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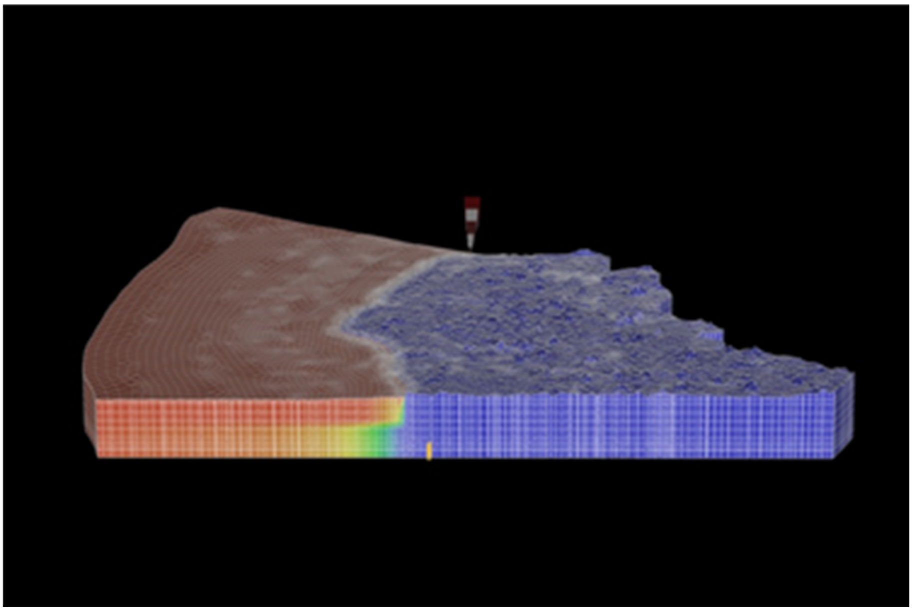
TANGGUH EXPANSION PROJECT GROUNDWATER STUDY

Contract No. 4420000665

Groundwater Supply Modelling

Submitted to:
BP Berau Ltd



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REPORT

Ringkasan Eksekutif

Dokumen ini menguraikan hasil pemodelan air tanah yang merupakan salah satu komponen dalam lingkup studi air tanah yang dilakukan sebagai bagian dari studi AMDAL untuk rencana pengembangan Proyek Tangguh LNG di KAbupaten Teluk Bintuni Provinsi Papua Barat. Golder Associates melakukan pemodelan numerik dari sistem air tanah di daerah Tangguh LNG untuk mengkaji potensi opsi pemanfaatan air tanah untuk memenuhi kebutuhan air Tangguh LNG, dan potensi dampak dari rencana pemanfaatan air tanah tersebut terhadap air tanah pada akuifer yang digunakan oleh masyarakat setempat untuk memenuhi kebutuhan air di kampung mereka dan potensi dampak salinitas air tanah sebagai konsekuensi dari kemungkinan intrusi air asin dari perairan Teluk Bintuni pada daerah yang berdekatan dengan batas utara properti Tangguh LNG. Hasil pemodelan air tanah juga digunakan sebagai dasar untuk perhitungan potensi amblasan pada wilayah Tangguh LNG yang akan disajikan pada laporan yang terpisah.

Lingkup pekerjaan untuk pemodelan air tanah ini meliputi kajian terhadap data-data yang relevan, memperbarui pemodelan hidrogeologi konseptual yang telah dilakukan sebelumnya dan pembuatan pemodelan air tanah numerik untuk wilayah Tangguh LNG.

Kebutuhan air selama 4 tahun tahap konstruksi fasilitas yang termasuk dalam lingkup pengembangan tahap awal Tangguh LNG termasuk pembangunan Kilang LNG 3 dan 4 beserta fasilitas pendukungnya diperkirakan akan mencapai puncaknya sebanyak 95 L/detik selama sekitar 100 hari. Kebutuhan air dalam jumlah besar ini adalah untuk memenuhi kebutuhan air untuk hydrotest. Perkiraan kebutuhan air untuk tahap konstruksi rata-rata adalah 32 L/detik, sementara untuk tahap operasi (25 tahun) adalah kurang lebih 50 L/detik untuk operasi 4 kilang LNG. Pemodelan kebutuhan air fasilitas LNG dengan demikian dilakukan dimulai dari tahap konstruksi sampai akhir tahap operasi (29 tahun).

Executive Summary

This document presents the groundwater modelling report for the Groundwater Study component conducted as part of the AMDAL study for the proposed expansion of the Tangguh LNG facility in Bintuni Bay Regency, West Papua. Golder Associates has undertaken numerical modelling of the groundwater system in the area in order to assess the potential for groundwater supply development, and the potential for adverse effects, both on groundwater levels in an overlying aquifer used locally for village water supply and on salinity of the groundwater as a consequence of potential saline intrusion from the nearby Bintuni Bay adjoining the northern boundary of the Tangguh LNG property. The groundwater model was also used to provide input to the assessment of potential subsidence due to drawdown in the aquifers at the LNG facility (which is the subject of a separate report)

The scope of work comprised the review of relevant data, updating the previous conceptual hydrogeological model and the development of a numerical groundwater model for the Tangguh area.

Water demand during the four year construction period for the initial development phase including the development of the new LNG Trains 3 and 4, and supporting facilities is expected to peak at 95 L/s for about 100 days (during construction) for the purpose of hydrotesting. Average demand during construction is 32 L/s, whilst a sustained water demand of 50 L/s is required for the operating life of the facility (25 years) with for four LNG trains. Modelling of the LNG facility water demand was therefore carried out for a total period of 29 years.

Studi sebelumnya menunjukkan adanya suatu sistem sedimen berlapis-lapis yang luas di Formasi Steenkool di Cekungan Bintuni. Formasi Steenkool memiliki ketebalan sampai dengan 2000 m pada wilayah Tangguh LNG, dengan akuifer yang didominasi pasir dibatasi oleh akuitar yang di dominasi oleh lempung. Terdapat bukti langsung adanya air tanah yang diperoleh dari akuifer bagian atas, yang telah dimanfaatkan oleh masyarakat untuk memenuhi kebutuhan air mereka di Kampung Tanah Merah Baru dan Saengga.

Pemodelan Hidrogeologi Konseptual mengindikasikan sedimen Formasi Steenkool terlipat lemah dengan singkapan batu pasir terdapat disebelah selatan dan barat daya lokasi Tangguh LNG. Korelasi telah dibuat untuk akuifer-akuifer di Formasi Steenkool bagian atas sampai dengan kedalaman 150 m yang meluas ke arah timur, mulai dari sumur masyarakat di Saengga dan Tanah Merah Baru hingga ke sumur uji SHD-1 di lokasi Tangguh LNG. Indikasi kemiringan lapisan, secara rata-rata, adalah kurang dari 1° yang mana cocok dengan hasil interpolasi dari penampang seismik.

Potensi dampak terbesar terhadap penurunan muka air tanah di sumur masyarakat dan terhadap amblesan diluar lokasi Tangguh LNG terjadi jika akuifer-akuifer ini terhubung dan tidak terdapat patahan yang bertindak sebagai penghalang terhadap aliran air tanah. Oleh karenanya pemodelan numerik menggunakan asumsi bahwa akuifer-akuifer Formasi Steenkool tidak bergeser karena patahan.

Kontur penurunan muka air tanah dan amblesan yang dihasilkan dari pemodelan numerik, oleh karena itu konservatif tinggi dalam hal dampak potensial terhadap sumur masyarakat. Jika penghalang patahan teridentifikasi di masa yang mendatang dari pengambilan secara menerus dan dari pemantauan air tanah, diperkirakan penurunan muka air tanah di lokasi Tangguh LNG lebih tinggi dari yang perkiraan saat ini dan penurunan di sumur masyarakat lebih kecil. Jika teridentifikasi, patahan ini akan dimasukkan kedalam pemodelan numerik yang akan diperbaharui setelah selesainya periode konstruksi empat tahun nanti ketika data-data yang lebih komprehensif tentang pemantauan penurunan muka air tanah, amblesan dan salinitas sudah tersedia.

Previous studies indicate an extensive, layered sedimentary system in the Steenkool Formation of the Bintuni Basin. The formation extends to depths of up to 2000 m beneath the Tangguh LNG facility, with sand dominated aquifers confined by clay dominated aquitards. There is direct evidence of fresh groundwater in the upper parts of the aquifer, which have been sourced locally for small water supplies by the indigenous people of the Tanah Merah Baru and Saengga villages.

The Conceptual Hydrogeological Model indicates gently folded Steenkool sediments with outcrop areas of sandstone to the south and southwest of the LNG site. A correlation of aquifer and aquitard units has been established for the Upper Steenkool aquifers down to 150 m depth extending eastwards from the community wells at Saengga and Tanah Merah Baru across to the SHD-1 exploratory well at the LNG site. The dip of the sediments is indicated to be, on average, less than 1° which matches the dips extrapolated from the seismic profiles.

The greatest potential impact to drawdown in the community wells and to ground subsidence outside the LNG site occurs if these aquifers are hydrogeological connected and there are no faults acting as barriers to groundwater flow. The numerical model has therefore assumed that the Steenkool Formation aquifers are not displaced by faulting to the extent that groundwater flow is impeded.

Drawdown and subsidence contours generated by the numerical model are therefore conservatively high in terms of potential impacts to community wells. Should fault barriers be identified in the future based on sustained groundwater abstraction and monitoring it is likely that drawdowns on the Tangguh LNG site will increase more than currently predicted and those at the community wells will be less. If identified, these faults will be incorporated into an updated numerical model at completion of the four-year construction period when a comprehensive set of drawdown, subsidence and salinity monitoring data is available.

Pemodelan 3-Dimensi aliran air tanah telah dilakukan dan dikalibrasi dengan mengamati elevasi air tanah pada sumur-sumur masyarakat dan pada Formasi Steenkool bagian atas. Daerah lingkup pemodelan diperluas secara vertikal hingga kedalaman 600 m, melebihi kedalaman akuifer yang ditargetkan (kurang dari 400 m). Daerah lingkup pemodelan secara horizontal adalah kira-kira 55 km ke arah timur-barat dan 29 km ke arah utara-selatan di sekitar Tangguh, yang merupakan bagian dari Cekungan Bintuni yang merupakan formasi sedimen yang pada dasarnya datar.

A three-dimensional groundwater flow model has been developed and calibrated with observed groundwater levels in the locally developed shallow alluvial aquifers and the upper part of the Steenkool Formation. The model domain extended to a depth of 600 m, beyond the target aquifers at less than 400 m. Laterally, the model extends some 55 km east-west by 29 km north-south around Tangguh, within a part of the Bintuni Basin with essentially flat-dipping sediments.

Pemodelan yang telah dikalibrasi mencakup kemampuan untuk mensimulasi pergerakan cairan dari batas air asin dan air tawar yang berada sekitar 2 km di utara dari garis pantai dan batas utara fasilitas LNG Tangguh.

The calibrated model included the ability to simulate solute transport from a fresh water-salt water interface that was nominally located 2 km to the north of the coastline and northern boundary of the Tangguh LNG facility.

Hasil pemodelan air tanah secara umum menunjukkan bahwa kebutuhan air Tangguh LNG dapat dipenuhi dari akuifer yang terdapat pada Formasi Steenkool bagian bawah yang terdapat di daerah di bawah properti Tangguh LNG (kedalaman antara sekitar 150 m sampai 400 m) , berdasarkan parameter-parameter yang diasumsi kan dari akuifer yang sama dan dianggap mewakili sistem akuifer yang berlapis-lapis di lokasi Tangguh LNG.

The results of the groundwater modelling indicate that Tangguh LNG's nominal water requirement would be available from the targeted aquifers in the Lower Steenkool Formation underlying the Tangguh LNG property based on parameters assumed from similar aquifers and judged appropriate for the layered system of aquifers at Tangguh.

Penurunan muka air tanah pada akuifer Formasi Steenkool bagian bawah menunjukkan bahwa dengan laju pemompaan dan jangka waktu yang direncanakan untuk opsi pemanfaatan air tanah untuk memenuhi kebutuhan air Tangguh LNG dapat menyebabkan penurunan muka air tanah sekitar 15 m pada daerah yang berdekatan langsung dengan lokasi rencana sumur produksi air tanah PW-1 dan PW-2, dan antara sekitar 13 m sampai 14 m pada lokasi rencana untuk sumur produksi air tanah PW-3 dan PW-4.

Drawdowns within the Lower Steenkool Formation aquifers indicate that the proposed pumping rates and durations will cause drawdown of about 15 m immediately near the planned locations of production wells PW-1 and PW-2, and between about 13 m and 14 m at the planned locations for PW-3 and PW-4.

Hasil pemodelan menunjukkan bahwa 90% dari penurunan muka air tanah terjadi pada empat tahun tahap konstruksi (14 m pada PW-2). Pada PW-2, penurunan muka air tanah sebesar 1,2 m terjadi pada akhir 25 tahun tahap operasi (15,2 m). Pemodelan juga menunjukan peak penurunan muka air tanah jangka pendek pada PW-2 pada tahap konstruksi yang terjadi jika air tanah digunakan sebagai sumber air untuk hidrotest.

The modelling indicates that 90% of drawdown occurs during the four year construction period (14 m at PW-2). At PW-2 a further 1.2 m of drawdown is indicated by the end of the 25 year operations (to 15.2 m). The modelling also indicates a short term peak drawdown to 22 m at PW-2 during construction should groundwater be used as the water source for hydrotesting.

Hasil pemodelan menunjukkan bahwa total penurunan muka air pada Formasi Steenkool bagian atas di dalam daerah properti Tangguh LNG dekat lokasi rencana sumur pemantauan yang berada pada jarak 150 m dari sumur PW-3 adalah 0,165 m, dimana sekitar 0,050 m dari nilai tersebut kemungkinan disebabkan oleh rencana pengambilan air tanah di Tangguh LNG dari akuifer Formasi Steenkool bagian bawah.

Penurunan muka tanah terbesar yang terjadi pada pagar batas properti Tangguh LNG sebelah utara PW-3 dekat Tanah Merah Baru sangat terkait dengan pengambilan air tanah oleh masyarakat. Perkiraan penurunan muka air tanah adalah 0,29 m di mana 0,050 m berasal dari pengambilan air tanah oleh Tangguh LNG.

Hasil pemodelan menunjukkan bahwa kemungkinan penurunan muka air tanah total sekitar 0,57 m (di kampung Tanah Merah Baru) sampai dengan 0,6 m (di Kampung Saengga) kemungkinan terjadi pada sumur air tanah masyarakat yang berasal dari akuifer Formasi Steenkool bagian atas. Sekitar 0,52 m dari total penurunan muka air tanah total tersebut disebabkan oleh pemanfaatan air oleh masyarakat di KampungTanah Merah Baru dan selebihnya sekitar 0,050 m diperkirakan terkait dengan rencana pengambilan air untuk memenuhi kebutuhan air Tangguh LNG.

Pada lokasi sumur masyarakat di Tanah Merah Baru dan titik pengamatan di perbatasan pagar dekat sumur PW-3, penurunan muka air tanah dalam Formasi Steenkool bagian atas yang disebabkan oleh rencana pemanfaatan air tanah Tangguh LNG diperkirakan dengan membandingkan antara:

1. perkiraan penurunan muka air tanah total yang diakibatkan pemanfaatan air oleh masyarakat setempat saja, dengan

2. perkiraan penurunan muka air tanah yang diakibatkan oleh gabungan pemanfaatan air oleh masyarakat setempat dan oleh Tangguh LNG dari akuifer Formasi Steenkool bagian bawah.

Penurunan muka air tanah di sumur di Tanah Merah Baru sudah mempertimbangkan penurunan muka air tanah karena pemaanfaatan air di Saengga.

Modelled drawdown in the Upper Steenkool Formation at the Tangguh LNG property boundary near the planned location for the 150 m deep monitoring well adjacent to PW-3 is 0.165 m, of which about 0.050m may be attributable to Tangguh LNG's planned abstraction from the Lower Steenkool Formation aquifers. The drawdown estimates from the model are assumed accurate to 0.005 m.

Greatest drawdown at the property boundary is indicated north of PW-3 near Tanah Merah Baru and is related mainly to community well abstraction. The estimated drawdown is 0.29 m of which about 0.05 m is related to Tangguh LNG abstraction.

Total drawdown between about 0.57 m (at Tanah Merah Baru) and 0.6 m (at Saengga) may also be expected in the community groundwater wells screened in the Upper Steenkool Formation aquifers. Approximately 0.52 m drawdown is from local pumping from the community supply well at Tanah Merah Baru, and about 0.050 m related to planned abstraction from the within the Tangguh LNG property.

At both locations (i.e. at the community supply well at Tanah Merah Baru and the monitoring point on the property boundary near PW-3) the enhanced drawdown in the Upper Steenkool Formation brought about by Tangguh LNG's planned pumping was estimated by comparing:

1. *total predicted drawdown in these aquifers due to community abstraction only, with*

2. *drawdown caused by both local groundwater abstractions coupled with Tangguh LNG's planned pumping from the Lower Steenkool Formation aquifers.*

As such the drawdown in the community well at Tanah Merah Baru includes drawdown caused by pumping at Saengga.

Berdasarkan perkiraan- mengenai posisi batas air asin dan air tawar dalam akuifer tertekan, parameter-parameter akuifer dan karakteristik akuitar, hasil pemodelan menunjukkan prediksi bahwa pertemuan air laut di bawah Teluk Bintuni akan bergerak sekitar 150 m menuju wilayah Tangguh LNG pada akuifer-akuifer tertekan di kedalaman antara 150 dan 400 m setelah 29 tahun pemanfaatan air tanah, dan hampir tidak ada rembesan air laut dari Teluk Bintuni menuju akuifer-akuifer tertekan di bawahnya. Hasil pemodelan ini menunjukkan bahwa dampak salinitas adalah kecil sekali terhadap air tanah pada rencana sumur-sumur produksi air tanah Tangguh LNG.

Hasil pemodelan menunjukkan bahwa perubahan salinitas pada Formasi Steenkool bagian bawah di PW-2 (rencana lokasi sumur produksi air tanah yang paling dekat dengan Teluk Bintuni) akibat rencana pengambilan air tanah untuk memenuhi kebutuhan air Tangguh LNG adalah kurang dari 10 mg/L. Dengan demikian PW-2 adalah satu-satunya sumur (aktual dan pemodelan) di mana hasil pemodelan menunjukkan ada indikasi terjadi kenaikan salinitas setelah pengambilan air tanah selama 29 tahun.

Based on estimates of the position of the fresh water / salt water interface in the confined aquifers, the aquifer parameters and the properties of the aquitards, the model predicts that the seawater interface beneath Bintuni Bay will migrate about 150 m towards the LNG site within the confined target aquifers between 150 and 400 m depth after 29 years of planned pumping, and with virtually no downward leakage of sea water from Bintuni Bay towards the underlying confined aquifers. These outcomes therefore suggest only marginal impact on salinities in the proposed production wells.

The predicted change in salinity in the Lower Steenkool Formation at PW-2 (i.e. the closest modelled provisional and modelled well to Bintuni Bay) due to Tangguh LNG's planned pumping is less than 10 mg/L; this is the only well (actual or modelled) where an increase in salinity was observed after 29 years of pumping.

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FIGURES

1.0 INTRODUCTION

This document presents the groundwater modelling report for the Groundwater Study component of the BP Berau Ltd expansion of the Tangguh LNG facility (the Site), located in West Papua, Indonesia.

Tangguh is situated in the Birds Head region of West Papua, at Bintuni and Berau Bays, with minimal local infrastructure and logistical support. The proposed expansion will include the construction of two new LNG trains (which will be the 3rd and 4th trains at the LNG facility), associated on-shore receiving facilities, a new (2nd) LNG loading jetty and general cargo jetty and the development of the ROA and WDA fields, together with associated transmission pipelines to transmit the gas to the on-shore LNG plant. The proposed expansion of the LNG facility will comprise a construction phase of 4 years and an operational life of 25 years. Its location is shown on **Figure 1**.

2.0 BACKGROUND

As part of the expansion, Tangguh LNG is proposing to use groundwater to replace or supplement the existing desalination system and has commenced investigation into the potential sustainable yield from deep aquifers below 150 m depth at the site. The ultimate operational water demand for all existing and currently proposed LNG trains at the Tangguh LNG facility during operation is estimated to be about 4,100 m^3/day (50 L/s), with a peak demand during construction of 8,500 m^3/day (95 L/s) for about 100 days.

The use of groundwater was not permitted in the original Analisis Mengenai Dampak Lingkungan (AMDAL, 2002). However the use of groundwater has been included in the AMDAL to be submitted for the Tangguh Expansion Project.

The objective of this report is to assist in assessing whether sufficient groundwater is available at Tangguh from the aquifers in the lower part of the Steenkool Formation to meet (or at least augment other water supplies for) the water demand during and post-construction of the 3rd and 4th LNG trains. Groundwater in the upper part of the Steenkool Formation beneath the LNG facility is reserved for potable supply for local villages.

3.0 GROUNDWATER MODEL OBJECTIVES

Technical objectives of the groundwater modelling were to:

- make an assessment of the availability of a groundwater supply for the LNG facility
- predict potential impacts associated with the risk of salt water intrusion and enhanced drawdown to local community water supply wells due to Tangguh LNG's planned use of groundwater beneath the facility, and
- provide input to the assessment of potential subsidence at the facility (which is the subject of a separate report).

The assessment of potential impacts associated with planned groundwater abstraction from selected aquifers beneath the Tangguh LNG property considered the hydrogeological setting, the renewable water supply potential (i.e. the likely recharge rates) of the targeted aquifers, and the groundwater flow mechanisms at the LNG facility under the existing environmental and aquifer management constraints.

The scope of work comprised five stages, as follows:

1. Stage 1 – collection and analysis of relevant geological and hydrogeological information
2. Stage 2 – development / revision of the conceptual groundwater model
3. Stage 3 – selection of the numerical groundwater modelling code
4. Stage 4 – development of the numerical groundwater model
5. Stage 5 – predictive modelling, including density-driven flow to simulate sea water intrusion.

4.0 DATA SOURCES AND GAPS

Golder was provided with a variety of reports relevant to the Tangguh LNG facility. These included hydrogeological and geotechnical reports, drilling and well installation reports, and topographic contours. The reports made available during the development of the groundwater model are listed in the References section of this report.

Geological and hydrogeological data was available from various drilling programs, notably for groundwater and hydrocarbon exploration, that have taken place at and surrounding the Tangguh property as well as throughout the greater Bintuni Basin (**Figure 2**). Data within the modelling domain was very limited and with the exception of the geological and geophysical log for the Slim Hole drilled in the northwestern portion of the property, did not extend to the Lower Steenkool Formation which includes the aquifers targetted for water supply. The proposed groundwater drilling programme, the groundwater quality sampling and field testing of the target aquifer could not be carried out prior to the development of the groundwater model needed to support the AMDAL preparation. Thus, at the time of modelling, no site-specific information or data was available regarding the hydraulic properties, hydraulic heads or groundwater quality of the hydrostratigraphic units in the lower Steenkool Formation (i.e. those aquifers targeted for use by Tangguh LNG).

Groundwater level and quality data from the region was compiled from the available reports although this information is extremely limited. Groundwater levels were available for aquifers <u>above</u> those to be targetted around the immediate vicinity of the Tangguh LNG facility but no regional groundwater level data was available.

Local and regional water bodies (i.e. the sea, rivers, creeks, wetlands etc.) were identified and delineated from aerial photographs and the 1:250,000 topographic map.

5.0 REVIEW AND UPDATE OF THE CONCEPTUAL HYDROGEOLOGICAL MODEL

Golder initially reviewed the available information and carried out an interpretation of the groundwater conditions at Tangguh. The review included climate, topography, geology and hydrogeological aspects of the LNG facility and surrounds, including details regarding current groundwater abstractions in the vicinity of the LNG facility. From this review, a conceptual groundwater model was developed, leading to numerical modelling of a sufficiently large area of the groundwater system around Tangguh.

5.1 Depth References

All depths stated in this report are referenced to ground surface (i.e. m below ground surface – m bgs). It is understood that, in the past, the aquifers of the Upper Steenkool Formation both beneath the LNG facility and beneath the villages of Saengga and Tanah Merah Baru have been defined on the basis of their depth beneath ground surface hence this system has been used in this document for consistency.

5.2 Topography and Drainage

Tangguh is located on the Bomberai Plains physiographic unit. This unit consists of areas of low rolling hills (where the Steenkool Formation outcrops) and low-lying alluvial areas along drainage pathways, both of which are bound by Bintuni Bay coastline to the north.

The physiography of Tangguh and its surrounds is characterized by low rolling hills with elevations typically between 20 and 40 metres above mean sea level (m msl). The hills are bounded to the north, east and west by alluvial flats and some are dissected by alluvial valleys associated with more prominent creeks and waterways. The most notable stream is the Manggosa River along the eastern boundary of the LNG Facility and a number of alluvial valleys and ephemeral waterways along the western boundary of the property. Waterways along the western boundary of the property form tributaries and sub-catchments of the Saengga River and are usually no more than a few metres above sea level.

Drainage at Tangguh has a trellis-like pattern. It is characterised by parallel main streams that typically have right-angled tributaries, which in turn are fed by elongated secondary tributaries parallel to the main streams. This drainage pattern reflects alternating hard and soft geological units of the Steenkool Formation which outcrop as parallel beds.

Several rivers, streams, and tributaries drain numerous catchments to the west, south and east of Tangguh within the groundwater model domain. The most prominent of these streams are the Tegenarategen River and Aroba River to the east and south-east of the facility and which drain towards the east and northeast to discharge into Bintuni Bay, and the Ofaweri River which flows from east to west and discharges to Berau Bay.

5.3 Climate

The climate of Indonesia is almost entirely tropical. Tangguh is wholly tropical with little seasonal variation in temperature and frequent rain.

Rainfall and evaporation data from Papua and the Tangguh LNG facility is presented in **Table 1** (ENV, 2012).

Table 1: Monthly and annual average rainfall and evapotranspiration

Month	Rainfall (mm)	Potential Evapotranspiration* (mm)
January	233	116
February	500	107
March	270	116
April	403	110
May	307	107
June	250	94
July	164	98
August	110	104
September	80	110
October	225	119
November	339	111
December	349	112
Annual total	*3231*	*1304*

Notes: * Source Chapter 2 of the ANDAL for the Tangguh Expansion Project

Monthly average rainfall greatly exceeds pan evaporation in all months except September, providing a surplus for groundwater recharge.

5.4 Geology and Groundwater Use

Tangguh and the groundwater model domain lie within the Bintuni Basin, which occupies a deep Tertiary age basement depression in the 'Birds Head' region of West Papua. The geology of the Bintuni Basin has been described in the map notes which accompany the Fak Fak sheet of the 1:250,000 Geological Map Series (**Figure 3**). At its thickest, the geological sequence is dominated by a 4000 m accumulation of generally flat-lying to shallow-dipping, gently folded, relatively immature and variably sorted sediments of the Steenkool Formation, broadly divided into sand and clay units at the depths of interest at Tangguh, but grading to sandstone and mudstone at greater depth.

Older limestones occur beneath the Steenkool Formation. Otherwise much of the basin is undeveloped and little researched.

Shallow sand, silt, and mud alluvium overlies the Steenkool Formation in low-lying areas. Beneath the LNG facility, the Steenkool Formation consists of interbedded mudstones and sandstones about 2000 m thick. Seismic profiles across the Site and Bintuni Bay show that the sedimentary sequence is generally flat-lying (with dips typically 0.5° or less) to depths of about 500 m. Dips increase to 2° or 3° to the southeast as the sediments thicken.

A correlation of aquifer and aquitard units has been established for the Upper Steenkool aquifers down to 150 m depth extending eastwards from the community wells at Saengga and Tanah Merah Baru across to the SHD-1 exploratory well at the LNG site. The dip of the sediments is indicated to be, on average, less than 1^0 which matches the dips extrapolated from the seismic profiles.

Based on the location of two regionally significant anticline structures to the north-east and south-west of the Tangguh LNG facility, ITB inferred that a regionally significant syncline axis may be situated roughly midway between the two anticlines, in this case beneath Bintuni Bay. As such ITB suggested that the Steenkool Formation in the vicinity of the LNG facility may be gently folded and that the Tangguh LNG facility may be situated on a gentle north-easterly dipping limb of a syncline; outcrops of sand-dominant layers of the Steenkool Formation were thought to delineate the axis of the syncline.

Figure 3 of the Baynes Geologic (2006) report shows that several faults have been either mapped or inferred at the Tangguh LNG facility. Most of these are located in the north-western portion of the property and are orientated either north-west to south-east or north-east to south-west, and whilst their slips or throws are not known most are inferred by Baynes Geologic (2006) to be strike-slip faults.

Reference to seismic lines 104, 105 and 108 which traverse the onshore area close to the location of the proposed test production well (PW-1) suggest some faulting in the Steenkool Formation is observable at depths of greater than 500 m. However, given the limited definition of the seismic data above about 500 m depth, it is not possible to ascertain whether the underlying faults in the Steenkool Formation (at depths greater than 500 m) extend to the surface in the immediate vicinity of the Tangguh LNG facility. Tangguh LNG's Subsurface Exploration Team indicate that there are no known faults in the immediate vicinity of the LNG facility.

The Fak Fak 1:250,000 scale geological map sheet suggests that two faults are located to the south of the Tangguh LNG facility. These are:

- a 10 km long east-west trending fault about 1 km south of the facility, and
- an 8 km long north-west – south-east trending fault situated about 10 km south of the facility.

Baynes Geologic (2006) postulates that both of these faults are small-displacement, left-lateral motion strike-slip faults, Hence, neither are expected to be significant barriers to groundwater flow.

Any faults through the claystones of the Steenkool Formation are likely to act as barriers to groundwater flow rather than conduits. If any faulting did act as a conduit then this would allow saline groundwaters from the Lower Steenkool to migrate to the Upper Steenkool. No evidence suggesting the vertical upward migration of saltwater was observed down to 300 m in the Slim Hole or in the resistivity traverses carried out by LAPI-ITB.

Five major subdivisions in the upper 300 m of the Steenkool Formation have been observed in the groundwater exploration boreholes drilled at the facility (i.e. namely TW-1, TW-2 and the Slim Hole) and those drilled at Saengga and Tanah Merah Baru. These are:

1) A clay-dominant layer which contains some thin, albeit continuous, sand layers and which is estimated to be between about 10 and 30 m thick. It is understood that the shallow community wells at Saengga and Tanah Merah Baru, which are typically no more than a few metres deep, source water from sands in this layer.

2) An 'upper' sand-dominant layer some 60 to 80 m thick which contains some 'thin' – and again continuous – clay and silt layers. This layer, which is referred to as the Upper Steenkool Formation in this report, forms the upper groundwater resource used in the community groundwater supply wells at the villages of Saengga and Tanah Merah Baru and the former Tangguh LNG survey and construction camps at and near Tanah Merah.

3) A clay-dominant layer (again containing some thin and continuous sand layers) which is between about 130 and 250 m thick. This layer thins to the east.

4) A 'lower' sand dominant layer (which again contains some 'thin' – albeit apparently continuous – clay and silt layers) which is between about 30 and 70 m thick. This layer, which is referred to as the Lower Steenkool Formation in this report, appears to thicken to the east beneath the northwestern corner of the Tangguh property and includes the series of aquifers targeted for future groundwater abstraction at Tangguh.

5) A clay-dominant layer of unknown thickness.

An alluvial sequence that lines the valley floors throughout the area and is of variable lithology and thickness (to a maximum of approximately 30 m). The alluvial sequence is located around the northern, eastern, north-western and parts of the southern boundary of the site.

5.5 Regional Hydrogeological Setting

The Steenkool Formation that underlies Tangguh includes a multi-layer aquifer system within the Kanoka-Babo groundwater basin, which lies within the Bintuni (geological) Basin, shown on **Figure 2**. The Steenkool Formation is dominated by interbedded mudstones and sandstones which form a layered sequence of aquitards and aquifers which, based on past investigations, are expected to host low-salinity groundwater to depths of at least 300 m.

The Kanoka-Babo groundwater basin is defined by a series of aquifers within the southern portion of the Bintuni Basin. It is bounded by the Banda Sea to the north (Bintuni Bay) and south and by outcropping basement limestones to the east and west. The groundwater basin covers an area of about 16,780 km^2 of which the Tangguh property occupies an area of 3200 ha (i.e. 32 km^2) at the northern end of the basin.

In much of the area shown on **Figure 2**, the basin sediments are largely unfolded. Around the margins of the area of interest, the sediments are very gently folded and faulted, providing both topographic margins to the area of interest and areas where the deep aquifers form outcrops where recharge can occur. Thus the area that we judge would be influenced by the proposed groundwater abstraction is bounded by structurally disrupted zones within the much larger Bintuni Basin, the exact edges of which are not relevant to the study.

The groundwater systems are recharged by the consistent rainfall excess over evaporation, with groundwater moving broadly to discharge at and beyond the coast.

According to the Papua Island Groundwater Basin Map Sheet 11 the average annual recharge of the unconfined aquifers in the Kanoka-Babo groundwater basin has been estimated to be about 11,300 Mm^3. Average annual recharge to the confined aquifers has been estimated to be about 560 Mm^3.

5.6 Local Hydrogeological Setting

5.6.1 Hydrostratigraphy

Three aquifers (or more precisely aquifer zones) have been identified to depths of 300 m both beneath and in the area surrounding the LNG Facility. These aquifer zones are of variable thickness and, although their lateral continuity is not proved regionally, continuity is expected beneath the facility, across the model domain and beyond. The aquifers are separated by clay aquitards of similar lateral extent and can be described as:

- a number of unconfined and discontinuous alluvial aquifers associated with Quaternary coastal and fluvial deposits at depths typically less than 10 m throughout the area
- a series of confined aquifers generally between about 30 and 150 m bgs in what is referred to as here the 'Upper Steenkool Formation', and
- a series of confined aquifers between about 260 and 600 m bgs in what is referred to in this report as the 'Lower Steenkool Formation'.

Hydrostragraphic work carried out by ERM (2007) suggests aquifers in the Upper Steenkool Formation (i.e. to depths of 150 m) may be continuous beneath much of the western portion of the Tangguh LNG facility and the villages of Tanah Merah Baru and Saengga. This interpretation, which was based on geological and down-hole geophysical profiles as well as groundwater quality information from the community supply wells at Tanah Merah Baru and Saengga as well as groundwater exploration boreholes TW1, TW2 and the Slim Hole at the Tangguh LNG facility, and also suggests:

- the dip of the sediments in the Upper Steenkool Formation is, on average, less than 1°
- aquifers in the Upper and Lower Steenkool Formation are separated by a regionally significant aquitard, and
- sand dominant layers in the Lower Steenkool Formation appear to become thicker and more common below a depth of about 250 m.

There are deeper confined aquifers below 600 m in the Steenkool Formation but these are outside the scope of this study and are separated from the target aquifer by further aquitards. These deeper aquifers are not of practical concern to the numerical analysis and do not need to be considered further in this study.

The aquifers zones and individual aquifers are separated by regionally significant clay aquitards that range from about 10 to 200 m thick. Aquitards below 400 m depth, i.e. beneath the targetted aquifer interval in the forthcoming drilling programme, could have greater thicknesses.

Individual aquifers within the larger aquifer zones are expected to commonly be heterogeneous and anisotropic. In both aquifers and aquifer zones, horizontal permeability is expected to be homogeneous or nearly so (i.e. $K_x \approx K_y$). However, vertical permeability (K_z) is expected to be significantly smaller, possibly by at least one order of magnitude.

Not all of the saturated thickness of the 'aquifer zones' are aquifers. The aquifers, at the scale of the site and the model, in the broadly sandy intervals are formed by thin zones of more permeable materials typically between 5 and 20 m thick. These local aquifers are hosted within what can be regarded as regionally significant aquitards at the larger scale.

The aquitards have untested vertical hydraulic conductivity. The extent to which these aquitards allow vertical leakage (both up and down) is therefore not known but it will be an important controller on the effects of drawdown from the proposed groundwater abstraction at Tangguh.

5.6.2 Hydraulic Properties

Aquifers

Hydraulic testing performed on sandy layers within the alluvial and perched aquifers of the Steenkool Formation consists mostly of slug testing carried out by PT Hydrocore and PT Taka Hydrocore during the monitoring and construction of the various landfill facilities at the Site. The maximum reported hydraulic conductivity was 3.3 m/day whilst the minimum value of hydraulic conductivity was 4.2×10^{-5} m/day; the average was about 0.8 m/day. No data are appropriate for calculation of specific yield.

Typical textbook values for common lithologies in alluvial-type sediments suggest specific yields between about 0.02 (e.g. for clays) and 0.2 (clean medium-grained sands).

Estimates of hydraulic conductivity within the Upper Steenkool Formation aquifers (i.e. those aquifers between about 30 and 150 m bgs) from pumping tests suggest that the more promising aquifer layers in this unit have horizontal hydraulic conductivities between about 1 and 15 m/day and are typically about 4 m/day. Values of transmissivity estimated by PT ERM Indonesia (ERM) from pumping tests vary between about 15 and 50 m^2/day. ERM's estimates of specific capacity for production wells varied between about 7 and 40 m^3/day per m drawdown.

Although no estimates of storativity were possible from the pumping test, ERM suggested that storativity of the Upper Steenkool Formation aquifers could be estimated by multiplying the aquifer thickness by its estimate of specific storage derived from model calibration, in this case 3×10^{-6}. Based on his relationship individual aquifers in this unit would have storativity estimates between about 5×10^{-4} and 5×10^{-3}.

Hydraulic properties of the Lower Steenkool Formation aquifers are not known. For this model however, the hydraulic properties of these aquifers have been assumed to be similar to those of the Upper Steenkool Formation aquifers as suggested by Tangguh LNG's Technical Advisor.

Aquitards

Estimates of hydraulic conductivity from four undisturbed samples of claystone collected from the Steenkool Formation during the geotechnical investigation for the new inert and organic waste landfill indicate that the aquitards may have permeabilites between 2 x 10^{-5} and 4 x 10^{-4} m/day.

There is no known information regarding the permeability of the aquitards below 15 m depth.

Estimates of horizontal hydraulic conductivity (i.e. both K_x and K_y) used by ERM in past numerical modelling were about 0.015 m/day with estimates of vertical hydraulic conductivity (K_z) about 0.0015 m/day. ERM's estimates of storativity were about 0.005.

5.6.3 Groundwater Recharge

The majority of recharge into the alluvial aquifer occurs as direct rainfall infiltration where these sediments occur. There may also be localised recharge from losing streams.

The Upper and Lower Steenkool Formation aquifers are recharged by rainfall infiltration where these aquifers outcrop (i.e. in the areas where geological structure has brought them to the surface), most notably those areas to the south and south-west of the facility and outside the model domain. Recharge to shallower aquifers is also likely from the upward leakage of groundwater from the deeper aquifers as a consequence of upward gradients from the Lower Steenkool Formation aquifers.

The area over which rainfall recharge of the confined aquifers in the Kanoka-Babo groundwater basin occurs (i.e. the rate of 560 M m^3 shown on the Kanoka-Babo groundwater basin map) is not known. As such the unit rate of recharge cannot be calculated from the published information.

Recharge is critical to understanding both conceptually how the development of a new groundwater supply at the Tangguh LNG facility might affect the groundwater system and how best to approach the modelling. As noted in **Section 5.3**, the rate of recharge in likely to exceed greatly the proposed rate of groundwater abstraction for Tangguh.

5.6.4 Groundwater Discharge

The unconfined alluvial aquifer probably discharges to Bintuni Bay. There may also be minor leakage into the underlying aquitard and transpiration from vegetation in drier periods. Local abstraction occurs from three shallow wells in Saengga and two in Tanah Merah Baru. The withdrawals from the wells are minimal with respect to the basin recharge rate and inconsequential to overall groundwater resource availability.

The Upper Steenkool Formation aquifers are expected to discharge to the ocean (Bintuni Bay and further west in the Banda Sea) by vertical leakage over large areas. We do not know whether there are localised recharges, for example through fault zones such as those known on land. However, given the generally flat-dipping character of the area within the model domain and surroundings, no preferential discharge zones have been incorporated in either conceptual or numerical models.

A number of community groundwater supply wells have been installed in this aquifer as part of Tangguh LNG's CSR program. Wells were installed at the villages of Saengga (2 wells) and Tanah Merah Baru (1 well) where yields are understood to be about 3 L/s for up to 8 hours (continuous pumping) per day. A number of former Tangguh LNG and subcontractor 'camp supply' wells were installed in this aquifer but are no longer in use.

Groundwater resources in the Upper Steenkool Formation (i.e. to a depth of about 150 m bgs) beneath the Tangguh LNG property have been embargoed (i.e. no further extraction is permitted) with this groundwater resource set aside for community potable water supply needs.

The Lower Steenkool Formation aquifers are available for groundwater supply.

5.6.5 Groundwater Levels and Flow Dynamics

Groundwater Levels

Within the alluvial aquifer groundwater has been encountered at depths of between 1 and about 10 m with shallow groundwater most common at lower elevations. Occurrence of localised perched groundwater has also been noted by Baynes Geologic and PT Hydrocore and in a number of geotechnical and environmental investigation boreholes drilled in the northwestern portion of the property, particularly those drilled in areas where alluvium is absent and the Steenkool Formation occurs at the surface. Groundwater levels within the alluvial aquifer are expected to mimic the topographic expression of the area with an overall flow direction to the north towards Bintuni Bay.

Groundwater elevations measured within the Upper Steenkool Formation aquifers have ranged between about 0.2 and 4.5 m msl. The inferred hydraulic gradient in these aquifers would drive movement of groundwater from south and southwest to the north and north-west beneath the facility and beyond.

No groundwater level measurements are available in the Lower Steenkool Formation aquifers or aquitards. However, head values similar (or possibly higher) than those in the Upper Steenkool Formation aquifers may be expected given the anticipated elevation of the recharge and discharge areas. The hydraulic gradients and groundwater movement directions may also be similar to those in the Upper Steenkool Formation aquifers.

Groundwater Level Fluctuations

There is no information regarding groundwater level fluctuations in the alluvial aquifer. Groundwater levels are expected to fluctuate with seasonal changes in rainfall recharge and, locally, in response to groundwater abstraction.

Within the Upper Steenkool Formation aquifers fluctuations in aquifer pressure have been observed in groundwater monitoring well TW-2. Fluctuations appear to mimic the tidal regime in Bintuni Bay and are inferred by Tangguh LNG's Technical Consultant to reflect hydrostatic pressure changes associated with tidal fluctuations above this (confined) unit as opposed to changing water levels associated with partial or complete hydraulic connection with Bintuni Bay.

There is no information regarding groundwater level fluctuations from the Lower Steenkool Formation aquifers.

5.6.6 Groundwater Quality

The groundwater quality parameters within the alluvial aquifer are not known but are likely to be variable. Fresh groundwater is likely in sands and gravels with higher salinities possibly near the coast. Low-pH groundwater (typically about pH 2 to 3) has been observed by Baynes Geologic draining from shallow aquifers in the Steenkool Formation at Temporary Construction Camp No. 2. The groundwater was thought by Baynes Geologic to have become acidic following the partial draining and subsequent oxidation of presumed sulphide minerals in these aquifers following excavations for a number of embankments in this area.

Groundwater samples collected from each of the community groundwater supply wells within the Upper Steenkool Formation aquifers indicate that the water in this aquifer is of low salinity. Major ion chemistry from groundwater monitoring well TW-2 indicates groundwater in these aquifers is sodium and bicarbonate dominant.

Single point resistance logs from the Slim Hole (maximum depth 300 m) were inferred by ERM to indicate that groundwater in the Lower Steenkool Formation aquifers is of low salinity and typically has TDS concentrations less than 500 mg/L.

Interpretation by Tangguh LNG of geophysical logs for several regional oil and gas exploration holes drilled through the entire thickness of the Steenkool Formation show that groundwater salinity increases with depth, with salinities possibly between 18,000 and 22,000 ppm in the lowermost 300 m of the Steenkool Formation (at about 1700 to 2000 m bgs) beneath the facility.

The targeted Lower Steenkool Formation aquifers are much shallower than the saline groundwater inferred by Tangguh LNG's deeper drilling and are inferred by Tangguh LNG's Technical Advisor to have fresh groundwater. Future drilling and testing will provide direct information.

There is no information regarding the location of any fresh water / saline water interfaces within any aquifer. The alluvial aquifer presumably has a conventional seawater interface near the coast.

In the Upper Steenkool Formation, if there is a saltwater interface, it is probably located to the north or northwest of TW-2 and the Slim Hole, and (as discussed in **Section 6.3.2.1**) most likely beneath Bintuni Bay.

6.0 NUMERICAL MODEL DEVELOPMENT

6.1 Past Numerical Modelling and Selection of Numerical Code

FEFLOW and MODFLOW are the two most commonly applied groundwater modelling codes worldwide. These two codes solve the same groundwater flow equation, by different numerical methods. The model described in this report uses the Finite Element based code FEFLOW developed by DHI-WASY, but could have been prepared with either MODFLOW or FEFLOW. FEFLOW was selected over MODFLOW for two principal reasons:

- FEFLOW has great flexibility in the model grid, allowing a high density of nodes within small areas of interest, such as a wellfield and areas of complex aquifer geometry, and a larger coarse mesh elsewhere.
- FEFLOW can simulate solute transport, and density driven flow within the same model code. MODFLOW can achieve these, but requires use of additional packages (MT3D and SeaWAT).

The difference between FEFLOW and MODFLOW lies in the numerical method used to solve the groundwater flow equation. FEFLOW uses the Finite Element (FE) method whilst MODFLOW uses Finite Differences (FD). Both methods have been widely applied to groundwater flow problems since the 1970s, with discussion on the merits of the two methods for a similar timescale (Mercer and Faust, 1980). The basic theory of both FE and FD methods is set out in groundwater text books such as Wang and Anderson (1982).

FEFLOW has been developed since the late 1980s. FEFLOW is now established as the leading commercial software package for modelling groundwater in porous and fractured media (Bundschuh and Arriarga, 2010). The full theory and testing of FEFLOW is set out in a number of White Papers together with FEFLOW documentation on the FEFLOW website.

The conceptual model on which the numerical model is based information from a number of groundwater exploration initiatives at the property, most of which were carried out following the completion of the model prepared by ITB. More recent investigations have included the geological and downhole-geophysical logging of the 'Slimhole' borehole which was drilled to 300m, the resistivity traverses and the geotechnical studies completed at the Tangguh property. Information from these initiatives indicates that the aquifer distribution is more limited than previously indicated and provides updated hydraulic parameters for the aquifers and aquitards beneath the northwestern portion of the property.

This FEFLOW model has also been extended to a depth of 600 m to account for the potential presence to that depth of usable aquifers with salinity less than 1,000 mg/L.

6.2 Numerical Model Design

6.2.1 Model Domain and External Boundaries

The model domain is approximately 55 km by 29 km (**Figure 4**) with a thickness of 600 m. The domain includes some recharge zones and accommodates others at greater distance by means of the selected perimeter boundary conditions. The domain perimeter location was selected by judgement to be beyond the likely area of any influence from the proposed abstraction wells.

6.2.2 Spatial and Vertical Discretisation

Figure 5 shows the spatial discretisation of the model domain by means of the Finite Element mesh created in FEFLOW. The domain is discretised spatially into 882,911 elements and 467,760 nodes. The model has 19 layers vertically and 20 slices and is shown in **Figure 6**. A finer resolution mesh was selected around the pumping wells and community wells, while the grid discretization was gradually decreased towards the boundary of the model domain.

It should be noted that the grid discretisation was designed such that the model run times were minimized and the overall efficiency of the model improved. Excessive complexity and grid discretization can hamper successful development and introduce numerical instability.

In regard to the vertical layers, 19 layers were defined by the conceptual model and hydrostratigraphic units. Aquifers (i.e. sand dominant units of the Steenkool Formation) were delineated as single layers in the model, whilst aquitards were typically divided into two or three layers to better assess the influence of vertical leakage (from these usually thick layers) on aquifer-aquifer interactions. Layers used in the model are summarised in **Table 2**.

Table 2: Vertical layer discretisation and hydraulic properties

Hydrostratigraphic Unit	Model Layer	Hydraulic Properties				Thickness (m)
		K_x & K_y (m/d)	K_z (m/d)	S_y	S_s (m^{-1})	
Alluvial sediments	1	5.0	5.0	0.5	-	10
Upper Steenkool Formation – clay dominant	2	0.0086	0.00086	-	3.35×10^{-5}	30
Upper Steenkool Formation – sand dominant	3	4.0	0.4	-	5.05×10^{-6}	60
Upper Steenkool Formation – clay dominant	4	0.0004	0.00004	-	3.35×10^{-5}	55
	5	0.0004	0.00004	-	3.35×10^{-5}	55
	6	0.0004	0.00004	-	3.35×10^{-5}	55
Lower Steenkool Formation – sand dominant	7	4.0	0.4	-	5.05×10^{-6}	30
Lower Steenkool Formation – clay dominant	8	0.0004	0.00004	-	3.35×10^{-5}	20
	9	0.0004	0.00004	-	3.35×10^{-5}	25
Lower Steenkool Formation – sand dominant*	10*	4.0	0.4	-	5.05×10^{-6}	10
Lower Steenkool Formation – clay dominant	11	0.0004	0.00004	-	3.35×10^{-5}	30
	12	0.0004	0.00004	-	3.35×10^{-5}	30
	13	0.0004	0.00004	-	3.35×10^{-5}	30
Lower Steenkool Formation – sand dominant*	14*	4.0	0.4	-	5.05×10^{-6}	10
Lower Steenkool Formation – clay dominant	15	0.0004	0.00004	-	3.35×10^{-5}	30
	16	0.0004	0.00004	-	3.35×10^{-5}	30
	17	0.0004	0.00004	-	3.35×10^{-5}	30
Lower Steenkool Formation – sand dominant*	18*	4.0	0.4	-	5.05×10^{-6}	10
Lower Steenkool Formation – clay dominant	19	0.0004	0.00004	-	3.35×10^{-5}	50

Notes: * unproven aquifer included at the request of Tangguh LNG's Technical Advisor

6.2.3 Boundary Conditions

The selected boundary conditions of the model are outlined below and shown in **Figure 7**. In selecting boundary locations the model domain has been chosen using experience-based judgement to allow the model objectives to be met. It is not necessary to simulate all the conditions that bound the Steenkool Formation aquifer system as a whole.

Constant head boundary conditions (1st kind: Dirichelt) were assigned at both the northern, western and southern edges of the model; these are representative of the ocean water levels as well as the regional aquifer system.

Along the eastern margin of the model, a variable constant head boundary condition was created to represent the Tegenarategen River, with variable decreasing elevation towards the ocean.

Since there are no observation wells at the southern boundary, a constant head of 24 m msl was applied along the sandstone outcrops of the Steenkool Formation in Layers 7, 10, 14 and 18. This head aims to represent regional recharge from areas south of the model domain. Rivers were simulated with a 3rd Cauchy type boundary condition which allows for fluid transfer and a set in/out conductance value.

6.2.4 Inflows and Outflows

6.2.4.1 Rainfall Recharge Rates

Long term average values of rainfall recharge applied in the numerical model are summarised in **Table 3**.

Table 3: Rainfall recharge

Scenario	Outcrop Type	Recharge (mm/yr)	Recharge (% of annual rainfall)	Recharge (m/d)
Base Case	Alluvials, clay-dominated Steenkool Formation	150	4.6	4.1×10^{-4}
	Sand-dominated Steenkool Formation	94	2.9	2.6×10^{-4}

6.2.4.2 Natural Groundwater Discharge

The model allows lateral discharge from shallow aquifers into Bintuni Bay and vertical leakage upwards into the sea from the Steenkool Formation aquifers where they occur beneath Bintuni Bay.

6.2.4.3 Well Discharge Rates

Abstractions from the model includes:

- pumping from the four proposed groundwater production wells for the Tangguh expansion project which will be screened in the Lower Steenkool Formation aquifers, and
- local community supply abstractions from the two community wells at Saengga (WWS-1, WWS-2) and single community well at Tanah Merah Baru (WWTMB-1).

Water demand and pumping rates during the construction of the 3rd and 4th trains at the Tangguh LNG facility will differ during different stages. Construction of the new trains and associated infrastructure is planned over 4 years, with 3 months pre-commissioning scheduled for the 3rd quarter of the final year followed by three months commissioning during the final quarter.

The groundwater abstraction scenario described in this report includes workforce numbers that will increase from about 1,000 people at start of construction to about 8000 people at the end of the second year (which is the estimated peak labour demand), before declining to about 1,000 at end of the final year (as advised by Tangguh LNG).

Average workforce water demand has been estimated by Tangguh LNG to be 300 litres per person per day with the peak workforce water demand estimated by Tangguh LNG to be about 2,400 m^3/d.

Water required for the hydrotesting of the offshore pipelines and onshore tanks and vessels may be required in sequence or in parallel to the water demand required to support the workforce. Although this demand has not yet been supplied by Tangguh LNG, it has been assumed by Tangguh LNG's Technical Advisor that a water supply of 95 L/s will be required for the pre-commissioning stage during the 3rd quarter of the final year. It is envisaged that this water will be pumped into a storage pond and delivered to the hydrotest at 190 L/s over 50 days.

Given the above, peak water demand will most likely be in the 3rd quarter of the final year and will total some 8,500 m^3/d comprising workforce demand and delivery of groundwater to storage pond for infrastructure hydrotesting.

Early works occupies 9 months prior to the start of this scenario; the water demand during this phase has not been included in the modelled water demand or timeframe.

It should be noted that the estimates for the construction phase are provisional only and are likely to vary according to the plan developed by the Engineering-Procurement-Construction contractor. These estimates however are considered reasonable and logical.

In addition, a sustained pumping rate of 50 L/s is required for the life of the facility (25 years).

Groundwater pumping from the two community supply wells at Saengga and the single well at Tanah Merah Baru has been modelled as 8 hours of continuous pumping per day for the duration of the modelled scenario.

Existing and proposed well locations, screen depths and pumping schedules are summarised in **Table 4** whilst the likely water demand and individual and cumulative groundwater pumping rates are shown on **Figure 8**.

Table 4: Pumping well details

Well ID	Easting (mE)	Northing (mN)	Anticipated Screen Depths (m bgs)	Pumping Duration	Individual Well Pumping Rate (L/s)	Cumulative Well Pumping Rates [i.e. LNG Facility Water Demand] (L/s)
Provisional production well locations	626,020 627,140 625,530 628,915	9,729,360 9,728,975 9,726,750 9,726,540	265 to 295 340 to 350	2 years	Starting at 1.3 and increasing to 7.5	Starting at 5 and increasing to 30
				18 months	7.5	30
				100 days	23.75	95
				100 days	Starting at 23.75 and decreasing to 12.5	Starting at 95 and decreasing to 50
				25 years	12.5	50
WWS-1	289,451	9,726,729	98 to 110 117 to 120	Continuously for 8 hours per day	3	3
WWS-2	289,502	9,726,729	101 to 122	Continuously for 8 hours per day	3	3
WWTMB-1	290,491	9,728,077	98 to110 122 to 125	Continuously for 8 hours per day	3	3

6.2.5 Model Parameterisation

6.2.5.1 Hydraulic Properties

The hydraulic parameters used for each layer of the model are presented in **Table 1** in **Section 6.2.2**.

Values of hydraulic conductivity for the aquifers in the Upper Steenkool Formation (i.e. layer 3 of the model) were estimated from pumping tests previously carried out both at the site and in the local community groundwater abstractions wells to the west and south-west of the facility. The pumping tests suggest that the more promising aquifer layers in this unit have horizontal hydraulic conductivities between about 1 and 15 m/day and are typically about 4 m/day.

Values of specific storage of the Upper Steenkool Formation aquifers were based on textbook values for the appropriate hydrostratigraphic units.

The hydraulic properties for the known and inferred aquifers in the Lower Steenkool Formation (namely layers 7, 10, 14 and 18 of the model) have been based on hydraulic conductivity and specific storage estimates for those aquifers in the Upper Steenkool Formation, as suggested by Tangguh LNG's Technical Advisor.

Hydraulic properties for the aquitards in the model (i.e. layers 2, 4, 5, 6, 8, 9, 11, 12, 13, 15, 16, 17 and 19 of the model) have been based on those values of hydraulic conductivity estimated from the four undisturbed samples of claystone collected from the Upper Steenkool Formation during the geotechnical investigation for the new inert and organic waste landfill.

The adopted range of hydraulic properties was used as a starting point for parameter variation during model calibration and a sensitivity analysis was conducted for selecting the final calibration parameters used for predictive simulations.

6.3 Model Calibration

6.3.1 Initial Steady – State Calibration

No regional monitoring wells or groundwater level time series data sets were available to assist in the calibration of the model. The available groundwater levels were obtained from a variety of drilling reports and geotechnical investigations limited to the area around infrastructure at the LNG facility, all of which document single measurements of groundwater levels at different times. These groundwater levels were used to calibrate the model to steady state conditions as best as practicable in the area surrounding the Tangguh property. The model was calibrated to steady state conditions by using the trial and error method, informed by experience-based judgement about the groundwater system. Target hydraulic heads of between 2 and 5 m msl were achieved at the community wells, and between 0 and 6 m msl in the vicinity of the geotechnical investigation boreholes drilled in the northwestern portion of the facility.

6.3.2 Transient State Calibration

6.3.2.1 Transient Model Setup and Calibration Methodology

The grid design and boundary conditions in the transient model setup are approximately the same as the steady-state model setup. Additional complexity is introduced as the mass concentration boundary condition as well as designation of salt water boundary conditions.

The groundwater system at Tangguh includes confined aquifers through which water moves towards the coast from inland recharge areas. In those aquifers, the groundwater is expected to move beyond the coast to discharge by diffuse upward leakage through low permeability aquitard layers or through local fault structures, which are not known to exist near the facility. Even if faults do exist through the aquitards, localised groundwater flow along them would not necessarily occur.

This situation is likely to result in fresh groundwater extending some distance beneath Bintuni Bay in the confined aquifers. This distance cannot be known but 1 to 5 km would not be unlikely. A distance of 2 km offshore for the location of the transition from fresh to saline groundwater has been judged reasonable for the analysis of potential saline migration towards a future wellfield at Tangguh; based on the geophysical log for the Slim Hole in the northern portion of the Site, fresh groundwater was inferred by ERM to be present in the Upper and Lower Steenkool Formation aquifers to elevations of about 300 m bgs.

The transient model was initially developed to establish steady state conditions of the salt water wedge within the Steenkool Formation. A mass concentration boundary condition representative of sea water (i.e. 35,000 mg/L) was placed on the ocean region of the model domain on the top-most layer to allow lateral and vertical migration through the Upper Steenkool Formation units. To represent a saline water / fresh water interface, mass concentration boundary conditions were applied approximately 2 km offshore on those layers below the clay-dominant Upper Steenkool Formation (that is, from layer 7 downwards).

The model was then run for 10^8 days (about 275,000 years) to allow ample time for the saline water / fresh water interface to reach steady state condition. To assist with this simulation, a constant head boundary with a water level of +24 m msl was assigned to all layers in the model along the southern extent of the model domain.

7.0 PREDICTIVE SIMULATION OUTCOMES

The objective of the predictive modelling scenario is the estimation of drawdown within aquifers in the Upper and Lower Steenkool Formation due to the planned pumping by Tangguh LNG. Drawdown will in turn control water resource availability, interference from the lower aquifer on supply wells in the upper aquifer and the extent of any adverse saline intrusion.

The combined pumping rates for the four proposed wells at the Tangguh LNG property are summarised in **Table 4** (in **Section 6.2.4.3**).

The calibrated model was used for the calculation of changed groundwater levels and associated saline intrusion, using conservative estimates of specific storage and vertical hydraulic conductivity as follows:

- Vertical hydraulic conductivity of the aquitards of 4.0×10^{-5} m/day
- Specific storage of the aquitards of 3.35×10^{-5}, and
- Specific storage of the aquifers of 5.05×10^{-6}.

Other hydraulic parameters and characteristics were consistent with previously stated values.

The results of the groundwater modelling broadly indicate that Tangguh LNG's nominal water requirement would be available from the targeted aquifers in the Lower Steenkool Formation underlying the Tangguh LNG property based on parameters assumed from similar aquifers and judged appropriate for the layered system of aquifers at Tangguh.

7.1 Drawdown Predictions

As seen in **Figure 9**, drawdown within the Lower Steenkool Formation aquifers is predicted to be about 15 m near the planned locations of production wells PW-1 and PW-2, and between about 13 and 14 m at the planned locations for production wells PW-3 and PW-4. The drawdown cone propagates north under Bintuni Bay, whilst the highest gradients are observed locally near the four proposed production wells. Modelled groundwater levels in the Lower Steenkool Formation aquifers at PW-2 (the closest provisional pumping well to Bintuni Bay) during the planned construction and operational phases of the Tangguh facility are shown on **Figure 10**.

Assuming the water demand for the construction of the 3rd and 4th LNG trains and ongoing operation of the LNG facility is sourced solely from groundwater, the drawdown in each of the proposed pumping wells at the Tangguh property is predicted to temporarily peak at the end of hydrotesting during the construction phase of work (**Figure 10**). Aquifer pressures are then expected to partially recover at the end of hydrotesting when well pumping rates will be reduced, and then decline about 1.2 m during the operational phase of the LNG facility. As such over 90% of the long-term predicted drawdown in PW-2 (an indeed in each of the planned groundwater abstraction wells) is expected to occur during the first four years of pumping, with only marginal additional drawdown is predicted over the next 25 years.

Maximum drawdown in the Upper Steenkool Formation aquifers due to both community water abstraction and Tangguh LNG's proposed pumping is predicted to be about 0.6 m in the local community supply wells at Saengga (**Figure 11**). Drawdown of about 0.55 m is also predicted at the community supply well at Tanah Merah Baru some 300 m southwest of the Tangguh LNG property, of which about 0.05 m is related to Tangguh LNG's planned abstraction from the within the Tangguh LNG facility property (**Figure 12**). The drawdown estimates from the model are assumed accurate to 0.005 m.

Modelled drawdown in the Upper Steenkool Formation at the Tangguh LNG property boundary near PW-3 is shown on **Figure 13**. This figure shows that total predicted drawdown in these aquifers at this location is likely to be about 0.165 m of which about 0.05 m may be attributable to Tangguh LNG's planned abstraction from the Lower Steenkool Formation aquifers.

The insert diagram on **Figure 11** shows that the greatest drawdown in the Upper Steenkool Formation aquifers along the boundary of the Tangguh LNG facility will occur near the community well at Tanah Merah Baru. Total drawdown in these aquifers at this location is predicted to be about 0.29 m, of which about 0.05 m is related to Tangguh LNG's planned abstraction from the Lower Steenkool Formation aquifers.

At each of the above locations [i.e. (i) the community supply well at Tanah Merah Baruh, (ii) the point on the property boundary nearest to the community supply well at Tanah Merah Baru, and (iii) the monitoring point on the property boundary near PW-3] the enhanced drawdown in the Upper Steenkool Formation aquifers brought about by Tangguh LNG's planned pumping was estimated by comparing:

(i) total predicted drawdown in these aquifers due to community pumping only, with

(ii) drawdown caused by both local groundwater abstractions coupled with Tangguh LNG's planned pumping.

As such the drawdown in the community well at Tanah Merah Baru includes drawdown caused by pumping from the community well at Saengga.

Modelled drawdowns in the Upper Steenkool Formation for groundwater abstraction from only the community supply wells during the construction and operational stages of the Tangguh LNG facility are shown for comparison purposes on **Figure 14**.

Considering spatial and vertical discretisation of the numerical model domain and allocation of hydraulic parameters, it is recognised that the greatest potential influence on predicted drawdown in the community wells will occur if:

(i) the aquifers in the Upper Steenkool and Lower Steenkool Formations are hydrogeologically connected, most likely via faulting, and

(ii) any faults in the model domain do not act as barriers to groundwater flow.

In the numerical model, the Steenkool Formation aquifers are not displaced by faulting to the extent that groundwater flow is impeded. As such the predicted drawdown contours generated by the numerical model are considered to be conservative in terms of potential impacts to the community wells at Tanah Merah Baru and Saengga.

Should fault barriers be identified between the community wells and proposed production well locations at the Tangguh LNG facility based on sustained groundwater abstraction and monitoring it is likely that:

- drawdowns in both the Upper Steenkool and Lower Steenkool formations beneath the LNG site will be greater than currently predicted, and
- drawdowns at the community wells will be less than currently predicted.

7.2 Saline Intrusion Predictions

The groundwater system at Tangguh includes confined aquifers through which water moves from groundwater recharge areas to the south and southwest of the Tangguh LNG facility towards discharge areas to the north of the facility and likely beyond the coast. This is likely to result in fresh groundwater extending some distance beneath Bintuni Bay in the confined aquifers; this distance is not known, but a distance of 2 km offshore for the location of the transition from fresh to saline groundwater has been assumed for the analysis of potential saline migration towards a future groundwater wellfield at Tangguh.

Pumping from the confined aquifers will cause groundwater levels to fall in the surrounding area. The extent of the zone of influence will depend upon both aquifer properties and the vertical hydraulic conductivity of the aquitards that lie above and below the aquifers. None of these parameters are specifically known, but the analysis has been carried out with a range of parameters selected by experience-based judgement. Future testing at the site will provide more reliable estimates of the parameters.

Based on the reasonable estimates of the position of the salt water interface in confined aquifers, the aquifer parameters and the properties of the aquitards, the numerical model was used to examine the likely behaviour of the interface over the planned 29 years of the groundwater wellfield operation. As shown in **Figure 15** and **Figure 16**, the model predicts virtually no lateral movement of saline groundwater towards the proposed wellfield within the confined aquifers; it also predicted virtually no downward leakage of sea water from the bay towards the underlying confined aquifers.

Figure 17 shows the mass concentration (salinity) conditions at the end of the planned 29 years of pumping; wherein the salinity interface in the Lower Steenkool Formation moved about 150 m south towards the Tangguh LNG facility.

Figure 18 shows the predicted change in salinity in the Lower Steenkool Formation at PW-2 (i.e. the closest provisional and modelled well to Bintuni Bay) due to Tangguh LNG's planned pumping is less than 10 mg/L; this is the only well (actual or modelled) where an increase in salinity was observed after the planned 29 years of pumping from both the Upper and Lower Steenkool Formation aquifers.

These outcomes are consistent with the conceptual understanding of the groundwater system, including the small rate of groundwater pumping relative the regional water balance in the aquifers.

Report Signature Page

For and on behalf of the consortium of

PT GEOTECHNICAL AND ENVIRONMENTAL SERVICES INDONESIA, AND

GOLDER ASSOCIATES PTY LTD

Craig Wicenciak Senior Hydrogeologist	John Waterhouse Principal

C.E. Perryman

Geoff Perryman
Project Manager, Associate

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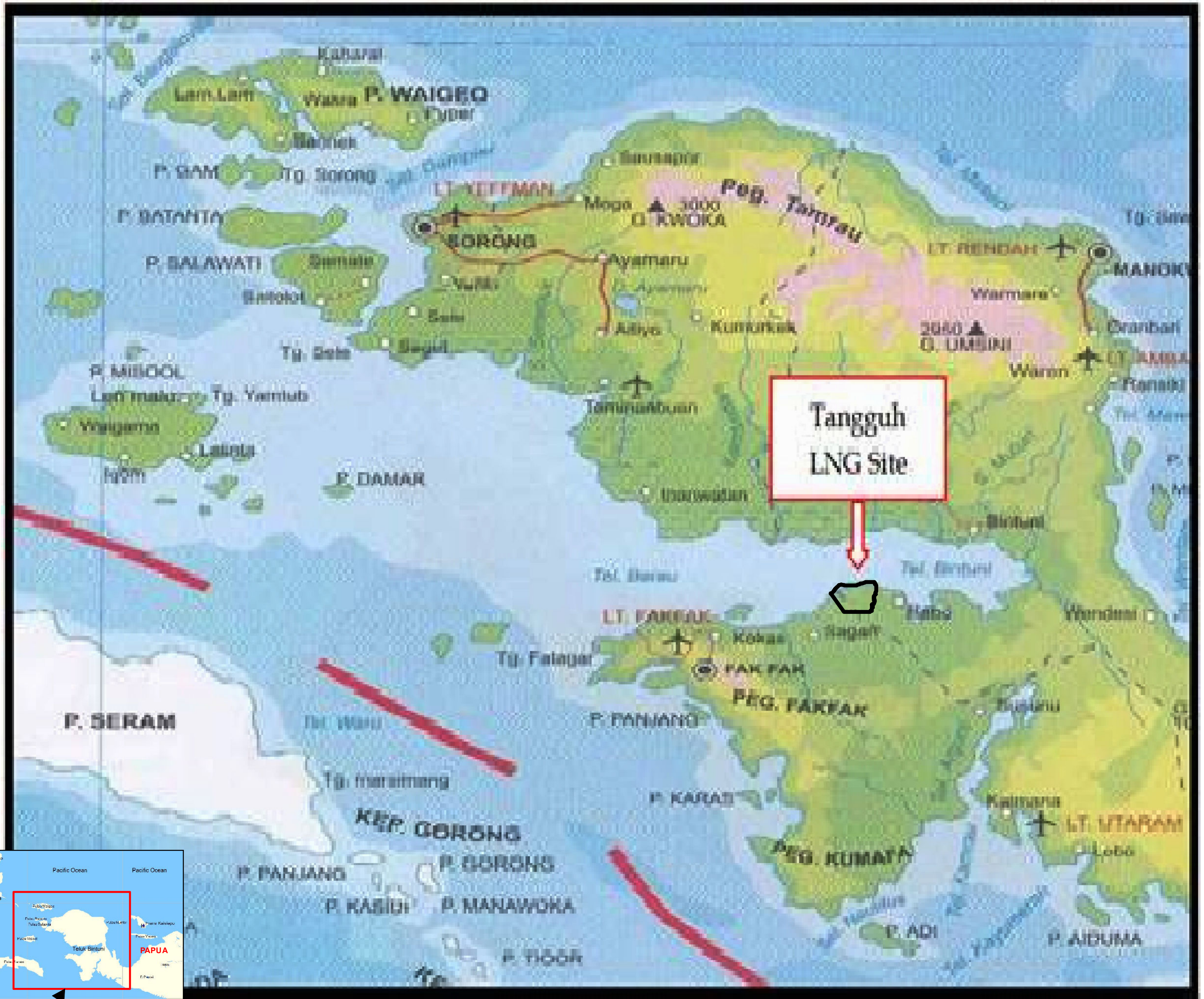

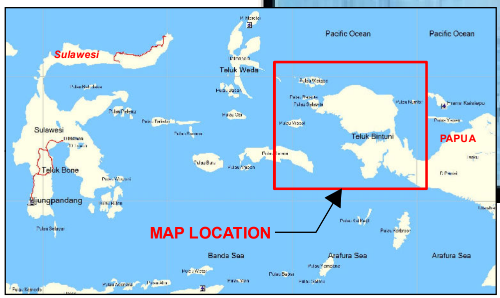

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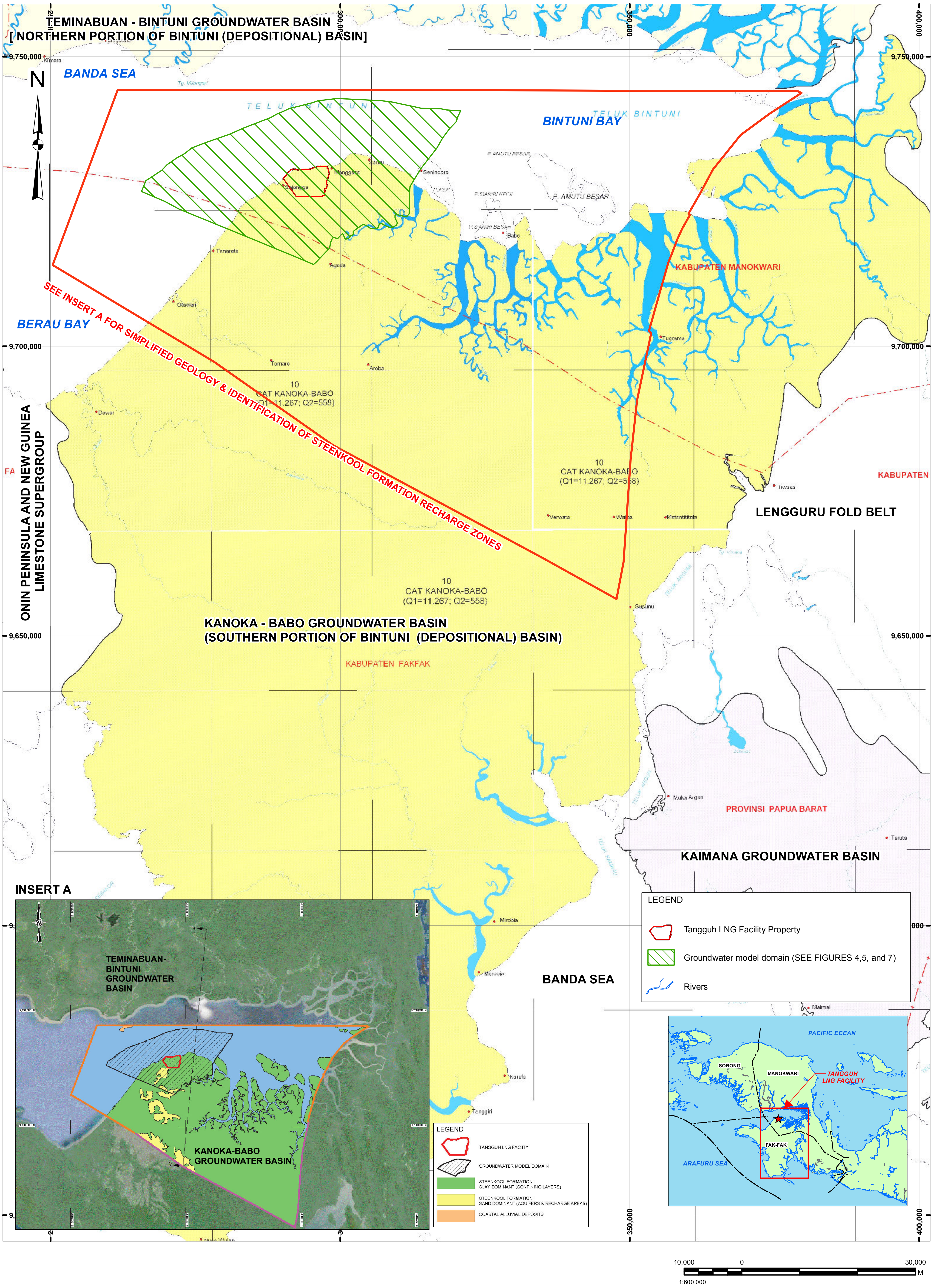

NOTE

Q1 = estimate of total recharge of unconfined aquifers in the Kanoka-Babo Groundwater Basin (M m^3/year).

Q2 = estimate of total recharge of confined aquifers in the Kanoka-Babo Groundwater Basin (M m^3/year).

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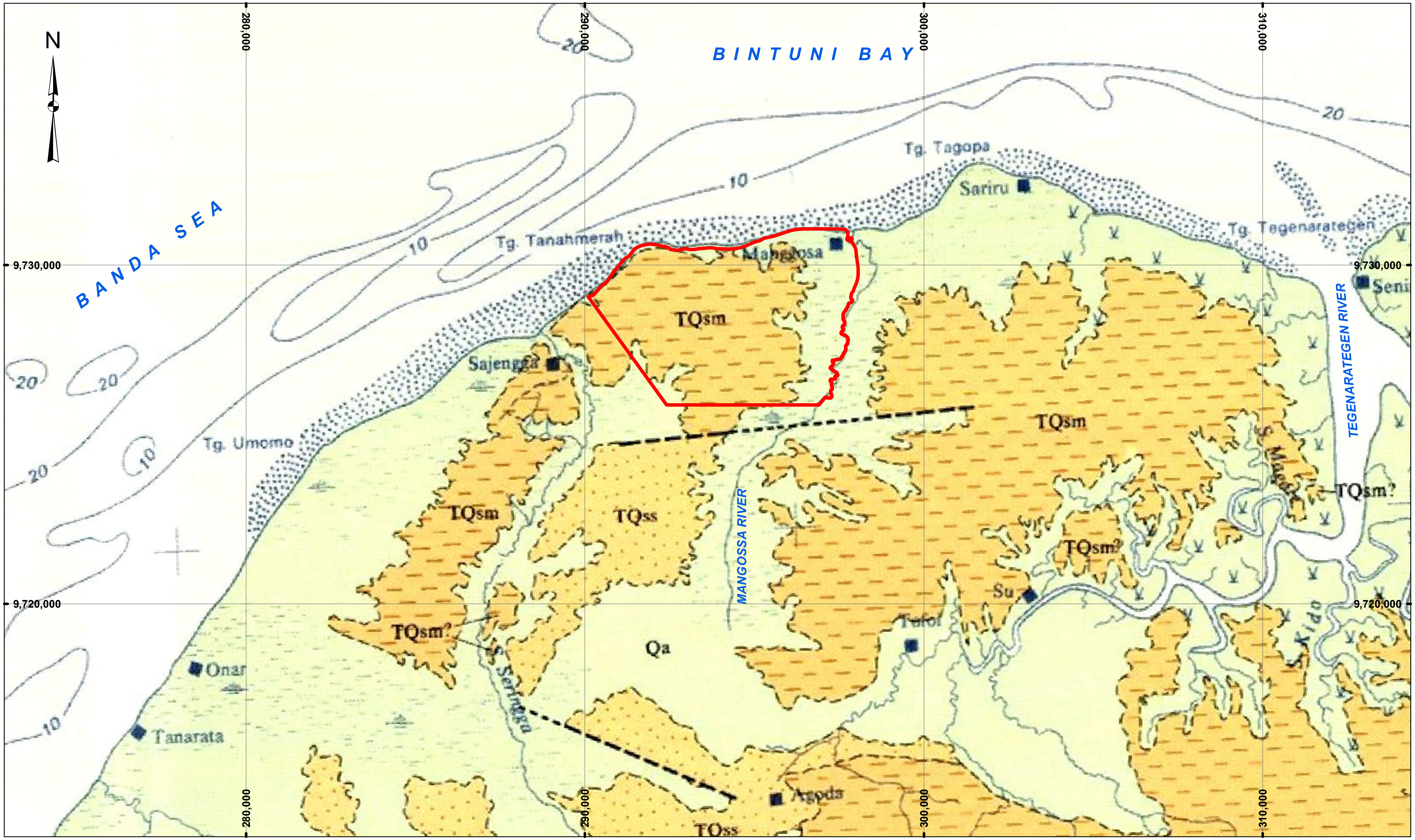

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Qa - Alluvial Sediments

TQss - Steenkool Formation Sand Dominated

TQsm - Steenkool Formation Clay Dominated

Tangguh property

Fault

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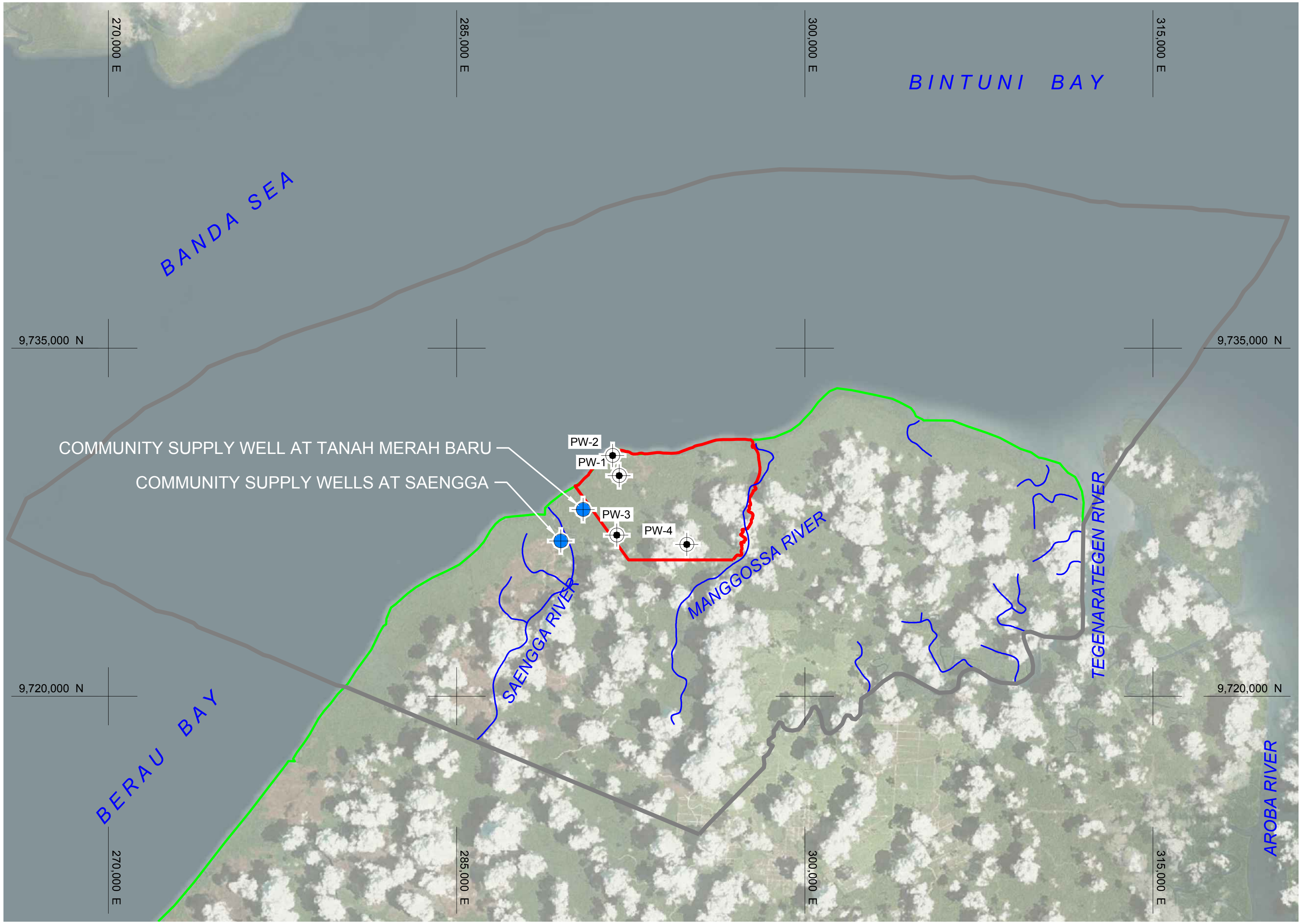

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- MODELLED PUMPING WELL LOCATIONS
- COMMUNITY WATER WELL LOCATION
- RIVER
- MODEL DOMAIN
- COASTLINE
- TANGGUH PROPERTY

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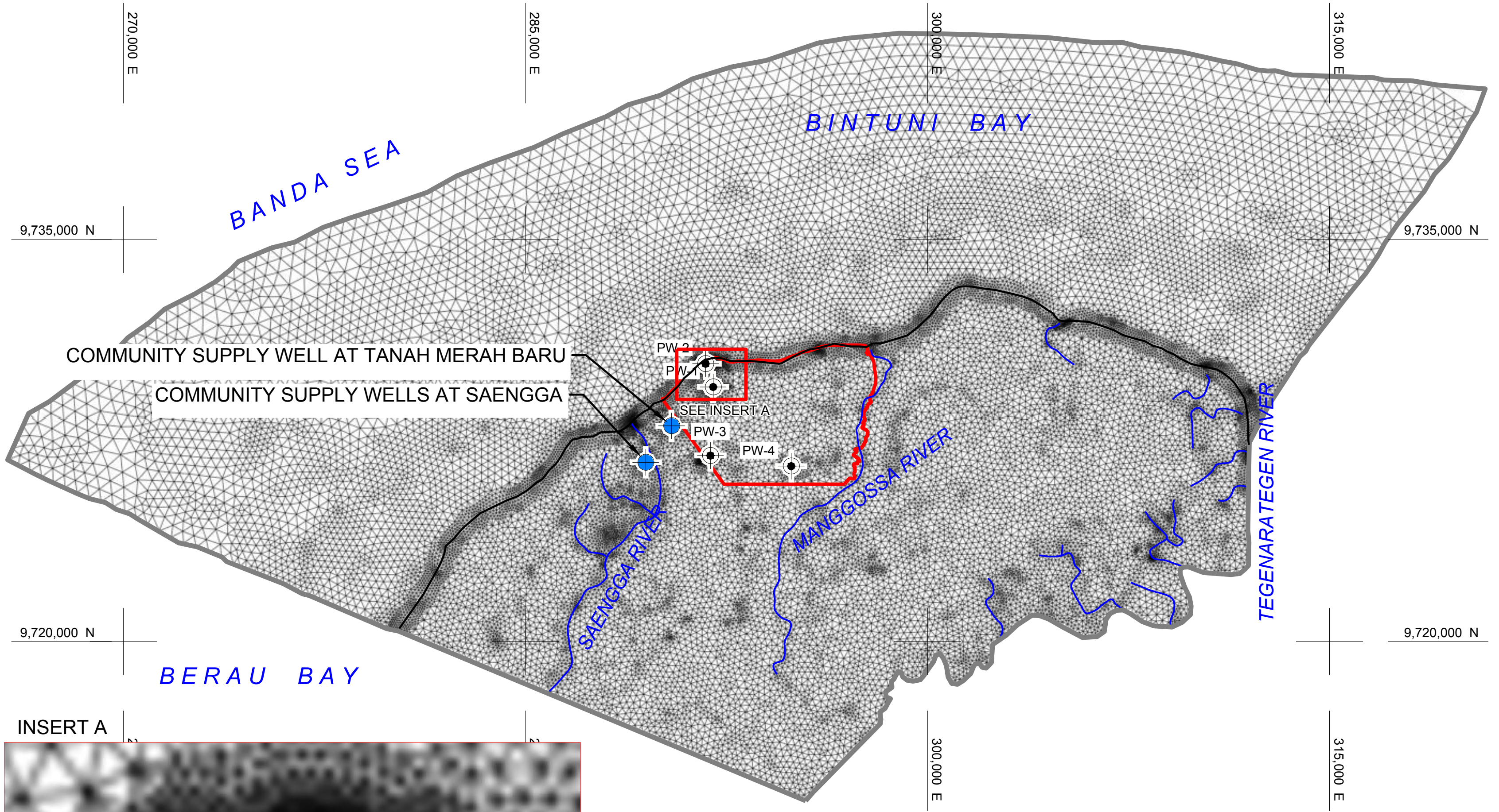

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- COASTLINE
- TANGGUH PROPERTY
- MODEL DOMAIN

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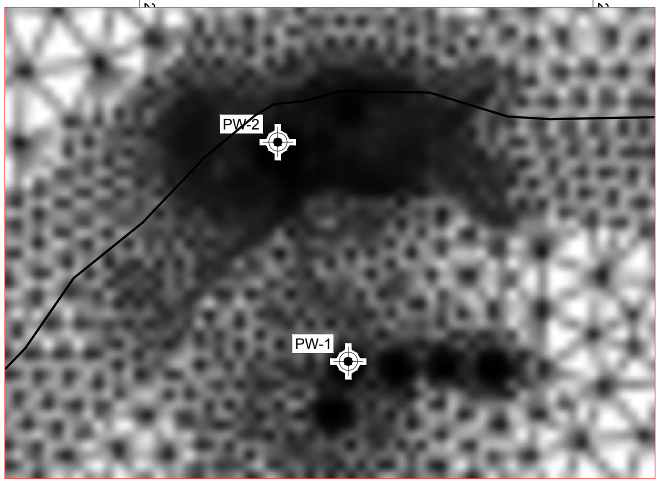

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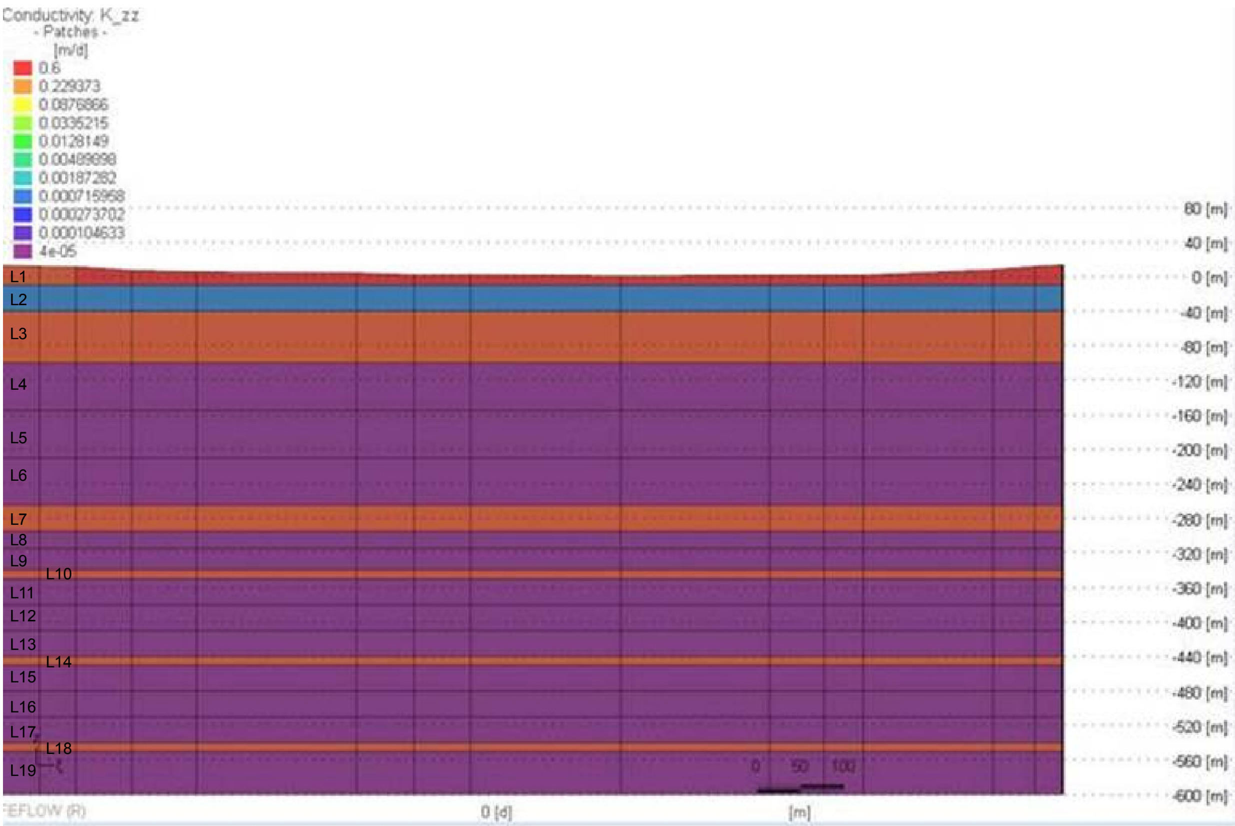
Hydrostratigraphic Unit	Model Layer	Hydraulic Properties				Thickness (m)
		K_x & K_y (m/d)	K_z (m/d)	S_y	S_s (m^{-1})	
Alluvial sediments	1	5.0	5.0	0.5	-	10
Upper Steenkool Formation – clay dominant	2	0.0086	0.00086	-	3.35×10^{-5}	30
Upper Steenkool Formation – sand dominant	3	4.0	0.4	-	5.05×10^{-6}	60
Upper Steenkool Formation – clay dominant	4	0.0004	0.00004	-	3.35×10^{-5}	55
	5	0.0004	0.00004	-	3.35×10^{-5}	55
	6	0.0004	0.00004	-	3.35×10^{-5}	55
Lower Steenkool Formation – sand dominant	7	4.0	0.4	-	5.05×10^{-6}	30
Lower Steenkool Formation – clay dominant	8	0.0004	0.00004	-	3.35×10^{-5}	20
	9	0.0004	0.00004	-	3.35×10^{-5}	25
Lower Steenkool Formation – sand dominant*	10*	4.0	0.4	-	5.05×10^{-6}	10
Lower Steenkool Formation – clay dominant	11	0.0004	0.00004	-	3.35×10^{-5}	30
	12	0.0004	0.00004	-	3.35×10^{-5}	30
	13	0.0004	0.00004	-	3.35×10^{-5}	30
Lower Steenkool Formation – sand dominant*	14*	4.0	0.4	-	5.05×10^{-6}	10
Lower Steenkool Formation – clay dominant	15	0.0004	0.00004	-	3.35×10^{-5}	30
	16	0.0004	0.00004	-	3.35×10^{-5}	30
	17	0.0004	0.00004	-	3.35×10^{-5}	30
Lower Steenkool Formation – sand dominant*	18*	4.0	0.4	-	5.05×10^{-6}	10
Lower Steenkool Formation – clay dominant	19	0.0004	0.00004	-	3.35×10^{-5}	50

Notes: * unproven aquifer included at the request of Tangguh LNG's Technical Advisor



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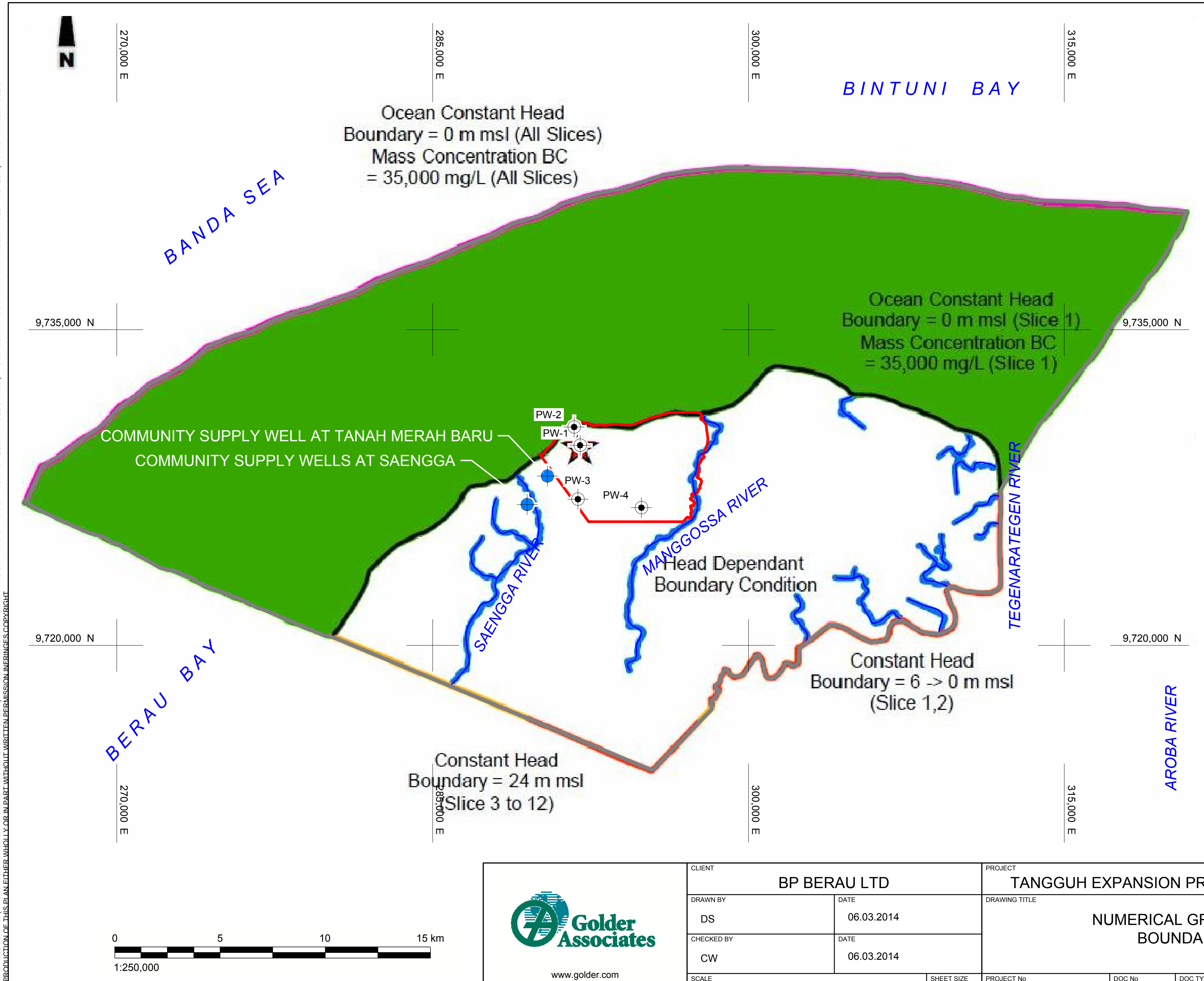

LEGEND

- Coastline

Boundary Conditions

- Constant Head
- Mass Concentration
- No Flow
- Ocean Constant Head
- Head Dependent

TANGGUH LNG PROPERTY

MODELLED PUMPING WELL LOCATIONS

COMMUNITY WATER WELL LOCATION

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Plot Date: 6 March 2014 Time:5:49:41 PM By: Suryadi, Dodi Path: J:\Water\2013\138716004-BP Tangguh\08Technical Doc\CAD\Figures\AMDAL - File Name:138716004-015-F-007-Rev1.dwg
Xref: xref-BP Property Boundary.dwg; rivers.DWG; GAP_LOGO-A3.dwg; NumericalConditions.JPG;

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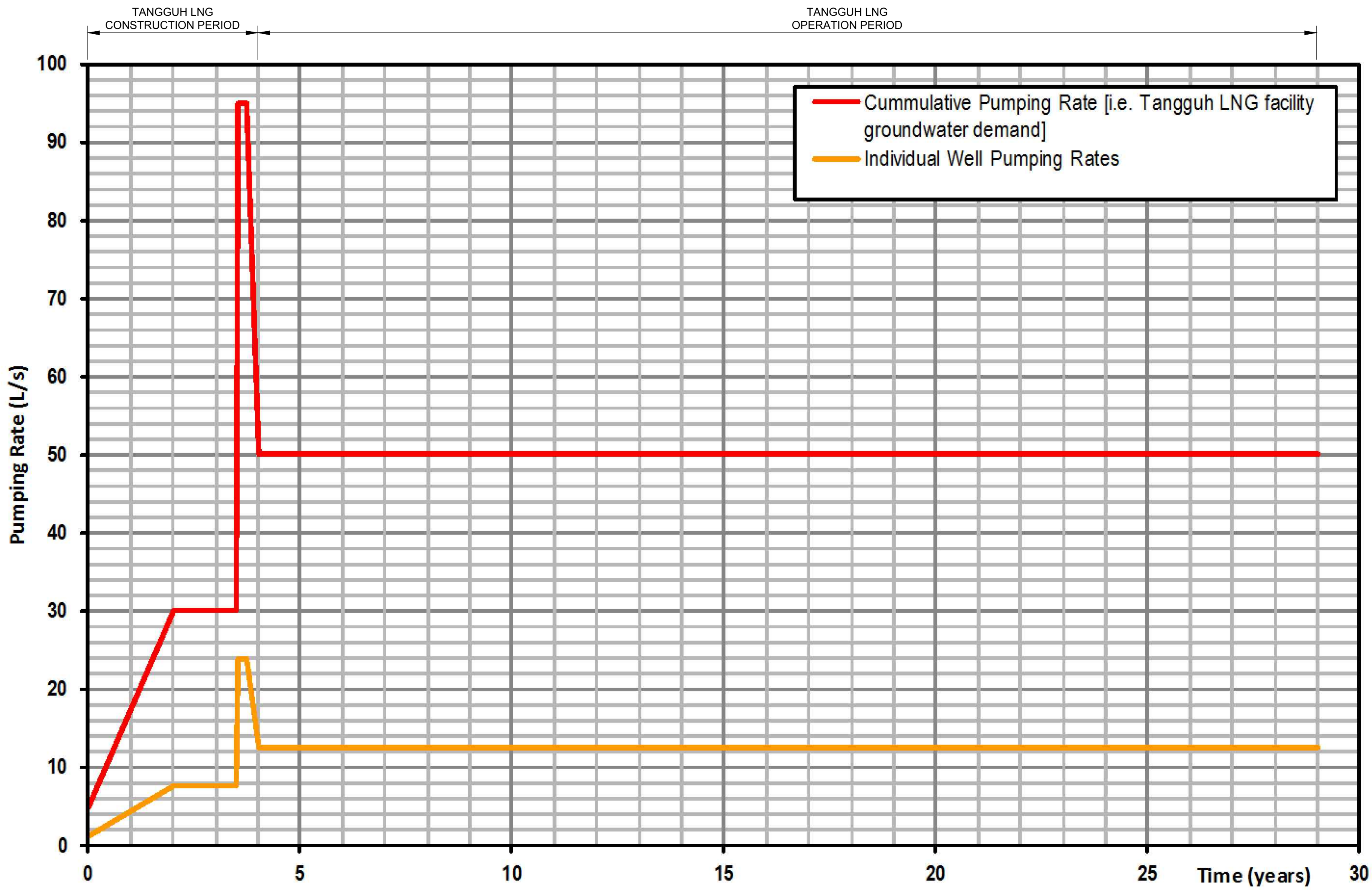

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	DRAWN BY DS	DATE 03.03.2014		DRAWING TITLE MODELLED WATER DEMAND AND PUMPING RATES				
	CHECKED BY CW	DATE 03.03.2014						
	SCALE AS SHOWN		SHEET SIZE A4	PROJECT No 138716004	DOC No 015	DOC TYPE F	FIGURE No F008	REVISION 1

FIGURE 8

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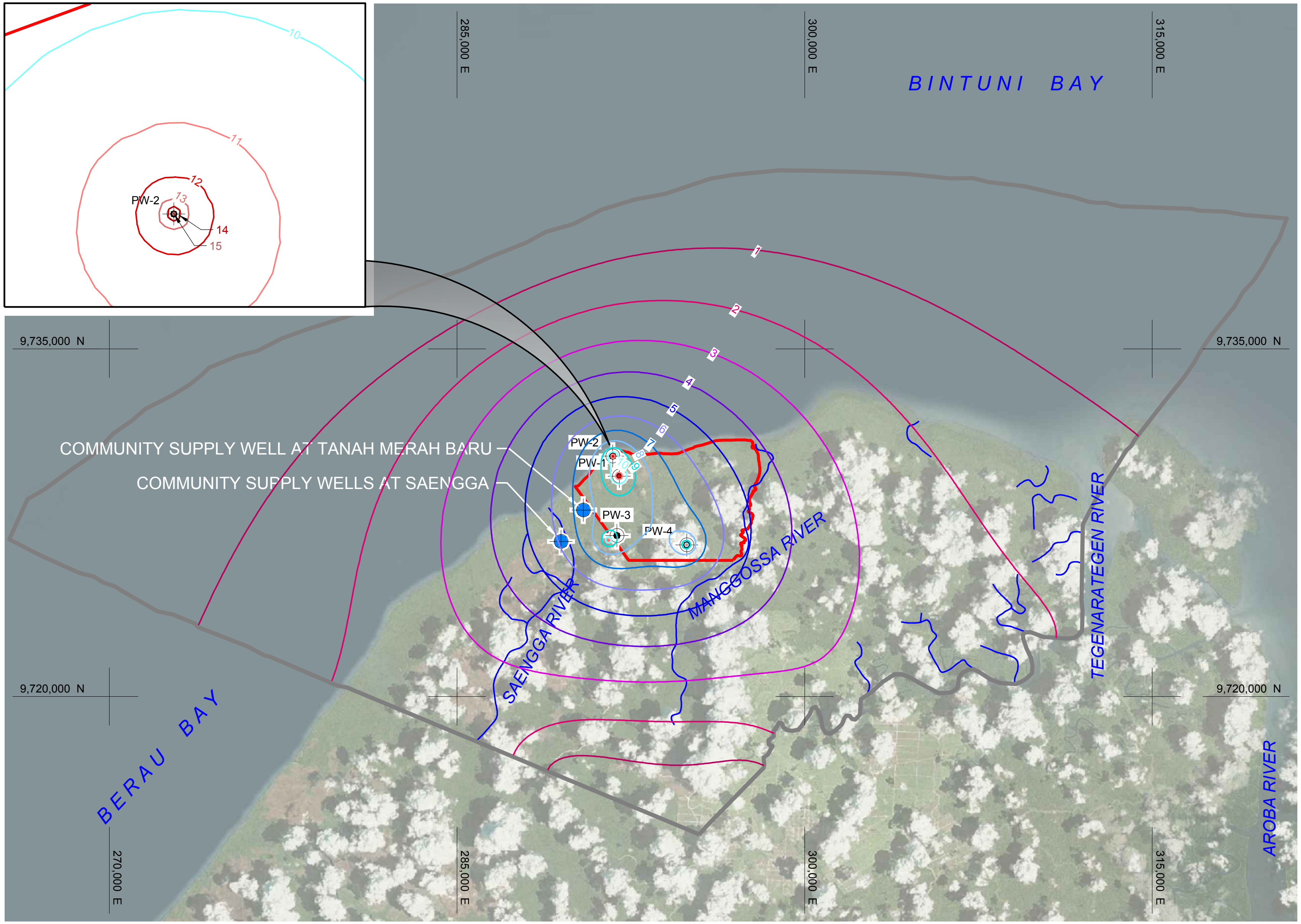

LEGEND

MODELLED PUMPING WELL LOCATIONS

COMMUNITY WATER WELL LOCATION

RIVER

MODEL DOMAIN

TANGGUH PROPERTY

DRAWDOWN (m)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

DRAWDOWN BASED ON PROPOSED PUMPING RATE WITHIN LOWER STEENKOOL AQUIFER

NOTE:

COORDINATE SYSTEM WGS 1984 UTM ZONE 53S

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0 5 10 15 km

1:250,000

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CLIENT		PROJECT				
BP BERAU LTD		TANGGUH EXPANSION PROJECT - GROUNDWATER STUDY				
DRAWN BY: DS	DATE: 03.03.2014	DRAWING TITLE: CALCULATED 29 YEAR DRAWDOWN WITHIN LOWER STEENKOOL FORMATION AQUIFER BASED ON PROPOSED PUMPING RATE WITHIN THE LOWER STEENKOOL FORMATION AQUIFER				
CHECKED BY: CW	DATE: 03.03.2014					
SCALE: AS SHOWN	SHEET SIZE: A4	PROJECT No: 138716004	DOC No: 015	DOC TYPE: F	FIGURE No: F009	REVISION: 1

FIGURE 9

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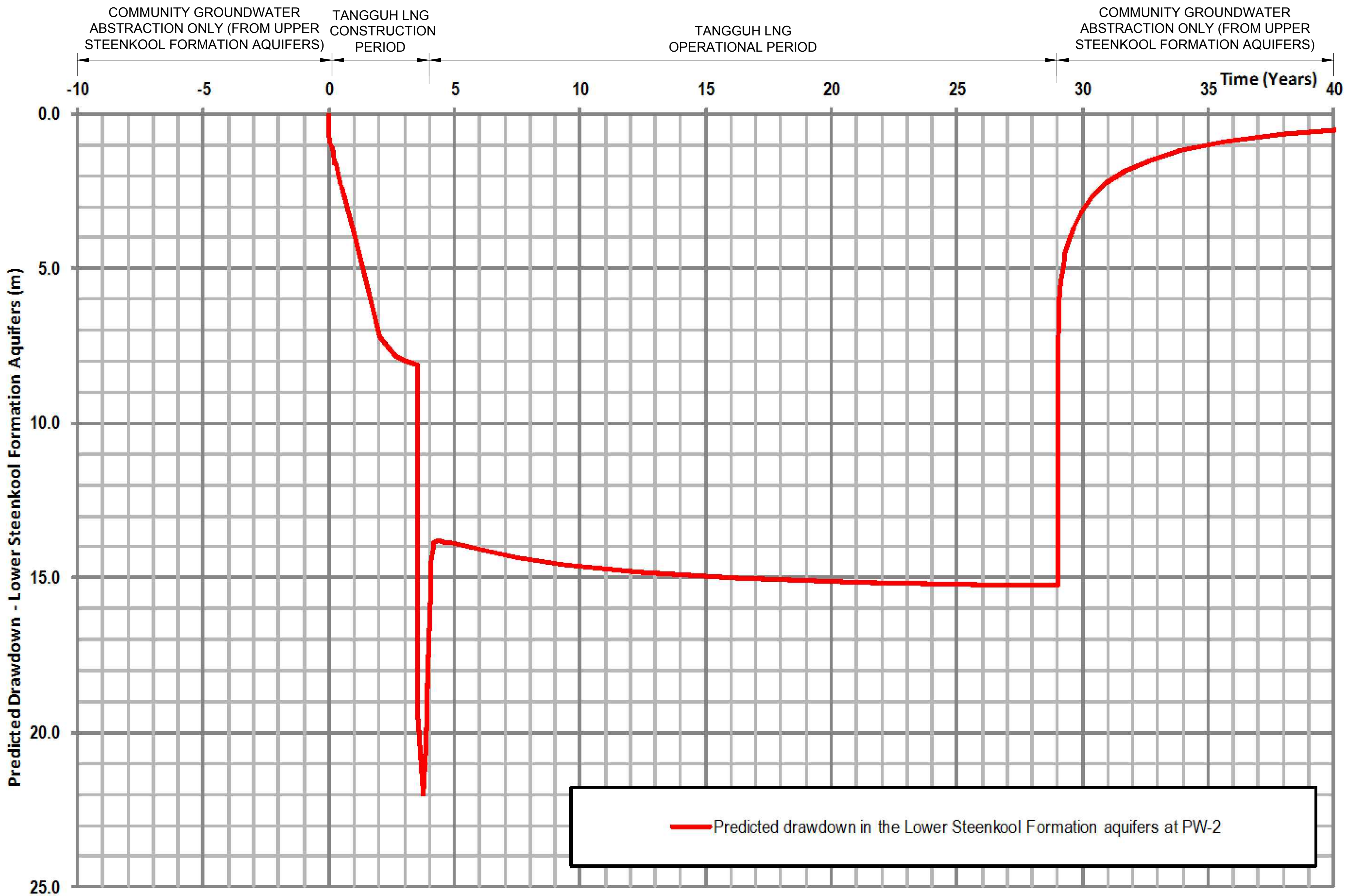
Xref: xref-BP Property Boundary.dwg; rivers.DWG; GAP_LOGO-A3.dwg; XREF_Fig 10 Fem15_DD_25yrs_LwrStkl.dwg; XREF_DD ComBP Lower Stkl 25yrs.dwg; XREF-20140305_DD Lay7 CommBP 25yrs HiRes.dwg; XREF20140307_DD Lay7 CommBP 29yrs HiRes.dwg; 138716004-013-F001-Rev0-F015.jpg; Calculated-Upper25Year.PNG;



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	DRAWN BY DS	DATE 08.04.2014		DRAWING TITLE PREDICTED WATER LEVEL CHANGES IN THE LOWER STEENKOOL FORMATION AT PW-2 DUE TO PLANNED BP ABSTRACTIONS FROM THE LOWER STEENKOOL FORMATION AQUIFERS			
	CHECKED BY CW	DATE 08.04.2014					
	SCALE AS SHOWN		SHEET SIZE A4	PROJECT No 138716004	DOC No 015	DOC TYPE F	FIGURE No F010 / REVISION 2 / FIGURE 10

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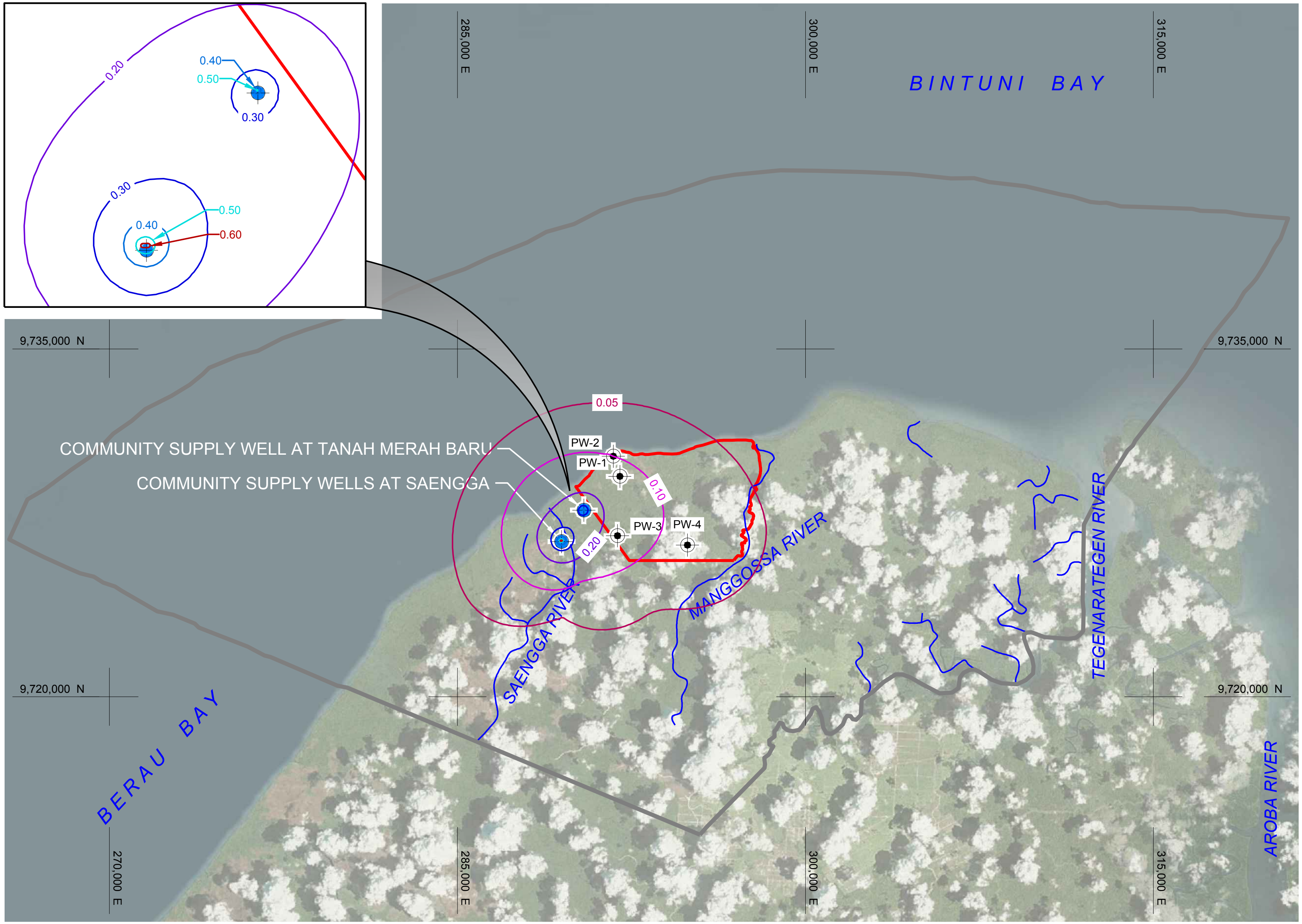

LEGEND

MODELLED PUMPING WELL LOCATIONS

COMMUNITY WATER WELL LOCATION

RIVER

MODEL DOMAIN

TANGGUH PROPERTY

DRAWDOWN (m)

0.05
0.10
0.20
0.30
0.40
0.50
0.60

NOTE:
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0 5 10 15 km

1:250,000

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KLIEN	BP BERAU LTD	PROYEK	TANGGUH EXPANSION PROJECT - GROUNDWATER STUDY
DIGAMBAR OLEH: DS	TANGGAL: 07.03.2014	JUDUL GAMBAR	CALCULATED 29 YEAR DRAWDOWN WITHIN UPPER STEENKOOL FORMATION AQUIFER BASED ON PROPOSED TANGGUH LNG PUMPING RATE WITHIN THE LOWER STEENKOOL FORMATION AQUIFER AND GROUNDWATER PUMPING FROM THE WATER SUPPLY WELLS AT TANAH MERAH BARU AND SAENGGA
DIPERIKSA OLEH: CW	TANGGAL: 07.03.2014		

SKALA	UKURAN	NOMOR PROYEK	NOMOR DOCUMEN	TIPE DOKUMEN	NOMOR GAMBAR	REVISI	
AS SHOWN	A4	138716004	015	F	F011	1	FIGURE 11

Plot Date: 7 March 2014 Time:6:35:44 PM By: Supriyatno, Eko Path: E:\Projects\138716004-BP Tangguh\CAD\Figures\AMDAL - File Name:138716004-015-F-011-Rev1A.dwg
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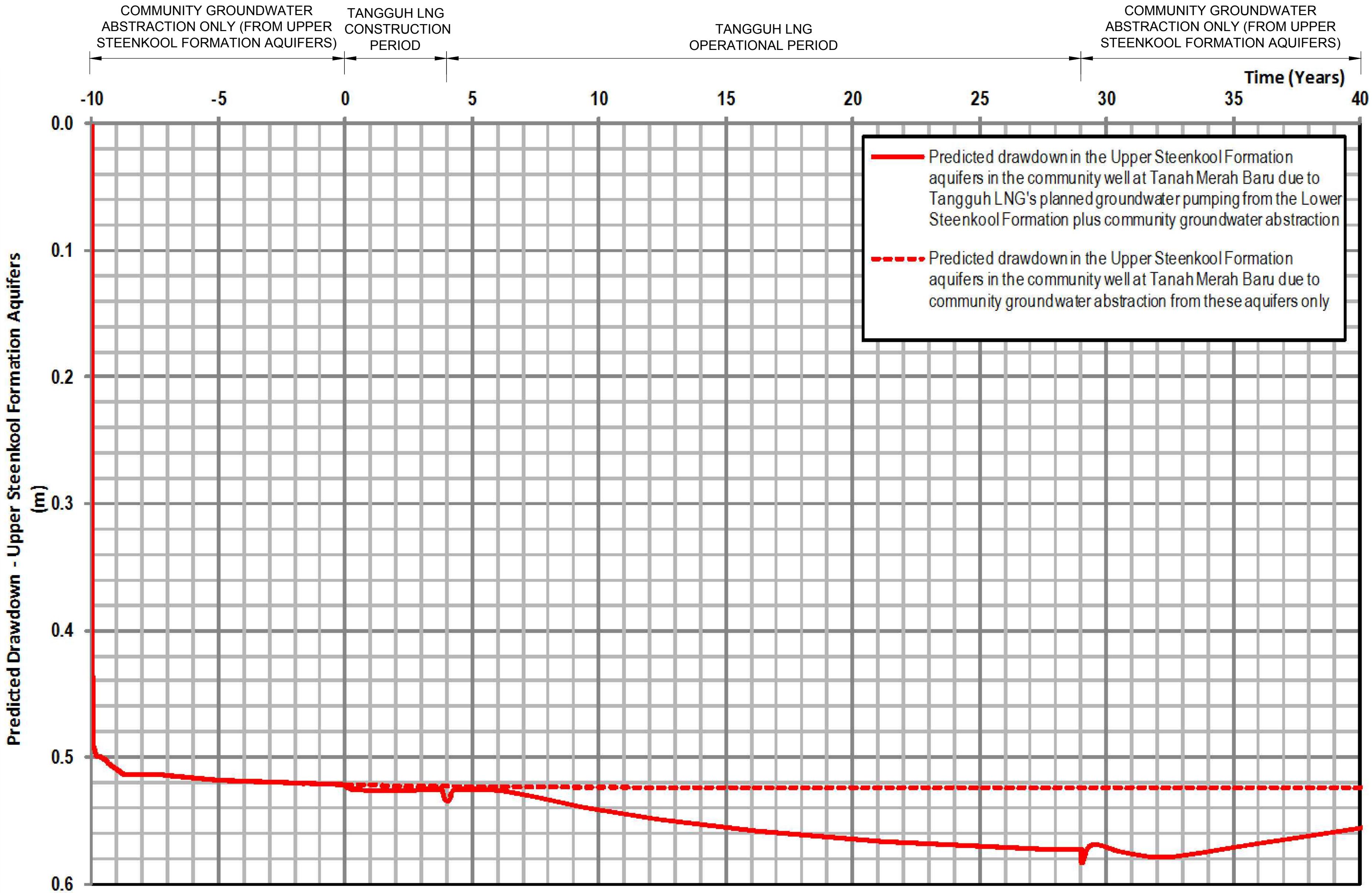

Golder Associates	CLIENT: BP BERAU LTD		PROJECT: TANGGUH EXPANSION PROJECT - GROUNDWATER STUDY			
	DRAWN BY: DS	DATE: 08.04.2014	DRAWING TITLE: PREDICTED WATER LEVEL CHANGES IN THE UPPER STEENKOOL FORMATION AT THE COMMUNITY SUPPLY WELL AT TANAH MERAH BARU			
	CHECKED BY: CW	DATE: 08.04.2014				
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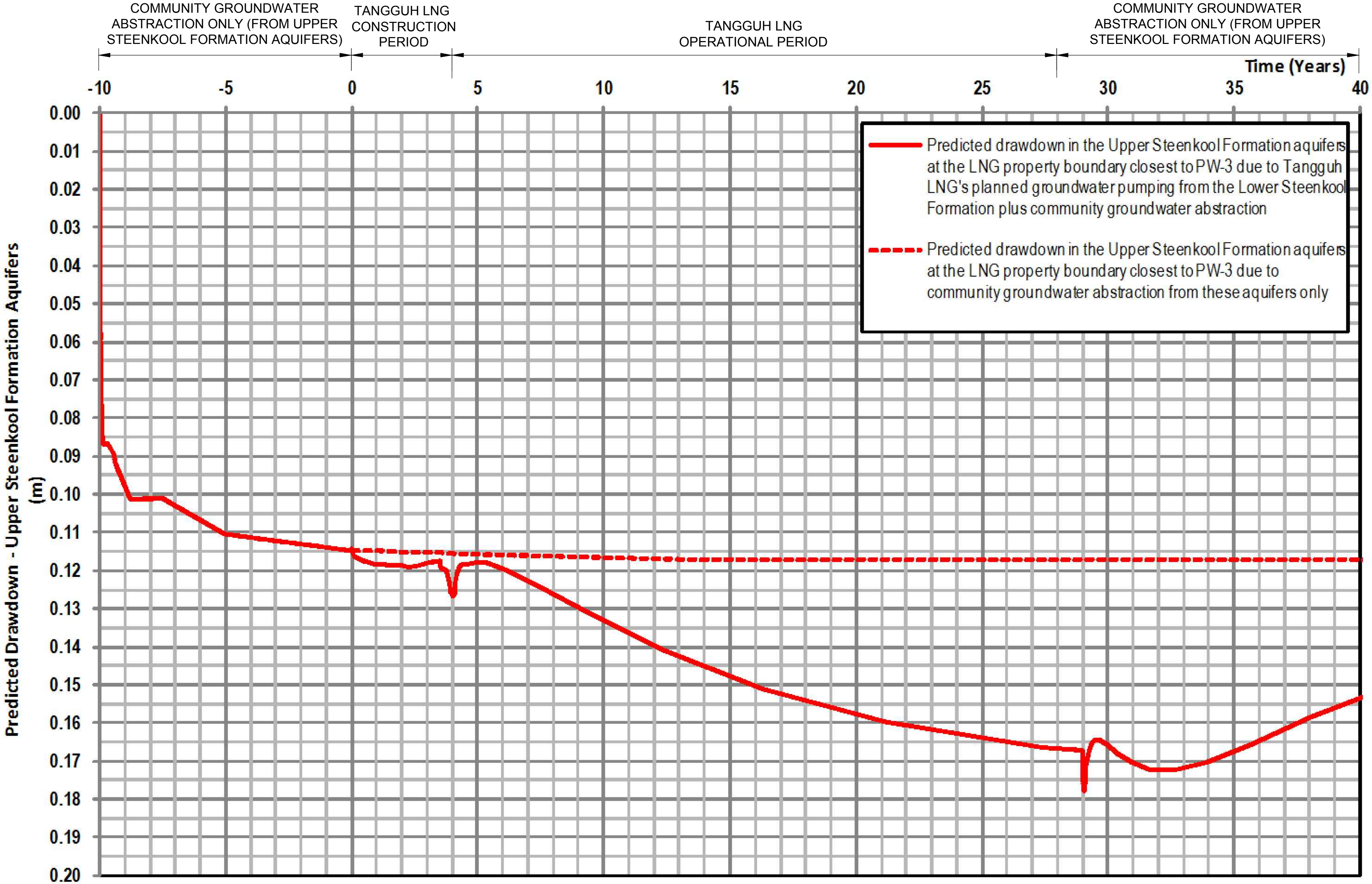

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	DRAWN BY: DS	DATE: 08.04.2014		DRAWING TITLE: PREDICTED WATER LEVEL CHANGES IN THE UPPER STEENKOOL FORMATION AT THE TANGGUH LNG PROPERTY BOUNDARY NEAR PW-3			
	CHECKED BY: CW	DATE: 08.04.2014					
	SCALE: AS SHOWN		SHEET SIZE: A4	PROJECT No: 138716004	DOC No: 015	DOC TYPE: F	FIGURE No: F013 / REVISION: 2 / FIGURE 13

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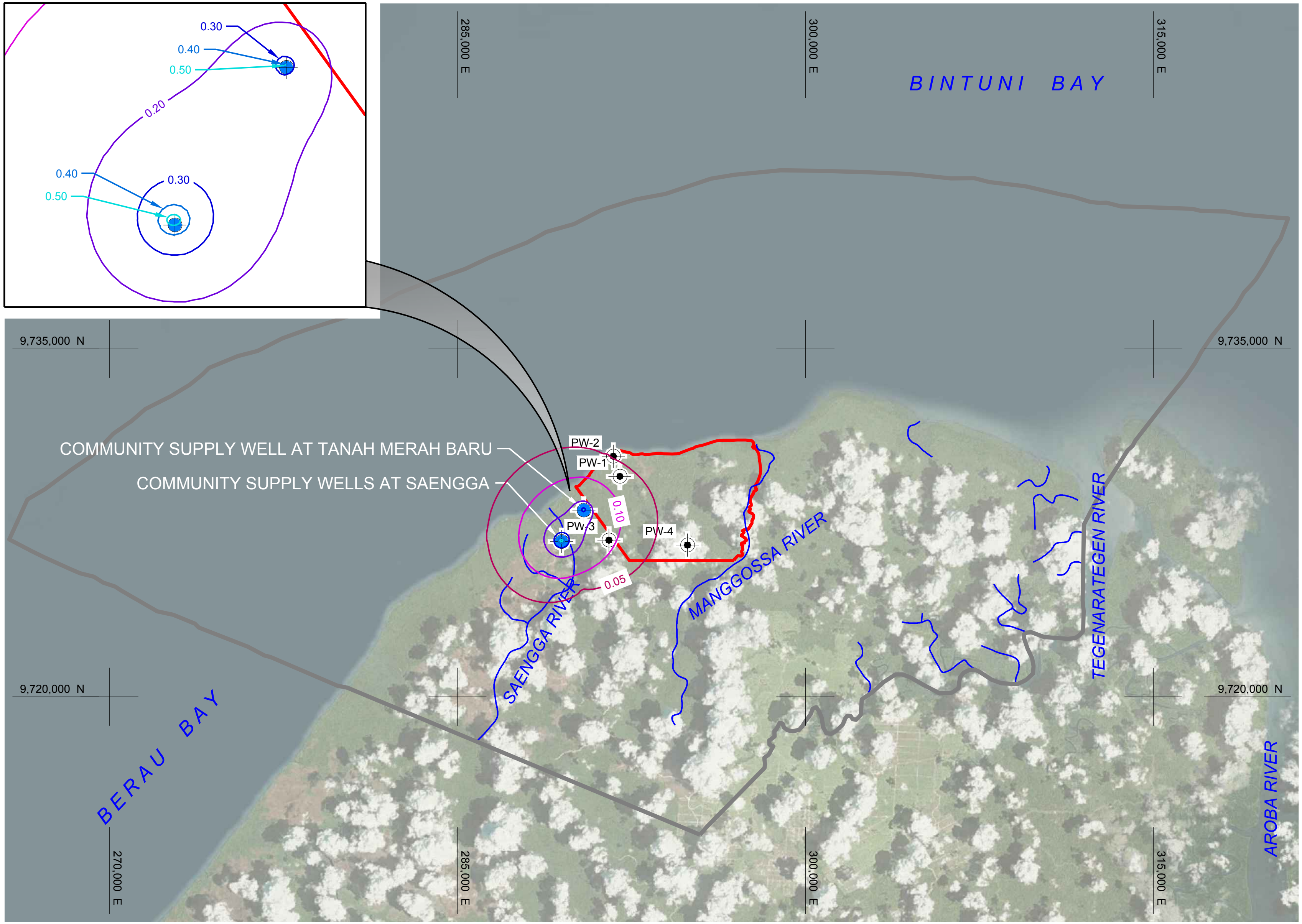

LEGEND

- PUMPING WELL LOCATIONS
- PROPOSED WELLS
- RIVER
- MODEL DOMAIN
- TANGGUH PROPERTY

DRAWDOWN (m)

- 0.05
- 0.10
- 0.20
- 0.30
- 0.40
- 0.50
- 0.60

ESTIMATED MAXIMUM DRAWDOWN OF 0.57 m IN COMMUNITY SUPPLY WELL AT TANAH MERAH BARU.

NOTE:
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0 5 10 15 km

1:250,000

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CLIENT		PROJECT
BP BERAU LTD		TANGGUH EXPANSION PROJECT - GROUNDWATER STUDY
DRAWN BY: DS	DATE: 07.03.2014	DRAWING TITLE: CALCULATED 29 YEARS DRAWDOWN WITHIN UPPER STEENKOOL FORMATION AQUIFER BASED ON COMMUNITY PUMPING ONLY
CHECKED BY: CW	DATE: 07.03.2014	

SCALE	SHEET SIZE	PROJECT No	DOC No	DOC TYPE	FIGURE No	REVISION	
AS SHOWN	A4	138716004	015	F	F014	1	FIGURE 14

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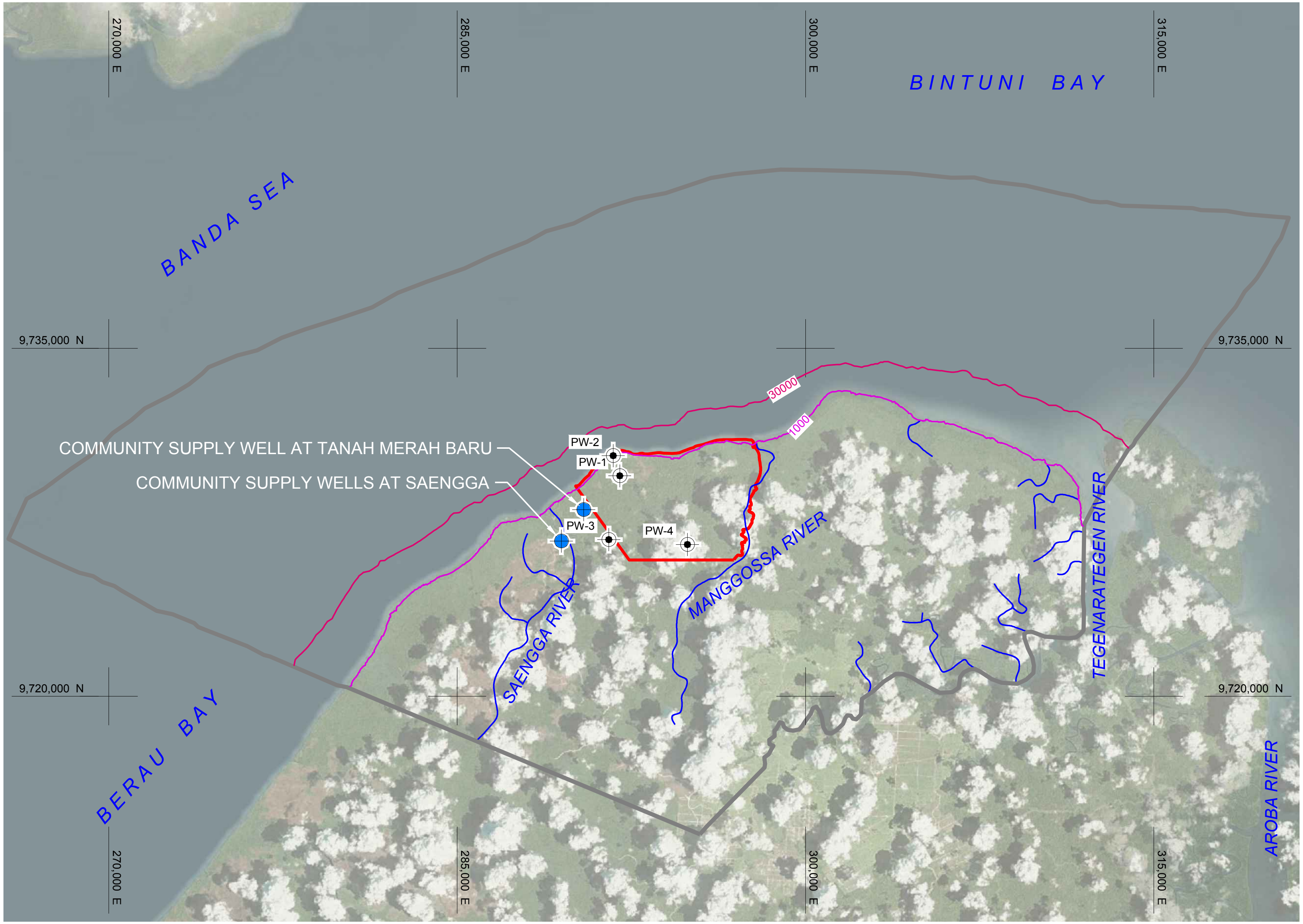
Xref: xref-BP Property Boundary.dwg; rivers.DWG; GAP_LOGO-A3.dwg; XREF_FIG 14 Fem15_SWI_25yrs_LwrStkl.dwg; XREF_Salinity Base ComBP Lay7 25yrs.dwg; XREF_DD ComOnly Upper Stkl 25yrs.dwg; XREF-20140307_DD Lay3 Comm 29yrs HiRes.dwg; 138716004-013-F001-Rev0-F015.jpg; Calculated-Upper25Year.PNG;



LEGEND

MODELLED PUMPING WELL LOCATIONS

COMMUNITY WATER WELL LOCATION

RIVER

MODEL DOMAIN

TANGGUH PROPERTY

SALINITY (mg/L)

30000

1000

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0 5 10 15 km

1:250,000

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CLIENT		PROJECT					
BP BERAU LTD		TANGGUH EXPANSION PROJECT - GROUNDWATER STUDY					
DRAWN BY: DS	DATE: 07.03.2014	DRAWING TITLE: MASS CONCENTRATION ISOLINES SHOWING PREDICTED SALINITY CONCENTRATIONS IN THE UPPER STEENKOOL FORMATION AQUIFERS AFTER 29 YEARS OF PUMPING FROM BOTH COMMUNITY WELLS AND TANGGUH LNG'S PROPOSED GROUNDWATER WELLS					
CHECKED BY: CW	DATE: 07.03.2014						
SCALE: AS SHOWN	SHEET SIZE: A4	PROJECT No: 138716004	DOC No: 015	DOC TYPE: F	FIGURE No: F015	REVISION: 1	FIGURE 15

Plot Date: 13 March 2014 Time:8:55:12 AM By: Supriyatno, Eko Path: J:\Water\2013\138716004-BP Tangguh\08Technical Doc\CAD\Figures\AMDAL - File Name:138716004-015-F-015-Rev1 SALINITY LAYER3.dwg
Xref: xref-BP Property Boundary.dwg; rivers.DWG; GAP_LOGO-A3.dwg; XREF_FIG 14 Fem15_SWI_25yrs_LwrStkl.dwg; XREF_Salinity Base ComBP Lay7 25yrs.dwg; XREF_DD ComOnly Upper Stkl 25yrs.dwg; XREF-20140306_Base Salinity Layer3 ComBP.dwg; 138716004-013-F001-Rev0-F015.jpg; Calculated-Upper25Year.PNG;

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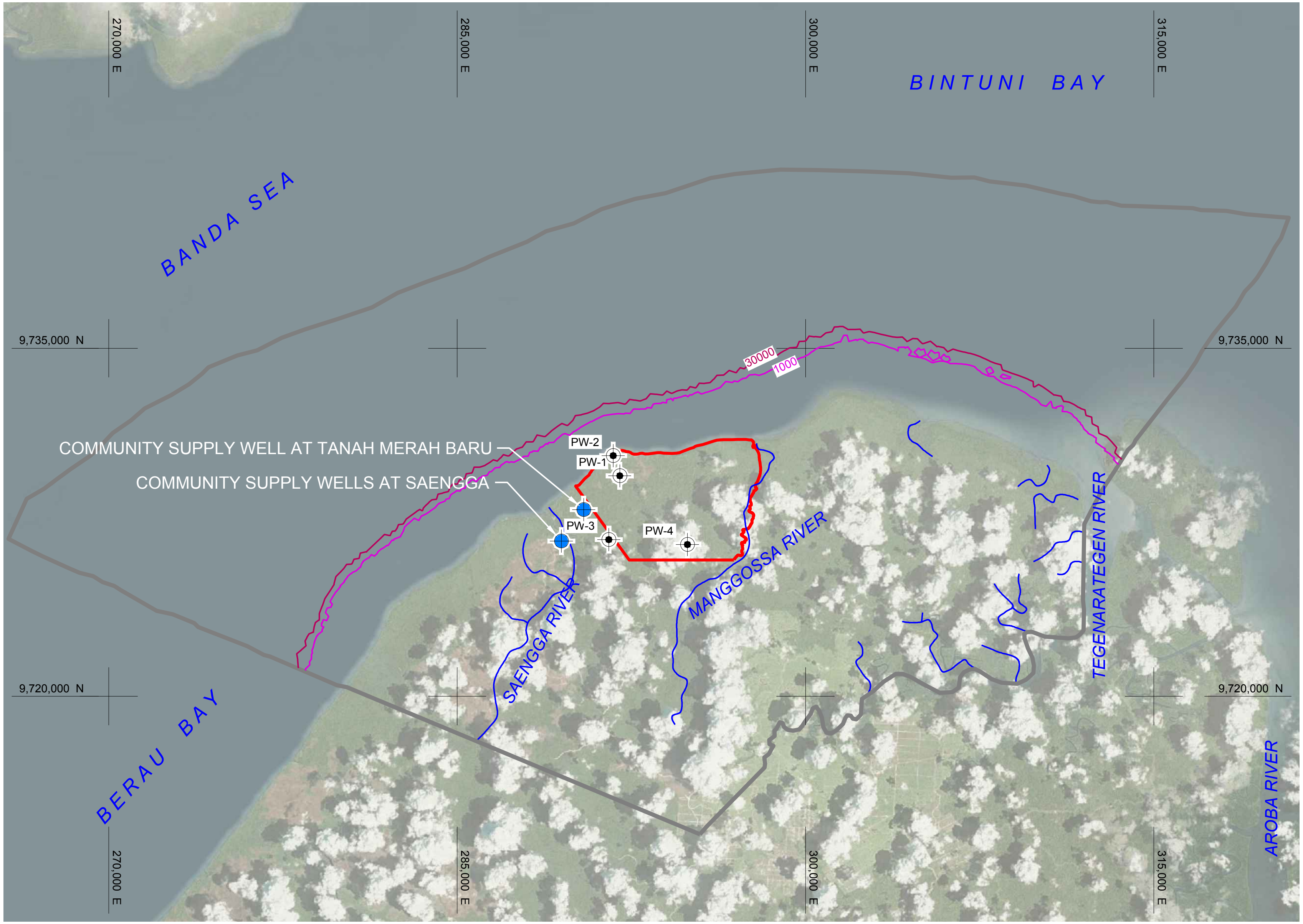

LEGEND

- MODELLED PUMPING WELL LOCATIONS
- COMMUNITY WATER WELL LOCATION
- RIVER
- MODEL DOMAIN
- TANGGUH PROPERTY

SALINITY (mg/L)

- 30000
- 1000

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0 5 10 15 km
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CLIENT: BP BERAU LTD		PROJECT: TANGGUH EXPANSION PROJECT - GROUNDWATER STUDY	
DRAWN BY: DS	DATE: 07.03.2014	DRAWING TITLE: MASS CONCENTRATION ISOLINES SHOWING PREDICTED SALINITY CONCENTRATIONS IN THE LOWER STEENKOOL FORMATION AQUIFERS AFTER 29 YEARS OF PUMPING FROM BOTH COMMUNITY WELLS AND TANGGUH LNG'S PROPOSED GROUNDWATER WELLS	
CHECKED BY: CW	DATE: 07.03.2014		
SCALE: AS SHOWN	SHEET SIZE: A4	PROJECT No: 138716004	DOC No: 015
DOC TYPE: F	FIGURE No: F016	REVISION: 1	FIGURE 16

Plot Date: 13 March 2014 Time:8:58:44 AM By: Supriyatno, Eko Path: J:\Water\2013\138716004-BP Tangguh\08Technical Doc\CAD\Figures\AMDAL - File Name:138716004-015-F-016-Rev1 SALINITY LAYER 7.dwg
Xref: xref-BP Property Boundary.dwg; rivers.DWG; GAP_LOGO-A3.dwg; XREF_FIG 14 Fem15_SWI_25yrs_LwrStkl.dwg; XREF_Salinity Base ComBP Lay7 25yrs.dwg; XREF_DD ComOnly Upper Stkl 25yrs.dwg; XREF-20140306_Base Salinity Layer7 ComBP.dwg; 138716004-013-F001-Rev0-F015.jpg; Calculated-Upper25Year.PNG;

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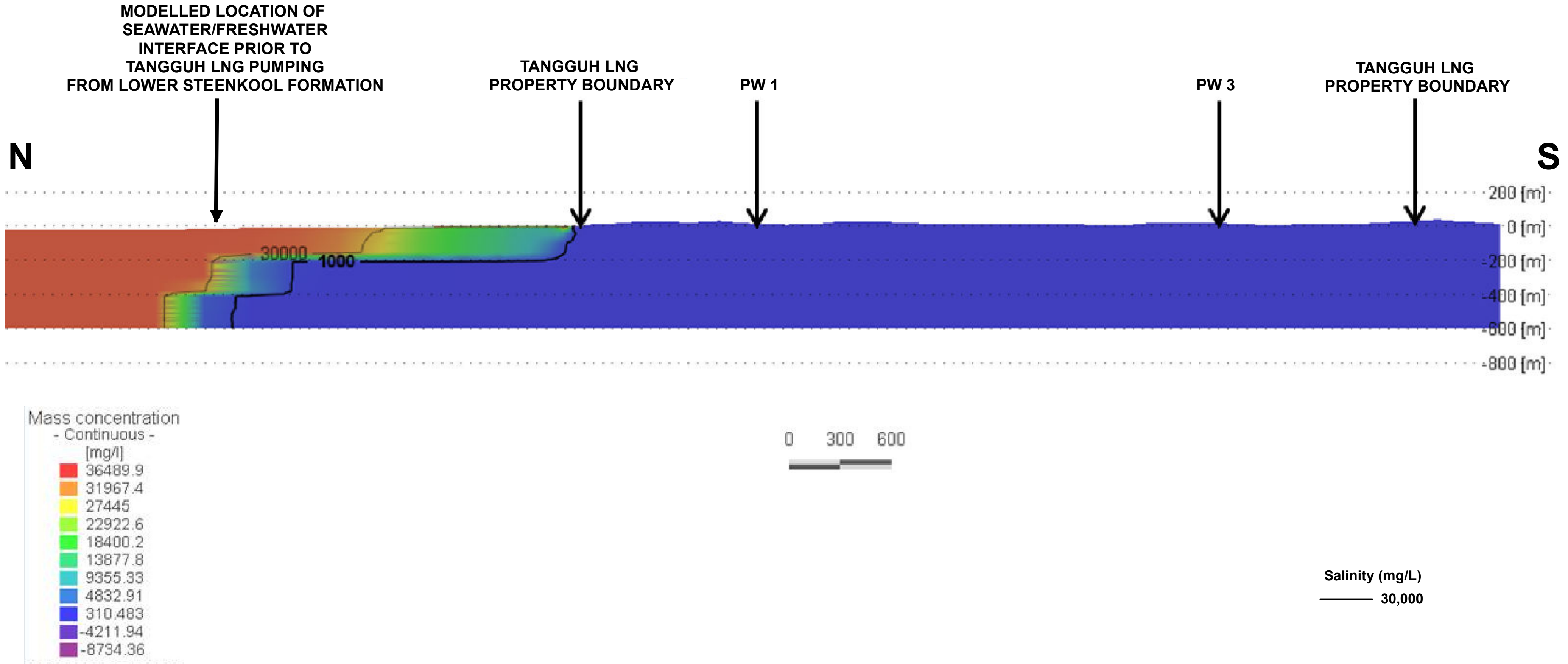
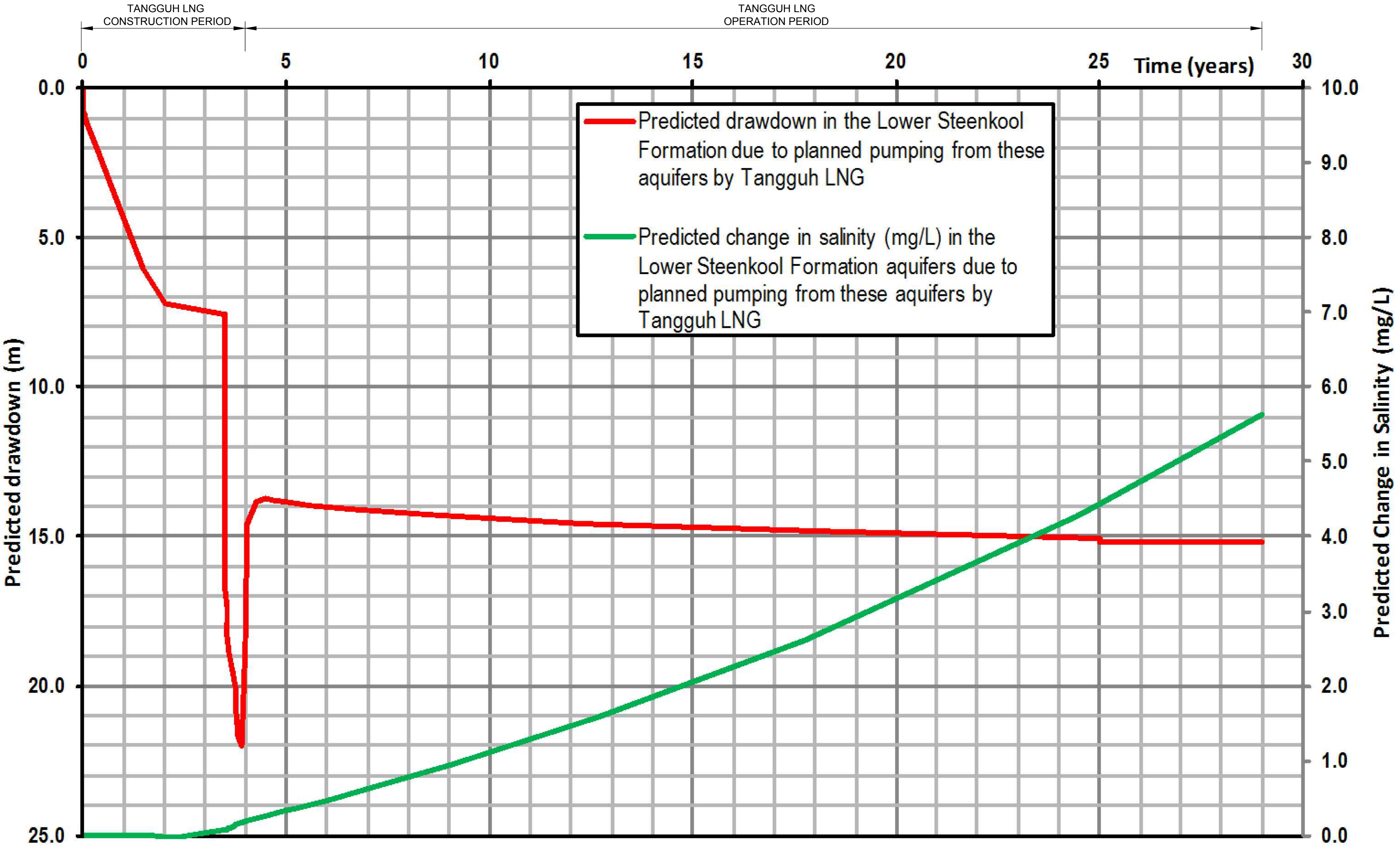


Golder Associates	CLIENT: BP BERAU LTD	PROJECT: TANGGUH LNG EXPANSION PROJECT - GROUNDWATER STUDY
www.golder.com GOLDER ASSOCIATES	DRAWN BY: NDL; DATE: 10/04/2014	DRAWING TITLE: SALINITY CROSS SECTION AT TANGGUH LNG FACILITY AND BINTUNI BAY AFTER 29 YEARS OF PUMPING
	CHECKED BY: CW; DATE: 10/04/2014	
	SCALE: NTS; SHEET SIZE: A4	PROJECT No: 138716004; DOC No: 015; DOC TYPE: F; FIGURE No: 17; REVISION: 0; FIGURE 17

Date Saved: 10/04/2014 9:38:50 AM User: NLestari Path: J:\Water\2013\138716004-BP Tangguh\08Technical Doc\GIS\Project\Arcgis\2014-04-03\138716004-015-F-017-Rev1.mxd



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CLIENT: BP BERAU LTD		PROJECT: TANGGUH EXPANSION PROJECT - GROUNDWATER STUDY	
DRAWN BY: DS	DATE: 06.03.2014	DRAWING TITLE: PREDICTED CHANGE IN SALINITY (mg/L) IN THE LOWER STEENKOOL FORMATION AT PW-2 DUE TO PLANNED PUMPING FROM THESE AQUIFERS BY TANGGUH LNG	
CHECKED BY: CW	DATE: 06.03.2014		
SCALE: AS SHOWN	SHEET SIZE: A4	PROJECT No: 138716004 / DOC No: 015 / DOC TYPE: F / FIGURE No: F018 / REVISION: 1	FIGURE 18

Plot Date: 7 March 2014 Time:5:02:04 PM By: Inayati, Laila Path: J:\Water\2013\138716004-BP Tangguh\08Technical Doc\CAD\Figures\AMDAL - File Name:138716004-015-F-017-Rev1 TABLE.dwg
Xref: GAP_LOGO-A3.dwg;

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solutions@golder.com
www.golder.com

Golder Associates (PT Geotechnical & Environmental Services Indonesia)
10th Floor, Graha Paramita
JI. Denpasar, Block D-2
Kuningan, Jakarta 12940
Indonesia
T: +62 21 252 1975

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