surficial sediments along the Budaa and its tributaries is limited and discontinuous. These alluvial sediments can be up to 4 m thick, but are typically in the order of a metre where present. Locally there has been some historical use of these by herders (see *Figure 6.13* and *Figure 6.14*) with the well Khoyor Mod, which is a monitored by Oyu Tolgoi, located at the terminus of a lense of alluvial sediments in the Ust bag mod ephemeral watercourse.

**Figure 6.12: Water Levels in area of the Tailing Storage Facility and inferred Flow Direction**



**Figure 6.13: Groundwater Levels for Selected Herder Wells and Rainfall Data for Mine Licence Area**



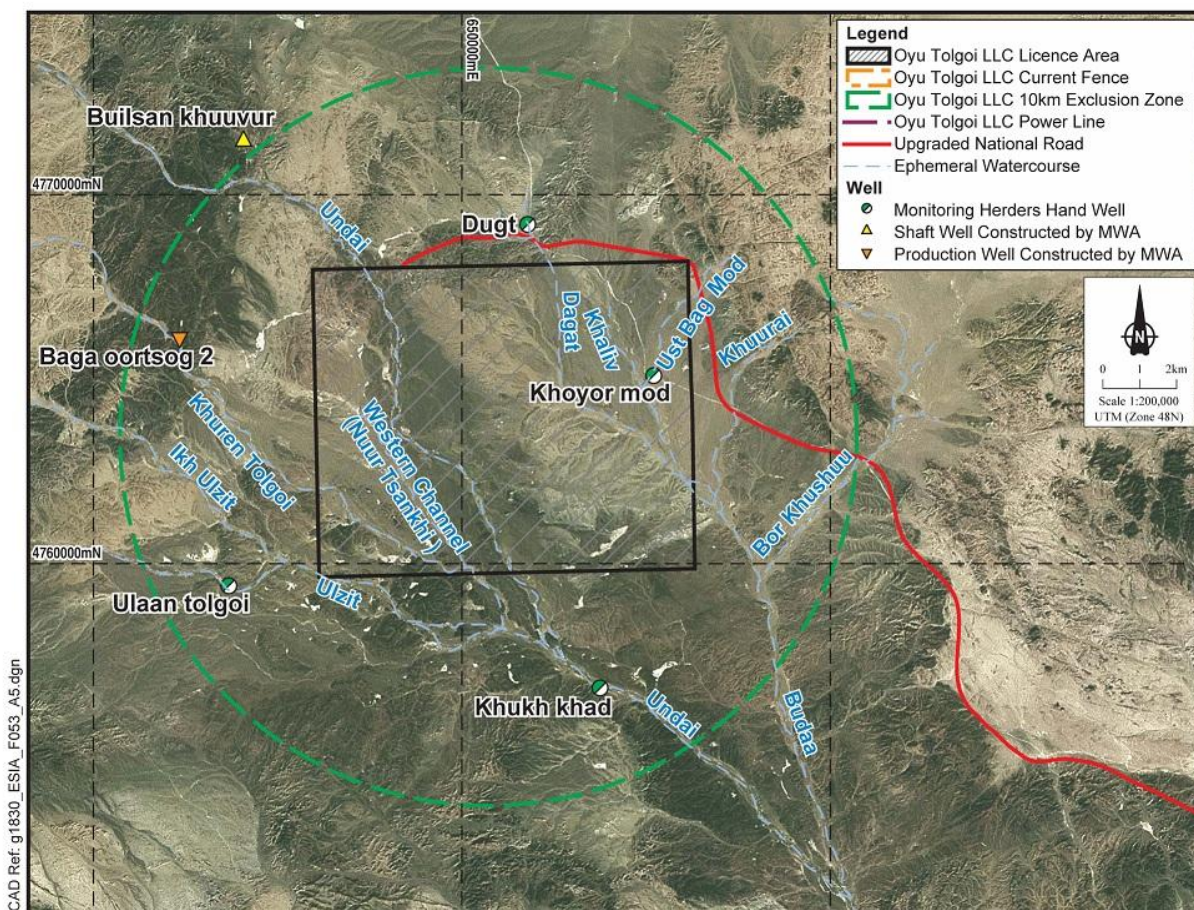
Source: RPS/Aquatera 2010/11 preparation of data for mine licence groundwater model, the location of the wells is shown in Figure 6.14

Note: Anomalous data points circled

### Influence of Rainfall on Herder Wells

The response of the alluvial aquifers to rainfall or flood events can be evaluated through the results of Oyu Tolgoi's monitoring of herder wells in the immediate environs around the Mine Licence Area. The hydrographs for six shallow herder wells are presented in *Figure 6.13* along with the monthly rainfall data from Oyu Tolgoi's meteorological station which is located within the current fence line. The locations of these herder wells are shown on *Figure 6.14*; the selected locations were chosen as monitoring points so as to provide groundwater data in all directions around the Mine Licence Area.

**Figure 6.14: Location of Selected Herder Wells**



The wells are located within the Undai, or ephemeral watercourses which form its tributaries and exploit groundwater in the quaternary alluvial sediments. The locations can be summarised as follows (working clockwise from Khukh Khad):

- **Khukh Khad:** Located in the Undai down gradient of the Mine Licence Area and below the confluence of the Undai and the Ulaan Tolgoi ephemeral watercourse. This is close to the Khukh Khad spring;
- **Ulaan Tolgoi:** Located in the Ulaan Tolgoi ephemeral watercourse, a catchment that extends some distance west which is equal to the catchment of the Undai, upstream of the Mine Licence Area;
- **Baga Oortsog-2:** Located in the northwest Khuren Tolgoi a minor tributary of the Ulaan Tolgoi ephemeral watercourse;
- **Builsan Khuuvur:** Located in the Undai catchment up-gradient of the Mine Licence Area;
- **Dugt:** Located in the Khaliv ephemeral watercourse, a tributary of the Budaa ephemeral watercourse; and

- **Khoyor Mod:** located near the confluence of the Ustbag Mod and Khaliv ephemeral watercourses in the Budaa catchment, alluvial sediments in these watercourses are poorly developed and have limited discontinuous flows. This well inside the Mine Licence Area is one of the herder wells remaining after the winter camps were relocated, and is situated at the end of a lense of alluvial sediments.

The behaviour of the groundwater levels shown in *Figure 6.13* illustrate some common characteristics, which include:

- Rapid response to many (but not all) of the high rainfall events, implying rainfall events do not result in recharge in all catchments and equally there are occasional flood flows in the watercourse associated with rainfall events outside of the meteorological monitoring area and therefore not recorded by Oyu Tolgoi's meteorological station;
- Groundwater fluctuations in the range 0.3-0.5 m associated with recharge (flood) events; and
- Steady falls in groundwater levels following a flood event, back to a standing water level ('base level') that is in the range 0.8-1.8 metres below ground level (mbgl).

On an individual well basis the water levels illustrated in *Figure 6.13* indicate that water levels have been generally rising in Khoyor mod, Dugt, and Builsan khuuvur. These all receive runoff from the hills to the north of the Mine Licence Area. By comparison there is a decline water levels in the Ulaan Tolgoi well on the Ulzit watercourse which receives runoff from the watercourses to the west. Water levels are relatively stable in Khukh Khad and Baga Oortsog. These latter two wells are on the same drainage system (the western channel) and show strong similarity in peaks and troughs which are inferred to be related stream flows along this system.

The seasonal decreases in groundwater levels following a flood event reflect reductions in the amount of groundwater stored in the aquifer storage. These reductions are considered to be due to one or more of the following:

- lateral flow (both down-gradient in the alluvial sediments and also into the adjacent hydrogeological units such as the weathered bedrock);
- vertical flow (to underlying hydrogeological units);
- direct evaporation from shallow aquifer; and/or
- herder's abstraction, although based on the information on herder abstraction rates this is not considered to be a major component.

The fact that there has been no decrease in the base levels, other than in Ulaan Tolgoi, indicates that at these wells there has been no impact from abstraction during the construction phase at the mine site. The Baga oortsog-2 and Builsan khuuvur wells both appear to show an increase in the base level of 0.5 m (Baga oortsog-2 since May 2009 and Builsan khuuvur with a steady increase over the last three years) which is not readily explained and will continue to be the subject of investigation. The Ulaan Tolgoi well (located 2.5 km from the Mine Licence Area and 7 km southwest of the Undai and Oyu Tolgoi's construction water supply) appears to show a decrease in base levels since mid-2009, with only minor responses to the rainfall events in 2010 compared to Baga oortsog-2. This is likely to be a reflection of the localised nature of the rainfall events, as the Ulaan Tolgoi well is in a different sub-catchment within the Undai basin to the other wells<sup>6</sup> and it is too far from the abstraction wells used in the construction phase to have been impacted by the pumping from these.

Although there appears to have been few flood events in the Ulaan Tolgoi catchment, there has been no reduction in the base levels in the Khukh khad, which being down gradient of the confluence of the Undai and Ulaan Tolgoi ephemeral water courses, is reliant on recharge from both. This indicates that there has been sufficient recharge down the Undai and other minor tributaries to compensate for the apparently limited recharge Ulaan Tolgoi.

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<sup>6</sup> Note that rainfall events are recorded at the Oyu Tolgoi meteorological station and therefore will not detect rainfall events which might result in recharge in other parts of the Undai catchment.

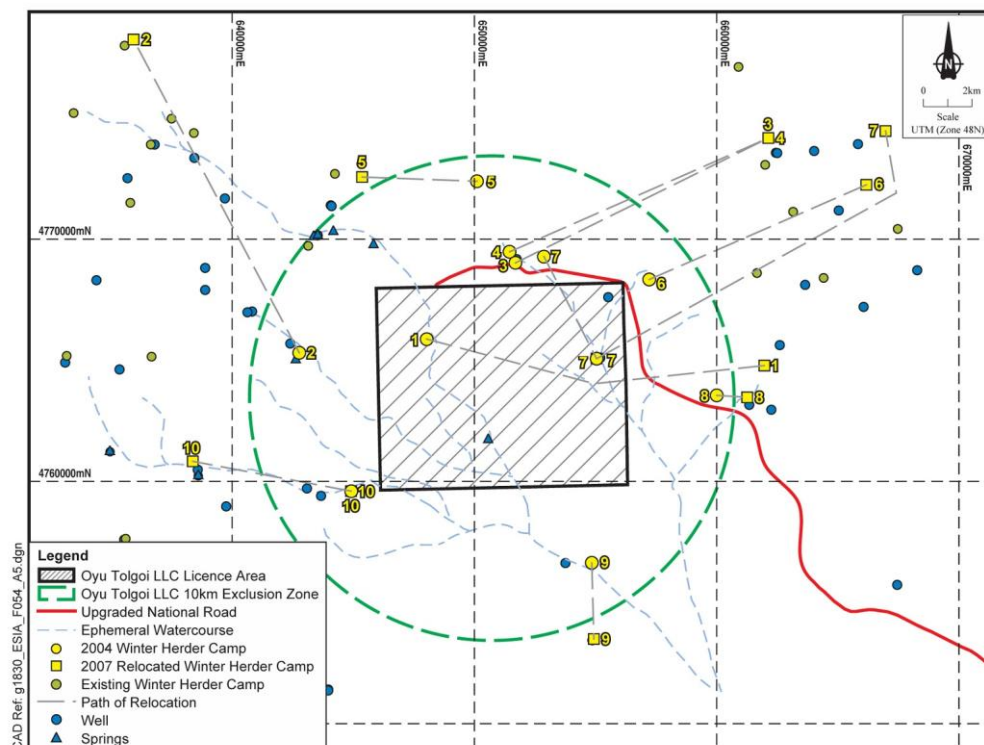
The on-going review of this data is being used by Oyu Tolgoi to design the monitoring system of stream gauging points, additional piezometers and rain gauges in the upper catchment which will be installed in 2011/2012<sup>7</sup>. The monitoring programme includes approximately 35 herder well locations. The data that Oyu Tolgoi gathers from this integrated monitoring programme will be used to better understand the surface water flows and the behaviour of the shallow aquifers; and lead to an improved interpretation of the behaviour of these herder water levels. The data presented on these six wells is available for the majority of the herder wells within 10 km of the Mine Licence Area which enables Oyu Tolgoi to be able to assess any future change in water level against a robust historical record. This will then inform the decision on the appropriate mitigation measures to be made to address any herder concerns.

#### *Historical Herder Wells within and Adjacent to the Mine Licence Area*

The alluvial aquifers in and immediately adjacent to the Mine Licence Area were historically exploited by approximately 10 hand-dug herder wells located at winter camps within 10 km of the centre of the Oyu Tolgoi Mine Licence Area. These wells were used for stock watering and drinking supplies.

As part of the herder winter camp resettlement programme in 2004, herder winter shelters within a 10 km radius of the Mine Licence Area were resettled. Replacement wells were established for the affected herders outside the Mine Licence Area (and 10 km exclusion zone) and, other than two wells (Khajuu Khuuvur and Khoyor Mod) within the eastern edge of the Mine Licence Area (see *Figure 6.2*), the older existing wells within the Mine Licence Area were abandoned. Replacement wells have been provided for Khajuu Khuuvur and Khoyor Mod and the associated winter camps relocated. The Khajuu Khuuvur and Khoyor Mod well are in the Budaa catchment and access water in the discontinuous Quaternary alluvial sediments which are present along these ephemeral watercourses. The traditional users, however, are permitted to use the wells on an ad hoc basis given their distance from the construction works and therefore relatively undisturbed state. During full operations, access to these is likely to not be permitted and the herder would then rely on the replacement well installed by Oyu Tolgoi. The historical location of the winter camps and wells along the ephemeral watercourses is illustrated in *Figure 6.15*.

**Figure 6.15: Herder Winter Camp Relocation**



<sup>7</sup> Aquaterra 2010; Oyu Tolgoi Mine Site Hydrogeological Assessment report, ref U25D/111c dated 9 December 2010

No other herder winter camps were identified as requiring relocation as none are present on the footprint of the airport, Gunii Hooloi borefield or pipeline nor will be impacted by the Project infrastructure corridor to Gashuun Sukhait.

### **Groundwater Quality Monitoring**

#### *Methodology*

Oyu Tolgoi has continually improved its water quality monitoring regime since this first started in 2002, increasing both the number of samples taken, as well as the frequency and scope of the analysis undertaken. The current monitoring regime comprises quarterly water sampling of the bores, manual wells and springs in the Oyu Tolgoi, Gunii Hooloi and Galbyn Gobi areas. The methodology employed is standardised and prior to sampling, the water level is recorded using a SOLINST 101 water level meter, unless automatic water level metering is in place. During sampling of the manual wells and springs, field measurements of water quality parameters are taken using a Hi 98 130 Waterproof pH & E.C, TDS instrument. Samples are then collected in sterilized 500 ml containers, which are over-filled to enable them to be sealed without any air bubbles. Containers are labelled with the sample location and date of sampling and then dispatched to either a Mongolian laboratory or an overseas laboratory depending on the parameters to be analysed and the detection limits required.

The 2010 monitoring regime was the most extensive to date, comprising 231 bores (test bores, exploitation and monitoring wellbores), 94 herder wells, and 8 springs totalling 333 water points. This is presented in *Table 6.1* with a comparison to 2009 data collection.

**Table 6.1: Water Monitoring Data Points**

Location	2009			2010		
	Wellbore	Herder well	Springs	Wellbore	Herder wells	Springs
Oyu Tolgoi	58	6	0	118	20	0
Gunii Hooloi	85	59	1	91	49	2
Galbyn Gobi	16	5	0	12	5	0
Undai riverbed	0	19	6	10	20	6
Total points	159	89	7	231	94	8
	255			333		

Selected data from the wealth of monitoring data available are presented in the following sections. In general the data presented are from points which have the longest monitoring records to enable an appreciation of the temporal variations which occur within the surface and groundwater monitoring locations.

#### *Groundwater Monitoring Results at Mine Licence Area*

Groundwater analysis has been undertaken on selected wells in and around the Mine Licence Area since 2002 with a more extensive network established in 2004 and built on in subsequent years. The analysis has included the following parameters:

Physio-chemical parameters	pH, temperature, electrical conductivity, TDS (field), hardness
Major Ions:	calcium, magnesium, potassium, sodium, fluoride, sulphate, chloride, nitrate
Metals:	iron, arsenic, cadmium, chromium, copper, lead, nickel, zinc, mercury,

Overall the analysis of metal concentrations in the springs, wells and boreholes of the Mine Licence Area did not detect any metals above the detection limits. The highest concentrations detected are reported in *Table 6.2* below. The results do not indicate any temporal changes in metal concentrations and the highest concentrations detected appear to be potential false positives; i.e. subsequent analysis has not reported the same concentrations.

**Table 6.2: Metal Analysis Results for Springs and Groundwater in the Mine Licence Area 2005-2010**

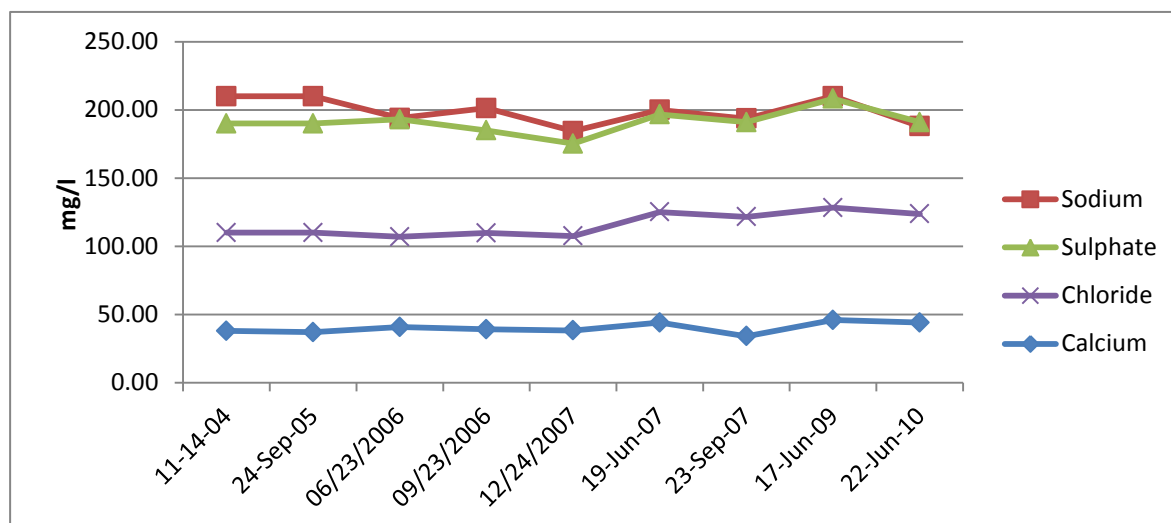
Metal	Maximum Concentration Reported (mg/l)	WHO Potable Standards (mg/l)	Comment
Arsenic	0.0772	0.01	Monitoring borehole CC-04, detection limit is 0.04 mg/l. This was reported in 2007 but subsequent analysis in 2009 and 2010 did not detect concentrations above the detection limit of 0.04 mg/l.
Cadmium	ND	0.003	None above the detection limit of 0.005 mg/l
Chromium	0.0082	0.05	Herder well Khukh khad (not in the spring) although subsequent analysis below the detection level of 0.005 mg/l
Copper	0.025	2	Monitoring borehole OTRC-148
Lead	0.08	0.01	Monitoring borehole BH07-09PZ marginally above the detection limit of 0.05 mg/l
Nickel	ND	0.02	No results above the detection limits
Zinc	1.71	3	Monitoring well CC-02 concentrations have varied from 0.01 to 1.71 over the monitoring period 2007-2010.
Mercury	0.0005	0.001	Mercury was only reported in one sample batch with a low detection limit (general detection limits are 0.005 mg/l).

This baseline quality data allows the groundwater chemistry to be characterised and general observations of trends in groundwater chemistry to be made across the Oyu Tolgoi area. This is illustrated by the increase in TDS concentrations away from the Undai, with the monitoring wells close to the Undai (southwest of the proposed Oyu Tolgoi open cut) having a TDS of <500 mg/L TDS; away from the Undai to the north, the TDS increases with the majority of bores in the vicinity of the proposed South-west pit having fresh to brackish water (less than 1,500 mg/L TDS). The lower TDS measured adjacent to the Undai is considered to reflect the recharge to these formations from the Undai flows, and potentially also the presence of less clay-rich soils, allowing greater direct rainfall infiltration rates. These fresher (less saline) groundwater resources along the Undai and similar watercourses have been accessed traditionally by herders for stock water using their wells.

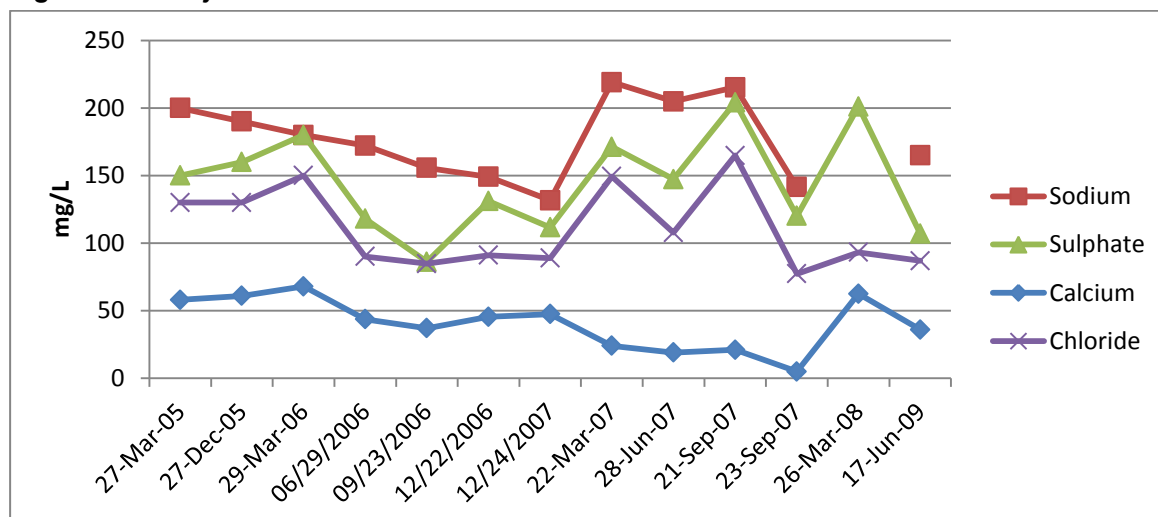
Further north from the Central Oyu area there is a steep salinity gradient with salinities increasing from less than 1,500 mg/L to greater than 11,000 mg/L around the Hugo deposit. The high salinity reflects the absence of recharge (due to the overlying Cretaceous Clay) and long residence time as would be expected with such low intrinsic permeability.

In addition to these areal variations in groundwater quality, the monitoring undertaken by Oyu Tolgoi has enabled the natural temporal changes in groundwater chemistry to be assessed as illustrated in *Figure 6.16* and *Figure 6.17*. The dominant ions in the groundwater of the shallow aquifers used by the herders are sodium and sulphate, with chloride and calcium also important. This data illustrates the fact that water quality in some wells is very stable over time such as in the Dugt well, while in others there are notable temporal variations such as in Khukh khad (*Figure 6.16*) as would be expected with seasonal “flushing” and remobilisation of salts accumulating in areas of shallow groundwater. As mentioned earlier, these wells are all outside of the influence of the construction borehole pumping and therefore the variations observed are either natural or due to the influence the herder has on the well (perhaps drawing lower or higher salinity waters into the well after pumping).

**Figure 6.16: Major Cations vs. Time for Dugt Herder Wells**



**Figure 6.17: Major Cations vs. Time for Khukh khad Herder Wells**



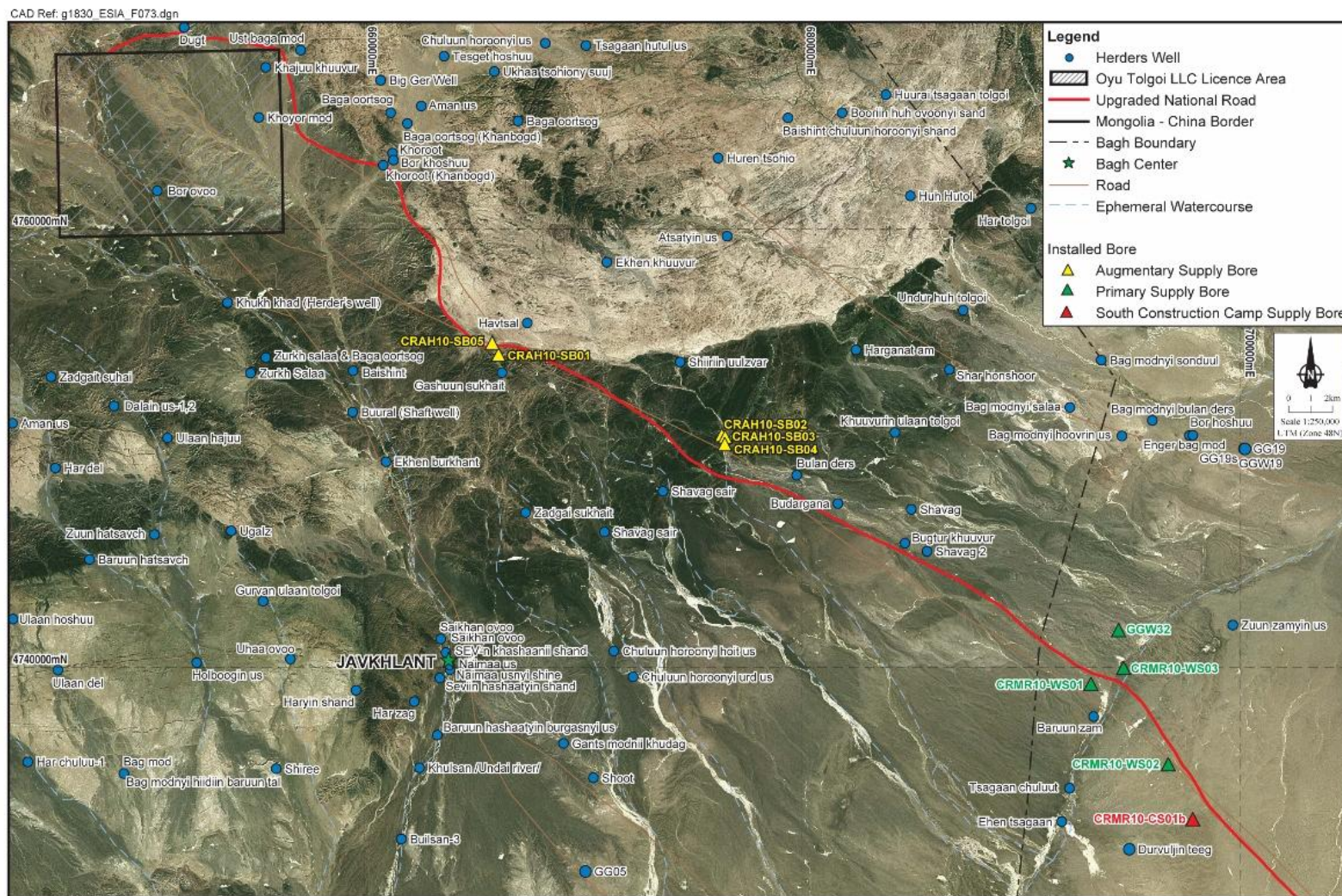
The groundwater quality in and around the Mine Licence Area is slightly alkaline with the majority of groundwater having a pH of between 7 and 8. There is no evidence of acid groundwater in the area. Metal concentrations are also all very low and generally below the detection limit. Within the shallower aquifer units the groundwater varies from soft to slightly hard and is suitable for human consumption.

This water quality data collected from in and around the Mine Licence Area, combined with the water level data collected from these wells provides Oyu Tolgoi with a robust baseline data set against which it can compare groundwater quality during the operational phase.

### 6.5.2 Shallow Aquifers along the Infrastructure Corridor

Baseline surveys have identified the herder wells along the corridor of the proposed road route and which are illustrated in *Figure 6.18*. These wells are shallow hand-dug wells that exploit the limited surficial aquifers in the ephemeral watercourses and/or are fracture fed. None of these herder wells are considered to require relocating to avoid the impacts arising from the construction and operation of the road, and no herders have requested to be relocated. Oyu Tolgoi undertakes monitoring of these boreholes to assess water quality and water levels such that, similar to the other areas monitored, any impacts can be identified and quantified.

**Figure 6.18: Location of Herder Wells along the Oyu Tolgoi- Gashuun Sukhait Route and Planned Water Supply Wells**



The primary supply bores for the construction water supply are located in the central Galbyn Gobi area with the nearest herder well (Baruum zam) being 1.4 km south. These Oyu Tolgoi boreholes will range from 200 to 220 m in depth and abstract from the Cretaceous sediments, and not the shallow aquifer used by the herder well. In the northern road section augmentary boreholes may be used, however this is yet to be finalised. These augmentary bores would abstract from fractured rock aquifer through a screened interval ranging from 90 to 120 m below ground level. The nearest herder well (Gashuun suhai which is exploiting the shallow alluvial aquifer in the area) is 770 m to the south of the nearest potential augmentary borehole.

### 6.5.3 Shallow Hydrogeology of Gunii Hooloi

A surficial aquifer is variably developed within the shallow Quaternary to Recent alluvium that exists over the surface of most of the Gunii Hooloi catchment area, although is only strongly developed along the ephemeral watercourses. Recharge to this surficial aquifer occurs directly by rainfall infiltration through the soils and more significantly by infiltration along the drainage courses during flow events. These shallow aquifers, mostly in the stream channel environments, are accessed by hand dug wells and are used by local herders for domestic and stock water supplies.

The long history of herder exploitation of the area for grazing has led to the establishment of a network of herder wells within the Quaternary to Recent alluvial deposits where there is permanent groundwater at shallow depths. Areas where the Quaternary to Recent aquifers are not developed are devoid of herder wells. Within the Gunii Hooloi this is manifest by the pattern of herder wells developing only along the ephemeral watercourses where there is sufficient aquifer thickness. This is illustrated in *Figure 6.18* where herder wells are restricted to the southern side of Gunii Hooloi (adjacent to the hard rock areas where run-off occurs, and along the easterly flowing ephemeral watercourses) and north of the central elevated area (where further easterly flowing ephemeral watercourses are present). The area of Oyu Tolgoi's proposed borefield sits between these two areas in a region with no shallow groundwater present and therefore no herder wells (see *Figure 6.19*).

Discussions with local herders<sup>8</sup> suggests that some of the existing wells are not sustainable throughout the year, but can be used for the months directly after periods of rain – this is the case for the well Ulaan Tolgoi (HW04) on the northern side of the Gunii Hooloi basin (see *Figure 6.19*) which has a limited upstream catchment area. A number of the wells are not located in clearly defined river channels (e.g. Shar Dov (HW05) on the north side of Gunii Hooloi and Suurin Shavag (HW13) on the southern side) but are located in areas where large upstream catchments and very flat topography result in broad sheet flow after rainfall events. In these areas, a more broadly spread poorly developed shallow aquifer exists which is clay dominated with lower permeabilities.

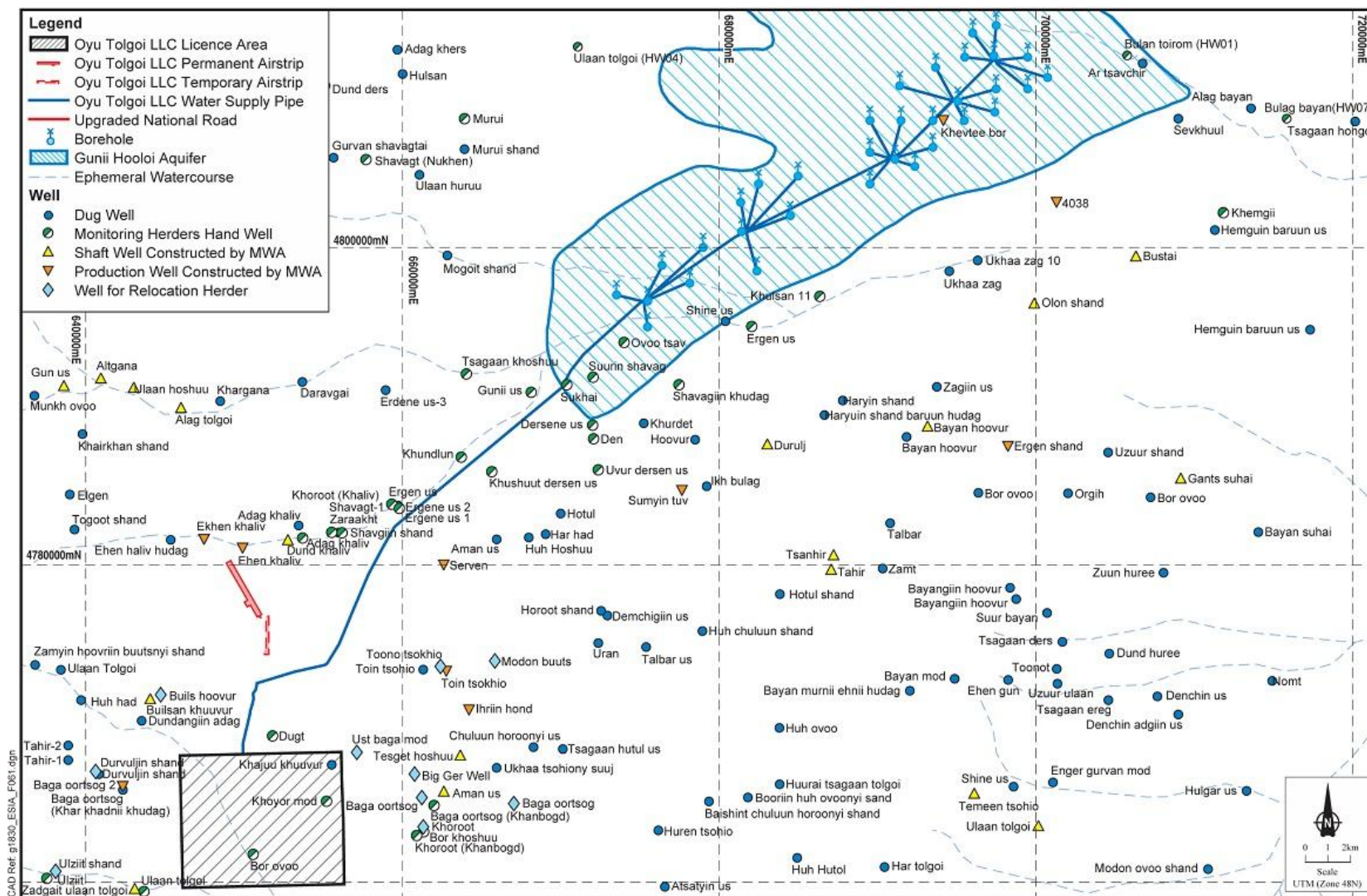
Water levels in the wells along the ephemeral watercourses are surficial and significantly shallower than water levels in bores drilled into the deeper Cretaceous aquifer system where water levels are typically 50 mbgl. As a result, it appears that the shallow aquifers are a “perched” system, although this has not been conclusively established in all areas. This issue is to be the subject of further study in Gunii Hooloi during late 2011/2012 investigations. A similar investigation is planned later for the Galbyn Gobi.

Oyu Tolgoi has been monitoring the water levels in selected herder wells in some instances since 2002 and the majority since 2004. At key wells, although the monitoring of water levels was timed to be undertaken before herders abstracted water for their herds and disturbed the standing water level, it was recognised that the data which could be obtained was limited. To improve the quality of data collected on the herder wells Oyu Tolgoi installed monitoring boreholes adjacent to these hand dug wells.

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<sup>8</sup> Aquaterra (2008), Gunii Hooloi Aquifer, Groundwater Investigation and Resource Assessment – 2007 (Revised Water Demand), Aquaterra Consulting Pty Ltd, March 2008

Figure 6.19: Location of Herder Wells in the Gunii Hooloi Area

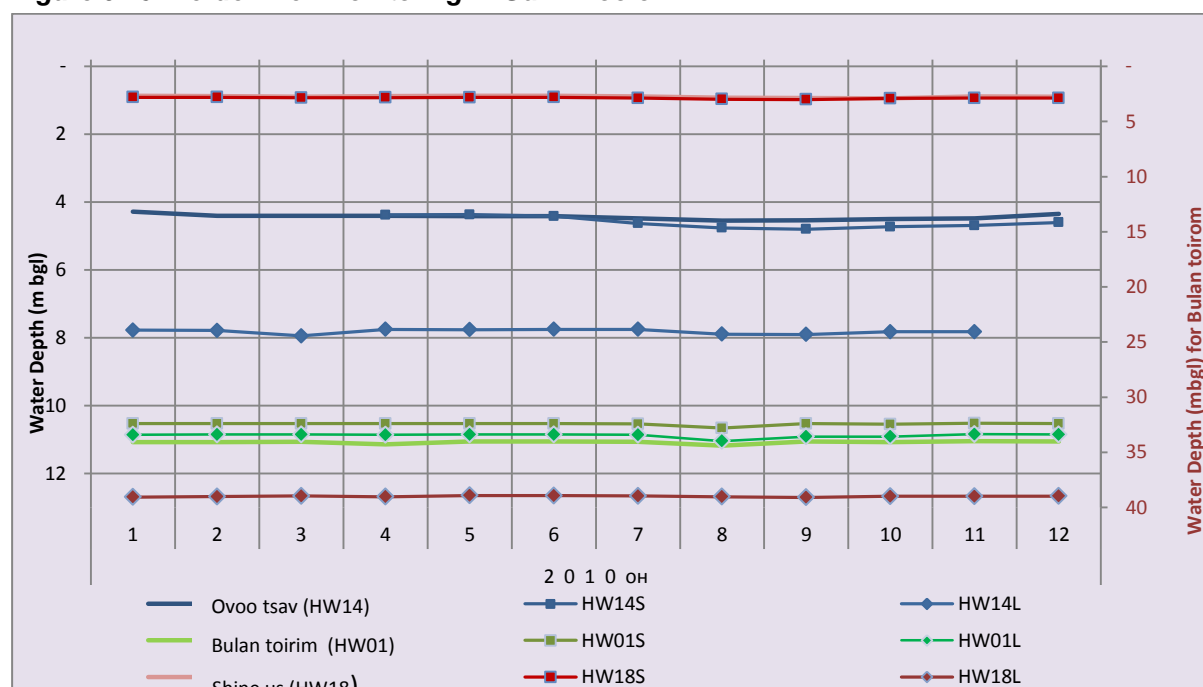


The installation of these boreholes has allowed Oyu Tolgoi to gain a good appreciation of the characteristics of the local shallow geology. With the exception of Bulan Toirim (HW01) in the eastern part of the area, all the herder wells comprise either a sand and gravel aquifer (up to 7 m thick) at the surface over a fine clayed sequence typically with over 10 m of a red plastic clay, or a sequence comprising dominantly silts and clays with occasional sands and gravels. At Bulan Toirim (HW01) in the eastern side of Gunii Hooloi, the shallow geology comprises up to 10 m of clay overlying 20 m of sands and gravels which the well exploits. The implication is that this deeper herder well differs from the others in Gunii Hooloi as it does not rely on a shallow aquifer for its water supply. All the wells along the southern margin of the basin closest to the proposed borefield typically comprise shallow alluvium over 30 to 50 m of clay rich sediments (monitoring boreholes did not extend beyond 50 m depth and therefore where bedrock was not encountered did not prove the base of the clay). Where the herder wells are close to the margins of the basin, shallow bedrock is encountered such as at Ulaan Tolgoi (HW04) in the northeast and Bulag Bayna (HW07) in the southeast of the basin; encountered shallow bedrock comprising schist at depths of 19 m and 29 m respectively.

These herder well monitoring boreholes comprise a shallow borehole screened across the same horizon as that used for the herder well, and an additional borehole screen at depth. They were installed in 2008 and have been monitored monthly since that date enabling water level and quality data in the shallow aquifer to be gathered without the influence of the herders' activities. It was noted that all boreholes had to be extensively purged before sampling, as the low yields made it exceptionally difficult to remove the drilling mud which had entered the formation.

The water levels in selected herder well locations (Shine us, Ovoo Tsav and Bulan Toirim) and their associated monitoring bores in the Gunii Hooloi area are illustrated in *Figure 6.20*. This data illustrates the stability of the water level over time reflecting firstly, the limited amount of water abstracted by the herders and secondly, the fact that during this monitoring period seasonal recharge does not appear to result in any significant rises in water level (metre scale changes) above the baseline. The degree of fluctuation in the water levels in the shallow aquifers associated with the ephemeral streams is likely to vary between locations depending on the local gradient, aquifer transmissivity and lateral extent of the aquifer and to be on a scale of cms.

**Figure 6.20: Herder Well Monitoring in Gunii Hooloi**



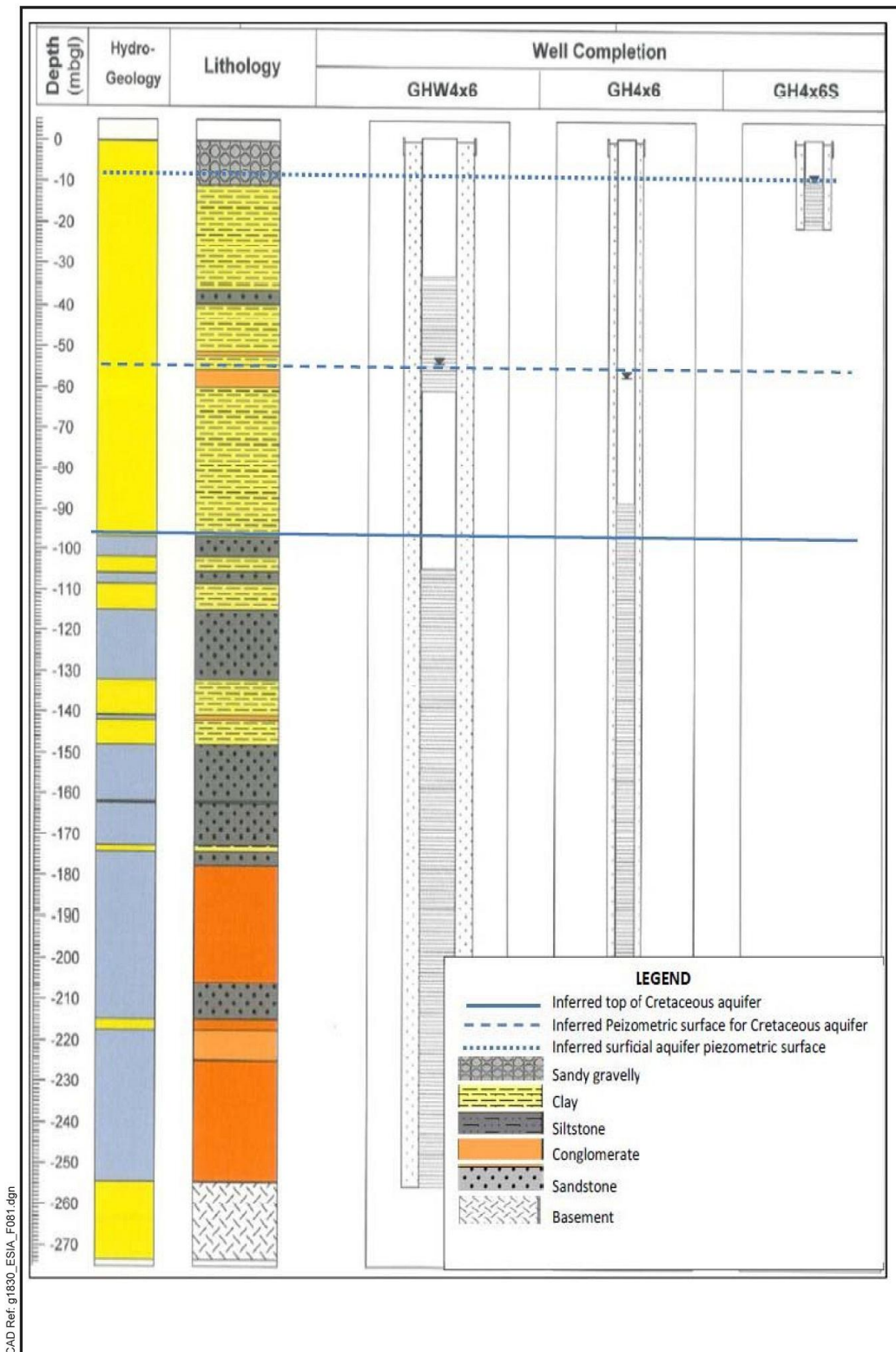
Source: Oyu Tolgoi Environment Department

Note: Water levels in the deeper Bulan Toirim well are presented separately on the right hand axis

Two of the wells presented in *Figure 6.20*, are typical shallow herder wells, which exploit the shallow groundwater (circa 1 mbgl in Shine us and 4.5 mbgl in Ovoo Tsav) in the alluvial aquifers. The third is a deeper drilled well at the eastern end of Gunii Hooloi. This deeper well (Bulan Toirim) is unusual both in

its depth and the fact that the herder uses a diesel powered pump to raise the water to the surface (summer use only) from a depth of circa 33 mbgl. This deeper herder well exploits an aquifer unit at depth which is not associated with surface alluvial sediments. The location of these three herder wells is shown in *Figure 6.30*.

**Figure 6.21: GH4x6 Water Borehole and Monitoring Wells**



In all cases the shallow monitoring bore, which is screened over the same aquifer unit as the herder well, reports the same piezometric horizon as the herder well. The water levels recorded in the deeper monitoring bores which are screened at depth (40-50 m) are all deeper than the shallow bores and the herder well indicating that the shallow water tables are perched and do not extend to depth. The water levels recorded in the deeper herder monitoring bore at Shine us and Ovoo Tsav are significantly above the depth of the piezometric horizon in the Cretaceous. This indicates that any degree of connectivity between this surface water and the deeper Cretaceous aquifers is very limited. At the Bulan toirim location, the level of the three piezometric surfaces is the same as or close to the inferred piezometric surface in the Cretaceous aquifer in this area (see *Figure 6.34*), and the implications of this are discussed further in *Chapter C6 Biological Resources and Ecosystem Services*.

The presence of these separate aquifers is illustrated by the monitoring boreholes at GH4x6 (see *Figure 6.21*) which are located approximately 6 km west of Khanbogd in an ephemeral watercourse which flows north from the Khanbogd massif towards Gunii Hooloi. This set of boreholes encountered a shallow aquifer associated with the surface clastic deposits with a standing water level of circa 9 m bgl, while the main aquifer unit has a standing water level of circa 56 mbgl. This difference in the standing water level is reflected in the different chemistry of the groundwater from these boreholes with the shallow groundwater, which is recharged by season rainfall, having lower concentrations of sodium and chloride ions (31 and 20 mg/l respectively) compared to the deeper aquifer (circa 100 and 95 mg/l respectively).

GHW4x6 has the sound of cascading water implying that there is potentially some seepage of water from the sandstone between 36.2 and 39.8 m depth (described when drilled as a gravelly sandstone, which is weakly cemented with a clay cement), cascading through the screen to the standing water level in the borehole of 56 mbgl. While this set of boreholes illustrates the different groundwater aquifers, it also illustrates the importance of appropriate screening of boreholes in the Gunii Hooloi to minimise the risk of connecting hydraulically separate aquifers. The assessment of the potential impact on the local groundwater at GH4x6 is discussed further in *Chapter C6.5.4*.

### **Ongoing Work**

While there is a high degree of confidence in the understanding of hydraulic conductivities and connectivity in the Gunii Hooloi basin, such as the degree of connection between the shallow aquifers and the deeper Cretaceous aquifers, a review of the data has identified a number of knowledge gaps/uncertainties. A comprehensive field investigation programme has been developed to address these gaps/uncertainties, and to augment the monitoring network. This comprises a well rehabilitation programme (to establish discrete monitoring facilities through conversion of a number of existing “composite” bores such as GH4x6), geophysical traverses and drilling/construction and testing of a number of new bores. These results are being used to upgrade the existing Gunii Hooloi numerical model.

The programme will include geophysical surveys, undertaken to characterise regional aquifer and stream bed geometry, better define aquifer boundary locations and refinement of the aquifer and aquitard units in the zone between the NE and SW borefields. The surface geophysics will be completed using Transient Electromagnetic (TEM) method. A total of 3,080 stations are estimated with 100 m station separation. TEM surveys sections will range from 3 to 39 km.

Drilling, construction and testing of 49 piezometers and 14 test bores is proposed at various locations around the Gunii Hooloi catchment. Diamond core drilling will be utilised to complete five of the piezometers to establish good understanding of lithological conditions and contacts. Select cores samples will be sent for laboratory analysis (i.e. permeability tests and grain size distribution). The remainder of the holes will be drilled using mud rotary technique.

The programme which started at the end of 2011 is enabling Oyu Tolgoi to:

- Establish an adequate operational groundwater monitoring network for borefield operations to include:
  - an appropriate areal distribution of discrete shallow, intermediate (aquitard) and deep (aquifer) monitoring facilities;
  - monitoring points in upstream and downstream areas to improve definition of recharge processes, through flow quantification, assessment of long term impacts from pumping and establishment of a technical basis for modification of groundwater inflow/outflow model boundaries; and

- Installation of data loggers, stream-flow gauges and additional rain gauges.
- Rehabilitate 13 existing bores to prevent inter-aquifer flow and convert these to provide single/multi piezometers that target discrete units;
- Provide hydraulic parameters for, and improve understanding of lithological variations within the aquitard within the borefield area through the installation of two bore clusters (SW and NE). These will better define the confining layer hydraulic parameters to a confidence level sufficient for numerical model refinement;
- Improve definition of potential connectivity between shallow/deep horizons at three sites along the southern basin margin. These will provide local characterisation of the aquitard and improved insight into potential for hydraulic connection between shallow streambed and deep aquifer systems in an area of existing shallow herder wells; and
- Define hydrogeologic conditions and refine aquifer boundaries as appropriate in key aquifer inflow/outflow areas using nine TEM transects and twelve drill locations (each location will comprise of a test bore drilled and installed into the aquifer and one adjoining nested piezometer installed into the aquifer and aquitard). Two investigation sites are also proposed in the upstream area of the Gunii Hooloi aquifer to improve the definition of the recharge process and quantification of through flow in the shallow systems.

#### 6.5.4 Springs

Important natural water sources for herders and their animals are the permanent springs such as Bor Ovoo in the Undai (*Figure 6.22*) or Bag bulag spring (*Figure 6.23*) on the northern side of the Khanbogd massif, and to a lesser extent the temporary pools that form in the watercourses following a flood. The herders rely on these permanent springs and their wells as a water supply for livestock whilst the temporary springs are utilised by herders and animals on an ad hoc basis when they are available.

**Figure 6.22: Bor Ovoo Spring Located on the Southern Part of the Oyu Tolgoi Mine Licence Area**



**Figure 6.23: Bag bulag spring located on the Northern edge of the Khanbogd Massif**



Source: Geomaster Engineering; Report on Groundwater Geophysical Exploration for water supply of Khanbogd soum, 2010

The Undai is the most significant hydrological feature within the Project Area of Influence, and its associated alluvial aquifer supports several surface ephemeral springs (persisting for up to two weeks after rainfall) as well as some more permanent springs. The springs are inferred to be caused by shallow impermeable bedrock, forcing the shallow groundwater flowing in the alluvial sediments to come to the surface. This water then either evaporates or seeps back into the aquifer downstream of the constriction. This is illustrated by *Figure 6.24*, which shows the narrowing in the Undai alluvial sediments caused by an outcrop of bedrock, which constricts the flow of groundwater through this point and results in the creation of the Khukh Khad spring. All springs only flow for the summer months as they are frozen for at least seven months of the year.

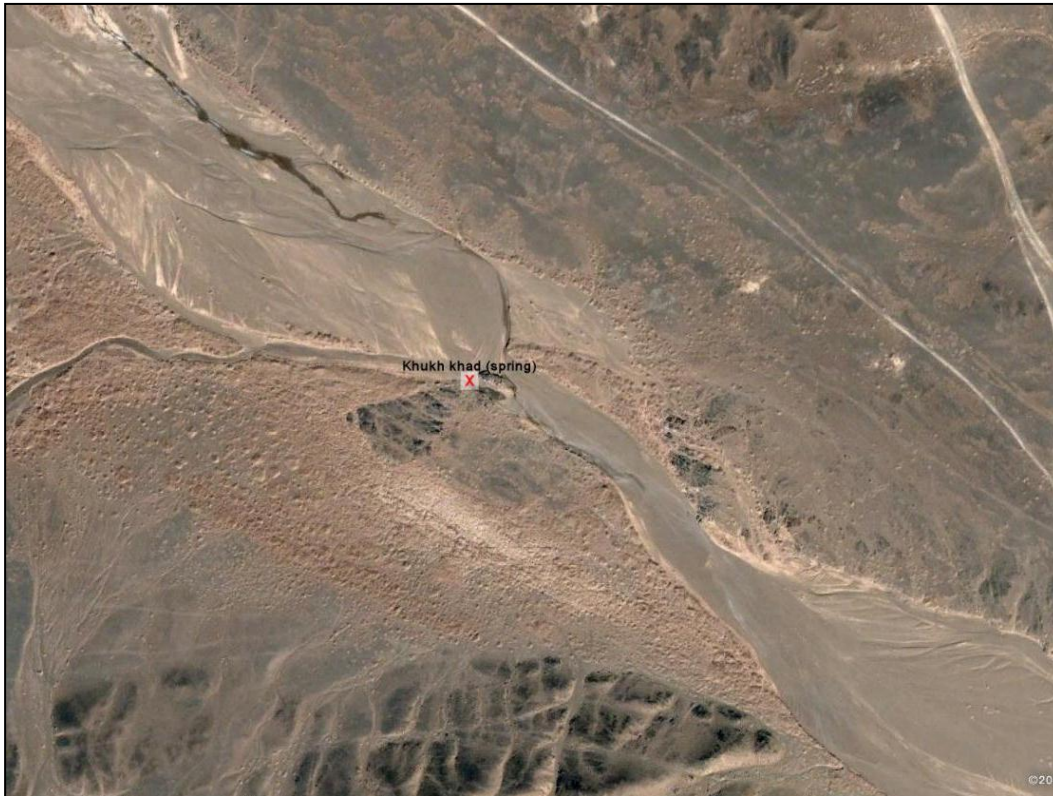
The only permanent spring within the Oyu Tolgoi Mine Licence Area is the Bor Ovoo spring which is a local water source for native animals and livestock that is supported by groundwater flow in the Undai.

A monthly photographic record, taken by Oyu Tolgoi as part of the monthly surface and groundwater monitoring regime, was started in 2004 and since then has been expanded in scope. This photographic record of the springs in the area, such as Bor ovoo and Khukh khad springs, illustrate how the size of the spring varies considerably from a relatively extensive volume of water (as shown in *Figure 6.25*) to a small limited resource. This reflects the seasonal variation in the volume of water passing downstream through the sediments in the bed of the Undai and other ephemeral watercourses which maintains these springs. Recent monitoring of the Bor ovoo spring in the summer of 2011 has indicated that the spring is drier than at any other time over the recording period, with a standing water level in the alluvial sediments between 20 and 30 cm below the surface.

Wildlife will use the spring locations in the Project area even when surface water has dried out under high evaporative demand as the groundwater typically remains only 0.2 to 0.3 m below the surface. Some wildlife, especially the Asiatic Wild Ass, can dig shallow depressions to enable them to access this water. These depressions are locally named “Water of Wild Ass” and these scrapes are used by other wildlife and domestic stock during dry periods. Migratory wildlife movements during summer months in the Gobi are likely to be dictated by the presence of surface water in the natural springs along the ephemeral watercourses as inferred by studies of Khulan migration<sup>9</sup>.

<sup>9</sup> World Bank, Room to Roam, The Threat to Khulan (Wild Ass) from Human Intrusion, September 2006

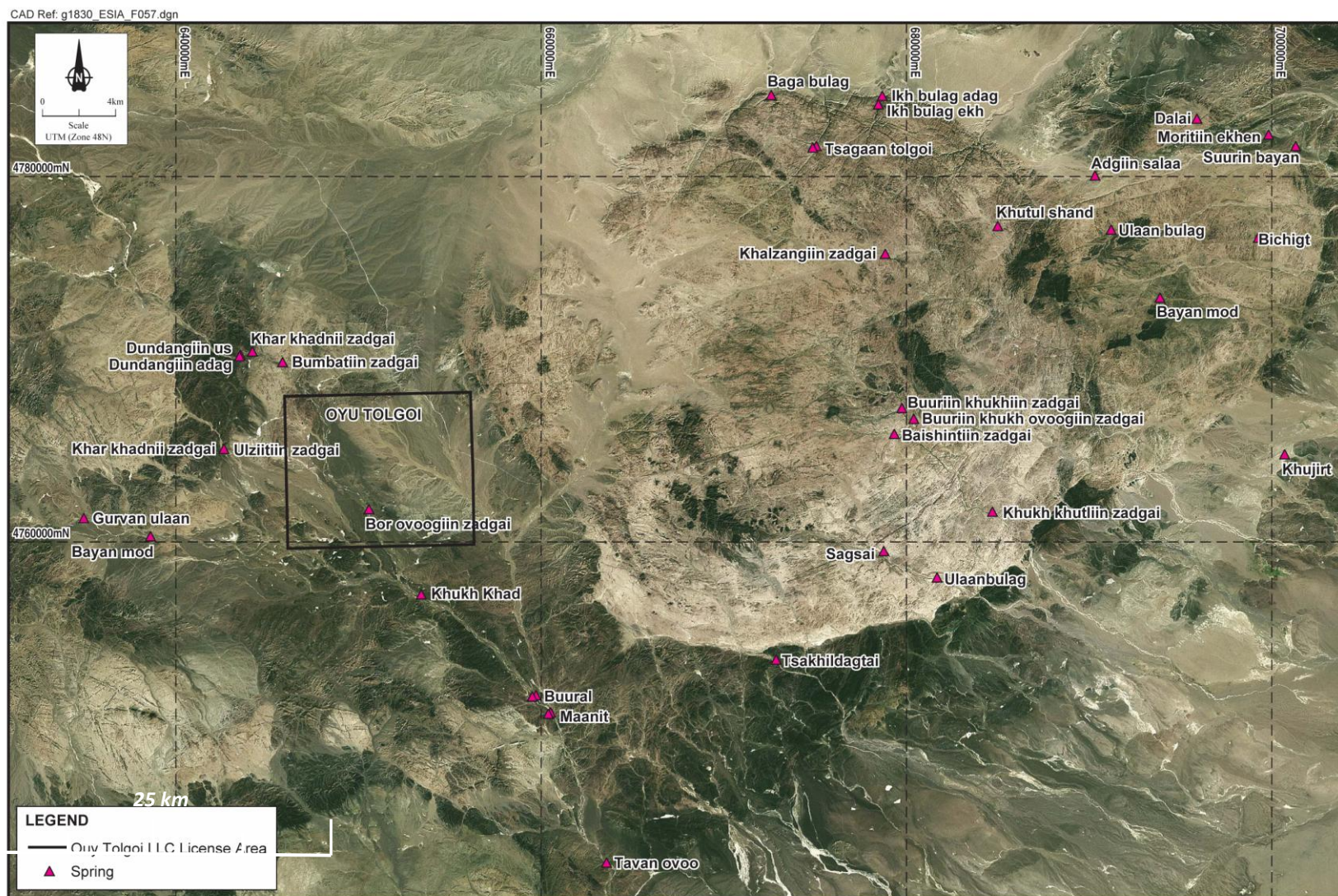
**Figure 6.24: Khukh Khad Spring Location in Undai**



The majority of springs in the vicinity of the Mine Licence Area are located up-hydraulic gradient of Oyu Tolgoi (northwest), the closest important spring down-gradient is Khukh khad (*Figure 6.25*) which is 5 km downstream of Bor Ovoo, with Buural and Maanit approximately 8 km further and Tavan Ovoo 7 km beyond them (circa 20 km south of Oyu Tolgoi). The Khanbogd massif is also an important area of springs with many occurring within the fissures of the bedrock around the northern periphery and within the massif.

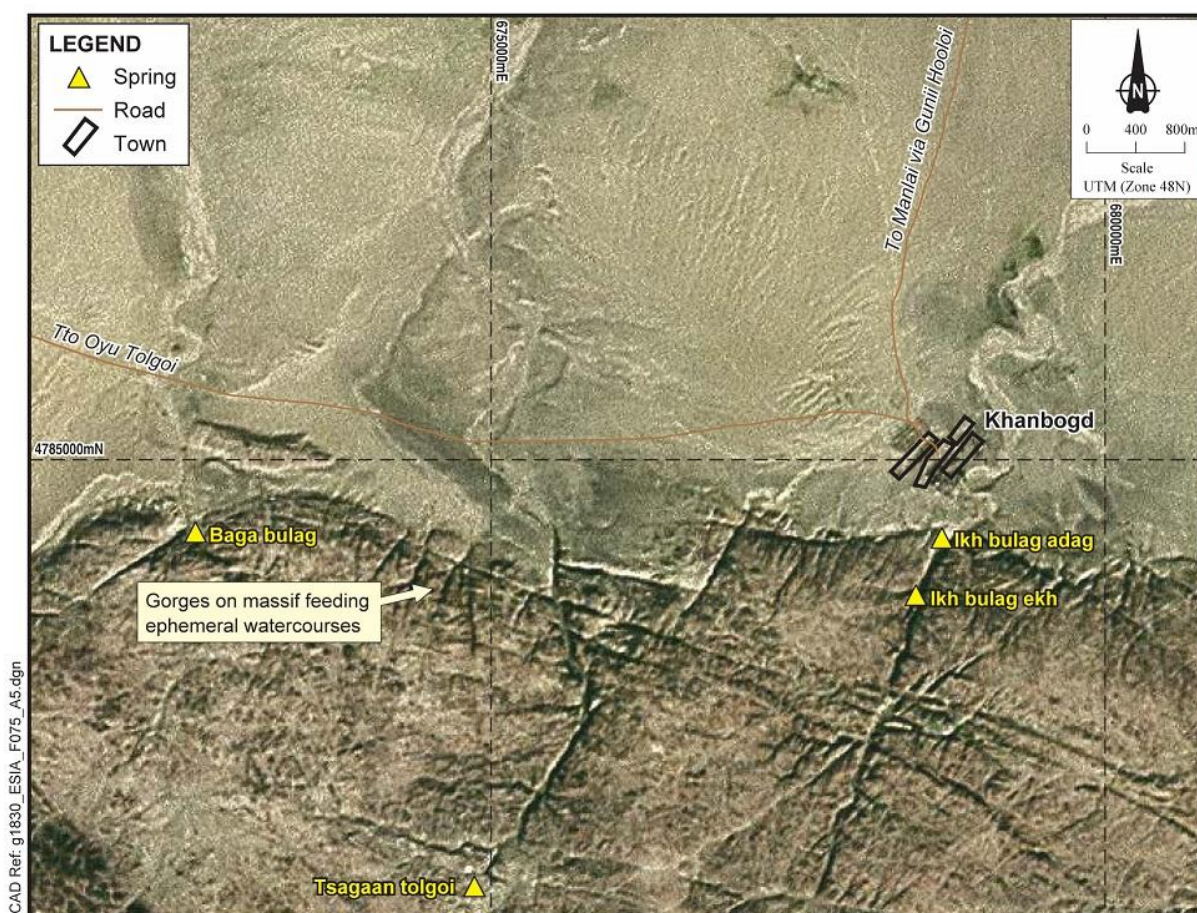
As part of the baseline assessment of the surface water features in the Project Area of Influence, Oyu Tolgoi has mapped the springs (as shown in *Figure 6.25*) and recorded details of their permanence and the number of herder households that utilise them. The number of households reported to be using a spring varies depending on its location and proximity to other springs and herder wells. Bor ovoo spring has historically been used by up to 20 families, whereas springs to the northwest are used by between one and ten households.

Figure 6.25: Springs around Oyu Tolgoi Mine Licence Area



The Khanbogd massif which is located immediately to the east of the Mine Licence Area and immediately to the south of the town of Khanbogd is an important source of surface and groundwater run-off. Surface run-off and fracture flow through the bedrock is focused along the 10-15 m deep gorges which are spaced every 2-3 km along the margin of the massif (*Figure 6.26*). The run-off feeds the shallow aquifers used by the herders as well as feeding some springs developed in scour features along the margins as the rainfall on the massif seeps through the fracture system in the granite towards the edges of the massif. These springs are typically ephemeral in nature and can have flow rates of between 0.1 and 1 l/s<sup>10</sup>. Periodic surface flows along the ephemeral watercourses and the underlying groundwater flow in the associated alluvial aquifers will be towards the north and ultimately enter the larger Gunii Hooloi basin located approximately 5 km to the northwest of Khanbogd.

**Figure 6.26: Northern Part of the Khanbogd Massif showing Khanbogd and the fractures system feeding the ephemeral watercourses**



### 6.5.5 Spring Water Quality

The analysis of the water quality in the surface springs surrounding the Project area has demonstrated it to be similar to the quality of water found in the shallow wells used by nomadic herdsman, reflecting the fact the water is derived from the same shallow aquifer. The analytical results of samples taken from the Maanit, Khukh Khad and Bor Ovoo Springs (see *Figure 6.25* for locations) during June 2010 are shown in *Table 6.3* where the data is compared to Mongolian Standard for water quality (MNS 4586-98). Variations in the total dissolved solids (TDS) reflect the timing since a rainfall event and also the fact that increasing evaporation downstream will increase the TDS. This could be the explanation for Maanit Spring and Khukh Khad (located 12 km downstream of the mining licence) having a higher TDS than the

<sup>10</sup> Geomaster Engineering (2010), Report on Groundwater Geophysical Exploration for Water Supply of Khanbogd Soum, Omnogovi Province

Bor Ovoo Spring. The waters are also generally slightly alkaline which reflects the carbonate rich nature of the soils (see *Chapter B5 in which soils are discussed*).

**Table 6.3: Water Quality Results for Springs Surrounding Oyu Tolgoi Area**

Sample ID	Units	Bor Ovoo	Maanit	Buural	(MNS 900:2005)	WHO potable standards
Sampling Date		18 06 10	18 06 10	18 06 10		
Laboratory		CGL	CGL	CGL		
pH	pH Units	6.6	6.2	7.5	6.5-8.5	
Total Dissolved Solids @ 180°C	mg/L	318	1120	608		
Bicarbonate, HCO <sub>3</sub>	mg/L	180	256	250		
Carbonate, CO <sub>3</sub>	mg/L		4.5	6		
Hardness meq/l/mg/l	mg/L	2.90	2.60	2.40		
Calcium, Ca	mg/L	48	34		100	
Magnesium, Mg	mg/L	6.08	10.9	8.51	30	
Potassium, K	mg/L	1.84	2.24	3.94		
Sodium, Na	mg/L	62.6	331.5	172.5	500	200
Fluoride, F	mg/L	2.61	4.1	0.5	0.8-1.5	1.5
Sulphate, SO <sub>4</sub>	mg/L	71.6	304.5	56.8	100	500
Chloride, Cl	mg/L	42.2	224.7	150.6	350	250
Iron (Total), Fe	mg/L	0.02	<0.02	0.03	0.3	
Arsenic	mg/L	<0.05	<0.05	<0.05		0.01
Cadmium	mg/L	<0.005	<0.005	<0.005		0.003
Chromium	mg/L	<0.02	<0.02	<0.02		0.05
Copper	mg/L	<0.01	<0.01	<0.01		2
Lead	mg/L	<0.05	<0.05	<0.05		0.01
Nickel	mg/L	<0.03	<0.03	<0.03		0.02
Zinc	mg/L	<0.01	<0.01	<0.01		3
Mercury	mg/L	<0.005	<0.005	<0.005		0.001
Ammoniacal Nitrogen, NH <sub>3</sub> -N	mg/L	0.6	0.2	0.7	0.5	
Nitrite as N	mg/L	0.2	0.2	0.2	1.0	0.2
Nitrate as N	mg/L	4.38	3.2	19	50	50

Note: Samples taken by OT as part of regular monitoring programme. Analysed at (CGL) Central geological laboratory

The water quality of these springs will improve following a rainfall/flood event and then deteriorate as the water level declines and salt and mineral concentrations increase with increased evaporation. Historical monitoring of the spring water for metal concentrations (arsenic, cadmium, chromium, copper, lead, nickel, zinc and mercury) has not detected any above the method detection limit. Monitoring of the variability in water quality of these springs has occurred on an irregular basis since 2004.

This historical monitoring data indicate that significant variations in TDS (salinity) occur in the springs. These are considered to be likely to be due to rainfall events (resulting in low TDS), evaporation during arid periods when TDS will increase, and potentially anthropogenic influences if herd animals have been standing for long periods in the spring. The flux of water through the spring will also be an influence on TDS. The data indicates that the Bor Ovoo, which is the most up-gradient of the three springs presented in *Table 6.3*, is consistently fresher in nature (300-300 mg/l) indicating freshwater recharge. Maanit and Buural both consistently have higher TDS (400-800 mg/l and 450-600 mg/l respectively) than the Bor ovoo spring. These are 13 to 15 km downgradient of Bor Ovoo, and may be subject to great evaporation, also the Maanit spring is essentially at the confluence of the Budaa ephemeral watercourse which is a smaller tributary of the Undai and may contribute higher salinity groundwater to the system. Whilst there are variations in salinity, the baseline data has allowed the understanding of the expected ranges in

salinities which can be used by Oyu Tolgoi in developing a better understanding of the factors influencing the spring salinities.

### 6.5.6 Cretaceous Clastic Aquifers Overview

The most significant aquifers (in terms of volume) in the Project Area of Influence are the Late Cretaceous aquifers which comprise a thick sequence of clastic sediments deposited into rift basins with a predominant WSW-ENE trend. The formation of these rift basins in the Cretaceous corresponded with a wet period which resulted in significant erosion of the surrounding Palaeozoic basement and deposition of a thick sequence of clastic sediments in the basins. In the vicinity of the Project area, Oyu Tolgoi identified three of the rift basins based on the gravity surveys of the area which were considered to be potential groundwater resource basins. These basins were Gunii Hooloi to the northeast of the Mine Licence Area, Galbyn Gobi to the southeast along the infrastructure corridor and Nariin Zag located to the northwest.

#### *Baseline Data Used*

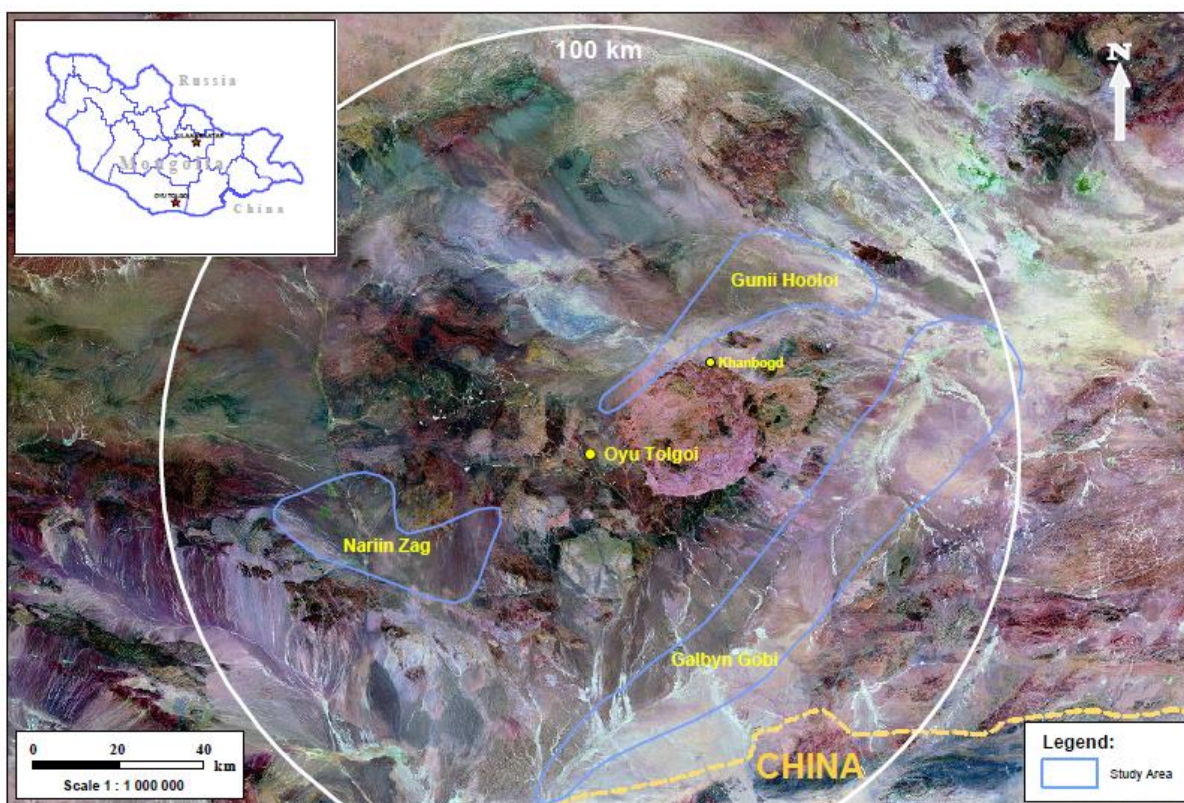
The assessment of the baseline characteristics of the Cretaceous aquifer such as its dimensions, lithology and chemistry of the Galbyn Gobi and Gunii Hooloi used in this Chapter have been based on Oyu Tolgoi's geophysical and hydrogeological investigations of the basins which included the following:

- Collation and assessment of all existing information (desktop study) and selection of areas for field investigation;
- Gravity surveys of the basins to establish their respective geometries and interrelationships;
- Broad scale TEM traversing geophysical investigation, to delineate the geometry of the areas of interest;
- Recovery of geological core (diamond drilling) to provide representative samples of the sediments in each area of interest and to calibrate TEM results;
- Completion of down hole geophysical logging to further assist in the delineation of geological boundaries and hydrogeological parameters;
- Identification of potential aquifer units from the exploration core and TEM;
- Drilling and construction of test production bores in areas that demonstrated greatest potential for groundwater development;
- Completion of aquifer tests to collect data to enable the calculation of aquifer hydraulic parameters;
- Development of conceptual geological and hydrogeological models for those aquifers of interest; and
- Development of computer models, calibrated by field data, to simulate the geological and hydrogeological regime.

#### *Groundwater Exploration Methodology*

The initial groundwater exploration undertaken by Oyu Tolgoi was in 2003-2004 and included the exploration of the Galbyn Gobi, Nariin Zag and Gunii Hooloi basins. These basins, which are all located within less than 100 km of Oyu Tolgoi, are illustrated in *Figure 6.27*.

**Figure 6.27: Deep Aquifer Basins around Oyu Tolgoi**



Source: Aquaterra (2004), *Groundwater Exploration Investigation, Oyu Tolgoi Process Water Supply, Volume 1*, Aquaterra Consulting Pty Ltd, October 2004

Prior to this there had been very limited exploration drilling in the region with some historical Russian exploration of the Galbyn Gobi and Nariin Zag basins, and essentially no exploration of the Gunii Hooloi. In all basins the only exploitation of groundwater was of the shallow surficial aquifers by the herders through their summer and winter wells. These wells are typically hand dug and have standing water levels 2-5 m below the surface.

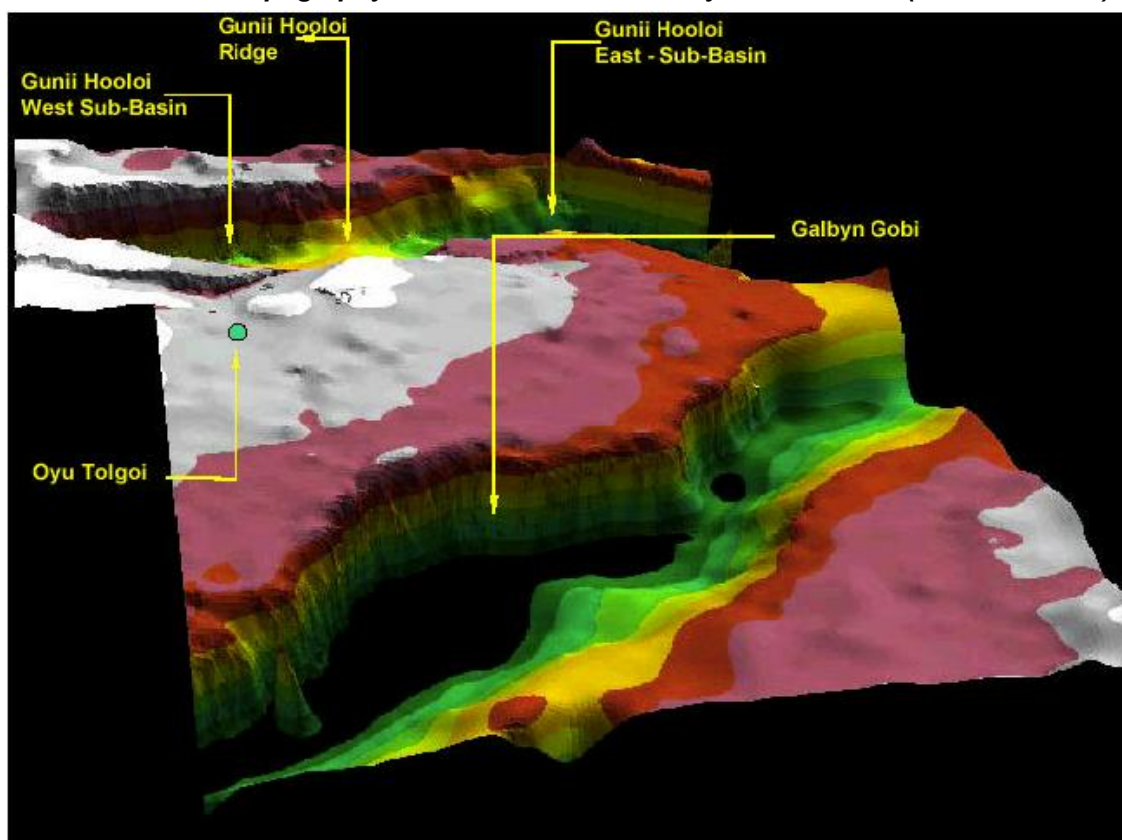
#### *Geophysical Assessment of the Basins*

The geophysical assessment of the basins involved the use of gravity to define the basin geometries as illustrated in *Figure 6.28* and *Figure 6.29*, and TEM surveys to define the potential permeable horizons. The gravity data illustrates the relationship between the solid Palaeozoic bedrock and the Cretaceous sedimentary basins within the fault defined rifts.

*Figure 6.29* illustrates the graben and horst nature of the Gunii Hooloi and Galbyn Gobi basins and the limited connection between the eastern part of the Gunii Hooloi basin (shown as Gunii Hooloi East in *Figure 6.29*), and the Gunii Hooloi NE Basins. The shapes of these basins, the nature of the bedrock on the margins, and the erosive nature of the rivers in the Cretaceous, will all have influenced the subsequent characteristics of the Cretaceous sediments in them. The interpreted gravity data for the Galbyn Gobi basin shows it to be controlled by a steep dominant northeast-southwest trending normal fault adjacent to the Khanbogd massif and to have a more gently sloping southern side reflecting rotation around the fault (see *Figure 6.28* and *Figure 6.29*) whereas Gunii Hooloi is controlled by steep faults on both sides.

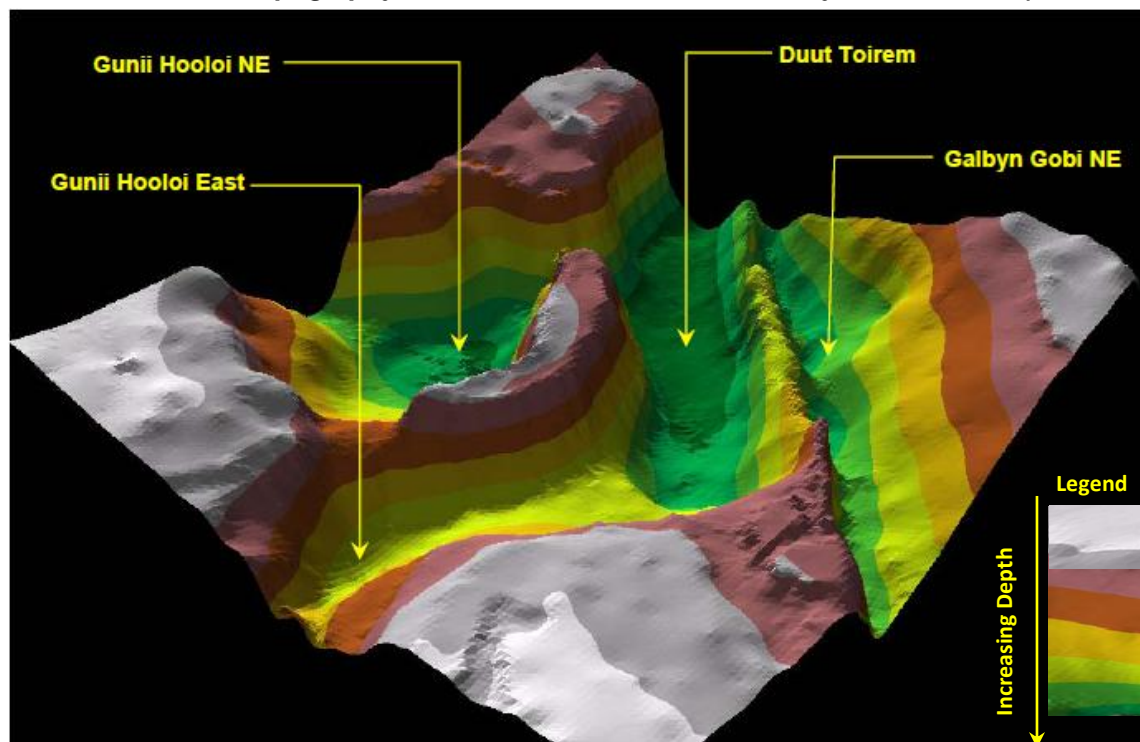
The gravity data shows that the Gunii Hooloi and Galbyn Gobi basins essentially merge at their eastern ends in the Duut Torim area (*Figure 6.29*), being only separated by a low horst (or fault defined ridge of basement). However, for the purposes of the baseline assessment, they are treated as individual units as the proposed exploitation area is in the central and western parts of Gunii Hooloi (as shown on *Figure 6.29*) a significant distance (over 50 km) from where the basins merge.

**Figure 6.28: Basement topography of Gunii Hooloi and Galbyn Gobi Basins (view northeast)**



Source: Aquaterra (2004), Groundwater Exploration Investigation, Oyu Tolgoi Process Water Supply, Volume 3, Aquaterra Consulting Pty Ltd, October 2004

**Figure 6.29: Basement topography of Eastern Gunii Hooloi and Galbyn Gobi Basins (view east)**



Source: Aquaterra (2004), Groundwater Exploration Investigation, Oyu Tolgoi Process Water Supply, Volume 3, Aquaterra Consulting Pty Ltd, October 2004

### *Initial Exploration Borehole Programme*

The objective of the first drilling programme in 2003-2004 was two-fold<sup>11</sup>:

- To prove the presence of a groundwater resource which could deliver the Project water requirements; and
- To assess the potential environmental and social impacts of such a groundwater resource development (specifically on natural vegetation and existing water supplies).

The drilling locations for the 2003-2004 investigation were based on the geophysical data which had been used to define the basins and the potentially permeable horizons. The investigation involved the drilling of an initial diamond core drill hole at each location which provided protection in the event that excess artesian water pressures were encountered. Artesian flow was encountered in parts of the Galbyn Gobi, however it was limited, with positive heads of up to 6 to 10 m above ground level which were easily controlled with equipment and resources readily available on site. Once this diamond cored hole was completed, if the site was selected as a water test borehole, the diameter of the diamond hole was enlarged using conventional mud rotary drilling to allow the production casing to be accommodated.

The core recovered from the diamond drilling enabled a far better understanding of the characteristics of the sediments, compared to earlier mud rotary drilling by previous workers in Galbyn Gobi and Nariin Zag. The investigation of the Gunii Hooloi by Oyu Tolgoi led to the discovery of the Cretaceous aquifers in the basin which were previously unknown. Based on these initial drilling results, a large scale exploration programme was implemented involving gathering further information on the basin and sediment characteristics through detailed geophysical electromagnetic surveys which traversed the basin and further diamond core drilling.

The results of this investigation<sup>12</sup> demonstrated that the basin with the greatest potential to supply the Oyu Tolgoi Project operational water demand was the Gunii Hooloi basin located 35 km to the northeast of the Mine Licence Area. The Galbyn Gobi basin also had significant potential, but was identified as having less well developed aquifer characteristics and greater potential for environmental impacts. This would therefore require further exploration to confirm which parts of the Galbyn Gobi basin could provide sufficient water supply, with minimal potential environmental risks. Following the initial investigation, Nariin Zag was not subject to further consideration as it was deemed to be not suitable for supplying water to the Project due to its more limited size, poorer aquifer characteristics and distance from Oyu Tolgoi. Therefore given the results of the initial investigation the Gunii Hooloi basin was chosen as the preferred option with the Galbyn Gobi providing a reserve for complimentary or future development.

### *Gunii Hooloi Borehole Construction Methodology*

The initial exploration boreholes were screened across the majority of permeable horizons encountered in the Cretaceous clastic sequence to maximise the potential for encountering productive groundwater horizons. No screens were placed across the shallower clay rich Cretaceous sequence, or the shallow Quaternary to Recent sediments which support the shallow aquifer used by the herder wells. In the Gunii Hooloi borefield area the top of the upper most screen varied significantly across the basin with the shallowest being a little over 20 m below the surface (e.g. at GHW14x2). At each location an observation borehole was drilled to the same depth as the pumping well and a shallow observation borehole installed (typically 20-30 m depth) to allow an assessment of the characteristics of any shallow groundwater and to evaluate whether there was any influence on these shallower Cretaceous aquifers from pumping of the main well. In only one known instance (GHW6x4) was a borehole screened across a hydraulically separate shallower (circa 38-40 m depth) permeable horizon in the Cretaceous sequence and also the deeper Cretaceous aquifer (the top of which is at a depth of circa 97 m). This resulted in the screen creating a connection between them. Oyu Tolgoi intends to convert the borehole to a piezometer (or nested piezometer) once given permission from the Mongolian Water Authority. This shallower (38-40 m) Cretaceous unit has a lower water level than the surficial aquifer (which extends to a depth of 10 m) and is not used by the herders.

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<sup>11</sup> Aquaterra (October 2004); Groundwater Exploration Investigation, Oyu Tolgoi Process Water Supply. Volume 1: Resource Assessment and Borehole Design, Page 1.

<sup>12</sup> Aquaterra (2004), Groundwater Exploration Investigation, Oyu Tolgoi Process Water Supply, Volumes 1-5, Aquaterra Consulting Pty Ltd, October 2004

### *Additional Gunii Hooloi Investigations*

The 2003-2004 investigation data enabled Oyu Tolgoi to prove the resource. It also demonstrated that the deeper (over 200 m depth) aquifer horizons in the Cretaceous sequence were the more transmissive and that the upper aquifer horizons (circa 50-150 m depth) did not contribute a significant flow to the wells. The shallow monitoring wells, where they were screened shallow enough, indicated that the upper section of the Cretaceous sequence often had shallower separate water tables. Screening across various levels of the deeper aquifer resulted in similar standing water levels, reflecting that the deeper clastic sequence was hydraulically connected and also reflecting the confined nature of the Cretaceous aquifer. These standing water levels in the main Cretaceous aquifer are typically 30-50 m deeper than the water level measured in the shallow monitoring boreholes.

An additional groundwater exploration programme was undertaken in Gunii Hooloi in 2007<sup>13</sup>. The key objectives of this were:

- To provide information for the Detailed Borehole Design process – obtained by the installation and testing of four trial production bores;
- To confirm key aquifer characteristics, improve definition of the areal extent of the aquifer, and provide further data for an upgraded calculation of the aquifer supply potential (known as the “Reserve” in Mongolia) – obtained by the installation and testing of eight exploration bores and two test bores;
- To satisfy regulatory authority requirements – including infill drilling and testing of sites, requested by the Mongolian Water Authority);
- To investigate the hydrogeological setting of the streambed aquifer and existing water supplies – including the drilling and installation of monitoring wells adjacent to 12 existing, shallow, water supply wells/bores used by local herders; and
- To identify any existing users or environments at risk of potential impact due to operation of the borefield – including a field survey of local and downstream supplies and environments.

The additional Gunii Hooloi boreholes were generally installed with deeper screens. They included new locations adjacent to existing groups of groundwater wells, and boreholes in new locations to better characterise the aquifer characteristics and boundaries away from the 2003/2004 exploration programme.

### **6.5.7 Cretaceous Basin Hydrogeology**

Based on the exploration drilling the geological sequence of the Galbyn Gobi and Gunii Hooloi sedimentary basins can be summarised as follows:

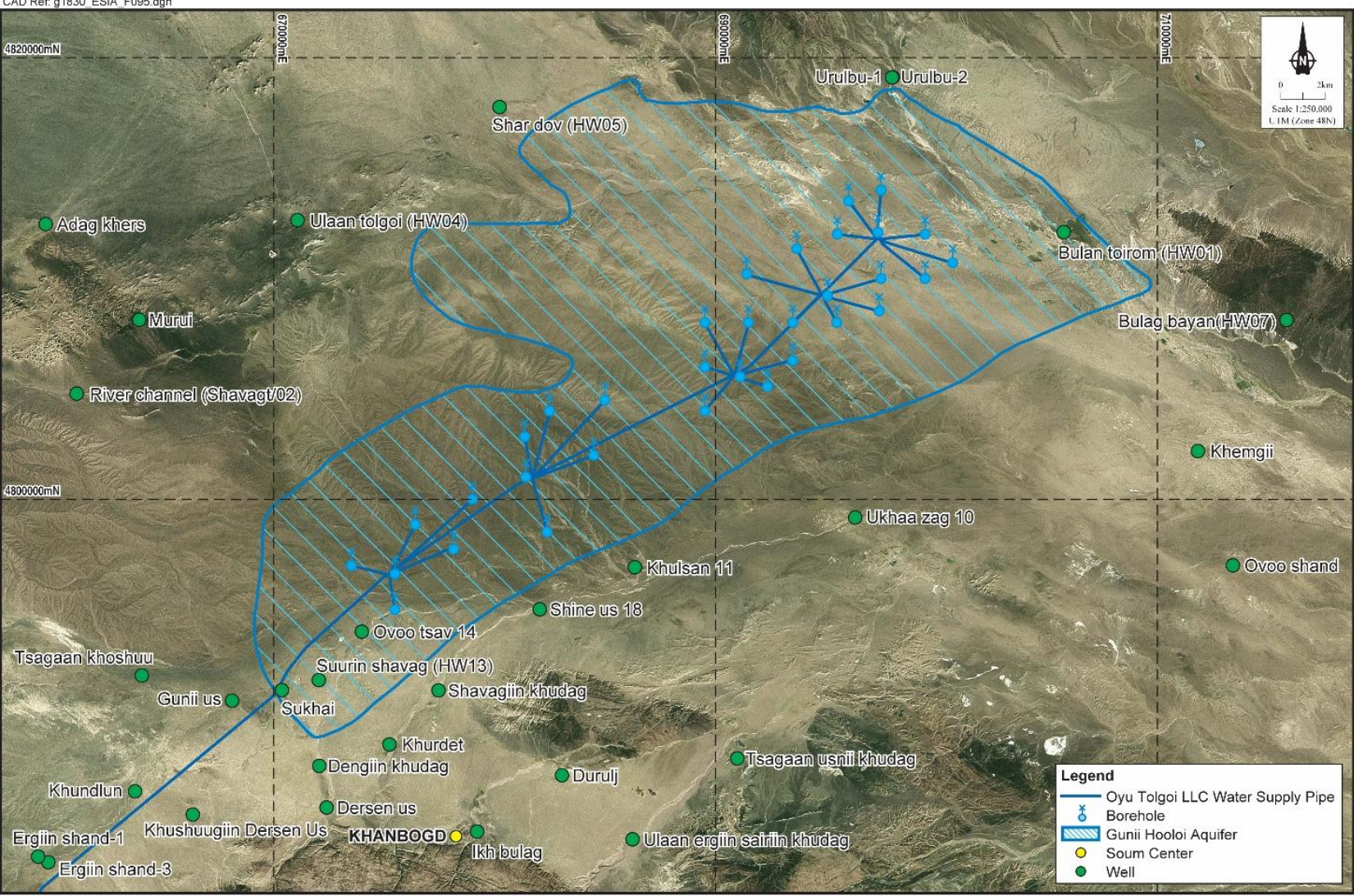
- Undifferentiated Quaternary sediments;
- Upper Cretaceous Bayanzag Formation;
- Upper Cretaceous Bayanshiree Formation;
- Cretaceous Hohteeg Formation (limited in lateral extent to the deepest parts of the basin); and
- Basement rock types: Generally Palaeozoic intrusives (granite, granodiorite, syenite), volcanics (basalt, andesite, rhyolite) or metamorphosed sediments (schist, sandstone, conglomerate).

The distribution and nature of the sediments within each formation is significantly different in each area and consequently the hydraulic behaviour of each unit varies considerably across the study areas.

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<sup>13</sup> Aquaterra (March 2008); Gunii Hooloi Aquifer; Investigation and Resource Assessment – 2007 (Revised Water Demand), Ref 658/F/331a

**Figure 6.30: Gunii Hooloi Herder Wells and Oyu Tolgoi Groundwater Monitoring and Exploration Wells**



The Cretaceous aquifers comprise significant thicknesses of coarser grained sediments deposited in a fluvial setting within the tectonically controlled basins. These sequences exhibit substantial sediment sorting which can enhance the hydraulic conductivity and porosity. Major aquifers are developed in the conglomerates present in the deeper parts of the basin that are inferred to be formed from debris flows closer to the provenance sources along the basin boundaries (in proximal to mid fan zones). These sediments have either maintained significant primary permeability or have well developed secondary permeability. Overall across the basin the geological sequence fines upwards (i.e. clay predominates in the upper section).

The major aquifer units and separating aquitards in the Galbyn Gobi basin are transgressive (i.e. boundaries are different ages in different parts of the basin). The converse is generally the case in the Gunii Hooloi region, where facies boundaries align with chronological boundaries.

### 6.5.8 Galbyn Gobi Hydrogeology

The results of the 2003-2004 baseline exploration programme, which extended along the length of the Galbyn Gobi basin, resulted in the definition of groundwater conditions in the basin to a sufficient level of confidence that Oyu Tolgoi could make a decision on whether this basin had the potential for to form the primary water supply for the Project.

The investigation indicated that groundwater flow in the Galbyn Gobi basin is split by a central groundwater divide in the area immediately southeast of Oyu Tolgoi, with flow either side of this divide towards the northeast and southwest (see *Figure 6.31*). This has been confirmed by Oyu Tolgoi's subsequent groundwater monitoring programme. During the drilling, downward and upward gradients were encountered in the boreholes. This indicates that the aquicludes are effective at both separating the aquifers in the basin, and creating artesian conditions (i.e. water in some locations is free flowing to the surface) in part of the distal north-eastern section of the study area. These artesian aquifer units could be contributing to maintaining saturation levels in the overlying clays and other sediments which could be important for the deep rooted groundwater dependent vegetation which is found around the peripheral areas of the study area.

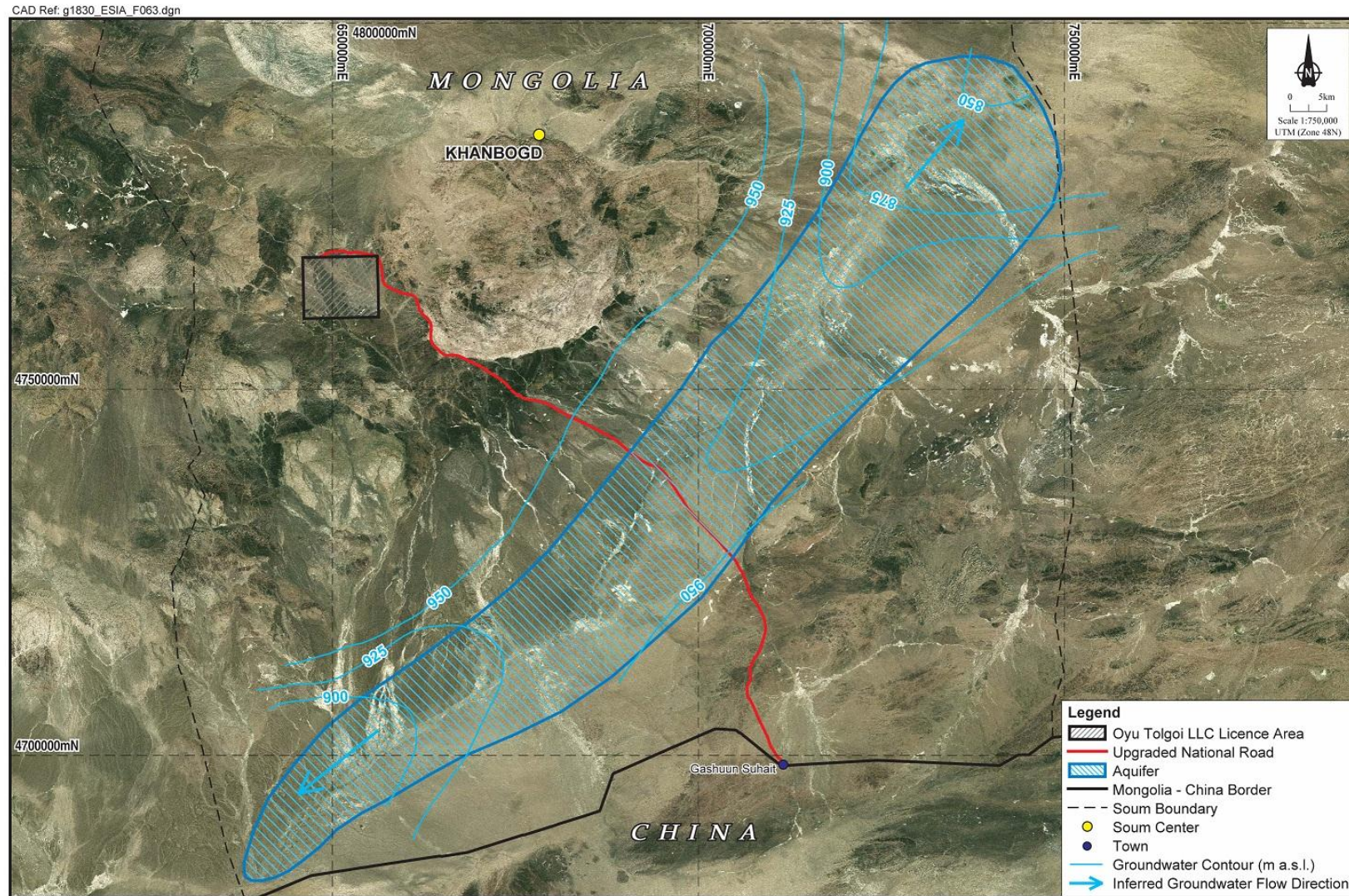
The Cretaceous aquifer units in the Galbyn Gobi comprise an upper and lower aquifer separated by an aquitard that ranges in thickness from 50 to 100 m. The upper Galbyn Gobi aquifer is considered to be the main groundwater resource in the Galbyn Gobi basin. This upper aquifer is semi-confined in the central area due to the presence of inter-bedded clays and clayey sands within the predominantly sand/sandstone lithologies. The aquifer plunges to the south-west and north-east, where it becomes confined. The aquifer generally ranges in thickness from 125 to 175 m over the central area, thinning to about 25 m at the limits of the investigation area in the southwest and northeast along an axial distance of over 60 km and a width of 15 to 20 km.

The lower Galbyn Gobi aquifer is well developed in the central to north-eastern Galbyn Gobi basin, where it attains a thickness of 150 m over a distance of 50 to 70 km. This thins towards the limit of the investigation area and is not well developed in the far northeast. In the southeast Galbyn Gobi, the lower aquifer is generally less than 50 m in thickness and is not developed at all in some areas.

The pump tests indicate that transmissivities in the basin vary between 5 and 150 m<sup>2</sup>/d (adopted average per borehole) with an average across the basin of 80 m<sup>2</sup>/d.

The saturated profile in the Galbyn Gobi aquifers extends to depths of the order of 350 m over a significant portion of the basin making the Galbyn Gobi basin a major groundwater resource. Preliminary estimates of the volume of groundwater held in aquifer storage and availability for abstraction have been developed for the aquifers which are considered to have the greatest potential for development (i.e. are of sufficient thickness and areal extent, and are general isolated from existing water users). Assuming a mean porosity of 30%, the total aquifer storage is estimated to be 72,000 Mm<sup>3</sup>. The total amount of this groundwater that can be removed from storage by gravity drainage is constrained by the specific yield of the material. Based on a conservative 2% specific yield, it is estimated that the total available groundwater is 4,800 Mm<sup>3</sup>. The actual volume of groundwater that can be recovered from aquifer storage will, however, be largely dependent upon bore and borefield design and the imposed abstraction regime. If this aquifer were to be exploited, further appraisal and modelling would be required to refine these estimates and formalise a reserve application.

Figure 6.31: Galbyn Gobi - Boreholes and Groundwater Contours and Flow Direction (2003-2004)



Source: Aquaterra (2004), Groundwater Exploration Investigation, Oyu Tolgoi Process Water Supply, Volume 1, Aquaterra Consulting Pty Ltd, October 2004

### *Galbyn Gobi Aquifer Chemistry*

During the 2004<sup>14</sup> investigation, field measurements of groundwater chemistry (pH, electrical conductivity and TDS) were undertaken on 56 samples collected from the borings. In addition detailed chemical analyses were undertaken on 19 groundwater samples collected from test production bores at the completion of the pumping tests. A separate programme of discrete interval down-hole sampling to determine the variations in groundwater quality between the various aquifer units at depth was also undertaken on 12 boreholes (32 analyses). The analyses of samples collected at the end of the pumping tests were assumed to represent the average groundwater chemistry of the Galbyn Gobi aquifer.

The results of the analysis indicated that, generally, the groundwater quality in the upper Galbyn Gobi aquifer is good, with salinities of <900 mg/L at most (60%) sites, while the lower Galbyn Gobi aquifer quality is poorer, but still less than 2,000 mg/L TDS. The distribution of groundwater salinity indicates that the best quality water occurs at the edges of the sedimentary basin (where infiltration of surface water inflows and local bedrock run-off are inferred to take place) and that water quality as reflected in increasing TDS generally deteriorates down-gradient of these areas.

### *Future Assessment of Galbyn Gobi Groundwater Resources*

Oyu Tolgoi will utilise the Gunii Hooloi aquifer for its operational water supply, and the current and on-going work in Gunii Hooloi is aimed at supporting an updated reserve that will enable future mine expansions. If these updated reserves are not proven, Oyu Tolgoi will assess options for additional water reserves outside of Gunii Hooloi. The Galbyn Gobi basin presents one option for development of a supplementary supply. As described above there is a significant body of work that has already been completed there by Oyu Tolgoi, which has proven the existence of a substantial water resource, and Oyu Tolgoi has formal registration of interest in developing this. It is also, to a large degree, isolated from the existing Gunii Hooloi borefield.

The scale of development of the Galbyn Gobi aquifer may however be constrained by environmental considerations; significant areas of groundwater-dependent vegetation exist that might be impacted by excessive water level drawdown. It will therefore require a suitably evaluated engineering solution to minimise such risks and establish a reserve of the order of 300 L/s which should be available with appropriate bore/borefield design and abstraction from deeper horizons.

In addition to the Galbyn Gobi, Gunii Hooloi NE (or Baishintsav) is a basin that is relatively unexplored with some Oyu Tolgoi boreholes installed in its western end. Based on the gravity data, this basin appears to be separated from the Gunii Hooloi basin by a ridge of bed rock (see *Figure 6.31*) although this has not been encountered in drilling to date.

If these basins were to be assessed further by Oyu Tolgoi, it would commission integrated hydrogeological/environmental investigations in the Galbyn Gobi and Baishintsav basins which would have the objective of improving the definition of the shallow groundwater environment and the vegetation it supports, and to identify/quantify any potential constraints on aquifer development. This work would likely include additional drilling and long-term aquifer testing as well as aquifer modelling. Any such work would be undertaken in accordance with Mongolian permitting requirements and be supported by a supplementary ESIA which meets IFC and EBRD requirements.

### **6.5.9 Gunii Hooloi Hydrogeology**

The initial Oyu Tolgoi exploration programme in the Gunii Hooloi basin immediately followed the Galbyn Gobi investigations in 2003-2004 as part of the assessment of the potential of both basins to provide the operational water supply.

The review of the results and initial modelling based on the 2003-2004 groundwater investigation demonstrated the Gunii Hooloi basin to have the greatest potential to supply the raw water for the Project due to the greater aquifer extent and therefore greater resource potential. The target aquifer, the Cretaceous, was also considered to pose the lowest risks to the surface ecosystems, such as groundwater-dependant vegetation.

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<sup>14</sup> Aquaterra (2004), Groundwater Exploration Investigation, Oyu Tolgoi Process Water Supply, Volumes 1-5, Aquaterra Consulting Pty Ltd, October 2004

In order to better delineate the aquifer, develop a detailed understanding of the aquifer characteristics and develop final design of the borefield, additional investigations were undertaken in 2007.

Based on the drilling and geophysical data, the Cretaceous aquifer is inferred to extend over 40 km, thickening to the northeast where it is approximately 10 km wide, with a corresponding thinning of the aquicludes units towards the northeast. While the aquicludes thin towards the northeast the main aquifer remains confined across the whole basin where it has been drilled. The 50 m herder monitoring boreholes installed by Oyu Tolgoi (such as HW05 and HW18) all encountered sequences dominated by clay with only the upper 2 to 10 m having any significant permeability associated with the surface sediments (note that these sediments are too shallow to be illustrated on *Figure 6.35*). In summary there is no evidence from the drilling undertaken to indicate that there is any increase in clastic content around the edges of the basin, which would result in the potential for greater vertical hydraulic connectivity between the shallow and deep aquifers to occur in these peripheral areas of the basin,

*Figure 6.34* illustrates the basement ridge (near borehole WATP01) where the shallower basement causes the sedimentary sequence to thin to approximately 300 m. It also illustrates how the basin deepens in its north-eastern part with a notable increase in conglomerates at depth. The north-eastern end of this cross-section extends into the adjacent Gunii Hooloi NE basin, where standing water levels are higher indicating that groundwater flow in Gunii Hooloi is toward the Galbyn Gobi (i.e. a south-easterly flow at the low point in the basin) rather than east into Gunii Hooloi NE. It should be recognised, however, that this assumption is based on limited data, and is one of the focuses of Oyu Tolgoi's 2011/2012 programme of additional works.

The northern and southern margins of the basin are fault controlled illustrated by the gravity data (see *Figure 6.28*) and the TEM surveys across the basin (see *Figure 6.35*). As illustrated in *Figure 6.35* the youngest Cretaceous sediments and Quaternary-Recent sediments extend beyond the edges of the main basin onto the basin margins overlying the shallow bedrock in these areas.

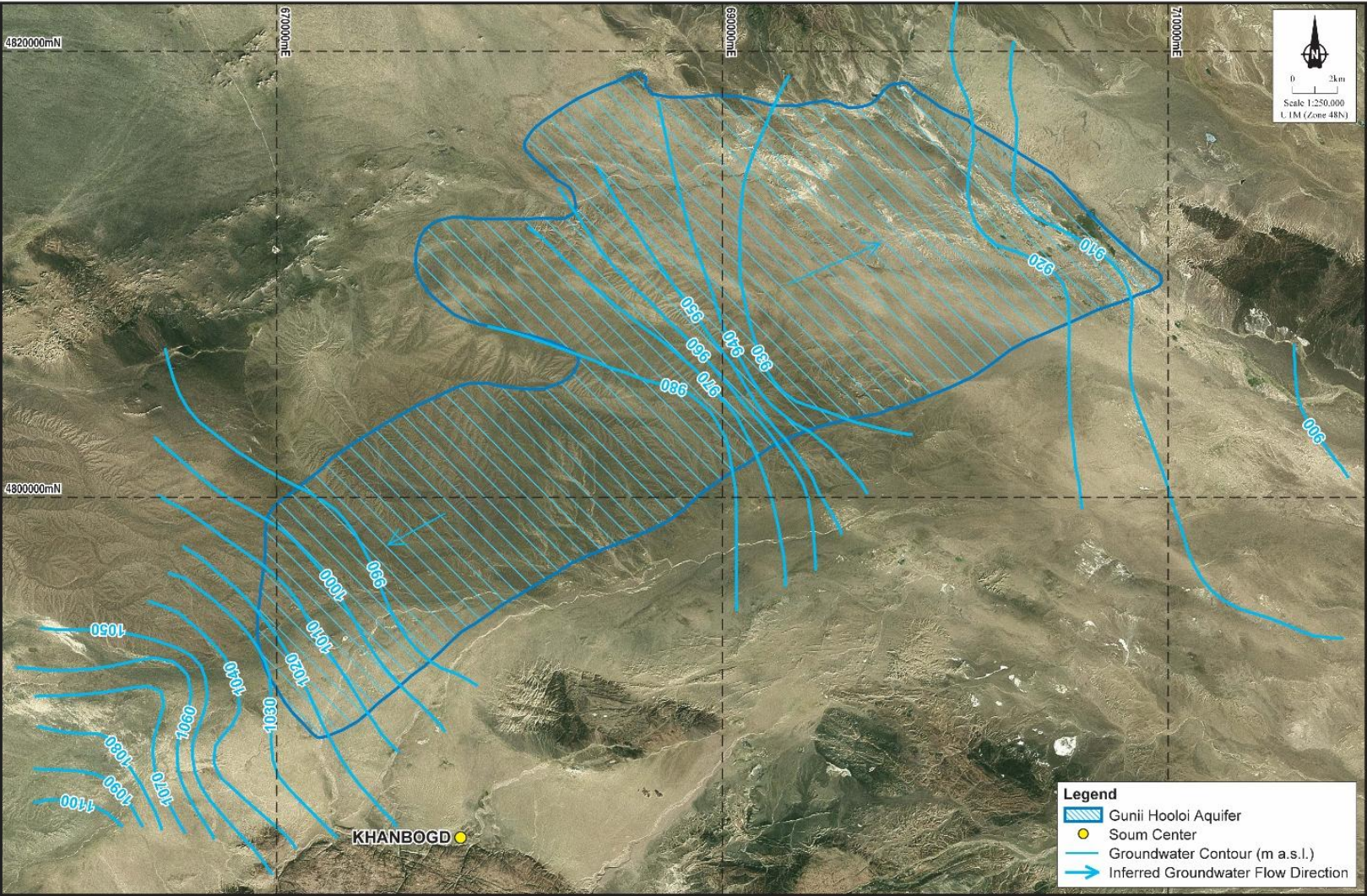
The Cretaceous sediments of the Gunii Hooloi basin comprise a heterogeneous sequence of clays, sandstones, siltstones and gravels, in which there is predominance of clays in the shallower sequence and increased occurrence of sandstones/gravels at depth. The definition of the upper and lower boundaries of the aquifer has been taken on lithological considerations supported by geophysical characteristics and flow logging. It is acknowledged that within such a heterogeneous system, there is an element of subjectivity in aquifer/aquitard differentiation.

To address this subjectivity Oyu Tolgoi's approach with regard to the definition of the top of the aquifer has been conservative (i.e. not count some higher thinner aquifer units). The definition of the base of the aquifer unit has been based either on the proven thickness in wells that penetrate the whole sequence or on geophysical data which have been calibrated to the well data to enable the interpolation of aquifer thicknesses in the deeper parts of the basin which have not been fully penetrated by the wells. This approach to the aquifer/aquitard definition used by Oyu Tolgoi has been approved by the Mongolian Water Authority.

This approach to defining the top of the aquifer is illustrated in the borehole presented in *Figure 6.33*. These borehole logs show the piezometric level to be significantly above the top of the aquifer which is defined as the top of the main sandy sequence taken as 178 m in GHTP01 (compared to the standing water level of 74 m) and the 169 m in GHTP03 (compared to the standing water level of 41 m). This relationship between the top of the aquifer and the piezometric sequence is also illustrated on the cross section (*Figure 6.33*).

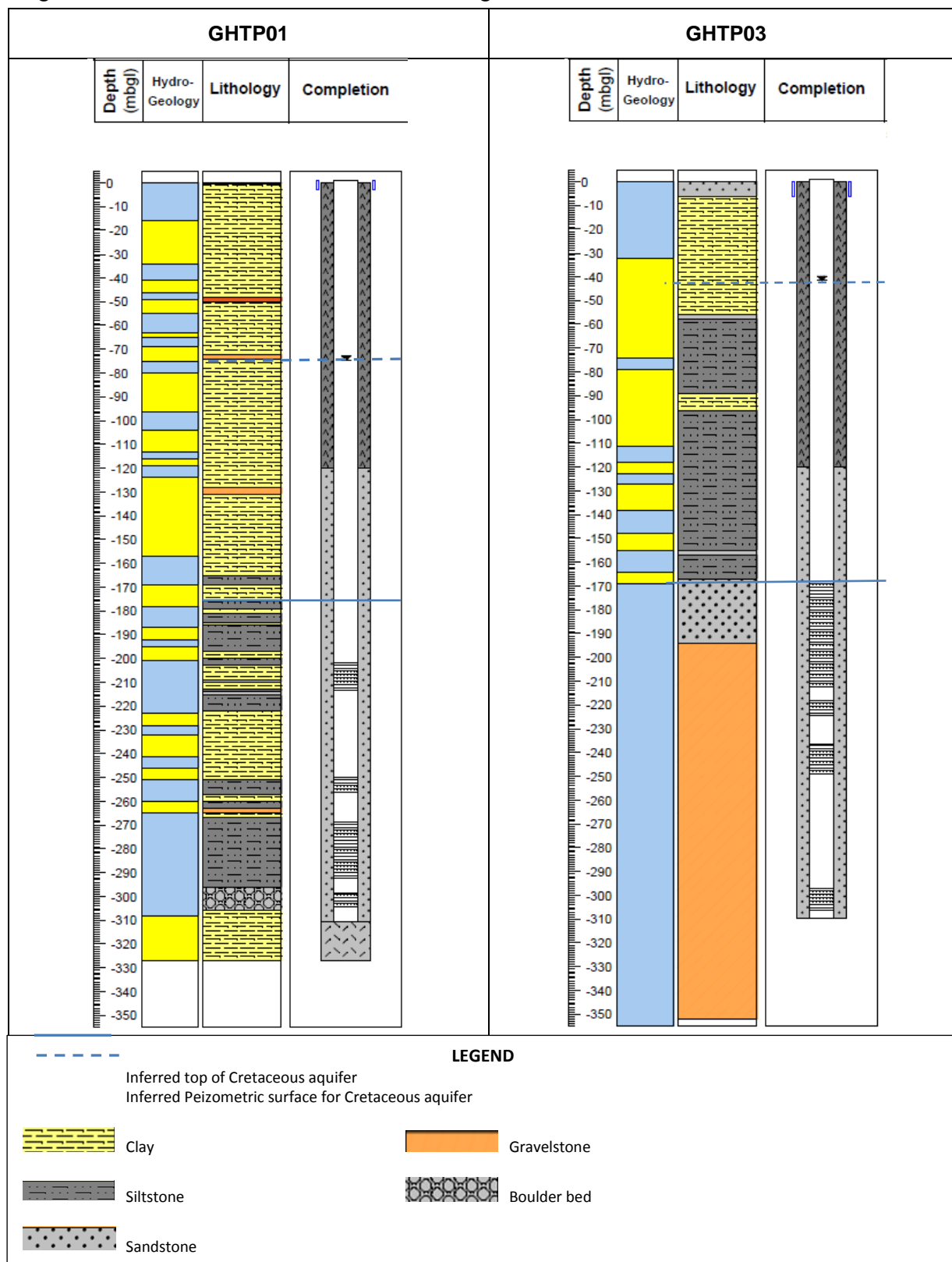
Both these boreholes were installed with a rotary drilling rig with a water based mud using a 444.5 mm diameter drill bit from 6 m to the base of the borehole. Casing is mild steel with stainless steel screen through the aquifer sections.

Figure 6.32: Gunii Hooloi - Boreholes and Groundwater Contours



Source: Aquaterra (2008), Gunii Hooloi Groundwater Investigation and Resource Assessment – 2007 (Revised Water Demand), Aquaterra Consulting Pty Ltd, March 2008

Figure 6.33: GHTP01 and GHTP03 Borehole Logs<sup>15</sup>



<sup>15</sup> Aquaterra 2007, Gunii Hooloi Aquifer Groundwater Investigation and Resource Assessment – 2007 (Revised Water Demand) Ref : 658/F/331a, March 2008

### **Groundwater Levels and Flow**

The depth to groundwater in the Cretaceous Aquifer varies from less than 20 mbgl at the distal parts of the basin in the east, to a maximum of 89 mbgl; with an average depth of approximately 50 mbgl for the majority of the basin. The groundwater contours are illustrated in plan view in *Figure 6.32* and the variation in water level for the Cretaceous aquifer along the axis of the basin is illustrated in the cross-section presented in *Figure 6.34*.

The data from the drilling investigation indicates that groundwater levels in the Gunii Hooloi basin fall towards the northeast along the basin. Gradients are highest towards the western edge of the basin, although the areas investigated by Oyu Tolgoi indicate that the aquifer is still confined (see *Figure 6.34*). The available data from Oyu Tolgoi's monitoring borehole system does not indicate any measurable recharge around the southern or northern parts of the aquifer system. The only evidence for a recharge area is in the far west of the groundwater study area (around GH2x3 17 km west of Khanbogd and 16 km southwest of the planned end of the production borehole field) where the piezometric surface for the Cretaceous may coincide with the shallow alluvium of the ephemeral watercourse in this area, indicating that some recharge may be expected to be occurring west of this location. Elsewhere in the basin the presence of clays in the upper Cretaceous sequence, such as the plastic red clays encountered in the deeper herder monitoring boreholes (with a total depth of 50 m), indicates recharge to the deeper aquifers in these areas is likely to be negligible.

The increased hydraulic gradient observed in the central area appears to relate to the presence of a basement ridge in this area which effectively constricts the cross sectional area of the aquifer and the groundwater flow. There are no apparent discharge areas for the groundwater in the basin, with no areas of springs or permanent deep rooted vegetation along the eastern edges of the basin. Flows from the basin may pass to a basin located further to the east (known as the Gunii Hooloi NE Basin) or south-eastwards to merge with the Galbyn Gobi basin (see *Figure 6.28*).

### **Aquifer Characteristics**

The results of the borehole pump tests have been used to assess the hydraulic characteristics of the Cretaceous aquifer. These results<sup>16</sup> indicate that aquifer transmissivities are in the order of 150 – 2,500 m<sup>2</sup>/d (northeast area) decreasing south-westward to between 200 – 500 m<sup>2</sup>/d as illustrated in *Figure 6.34*. Aquifer storage is calculated to range between  $2.5 \times 10^{-4}$  and  $5.0 \times 10^{-3}$ , which is broadly consistent with a confined to semi-confined aquifer system, and the specific yield in the upper 120 m of the Gunii Hooloi aquifer is assumed conservatively to be 3%.

The boreholes illustrated in *Figure 6.33* provide a comparison between a borehole (GHTP01) from the western part of Gunii Hooloi where transmissivities are lower (250 m<sup>2</sup>/d), and a borehole (GHTP03) from the central part of the basin where the transmissivities are much higher (2,500 m<sup>2</sup>/d). This is reflected in the coarser less clay-rich aquifer sequence encountered in GHTP03.

The initial approach to appraising the aquifer was to install screened intervals from the first aquifer formation to the total depth of the borehole (*Figure 6.34* illustrates some of these boreholes such as GHEB07). The subsequent flow testing of the aquifer identified discrete preferential flow horizons within the main aquifer profile which contribute the majority of flow to the pumping bore. These preferential flow horizons are 30–50 m thick and occur deep within the aquifer profile, and thicken towards the northeast of the basin. As a consequence the boreholes in this area can sustain higher flow rates.

Overall the deeper aquifer units contribute the majority of flow to the bores tested and provide the primary target zone for production bore design. It is this zone which is the target of the next programme of borehole development planned for late 2011/2012. It is apparent that there is little benefit in screening the upper levels of the formation, and the implications of the earlier exploration boreholes being screened over the whole well bore is discussed further in the Chapter C5 where the potential impacts of this are assessed. Once the 2011/2012 18 borehole programme is complete the base of the aquifer can be better defined by drilling results which additionally, together with additional surveys currently underway, will establish a higher level of “calibration” of geophysics, and also improve definition of any areas where

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<sup>16</sup> Using Theis and Cooper-Jacob which show there is a contribution from leakage out of the surrounding lower permeability formations, and also evidence of aquifer layering and/or barrier boundary effects in some parts of the basin.

greater Cretaceous thicknesses may occur that might be usefully explored (which could then become site of deep borehole if considered to be required).

### Resource Estimate

The saturated profile of the main Gunii Hooloi aquifer extends to depths of the order of 350 m over a significant portion of the central Gunii Hooloi basin and constitutes a major groundwater resource. Estimates of the volume of groundwater held in aquifer storage and water availability have been developed for that section of the Gunii Hooloi aquifer, which is considered to have the greatest potential for development - based on measured and interpreted thicknesses, areal extent and general isolation from existing water usage (see *Table 6.4*).

**Table 6.4: Estimated Storage and Groundwater Availability in Gunii Hooloi**

Parameter	Gunii Hooloi Aquifer
Average Aquifer Dimensions	45 km length, 12.5 km width, 185 m thickness
Areal extent of main aquifer	560 km <sup>2</sup>
Saturated volume of main aquifer	100,000 Mm <sup>3</sup>
Saturate volume of leaky aquitard	60,000 Mm <sup>3</sup>
Total saturated aquifer volume	160,000 Mm <sup>3</sup>
Estimated groundwater stored (based on 30% porosity)	48,000 Mm <sup>3</sup>
Groundwater availability from main aquifer (based on specific yield of 5%)	5,000 Mm <sup>3</sup>
Groundwater leakage from overlying aquiclude (based on specific yield of 3%)	1,800 Mm <sup>3</sup>
Total Groundwater Availability	6,800 Mm <sup>3</sup>

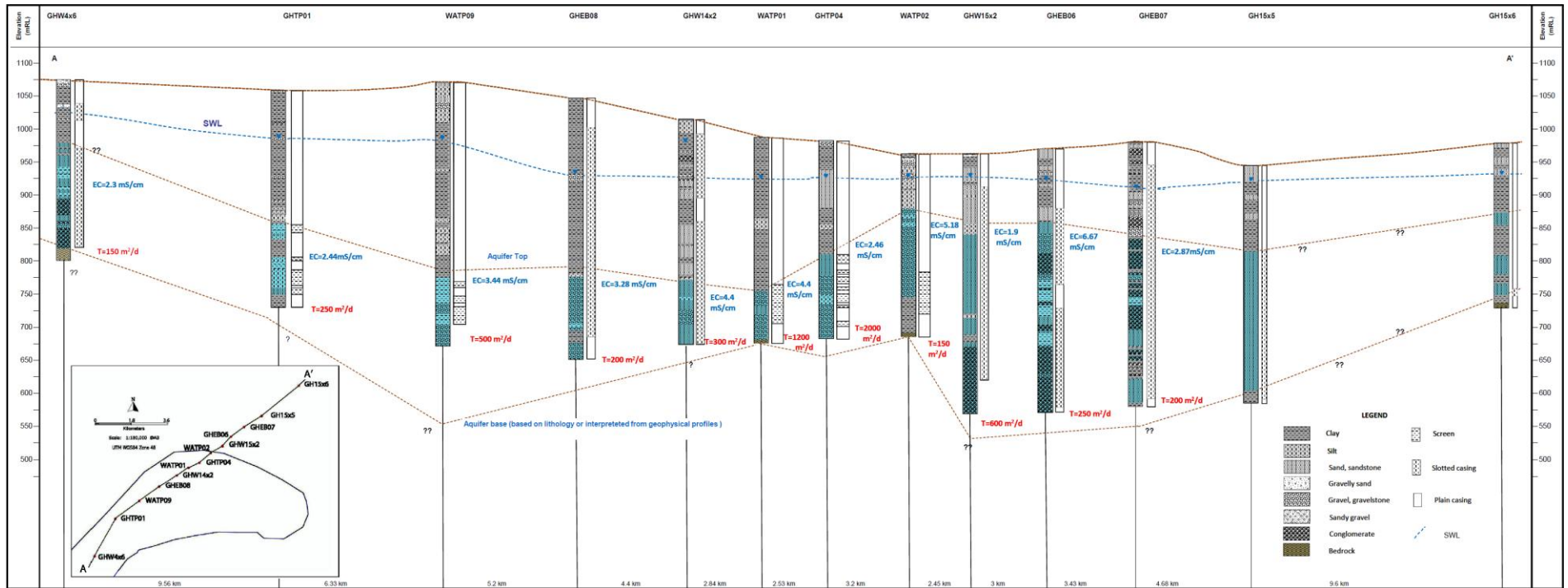
*Note: The actual volume of groundwater that can be recovered from aquifer storage will be largely dependent upon bore and borefield design and the imposed abstraction regime.*

The available groundwater presented in *Table 6.4* has been developed in conjunction with the Mongolian Water Authority and has, for key parameters, taken a conservative approach in its assessment (e.g. adoption of the lower end of the range of potential specific yields (3-5%).

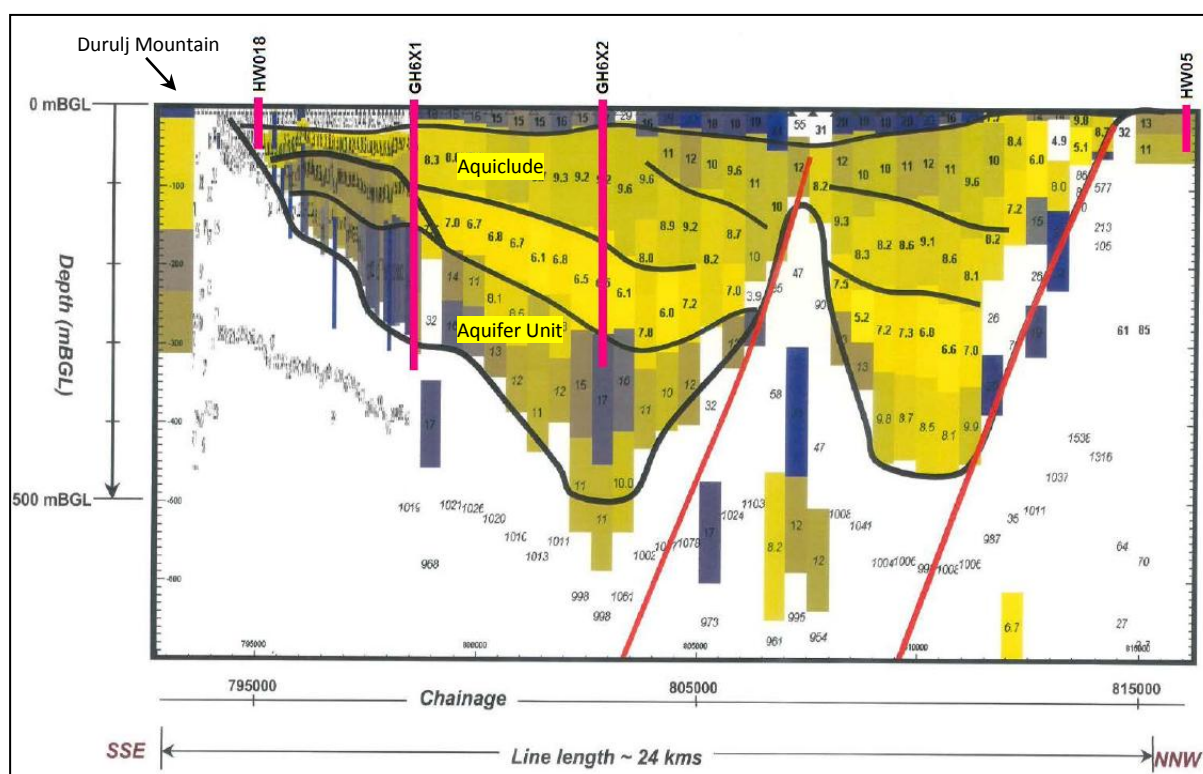
It is recognised that there is an element of uncertainty with regard aquifer thickness (and thus saturated aquifer volume) given the necessity to interpret the base of the aquifer from geophysical characteristics where borehole data not available. It should be noted however that the impact of this uncertainty on model predictions of aquifer responses to abstraction is considered negligible given the approach to assigning hydraulic conductivities to the interpreted aquifer thickness in the model aquifer layer that honour field-determined transmissivity values and transmissivity distribution. In this regard, predictions of drawdown may actually be over-estimates where there to be any interpreted deeper sediments that have hydraulic conductivities greater than those of the overlying sediments on which the aquifer tests were conducted.

Overall the resultant estimate of groundwater availability is considered likely to be an under-estimate of the volume actually available (for a 15% specific yield from only the main aquifer the total groundwater available would be 15,000 Mm<sup>3</sup>). A further level of conservatism in the resource assessment is the use of 30% porosity, and not including any additional water released as a consequence of potential settling of the aquifer as the pore pressures are reduced through pumping.

Figure 6.34: Schematic Southwest-Northeast Section through Gunii Hooloi based on Boreholes



**Figure 6.35: Schematic SSE-NNW Section through Gunii Hooloi based on Boreholes and TEM**



Note: TEM calibrated on drilling data

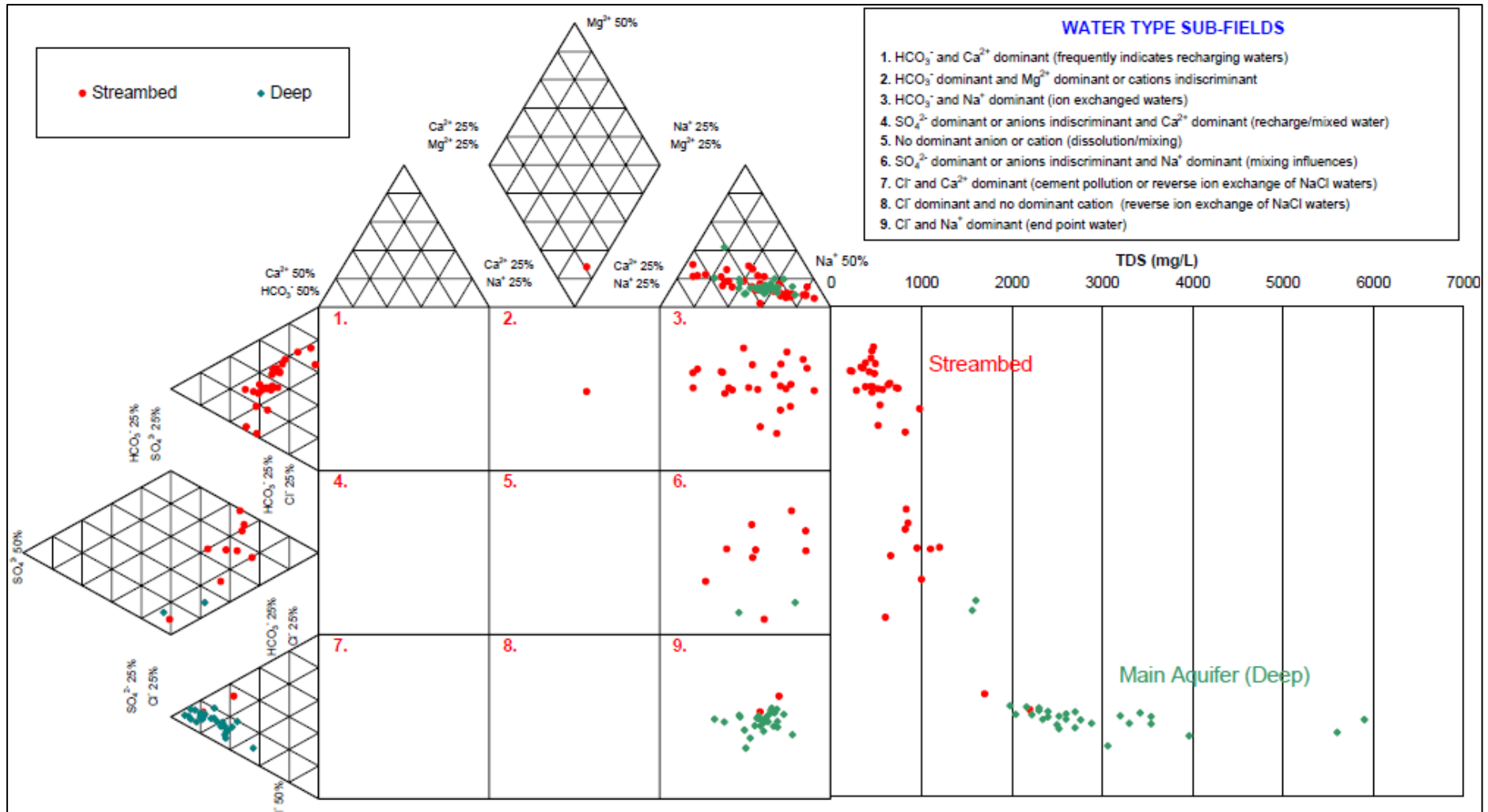
### Gunii Hooloi Aquifer Chemistry

Field measurement of the groundwater (pH, electrical conductivity and TDS) was undertaken on samples collected in the field from the herder wells across the basin as well as the investigation boreholes. At the completion of the pumping tests groundwater samples were taken and submitted for laboratory analyses from each of the test production bores and from the herder wells in the basin. A separate programme of discrete depth-specific down-hole sampling was undertaken in 10 bores to assess the variation in water quality between the various aquifer units with undertaken. The analyses of groundwater samples collected at the end of the pumping tests were used as an indication of the representative groundwater chemistry of the Gunii Hooloi aquifer.

The analysis demonstrated that, generally, groundwater quality in the surficial aquifer (2-5 m depth) as reflected in the herder wells was variable and TDS range for the majority of wells is 300-800 mg/l with some as high as 2,000 mg/l.

Groundwater quality in the deeper aquifer (piezometric head of 35-80 mbgl) is general poorer with a TDS (salinity) typically between 1,600 and 4,300 mg/L and an average of 2,800 mg/L TDS. The deeper aquifer shows sodium-chloride type waters which indicated long residence time and an absence of recent recharge. The majority of the herder waters are sodium-bicarbonate type waters, although with increasing salinity some become sodium-chloride dominated. The average pH in the main aquifer is 7.5 whilst that of the herder wells is 7.8. A Summary of the Gunii Hooloi chemistry is presented in *Table 6.5* and the chemical variation between the shallow and deep groundwater is presented in *Figure 6.36*. *Figure 6.36* illustrates shallow lower TDS sodium-bicarbonate groundwater in the streambed which are used by the herders and the higher TDS sodium-chloride groundwater in the main aquifer. The intermediate shallow groundwater which appears to be transitional between the sodium-bicarbonate and sodium-chloride groundwater is interpreted to be shallow groundwater which has limited recharge.

Figure 6.36: Expanded Durov Diagram for Gunii Hooloi Basin



Source: Aquaterra 2008, Gunii Hooloi Borefield Detailed Design – Bore Design (Revised Water Demand), ref: 658/G/328b, February 2008, Figure 19

**Table 6.5: Gunii Hooloi Water Chemistry<sup>17</sup>**

Area	Value	Sample Size	Field pH	Field Temp	TDS <sup>1</sup>	Chloride (Cl)	Sulphate (SO <sub>4</sub> <sup>2-</sup> )	Alkalinity	Total Hardness <sup>2</sup>	Hardness
				°C					mg/L as CaCO <sub>3</sub>	
Southwest	minimum	18	7.0	10.2	1,300	280	370	75	130	very hard
	maximum		8.4	21.0	4,300	1,700	1,100	190	962	very hard
	mean		7.5	15.1	2,900	940	730	130	540	very hard
Northeast	minimum	11	6.8	12.4	1,600	410	460	70	310	very hard
	maximum		8.5	19.1	3,800	1,200	1,300	120	1,248	very hard
	mean		7.4	15.3	2,600	795	820	95	625	very hard
Blended Output <sup>3</sup>	mean	29	7.5	15.1	2,800	910	750	120	560	very hard

Notes: 1. TDS = Total Dissolved Solids  
 2. Following USGS Total Hardness classification  
 3. Based on total output comprising 67% from northeast area and 33% from the southwest area

This initial groundwater quality data has been supplemented with a more extensive monitoring regime which extended the monitoring around the Oyu Tolgoi Mine Licence Area through the Gunii Hooloi and other areas. The analysis has included the following parameters:

Physio-chemical: pH, temperature, electrical conductivity, TDS (field), hardness

Major Ions: calcium, magnesium, potassium, sodium, fluoride, sulphate, chloride, nitrate

Metals: iron, arsenic, cadmium, chromium, copper, lead, nickel, zinc, mercury,

This has included the deeper boreholes installed by Oyu Tolgoi as well as the shallow herder wells in the Gunii Hooloi area. The analysis of metal results in the period 2004-2009 have not detected any significant elevated metal concentrations in the groundwater with the majority of the groundwater analysis reporting concentrations below the respective detection limits. The maximum reported metals concentrations are presented in Table 6.6. Only lead was reported in one instance above the WHO potable water standard; this result is just above the detection limit and may be erroneous; but will be subject of careful future monitoring by Oyu Tolgoi.

**Table 6.6: Metal Analysis of Groundwater in Gunii Hooloi**

Analyte	Maximum Conc Reported (mg/l)	WHO Potable Standards (mg/l)	Comment
Arsenic	0.0741	0.01	GH3x1
Cadmium	ND	0.003	None above the detection limit of 0.005 mg/l
Chromium	0.03	0.05	Herder well Elstei
Copper	0.14	2	Herder well Khemgii samples for the first time in 2010
Lead	0.06	0.01	Ovoo Tsav marginally above the detection limit of 0.05 mg/l
Nickel	ND	0.02	Herder well Ulaan Tolgoi Hudag in 2006 reported 0.0133 mg/l but later analysis was below the detection limit of 0.01 mg/l inferring it is a data error.
Zinc	1.46	3	Herder well Ereet subsequent analysis in 2009 reported a concentration of 0.08 mg/l
Mercury	0.0004	0.001	Herder well Dengiin Hudag – only well reported above detection limit in 2005 of 0.0001 mg/l subsequent detection limits higher and not detected.

<sup>17</sup> Aquaterra 2008, Gunii Hooloi Borefield Detailed Design – Bore Design (Revised Water Demand), ref: 658/G/328b, February 2008, Table 3, Page 14.

### 6.5.10 Khanbogd Groundwater Supply

The community of Khanbogd is located at the foot hills of the Khanbogd alkaline (granite) massif on the southern side of the Gunii Hooloi basin. Khanbogd is located south of the main Cretaceous Basin and the community relies on wells exploiting shallow groundwater in the surficial Quaternary to Recent sediments. These sediments are inferred to be recharged by groundwater flowing through the fractures and fissures of the weathered zones of the granite body immediately to the south and discharging into the associated sedimentary formations, as well as direct recharge during storm events. Groundwater flow in these shallow aquifers will be in a northerly direction close to the Khanbogd massif and then follow the course of the ephemeral river beds around the Durulj Mount and then into the Gunii Hooloi basin. The Durulj Mount is an outcrop of basement approximately 4 km to the north of Khanbogd *soum* centre.

Water supply for the residents and public buildings in Khanbogd currently comes from a mixture of private and public wells exploiting these shallow sediments; i.e. essentially the same formation as exploited by the herders' wells. There is little detail on the well construction and generally no information on the aquifer parameters is available from the local community. The main wells present in Khanbogd are summarised in *Table 6.7*.

**Table 6.7: Khanbogd Wells Yields**

Borehole No.	Max Yield (l/s)	Comments
Borehole in Chuluun Khashaa	1.0	3 wells with capacity 0.8-1.2 l/sec drilled, 2 of them closed because of low water level. Only one is currently working
Borehole 11 (Khan Diesel Co.)	10 l/sec	1998
Borehole 13	2.14 l/sec	1998
Total	13.14 l/sec	

Source: Asian Development Bank

**Table 6.8: Khanbogd Water Quality January 2011**

Analyte	Units	Khanbogd <i>soum</i> main well	Khanbogd bath house	Mongolian Drinking Water Standard ((MNS 900:2005))	WHO Potable Standards (mg/l)
pH		7.07	7.51	6.5-8.5	-
EC	µS/cm	563	398	-	-
Ca <sup>2+</sup>	mg/l	39.7	17.8	100	-
Mg <sup>2+</sup>	mg/l	6.3	3.4	30	-
Na+K	mg/l	65.8	64.8	-	-
SO <sub>4</sub> <sup>2-</sup>	mg/l	64.3	28.8	500	500
Cl <sup>-</sup>	mg/l	24.8	14.5	350	-
Hardness	meq/l	2.5	1.17	7.0	-
HCO <sub>3</sub> <sup>3-</sup>	mg/l	188.5	167.8	-	-
Salinity	mg/l	389.4	297.1	-	-
Suspended Solids	mg/l	0.8	1.6	1,000	-
NH <sub>4</sub>	mg/l	<b>0.001</b>	<b>0.002</b>	1.5	-
NO <sub>2</sub>	mg/l	<b>4.15</b>	<b>2.95</b>	1.0	0.2
NO <sub>3</sub>	mg/l	1.02	1.46	50	50
P min	mg/l	0.005	0.001	3.5	-
F	mg/l	1.02	1.46	0.8-1.5	-
Fe	mg/l	0.01	0.03	0.3	-

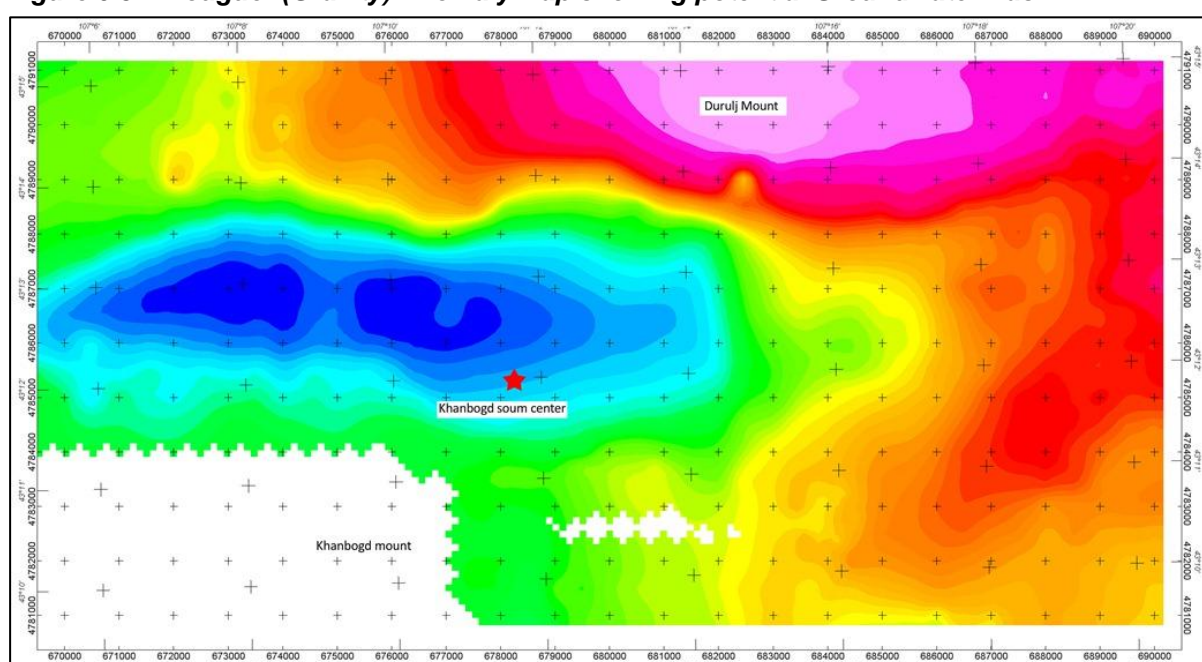
Note: Figures in **Bold Italic** exceed the Mongolian and/or WHO potable water standards

The water is not treated before use. Oyu Tolgoi started monitoring the Khanbogd water supply in Q1 2011 in response to a request from a community member for Oyu Tolgoi to check the water bore quality.

Oyu Tolgoi sampled from the main water supply wells used by the community in January 2011 and the analytical results area presented in *Table 6.8* and compared against the Mongolian Drinking Water Standard (MNS 900:2005).

The analytical results indicate that the groundwater contains concentrations of some parameters which exceed the potable water limits, such as nitrite. In the long term the shallow aquifer system currently used by the community is not considered to be suitable for providing the water supply that would be required for an increased population. This is due to its shallow nature and the significant risk of contamination from the lack of a reticulated wastewater system (the elevated nitrate indicates there may be some impact occurring already from sanitary waste). In order to identify a suitable groundwater supply for Khanbogd, Oyu Tolgoi contracted Geomaster Engineering LLC to conduct a geophysical investigation of a 20 by 10 km area around the community of Khanbogd, to study the potential groundwater resources which could be used for the Khanbogd *soum* centre water supply. The geophysical survey has identified a prospective groundwater basin called the Durulij Mount Southern Basin<sup>18</sup> which is located 2-6 km from Khanbogd *soum* centre (*Figure 6.37*).

**Figure 6.37: Bouguer (Gravity) Anomaly Map showing potential Groundwater Basin**



Source: Geomaster Engineering (2010), Dark blue area indicates sedimentary basin

This basin appears to have 100-400 m thick sequence of Upper Cretaceous Bayanshiree formation which, based on the geophysics, appears to have less saline groundwater than the Gunii Hooloi Bayanshiree formation aquifers to the north. The area is inferred to be recharged by run-off from the Durulij Mount and Khanbogd Massif. The Basin is away from the proposed Gunii Hooloi borefield and in an area with a few herder wells exploiting the surficial aquifers associated with the sediments of the ephemeral watercourses and some springs along the northern side of the Khanbogd massif. The late 2011/2012 exploration programme (see below) will enable Oyu Tolgoi to establish whether there is the potential for any vertical linkage with the overlying alluvial aquifers.

Oyu Tolgoi commissioned the drilling of exploration boreholes into this aquifer Q1/Q2 2011 which encountered a substantive aquifer unit and the results of this programme are now being evaluated. The objective of the exploration programme was to allow the character of the sediments in the basin to be evaluated, the hydraulic characteristics evaluated and the quality and quantity of the groundwater to be established. The results will be used to prepare a submission of a water reserve estimate for Government approval and enable the design of a water abstraction system to be developed. Based on

<sup>18</sup> Geomaster Engineering (2010), Report on Groundwater Geophysical Exploration for Water Supply of Khanbogd *Soum*, Omnogovi Province

the geophysics undertaken the basin appears to be separated from the Gunii Hooloi basin by shallower bedrock. There is, therefore, no interaction between abstraction from this and Oyu Tolgoi's abstraction from Gunii Hooloi's Cretaceous sedimentary sequence. Furthermore the exploration wells are located at the eastern end of the sedimentary basin identified by the geophysics. Similarly, the inferred depth of the groundwater suggests that there is unlikely to be a significant hydraulic connection with the overlying surficial aquifers associated with the ephemeral watercourses on which the herders in the area rely.

The analytical results from the testing of the groundwater from the boreholes that have been installed indicated that the water is of good quality, although some metal concentrations (e.g. arsenic) exceed WHO and/or Mongolian potable water standards. The results of the analysis undertaken are presented below in *Table 6.9* and *Table 6.10* and compared to both Mongolian Limits and WHO potable water standards. Oyu Tolgoi is currently verifying the analytical results and based on this will assist design any necessary water treatment for the potable water supply.

**Table 6.9: Groundwater Analysis Results Khanbogd Wells M-01 and M-03**

Applicable Testing Standards	Analyte	Mongolian Limits	WHO Potable Standards (mg/l)	Analysis	
				M-01	M-03
MNS 4432: 1997	Colour, degree	20	-	<b>30</b>	3.8
MNS 3900: 1986	Smell	2	-	2	0
Horiba U-10	Turbidity, NTU	5	-	1	0
MNS ISO 4889: 2005	Conductivity ms/m		-	0.802	0.927
MNS ISO 6059: 2001	Calcium, Magnesium (hardness) mg/l	7	-	0.84	1.18
MNS ISO 2572: 1999	Calcium, mg/l	100	-	9.62	15.47
MNS 4341: 1996	Magnesium, mg/l	30	-	4.38	4.98
MNS ISO 9297: 2005	Chloride mg/l	350	-	97.27	121.94
MNS 4428: 1997	Ammonium mg/l	1.5	-	0.062	0.005
MNS 4431: 2005	Nitrite mg/l	1	0.2	0.006	0.003
MNS ISO 7890-3: 2001	Nitrate mg/l	50	50	8.131	0.624
MNS ISO 10523: 2001	pH	6.5-8.5	-	7.904	8.138
MNS 4425: 1997	Bicarbonate mg/l		-	178.12	175.68
MNS 4430: 2005	Iron mg/l	0.3	-	0.138	0.101
MNS ISO 9280: 2001	Sulphate mg/l	500	500	115.38	135.42
MNS 4423: 1997	Dry residue mg/l	1000	-	490	247
MNS ISO 6878: 2001	Orthophosphate mg/l	3.5	-	0.006	0.002

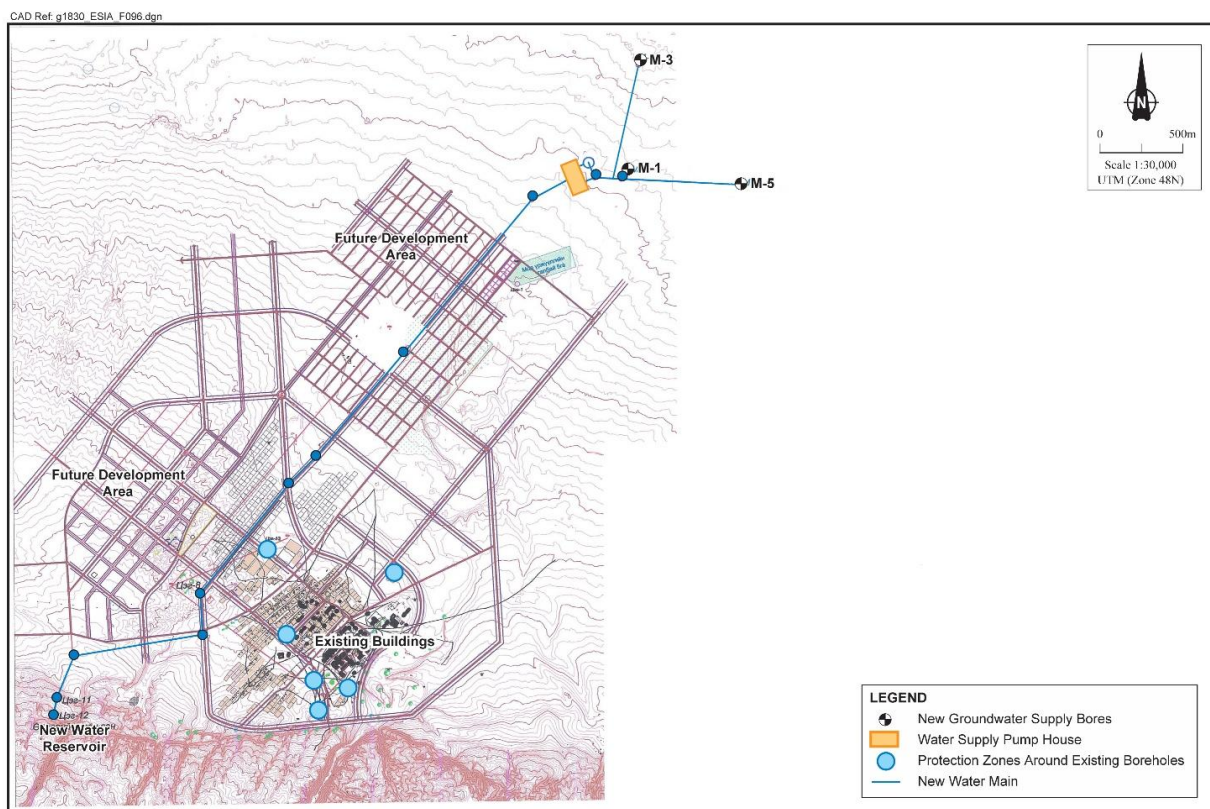
**Table 6.10: Groundwater Metal Analysis Results Khanbogd Wells M-01 and M-03**

Analytical Standard	Analyte	Mongolian Limits (mg/l)	WHO Potable Standards (mg/l)	Analysis (mg/l)		
				M-01	M-02	M-03
ISO 11885: 2007	Silver	0.1	-	ND	0.008	0.002
	Aluminium	0.5	0.2	0.004	0.039	0.025
	Arsenic	0.01	0.01	<b>0.022</b>	<b>0.047</b>	<b>0.028</b>
	Boron	0.5	-	0.358	<b>0.545</b>	0.272
	Barium	0.7	0.3	0.002	0.004	0.006
	Beryllium	0.0002	-	ND	ND	ND
	Calcium	100	-	10.607	7.687	12.768
	Cadmium	0.003	0.003	ND	ND	ND
	Cobalt		-	ND	ND	ND
	Chromium	0.05	0.05	ND	ND	ND

Analytical Standard	Analyte	Mongolian Limits (mg/l)	WHO Potable Standards (mg/l)	Analysis (mg/l)		
				M-01	M-02	M-03
	Copper	1.0	2	ND	ND	0.002
	Iron	0.3	-	0.1356	<b>0.4615</b>	0.082
	Potassium		-	0.9534	0.7844	0.8486
	Magnesium	30	-	3.2657	2.0414	3.7991
	Manganese	0.1	0.5	0.0018	0.0094	0.0034
	Molybdenum	0.07	0.07	<b>0.085</b>	<b>0.09</b>	0.071
	Sodium	200	200	164.93	182.23	181.66
	Nickel	0.02	0.02	ND	ND	ND
	Lead	0.01	0.01	0.002	ND	0.001
	Antimony	0.02	0.005	0.006	0.012	ND
	Selenium	0.01	0.01	ND	0.033	0.03
	Strontium	2.0	-	0.151	0.117	0.22
	Zinc	5.0	3.0	0.004	0.016	0.058

Note: Figures in **bold italic** indicate results that exceed WHO and/or Mongolian limits

**Figure 6.38: Plan of Khanbogd Groundwater Supply Network**



The water supply boreholes are located to the northeast of the town of Khanbogd (see *Note: Figures in bold italic* indicate results that exceed WHO and/or Mongolian limits

Figure 6.38) and will be connected to a water pumping station which will transfer the water to a holding reservoir on the edge of the Khanbogd Massif from where it will gravity feed into the towns water supply when constructed. The current wells supplying the town will be decommissioned once the new system is up and running. It is anticipated that the wastewater treatment centre is likely to be located to the east of the town.

Oyu Tolgoi is awaiting confirmation of the reserve estimation from the Mongolian Water Authority. However in the meantime the design for the system is being carried out with the anticipated supply rate being approximately 30 l/s in the first phase.

## 6.6 CONCLUSIONS

Surface water in the Project Area of Influence is limited and, other than the intermittent summer flows in ephemeral watercourses, is limited to a few springs in the major watercourses and around the periphery of the Khanbogd Massif. The water levels in the shallow surficial aquifer are typically 2-5 m below ground level, and are relied on by the herders for their drinking water and stock supplies. Based on the monitoring data collected by Oyu Tolgoi which dates back in places to before 2004, the water levels fluctuate in each well dependent on its local setting and the degree to which it is reliant on seasonal recharge from flood events. This data provides Oyu Tolgoi and the local communities with a good baseline on which to monitor and evaluate future water level fluctuations. Overall water levels are stable (within each well's individual range) and the greatest fluctuations are associated with the seasonal recharge events associated with summer rain and flood events. Given that the inferred limited lateral extent of these aquifers is typically tied to the watercourses, these aquifers are not considered to be able to sustain significant increases in abstraction rate.

Oyu Tolgoi has undertaken an extensive investigation programme to appraise the potential groundwater supplies in the area around the Project area. This investigation of the hydrogeological characteristics of the Galbyn Gobi, Gunii Hooloi and Nariin Zag, has resulted in a good understanding of the baseline conditions in these Cretaceous basins. Significant aquifer systems have been identified and delineated in the Galbyn Gobi and Gunii Hooloi basins, both of which form substantial groundwater resources. The aquifer resources in the Nariin Zag area are relatively limited and, given this limited capacity, are not considered a viable source of water for the Project.

Of the Gunii Hooloi and Galbyn Gobi, only the Gunii Hooloi aquifer has sufficient reserves to supply the Project water demand of 696 L/s over 27 years (or approximately 878 Mm<sup>3</sup>), and remain a significant future reserve for further abstraction by Oyu Tolgoi or others. Following the initial investigation the Gunii Hooloi basin has been further appraised with additional investigation bores at locations chosen by Oyu Tolgoi and those requested by the Mongolian Water Authority. The subsequent aquifer tests, pumping tests and chemical analyses have been used to develop a detailed Modflow model for the basin to appreciate the groundwater flows in the basin and the effect of pumping on the aquifer. The upgraded groundwater model based on these results is enabling Oyu Tolgoi to assess the potential connectivity with shallow aquifers and identify any areas where limited linkages with herder wells could occur. This linkage to shallower aquifers is considered limited to a few areas and where the herder wells are deeper than the norm. There is no groundwater-dependant vegetation in the basin, indicating no upwelling of the deep aquifer, and all vegetation in the area is limited to that which is sustainable by the seasonal rainfall in the basin. The groundwater model for Gunii Hooloi has been repeatedly peer reviewed by a number of independent companies. The model has been found to be robust and any comments provided by the reviewers have been incorporated as model refinements. These reviews have focused initially on the robustness of the definition of the resource with subsequent reviews including consideration of potential impacts including leakage from the upper aquicludes and aquifers.

The current focus is on the appraisal and modelling of the Gunii Hooloi aquifer with more detailed modelling of the potential impacts of vertical leakage created by the reduction in the piezometric surface associated with the Cretaceous aquifer. Separately a significantly improved model for the mining area is currently being developed which utilises the significant monitoring data set now available for the area, and this will enable a better evaluation of the radius of influence of any drawdown. Further exploration and testing of the Galbyn Gobi and other aquifers is also planned to identify future resources which Oyu Tolgoi can apply for permitting to satisfy water demands and complement the supply from the Gunii Hooloi basin and sustain the Oyu Tolgoi Project beyond the current projection of 27 years.

The Khanbogd *soum* centre is currently reliant on some limited groundwater wells, with further groundwater exploration limited by a lack of understanding of the local aquifers. Oyu Tolgoi has completed a geophysical appraisal of the local aquifers in 2010 which has identified a potential Cretaceous aquifer in a small basin 4 km from Khanbogd. Oyu Tolgoi is now finalising plans to install groundwater appraisal boreholes into this area to assess the aquifer characteristics and groundwater quality.