CHAPTER II
ENVIRONMENTAL BASELINE

2.1 GEOPHYSICS AND CHEMISTRY

2.1.1 Climate and Meteorology

Climate is defined as average condition of physical elements of the atmosphere over a long period, from tens to millions of years (IPCC, 2001). The World Meteorological Organization (2003) explains that the classic period to determine climate in a region is 30 years. However, based on the study by Coumou (2011), the duration of climate data of ten years is considered sufficient to illustrate the climatic condition in tropical areas due to the relatively homogenous climate fluctuation. Thus the climate condition of Tangguh LNG, located on the Southern Shore of Bintuni Bay waters in Teluk Bintuni Regency, West Papua Province, is illustrated using climate elements with minimal period of ten years. Physical elements of atmosphere that are used to analyze the climate condition in Tangguh LNG consist of rainfall, humidity, air temperature, evapotranspiration, wind speed and wind direction.

Physical elements of the atmosphere consist of humidity, air temperature, wind speed and direction in Tangguh LNG area are analysed using data obtained from AERMET MM5 Worldwide Meteorological Data in the project site at coordinates 2,4° S and 133,1° E as shown in **Map II-1**. This is due to the fact that the nearest meteological stations to the Tangguh LNG area are located quite far, in Fakfak Meteorology Station (± 105 km) and Manokwari Meteorology Station (± 206 km). Additionally, the availability of data (temperature, air humidity, pressure as well as wind direction and speed) at the meteorology station located at AWS (Automatic Weather System) Sierra Bravo in the Tangguh LNG area is less than 50%. Therefore, it is considered that the station is not representative for the condition of atmospheric physical elements at the project location.

Data of atmospheric physical elements in the form of rainfall is acquired from TRMM (Tropical Rainfall Measuring Mission) radar type 3A12 V7 in the period from 1998 to 2012 through http://disc.sci.gsfc.nasa.gov/precipitation/tovas supported by rainfall data from Lister (2002) to analyze rainfall of the region around Tangguh LNG.

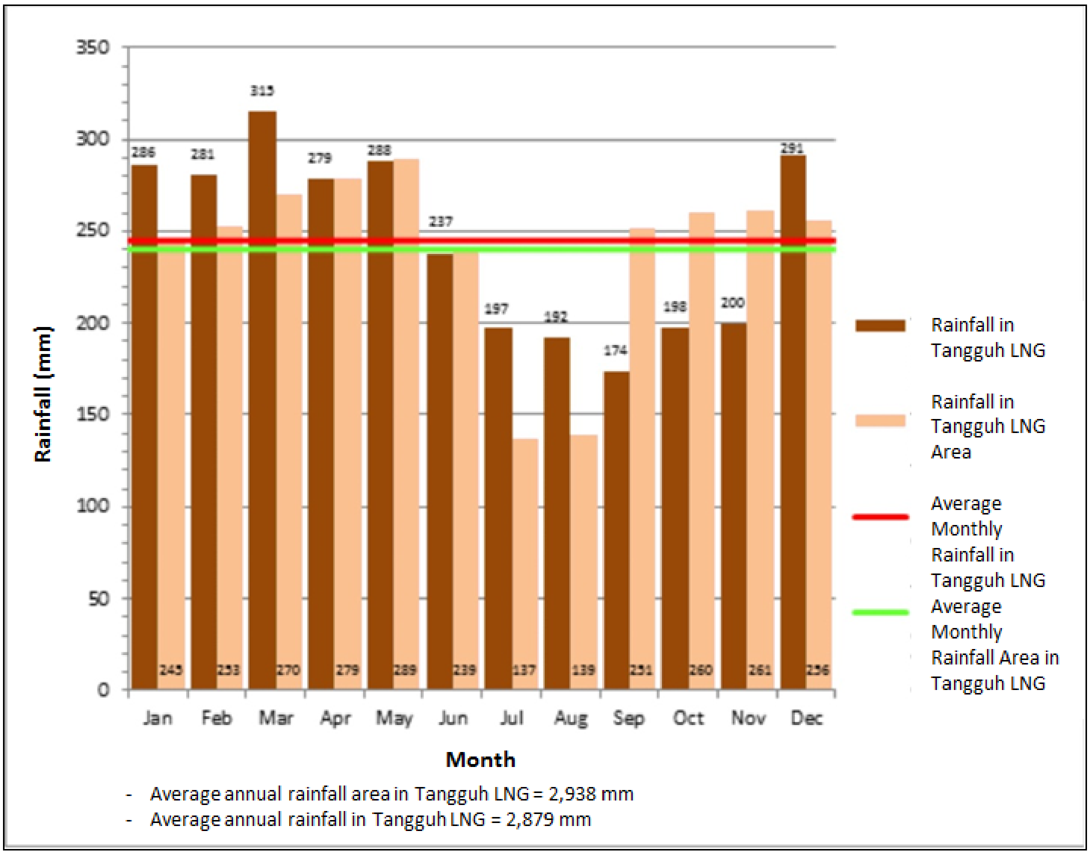
As observation data, rainfall data of Fakfak Meteorology Station (1958-1983 and 2004-2008) as well as Manokwari Meteorology Station (1998-2011) are used as found in **Appendix II.6 Meteorology Data**. The next phase is to perform calibration and validation toward the radar data using the observation data.

Unlike the five other atmospheric physical elements, evapotranspiration data in the Tangguh LNG area is acquired from estimation using Aquastat based on the study made by Lister (2002).

2.1.1.1 Rainfall

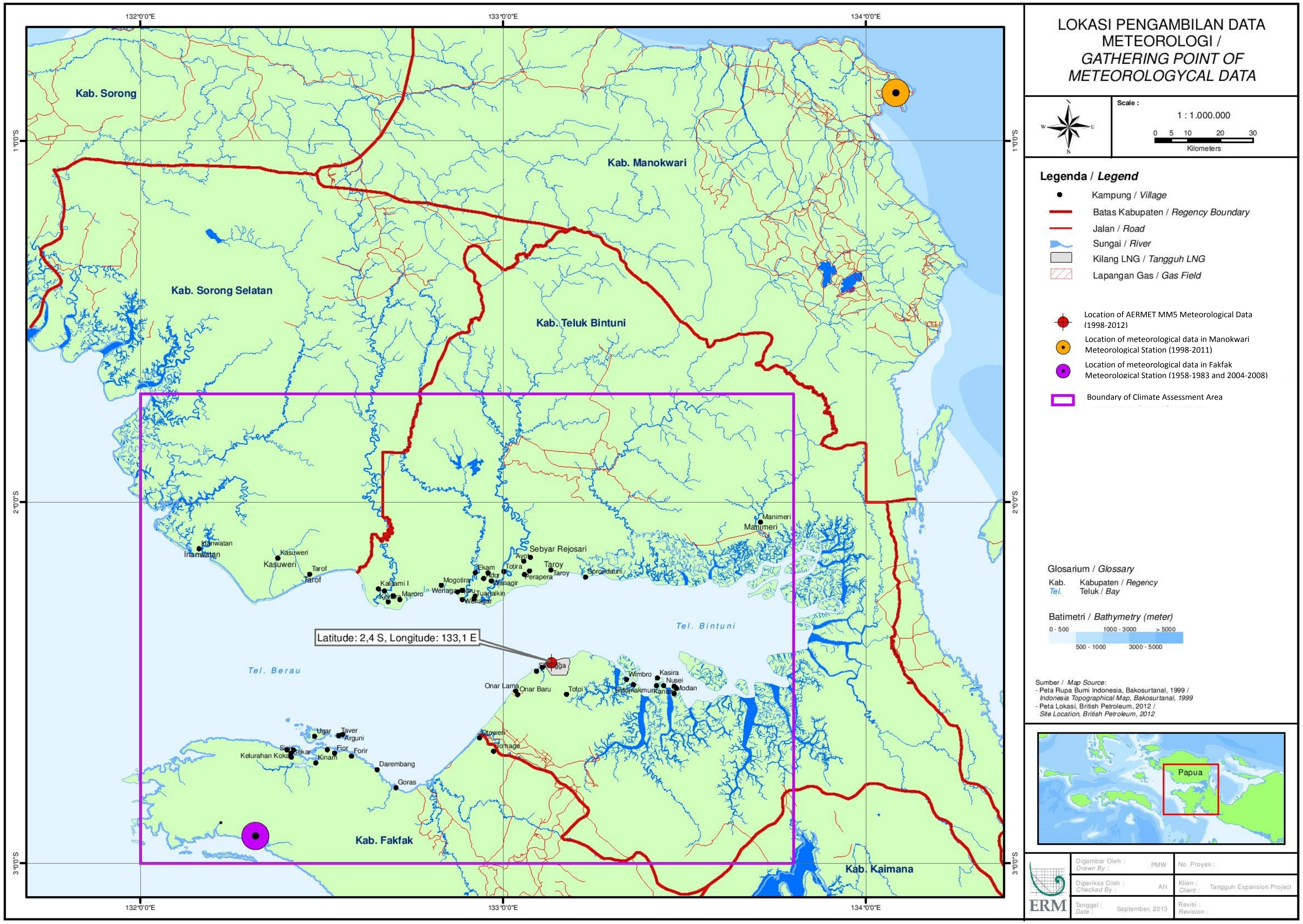
From data processing using TRMM radar data and observation data at Fakfak and Manokwari meteorology stations as well as Lister (2002), average monthly regional rainfall for 1998 – 2012 were obtained at coordinates 132° -133,8° E and 1,7° – 3,0° S as well as point rainfall at coordinates 2,4° S and 133,1° E as shown in **Figure II-1.**

Figure II-2 and **Figure II-4** illustrate spatial rainfall distribution around the project site, while **Figure II-3** portrays rainfall distribution in Indonesia. Referring to **Figure II-1 and Figure II-3** it may be seen that average regional monthly rainfall in Tangguh LNG during a 14 years period was 240 mm with lowest rainfall occured in the months of July and August. Highest regional rainfall occurred in the month of May, reaching 288 mm. Referring to **Figure II-1, Figure II-2 and Figure II-4** and supported by **Figure II-3**, it is shown that the rainfall type at the project location is local type rainfall.



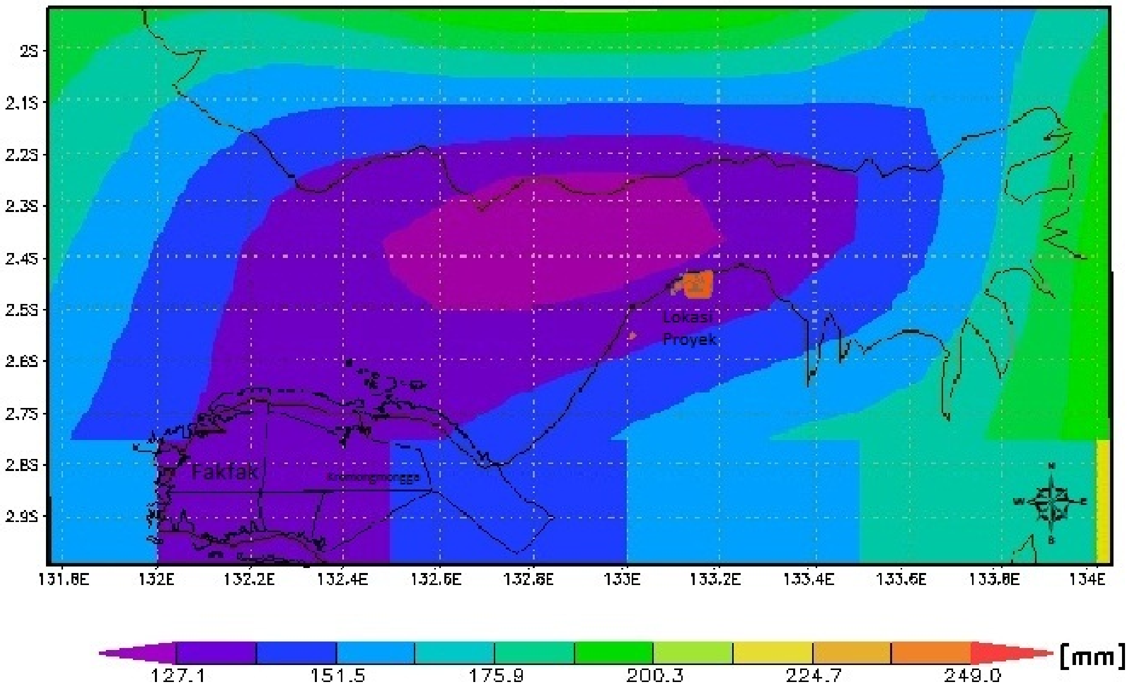
Source : Radar TRMM (Tropical Rainfall Measuring Mission) tipe 3A12 V7 (http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=TRMM_Monthly), Lister (2002)

Figure II-1 Rainfall Pattern in the Tangguh LNG Area (132,0° -133,8° E and 1,7° – 3,0° S) and Point Rainfall Pattern at Tangguh LNG (2,4° S and 133,1° E)



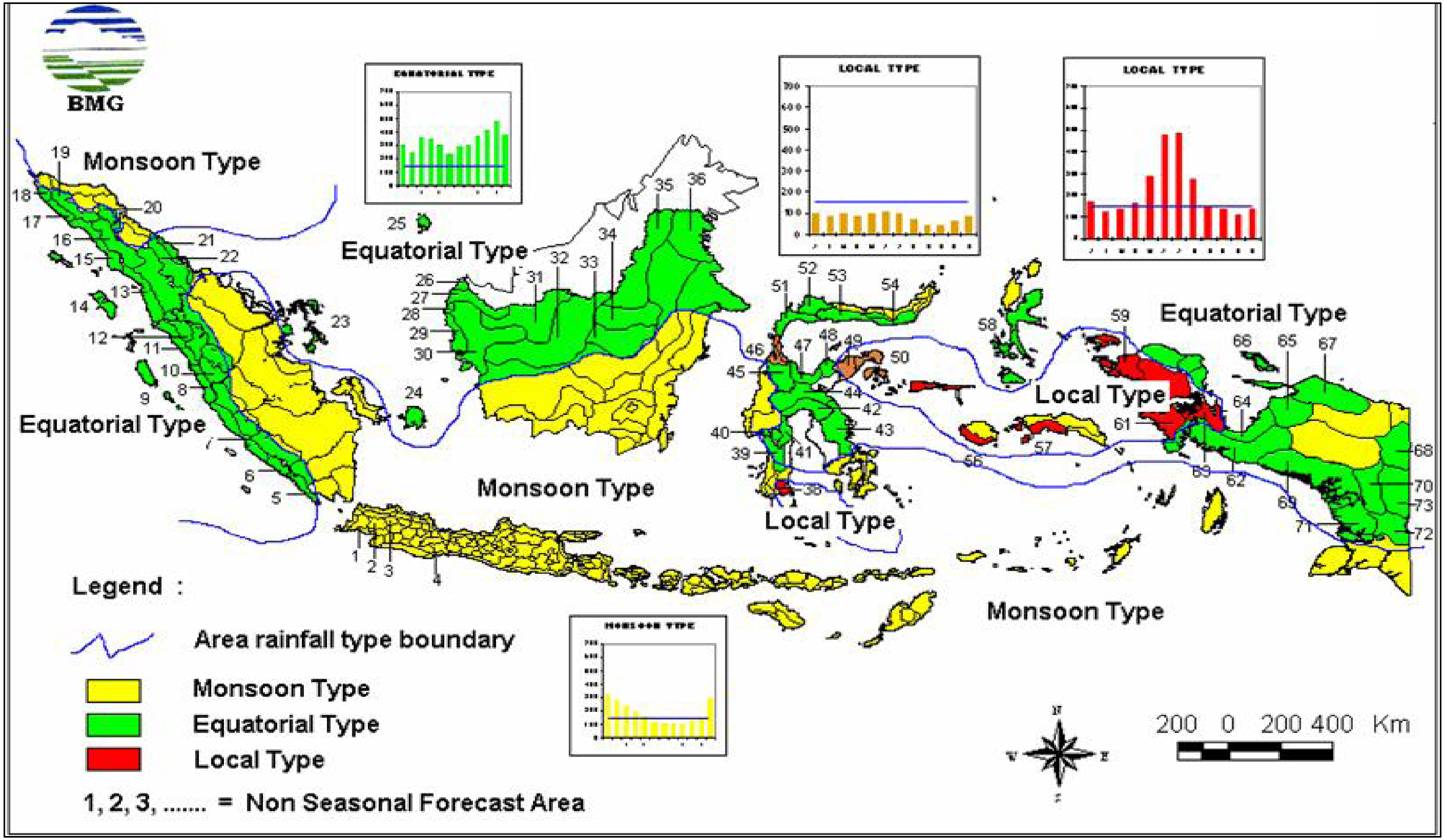
Map II-1 Meteorological Data Locations

Local type rainfall is characterized by unimodial rainfall pattern (one peak rain) referring to **Figure II-1 and Figure II-4**. Regional rainfall at coordinates 132,0° - 133,8° E and 1,7° – 3,0° S with local type believed to be caused by the influence of physical environment condition. Physical influence may be expanse of water or sea, high mountains and intensive local warming (Tukidin, 2010). Overall, rainfall in the vicinity of Tangguh LNG is very high with average annual rainfall of 2.938 mm.



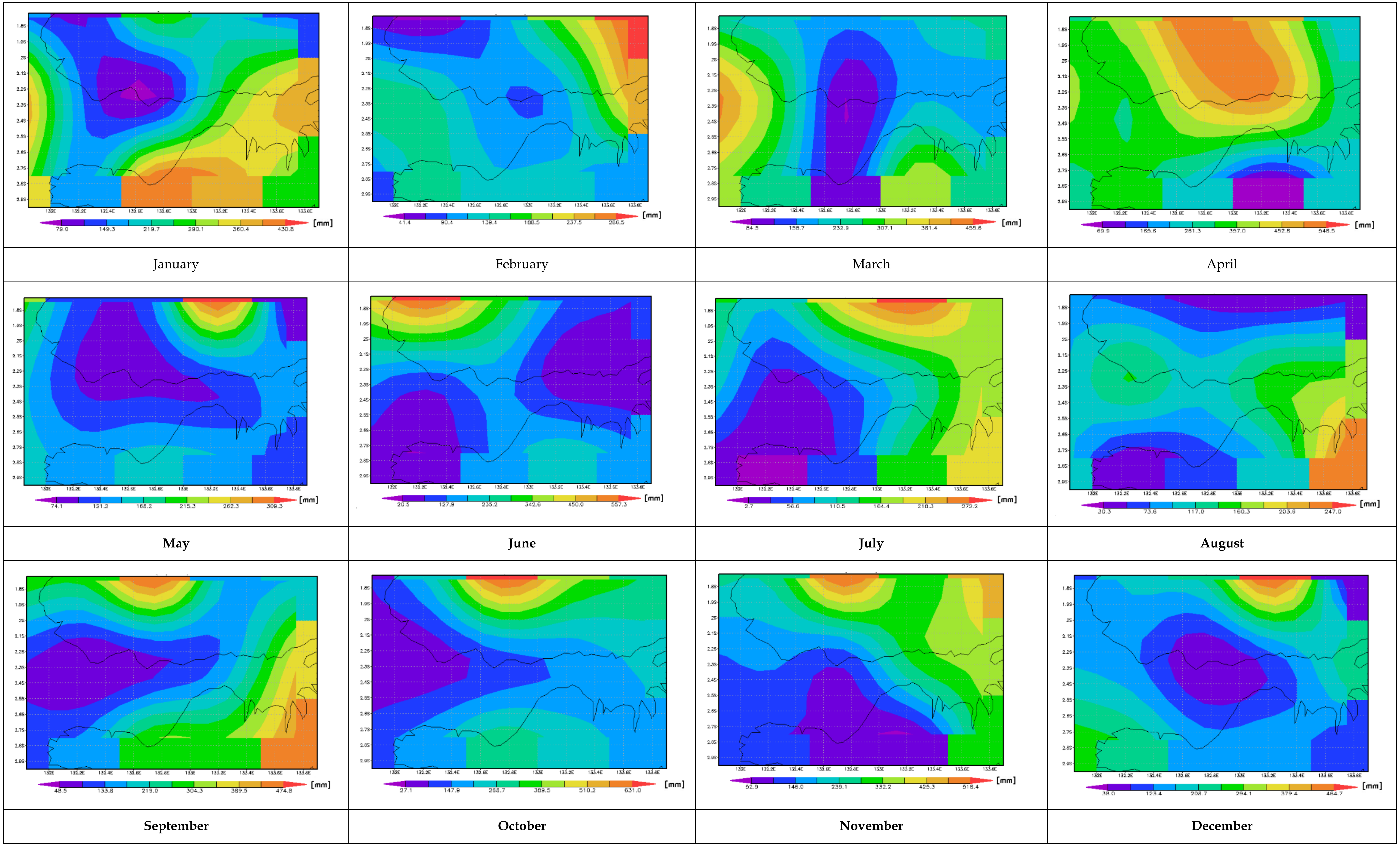
Source : TRMM (Tropical Rainfall Measuring Mission) Radar type 3B43, 3A12 and 3A25 V7

Figure II-2 Spatial Distribution of Average Monthly Rainfall over a 14 Year Period (1998 – 2012) in the Bintuni Bay Area



Source : TRMM (Tropical Rainfall Measuring Mission) Radar type 3A12 V7

Figure II-3 Rainfall Distribution Pattern in Indonesia

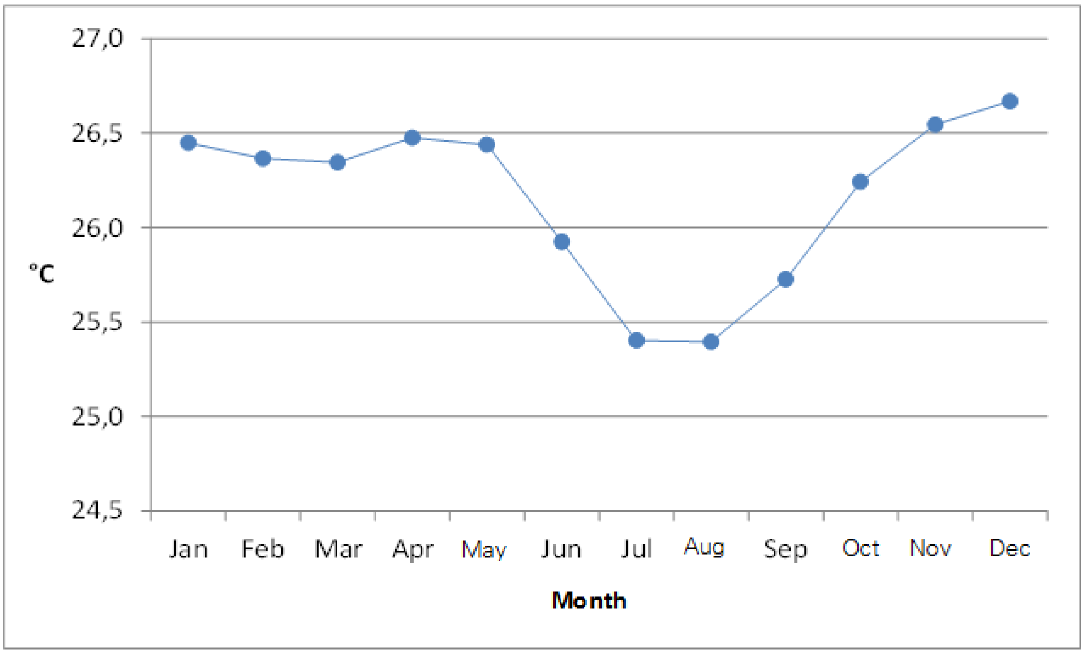


Source : Radar TRMM (Tropical Rainfall Measuring Mission) tipe 3A12 V7 (http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=TRMM_Monthly)

Figure II-4 Spatial Distribution of Average Monthly Rainfall over a 14 Year Period (1998 – 2012) in the Bintuni Bay Area

2.1.1.2 Air Temperature

Based on data of air temperature in Tangguh LNG through data taken from AERMET MM5 Worldwide Meteorological Data during a ten-year period (2002 – 2011) (**Figure II-5**), it is known that the lowest temperature in Tangguh LNG occurs in the month of July, at 25.3 °C. Minimum temperature in the study area during a ten-year period occurred in the dry season in which the sun moved north of the equator. At the start of the wet season, generally in September, temperature in the study location tend to rise. Absolute maximum temperature was recorded in the month of December, at 26.6° C. Overall, air temperature in the study location ranged between 25.3° C to 26.6° C with average monthly temperature of 23° C. Fluctuation of average monthly temperature during ten years (2002 – 2012) is shown in **Appendix II.6 Meteorology Data**. Therefore, temperature condition in the study location was in the warm category with air temperature fluctuation tending to be stable. Dynamics of air temperature will further affect atmospheric stability.



Source : AERMET MM5 Worldwide Meteorological Data (2002-2011)

Figure II-5 Graph of Average Monthly Temperature in Tangguh LNG (2002 – 2011)

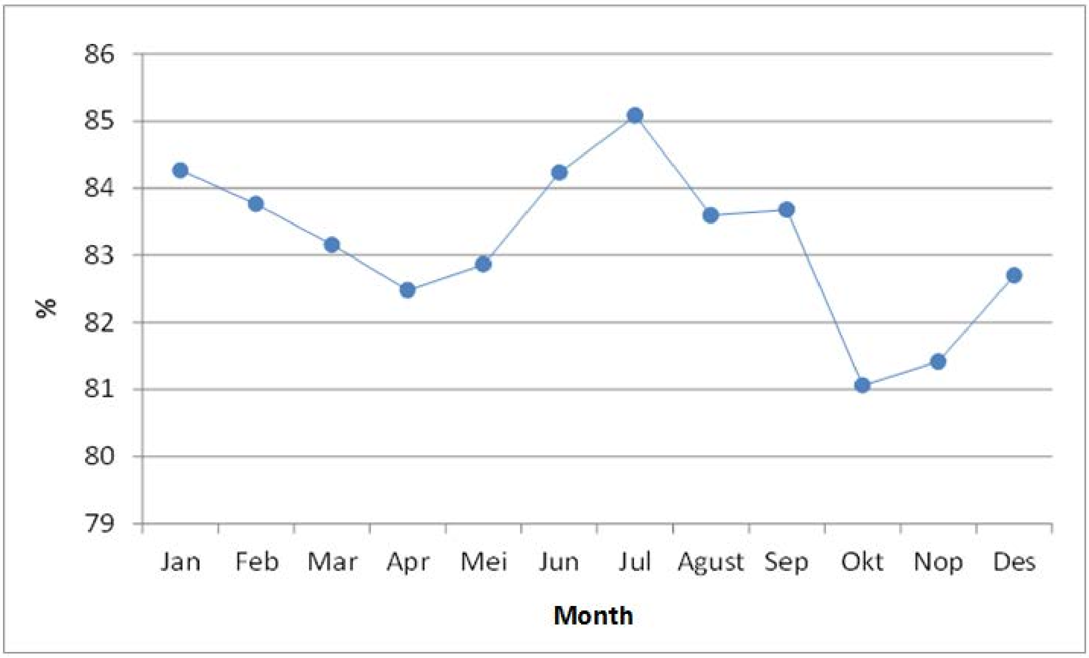
Through hourly air temperature data obtained from AERMET MM5 Worldwide Meteorological Data, maximum air temperature during a ten-year period (2002 – 2012) occurred at 15:00 Indonesia Eastern Time with air temperature of ± 28.3° C. This condition indicates that at 15:00 Indonesia Eastern Time, solar radiation was mostly used to heat the air near the surface or known as soil heat flux and sensible heat flux.

Minimum air temperature over a ten-year period (2002 – 2012) occurred at 5:00 Indonesia Eastern Time. This condition illustrates that heat originating from long wave radiation emitted by the earth's surface decreased in line with short-wave radiation emitted by the sun.

2.1.1.3 Relative Air Humidity (RH)

Relative air humidity (RH) is one of the atmospheric physical variables illustrating the ratio between actual air pressure and saturated air pressure. Relative air humidity can illustrate the quantity of water vapor in a particular location.

Based on relative air humidity data during ten years as shown in **Figure II-6**, the climate condition in Tangguh LNG is classified as humid, with average humidity 83.2%. Fluctuation of humidity level is not significant during seasonal change. This condition is shown with standard deviation of air humidity of 1%. In the months of April and May, relative humidity reaches 82.5% and 82.9%. Lowest humidity occurs in October at 81.0%. Values of monthly humidity in a ten-year period (2002 – 2012) is shown in **Appendix II.6 Meteorology Data**.



Source : AERMET MM5 Worldwide Meteorological Data (2002-2011)

Figure II-6 Graph of Average Monthly Humidity in Tangguh LNG (2002 – 2011)

Similar to air temperature, humidity is also one of elements of weather affecting atmospheric stability. Low air humidity may hinder surface warming by solar radiation (Fairuzi, 2012). During the day, air temperature is relatively higher than at night so that water vapor content is lower than at night. This condition enables maximal air mass rising, therefore it enables various air pollutants to rise from the surface to the atmosphere.

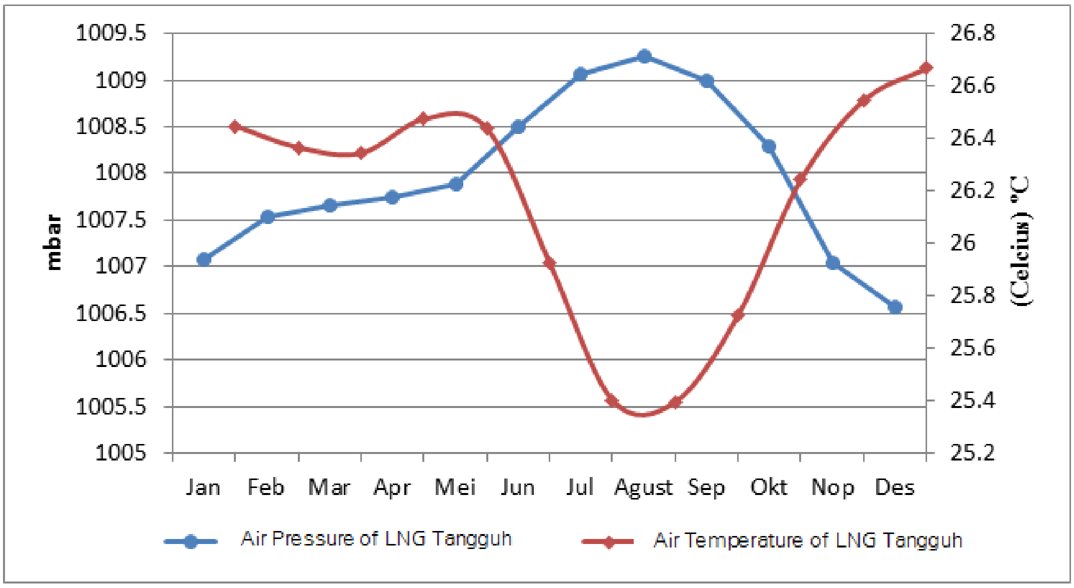
2.1.1.4 Air Pressure

Air pressure is energy used to move air mass in every unit of area. In areas receiving the sun's heat, the air will expand and rise with low air pressure.

Shifting of the sun's orbit causes fluctuation of seasonal temperatures, mainly in the middle latitudes. Air temperature will cause air volume to expand and contract. When air expands, it will become less dense and consequently pressure will decrease, on the contrary when air volume contracts, air density will become greater and cause pressure to rise.

Based on the principle that pressure is inversely proportional to temperature, this phenomenon is also shown by inverse proportion of average monthly temperature around Tangguh LNG with average monthly air pressure. In the months of July and August average monthly temperatures are at their lowest over one year and average monthly air pressure is highest around Tangguh LNG.

The presence of the sea near the location of Tangguh LNG serves to influence air pressure fluctuation, as the sea supplies water vapor in the air (through the evaporation process). Additional water vapor in the air will cause air pressure to rise. This phenomenon also proceeding around the Tangguh LNG area as shown in **Figure II-7** indicates that the months of July and August have relatively high air pressure, of around 1,009 mBar. Average air pressure throughout the measurement period was 1,007 mBar.



Source : AERMET MM5 Worldwide Meteorological Data (2002-2011)

Figure II-7 Graph of Average Monthly Air pressure (2002-2011) to Average Monthly Air Temperature (2002-2011)

2.1.1.5 Wind

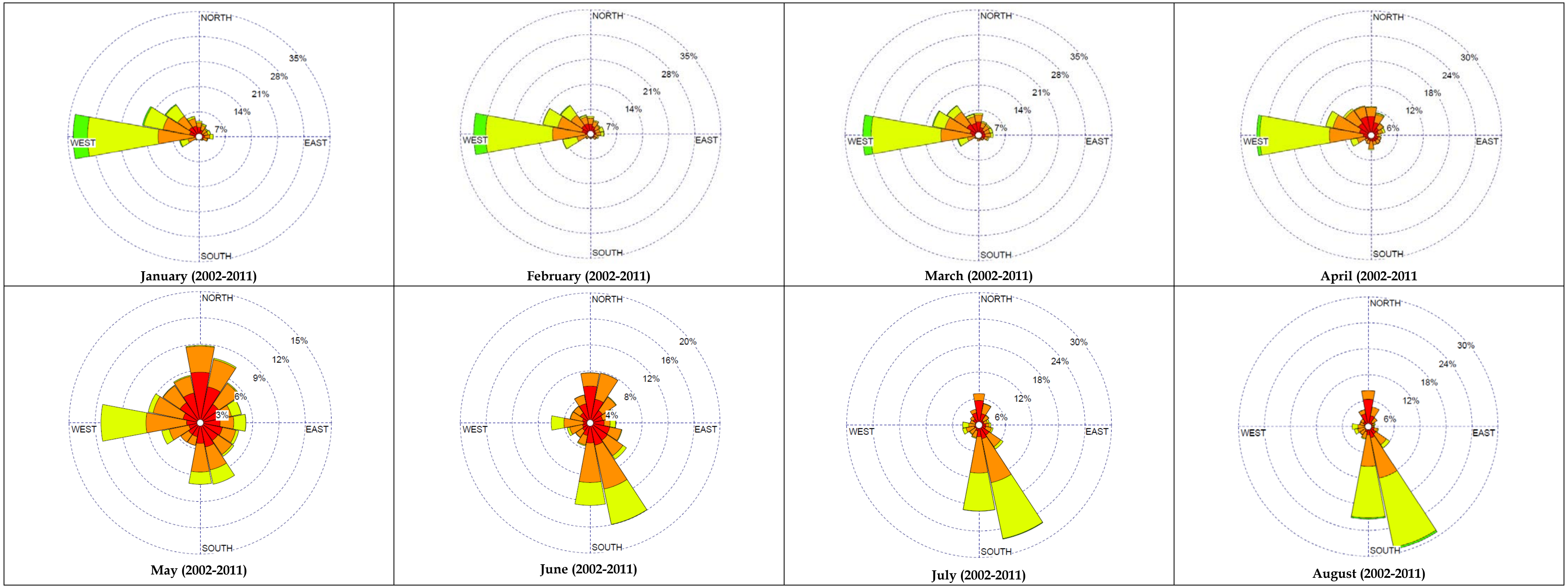
The windrose diagram illustrates distribution of wind speed and direction (BMKG, 2000). The Windrose at Tangguh LNG is processed using data of wind speed and direction obtained from AERMET MM5 Worldwide Meteorological Data during ten years (2002 - 2011) and built using WRPlot software.

Based on monthly windrose for a ten-year period (**Figure II-8**) and overall distribution of wind speed (**Figure II-10**), it is known that 18% of wind direction comes from the West with average wind speed of 8.8 m/s and 10% wind direction blows from the Southeast at speed of 5.7 m/s.

Overall wind class frequency distribution **(Figure II-10)** also shows that 4.4% of wind speed frequency is calm wind class (wind speed ≤0.5 m/sec and with no direction). Wind speed frequency of calm wind class occurs mostly in the wet season.

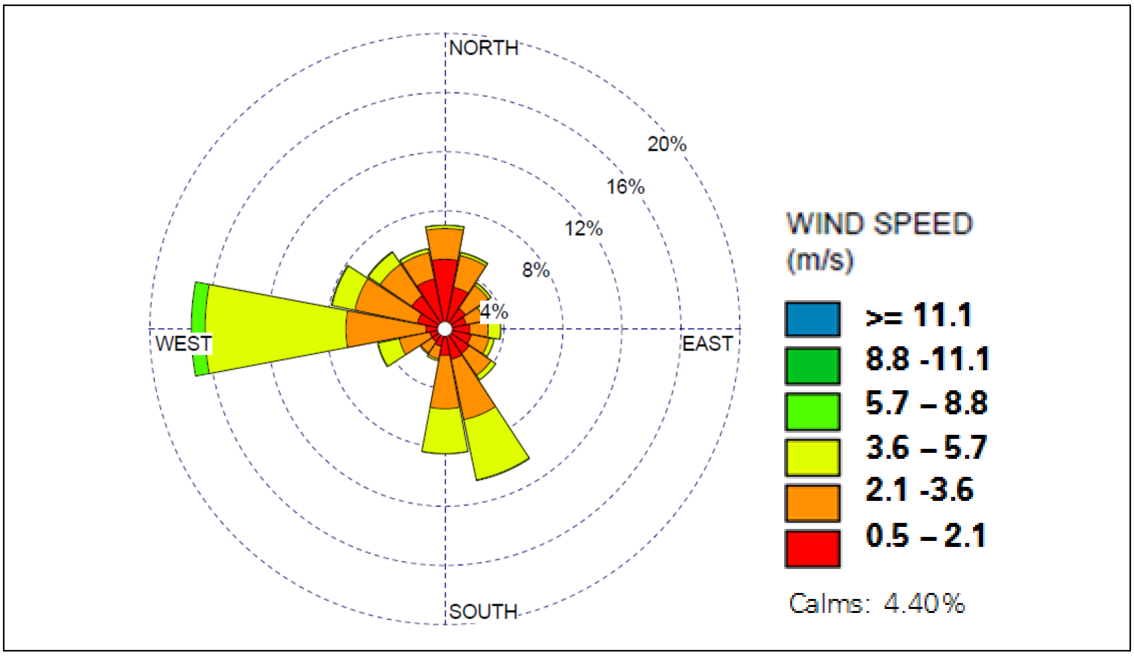
Referring to **Figure II-8** and **Figure II-9**, it was found that in November to May, dominant wind direction blows from the west with frequency of occurrences of 25.3% and average range of wind speed from 2.1 m/sec to 3.6 m/sec with frequency of occurrence of 35.6%. Meanwhile, from June to October, dominant wind direction is from the southeast with frequency of occurrences of 20.7% and from the south at 15.6%, with range of average speed of 2.1 m/sec to 3.6 m/sec with frequency of occurrences of 39.9%.

Overall, dominant annual wind direction in the Tangguh LNG is from the west with frequency of occurences of 17.1% and from the southeast with frequency of occurences of 10.5%. Average annual wind speed ranges between 2.1 m/sec to 3.6 m/sec with frequency of occurences of 37.4% (**Figure II-10**).



Source : MM5 data by Lakes Environmental (http://www.weblakes.com/) 2002-2011

Figure II-8 Monthly Windrose in the area of Tangguh LNG



Source : MM5 data by Lakes Environmental (http://www.weblakes.com/) 2002-2011

Figure II-9 **Average Annual Wind Direction and Wind Speed (Windrose) Around Tangguh LNG**

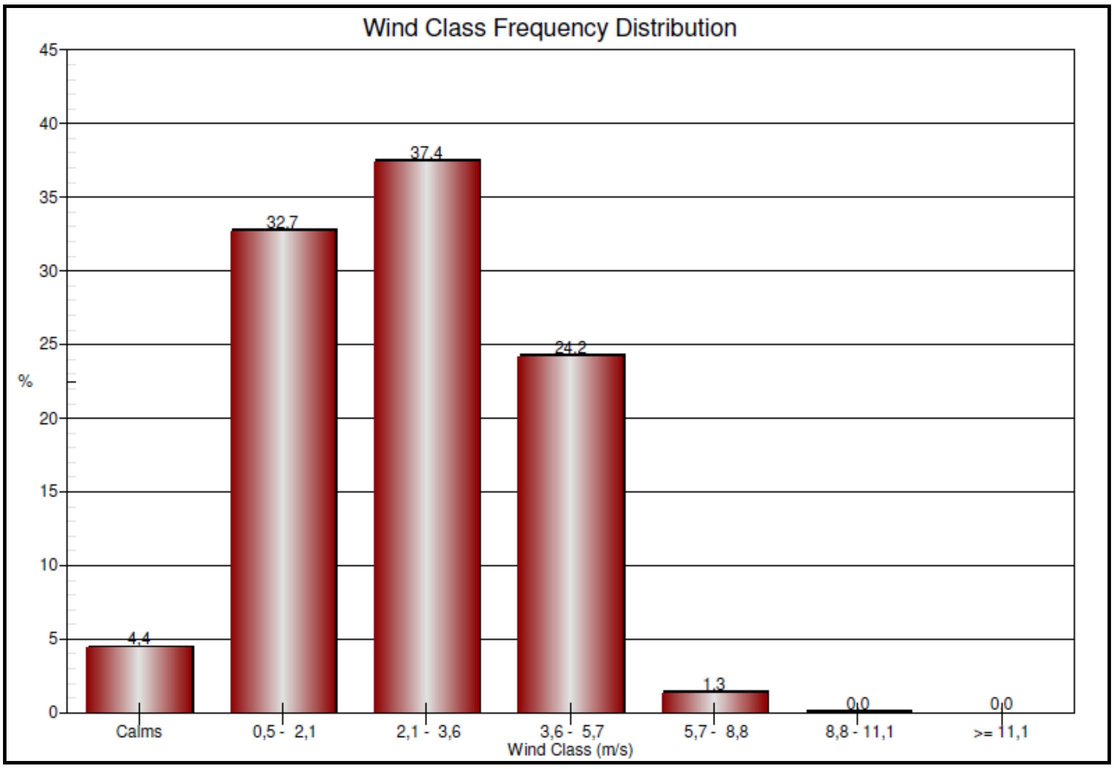


Figure II-10 **Wind Class Frequency Distribution around Tangguh LNG**

2.1.1.6 Evapotranspiration

Evapotranspiration (ET) is defined as the overall quantity of water originating from soil and water surface (evaporation), re-evaporation of rainwater from the surface of vegetation (interception) and groundwater evaporation to the atmosphere through vegetation (transpiration). Based on determinant factor, ET is differentiated as potential evapotranspiration (ETP) and actual evapotranspiration (ETA). ETP is influenced more by meteorological factors, while ETA is affected by plant physiology and soil elements.

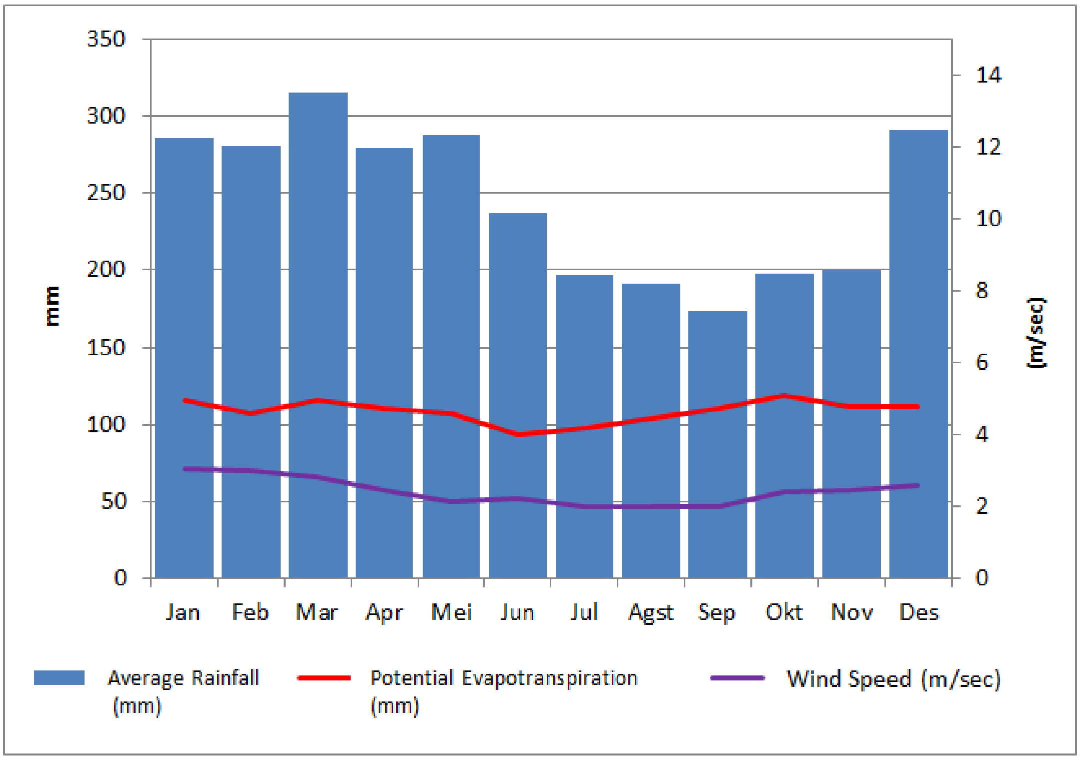
Referring to the principle that ETP is the amount of evapotranspiration affected greatly by meteorological factors, estimation of evapotranspiration in the Tangguh LNG was done through estimation of potential evapotranspiration level in the area. The estimated high potential evapotranspiration was based on data from Aquastat and Lister (2002). The both data sources possess high resolution and are results of ETP estimates on the ground surface toward global climate regions.

Table II-1 Potential Evapotranspiration in Tangguh LNG (2002)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Potential Evapotranspiration (mm)	116	107	116	110	107	94	98	104	110	119	111	112

Source : Lister (2002).

From the data of potential evapotranspiration in the Tangguh LNG from Aquastat and Lister (2002), the ETP graph as presented in **Table II-1** and **Figure II-11** was obtained. Referring to **Table II-1** and **Figure II-11**, ETP at the Tangguh LNG tends to be stable ranging between 94 mm and 119 mm. The high ETP at the Tangguh LNG is affected by air temperature and high humidity at the location. Fluctuation of monthly ETP level is also proportionate to the increase of wind speed at the Tangguh LNG that was obtained from average wind speed over a ten-year period at the Tangguh LNG (**Figure II-11**).



Source : TRMM (1998 – 2012), Lister (2002) and AERMET MM5 Worldwide Meteorological Data.

Figure II-11 Average Rainfall (mm), Potential Evapotranspiration (mm) and Wind Speed (m/sec)

2.1.1.7 Climate Types

The World Meteorological Organization (2009) explains that the application of climate classification system is based on its purpose. In the forestry sector, climate classification systems such as Thornwaite and Schmidt-Ferguson are used. For the agricultural sector, the climate classification system commonly used is the Oldeman climate classification system. In global climate analysis, the Holdridge and Budyko climate classification systems are used . Analysis of past climate (paleoclimatology) used the Bergeron and Spatial Synoptic climate classification system. For the purpose of local climate analysis, the commonly used classification system is the Koppen climate classification system.

Based on the principles of climate classification system , the Koppen climate classification system is used for the analysis of climate type in the Tangguh LNG, which is based on temperature, average annual rainfall and monthly annual rainfall. The Koppen climate classification is divided into five climate classes, i.e. type A, B, C, D and F as shown in **Table II-2**.

Table II-2 Formulation of *Koppen* Climate Classification System

Type	Description	Criteria
A	Equatorial tropical climate	Minimum temperature ≥ 18° C
Af	Equatorial tropical rainforest climate	Lowest rainfall ≥ 60 mm
Am	Equatorial monsoon climate	Annual rainfall ≥ 25 (100-lowest rainfall)
As	Equatorial savanna climate with dry summer	Lowest precipitation < 60 mm in summer
Aw	Equatorial savanna climate with wet summer	Lowest precipitation < 60 mm in winter
B	Arid climate	Evaporation > Rainfall
BS	Steppe climate	Annual precipitation < 5 P_{th}*
BW	Desert climate	Annual precipitation ≤ 5 P_{th}*
C	Warm climate	-3° C < lowest temperature < 18° C
Cs	Warm climate with dry summer	Lowest precipitation in the summer < Lowest precipitation in winter. Highest precipitation in winter > 3 times lowest precipitation in summer, and lowest precipitation in summer < 40 mm
Cw	Warm climate and dry winter	Lowest precipitation in the winter < Lowest precipitation in the summer and highest precipitation in summer > 10 times lowest precipitation in winter
Cf	Warm and wet climate	Other than Cs and Cw
D	Cold climate	Lowest temperature ≤ -3 ° C
Ds	Cold climate with dry summer	Lowest precipitation in summer < Lowest precipitation in winter, highest precipitation in winter > 3 times lowest precipitation in summer, and lowest precipitation in summer < 40 mm
Dw	Cold climate with dry summer	Lowest precipitation in winter < Lowest precipitation in summer and highest precipitation in the summer > 10 times the lowest precipitation in the winter
Df	Cold wet climate	Other than Ds and Dw
E	Polar climate	Lowest temperature < 10 ° C
ET	Tundra Climate	0 ° C ≤ maximum temperature < 10 ° C
EF	Frost Climate	Lowest temperature < 0 ° C

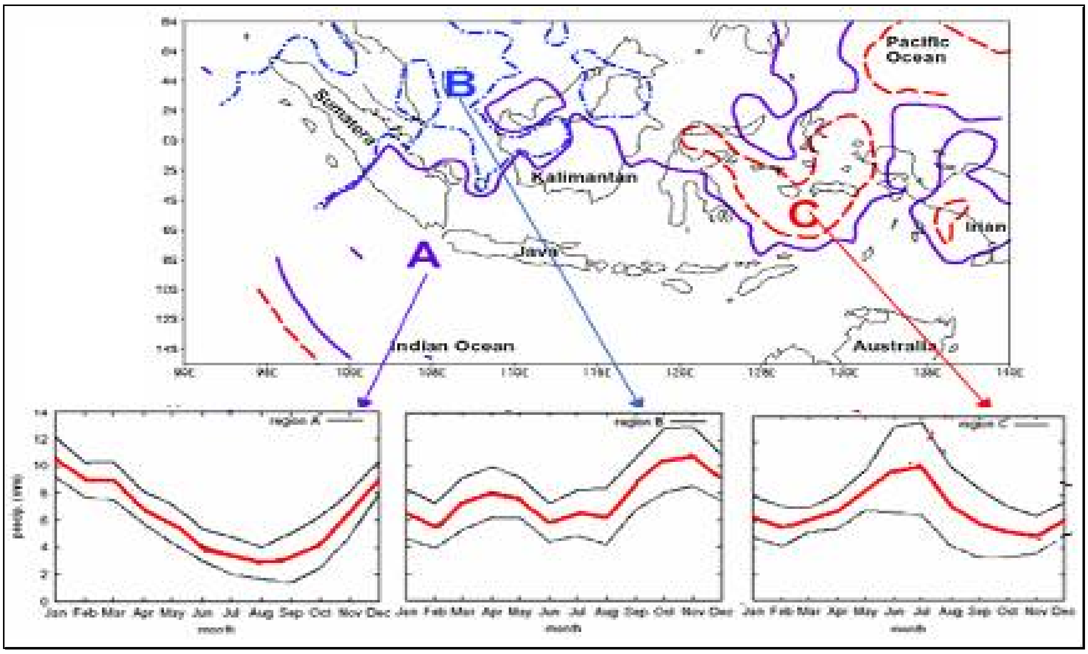
Source: Kottek (2006).

*P_{th} is defined as follows if $^2/_3$ annual rainfall occurs in the winter, P_{th} = 2 (annual air temperature), if $^2/_3$ annual rainfall occurs in summer, P_{th} = 2 (annual air temperature) +28, if rainfall only occurs in summer or wet season, P_{th} = 2 (annual air temperature)+14.

Based on **Table II-2** and considering the condition of atmosphere physical elements as described in Sub-chapter 2.1.1.1 to Sub-chapter 2.1.1.6, the climate type in the Tangguh LNG area is climate type of Af. This is based on average monthly temperature in the study area of 26.1 °C with maximum monthly temperature of 26.6 °C and minimum monthly temperature of 25.3 °C and average annual rainfall (CH) in Tangguh LNG area at 2.938 mm with monthly rainfall > 60 mm. The Af climate condition in the project location indicates the area with climate elements tending to be stable and wet. Fluctuating variability of climate elements of rainfall, temperature, humidity and other elements do not obviously differ from month to month.

2.1.1.8 Influence of Climate Change

In general, Indonesia lies on the equator and this is the main factor affecting weather and climate conditions in Indonesia. The climate in Indonesia is generally divided in three climate patterns as shown in **Figure II-12**. Region A experiences Australian monsoon and occurs in a large portion of the southern regions of Indonesia, region B shows condition of semi-monsoon, while region C (marked by red disconnected lines) experiences anti-monsoon/Indonesia through flow climate.



(Source : Edvin A. et al 2003 in LAPAN/ National Aeronautics and Space Agency, 2009

Figure II-12 Map of Indonesian Climate Regions

Climate change will have an impact on human lives, possibly in the form of lower food production, rising sea surface levels, longer dry seasons and shorter wet seasons with higher intensity. This condition is believed to be able to occur in most of the Indonesia territory, including the eastern part of Indonesia and West Papua.

The West Papua region is still predominantly covered by forest that are in good condition. Papua, including West Papua, is one of the regions with the largest forest area of lowland forest remaining in Indonesia.

Based on latest studies, the Papua region including West Papua, will also be influenced by climate change with high frequency of extreme climate conditions; for instance, occurrence of rain outside the forecasted period. Weather and climate-related disasters have side effects that are quite significant for community and economic condition, including: (i) landslides and erosion, mainly in the highlands, (ii) floods in a large portion of the islands, mainly the lowlands; (iii) drought in several islands that are often linked to El Nino condition. In the future, sea levels are estimated to continue to rise.

Climate projections for 2050 are shown in **Table II-3**. Temperatures are predicted to rise until the middle of the 21st century. Variations in rainfall are unpredictable, however flood and drought might increase in intensity between now and the middle of this century.

Table II-3 Climate Variability Scenario for 2050 Using the MAGICC/Model for Assessment of Greenhouse Gases Affecting Climate Change and SCENGEN/Scenario Generator Model from IPCC

Temperature increase (°C)	Rise of seawater level (cm)	Rain
0.9 – 1.45	12.5 - 16	Variability: 5.20 – 8.63%
		Probability of Change: 0.68 – 1.0 (likely causing flood or dry season)

(Source: LAPAN/National Aeronautics and Space Agency)

Potential impact of climate change on the Tangguh LNG facilities and operations have been studied as part of the project technical design and development. This includes considerations of 100 year Tsunami events in the marine facilities design, high rainfall in most of the area, tidal waves and coastal abrasion due to natural phenomena in the area.

2.1.2 Ambient Air Quality

Ambient air quality data was obtained from observation results of two seasons, i.e. the dry season and wet season. Sampling during the dry season was undertaken from August 5th to August 16th, 2012, while sampling in the wet season was undertaken on October 27th and October 28th, 2012. In general, ambient air sampling was divided into two locations i.e. onshore and offshore. The onshore location was divided into two groups: (a) inside the Tangguh LNG area and (b) nearest settlement outside the Tangguh LNG area boundary. Sampling locations of ambient air in the dry season and wet season are shown in **Map II-2** and **Table II-4**. The overall offshore locations are in the Tangguh LNG area.

Table II-4 Samples of Ambient Air and Noise

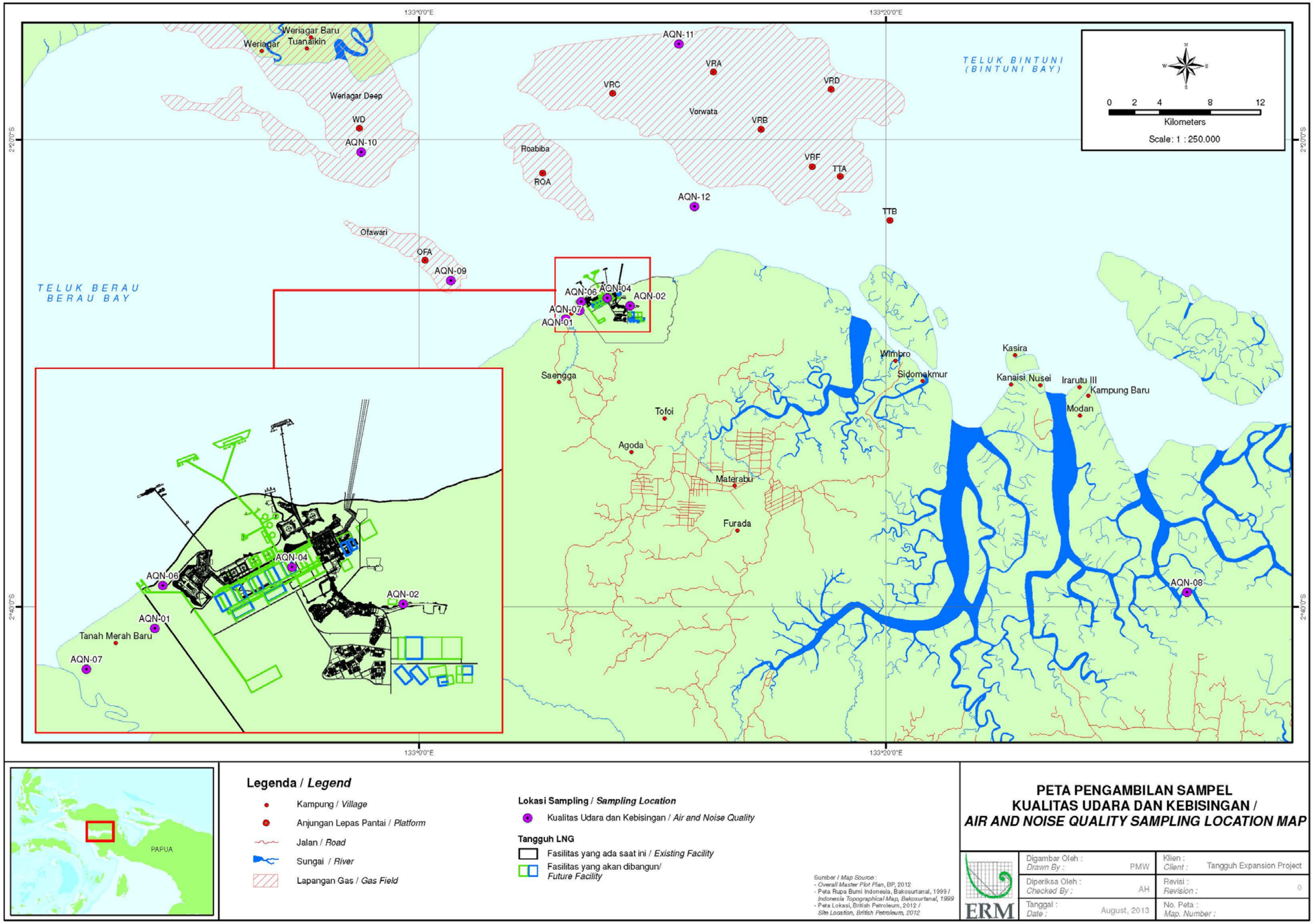
Sample Point	Location Type	Location	Coordinates		Dry Season	Wet Season
			South	East		
AQN-1	Onshore (Tangguh LNG - Forest)	Proposed Jetty	02° 27' 18.8"	133° 06' 52.0"	√	√
AQN-2	Onshore (Tangguh LNG - Forest)	Proposed Airfield	02° 27' 06.1"	133° 09' 02.1"	√	x
AQN-4	Onshore (Tangguh LNG –Open Area)	Proposed LNG Train	02° 26' 46.7"	133° 08' 03.8"	√	√
AQN-6	Onshore (Tangguh LNG – Open Area)	Proposed Jetty	02° 26' 56.3"	133° 06' 56.1"	√	√
AQN-7	Onshore (Settlement)	Tanah Merah Baru	02° 27' 40.1"	133° 06' 16.2"	√	√
AQN-8	Onshore (Settlement)	Arguni	02° 39' 22.2"	133° 32' 53.4"	√	√
AQN-9	Offshore	Offshore - OFA	02° 26' 02"	133° 01' 21"	√	√
AQN-10	Offshore	Offshore – WD	02° 20' 32"	132° 57' 31"	√	√
AQN-11	Offshore	Offshore - VRA	02° 15' 54"	133° 11' 07"	√	√
AQN-12	Offshore	Offshore	02° 22' 52"	133° 11' 47"	√	√

Parameters of ambient air quality analyzed include sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxide (NO_2), tropospheric ozone (O_3), hydrocarbon (HC), total suspended particulates (TSP), particulates of size less than or equal to 10 microns (PM_{10}), particulates of size less than or equal to 2,5 microns ($PM_{2.5}$) and lead (Pb). The measurement periods of each parameter were as follows:

- One hour for parameter SO_2, CO, NO_2 and O_3;
- Three hours for parameter HC; and
- One hour interval with maximum sampling period of three times for parameters of TSP, PM_{10}, $PM_{2.5}$ and Pb.

Overall results of ambient air quality measurement are presented in **Table II-5** (dry season) and **Table II-6** (wet season). The overall laboratory analysis results are shown in **Appendix II.1** and **Appendix II.2**. Concentrations of ambient air quality parameters from the measurements in both the dry season and the wet season were compared with ambient air quality standard in accordance with Government Regulation Number 41 Year 1999 regarding Air Pollution Control. Concentrations of each parameter compared with the quality standard are shown in **Figure II-13.** In general, entire air quality parameters analysed had concentration values relatively far below the threshold limits of quality standard, which complies with Government Regulation Number 41 Year 1999 regarding Air Pollution Control.

In general, there are two main factors to determine concentrations of gas and pollutant particulates in ambient air i.e. the components of climate and residence time of pollutants in the atmosphere. The climate components include air temperature, air humidity, air pressure, rainfall and wind. The climate components greatly influence dilution, dispersion, physical-chemical transformation and pollutants transportation emitted. From previous climate description, it was known that air temperature in the Tangguh LNG area was in the warm category with air temperature fluctuations tending to be stable throughout the year, likewise, air humidity in the Tangguh LNG was categorized as humid, with average humidity of 83.2%. Fluctuations of humidity levels were not significant during seasonal change. Additionally, air pressure at the Tangguh LNG was relatively stable at approximately 1,000 mbar throughout the year. With sufficient stability of the three climate components in the Tangguh LNG location, it was estimated that the climate components do not significantly affect seasonal variation of air pollutant gas concentrations. Meanwhile, high rainfall in the Tangguh LNG location enabled occurrence of wash-out and rain-out in some ambient air quality parameters. With wash-out and rain-out of pollutant gases and particulates there is possibility of low concentration of pollutants in the Tangguh LNG location. Meanwhile, observing the tendency of wind speed with relatively low percentage of calm wind (average 4.4%), wind also contributes to the dispersion and transportation of air pollutants in the Tangguh LNG area.



Map II-2 Sampling Locations of Ambient Air and Noise

Table II-5 Ambient Air Quality and Noise Measurements in the Dry season

No.	Parameter	Unit	Acceptable Limit of Quality standard*	Onshore						Offshore				Analytical Methhod	Duration of Measurement
				AQN-1	AQN-2	AQN-4	AQN-6	AQN-7	AQN-8	AQN-9	AQN-10	AQN-11	AQN-12		
Ambient Air Quality															
1	Sulfur Dioxide, SO_2	µg/Nm^3	900	255	154	130	86	<20	355	60	66	67	77	Pararosaniline	1 hour
2	Carbon Monoxide, CO*	µg/Nm^3	30,000	<1,140	<1,140	<1,140	<1,140	1,150	1,150	<1,140	<1,140	<1,140	<1,140	CO Anlayzer	1 hour
3	Nitrogen Oxide, NO_2	µg/Nm^3	400	<5	<5	6	<5	6	<5	<5	<5	11	<5	Satzman	1 hour
4	Oxidant, O_3	µg/Nm^3	235	<1	<1	<1	<1	<1	<1	14	25	10	20	Chemiluminescent	1 hour
5	Hydrocarbon, HC*	µg/Nm^3	160	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	GC-FID	3 hours
6	Particulate <10mm (PM_{10})	µg/Nm^3	150	8	8	9	12	9	13	15	11	17	17	Dust Analyzer	Grab
7	Particulate <2,5mm ($PM_{2.5}$)	µg/Nm^3	65	10	9	11	16	13	5	9	2	3	11	Dust Analyzer	Grab
8	Total Suspended Particulates (TSP)	µg/Nm^3	230	19	20	22	32	24	19	19	13	19	26	Dust Analyzer	Grab
9	Lead, Pb	µg/Nm^3	2	<0,1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	GFAAS	Grab
10	Noise, L_{avg}**	dB	-	4.7	41.1	54.2	40.8	49.5	53.2	55.3	55.3	57.0	62.8	Noise Levelmeter	Grab

Note : * Government Regulation No. 41 Year 1999 regarding Air Pollution Control
** MoE Decree No 48 Year 1996

Table II-6 Ambient Air Quality and Noise Measurements in Wet Season

No.	Parameter	Unit	Acceptable Limit of Quality standard*	Onshore						Offshore				Analytical Method	Duration of Measurement
				AQN-1	AQN-2	AQN-4	AQN-6	AQN-7	AQN-8	AQN-9	AQN-10	AQN-11	AQN-12		
Ambient Air Quality															
1	Sulfur Dioxide, SO_2	µg/Nm³	900	44	***	<20	<20	34	127	<20	<20	<20	<20	Pararosaniline	1 jam
2	Carbon monoxide, CO*	µg/Nm³	30,000	1,490	***	<1,140	1,370	<1,140	1,490	1,260	<1,140	1,370	<1,140	CO Analyzer	1 jam
3	Nitrogen Oxide, NO_2	µg/Nm³	400	<5	***	<5	<5	<5	12	<5	<5	<5	<5	Satzman	1 jam
4	Oxidant, O_3	µg/Nm³	235	<2	***	<2	<2	<2	<2	<2	<2	<2	<2	Chemiluminescent	1 jam
5	Hydrocarbon, HC*	µg/Nm³	160	<5	***	<5	<5	<5	<5	<5	<5	<5	<5	GC-FID	3 jam
6	Particulate <10mm (PM_{10})	µg/Nm³	150	30	***	4	13	13	32	3	13	4	13	Dust Analyzer	Grab
7	Particulate <2.5mm ($PM_{2.5}$)	µg/Nm³	65	24	***	6	2	4	11	27	12	19	4	Dust Analyzer	Grab
8	Total Suspended Particulate (TSP)	µg/Nm³	230	73	***	40	74	71	115	31	27	64	33	Dust Analyzer	Grab
9	Lead, Pb	µg/Nm³	<0.1	<0.1	***	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	GFAAS	Grab
10	Noise, L_{avg}**	dB	-	45.8	***	73.7	52.5	71.1	58.7	58.1	58.8	56.6	59.7	Noise Levelmeter	Grab

Note : * Government Regulation No. 41 Year 1999 regarding Air Pollution Control
** MoE Decree No 48 Year 1996

Besides the climate components, the pollutants concentration will depend on the emission rate of each pollutant from ongoing activities, residence time and rise level of each pollutant. Pollutant gases such as SO_2, NO_2, CO, O_3 and HC will rise to the higher atmosphere with varying residence time (SO_2: 2-8 days, NO_2: 0.5-3 days, CO: 30-90 days, O_3: 1-3 months, and HC: 0.5 - 2 years). Particulates pollutants will rise to lower level of the atmosfer with residence time of a few days to several weeks. With the different residence times of each pollutant, the measured concentration of pollutants during each sampling will vary.

Measured concentrations of each air quality parameter during both the dry season and wet season are shown in **Figure II-13**. From the graph in **Figure II-13,** it is shown that the tendency of SO_2, NO_2 and O_3 concentrations were lower in the wet season. The wet season enabled the occurrence of rain-out causing measured concentrations to be lower. Hydrocarbon (HC) and Pb concentrations in the wet season and dry season were not detected (below the instrument detection limit).

Concentrations of particulate parameters (TSP, PM_{10} and $PM_{2.5}$) were monitored relatively higher in the wet season. In this case, seasonal variations toward concentrations of TSP, PM_{10} and $PM_{2.5}$ did not appear to be significant, since particulate concentrations were greatly affected by ongoing local activities during sampling. Besides, the percentage of calm winds in the month of August (dry season) was recorded as lower than in October (wet season). With increasing calm winds in the wet season, the longer TSP, PM_{10} and $PM_{2.5}$ will remain in the ambient air (as they are not well-dispersed). The same condition could also occur with CO, due to CO is a pollutant with greatest emission sources compared with other pollutant gases, in relate to imperfect fuel combustion system. Combustion can occur in various activities either stationary sources or mobile sources (transportation).

Figure II-13 shows the comparison of air parameter concentrations at offshore and onshore locations. From this figure, it is indicated that concentrations of Ozone (O_3) tend to be higher at offshore than onshore location. This is among others due to the deposition speed of O_3 , which on seawater surface tends to be lower than on land (Pleijel et. al., 2013). For other parameters, no significant differences in concentration values between offshore and onshore locations were identified. The values of Pb concentrations were not detected throughout all observation locations or in other words <0,1 $\mu g/Nm^3$.

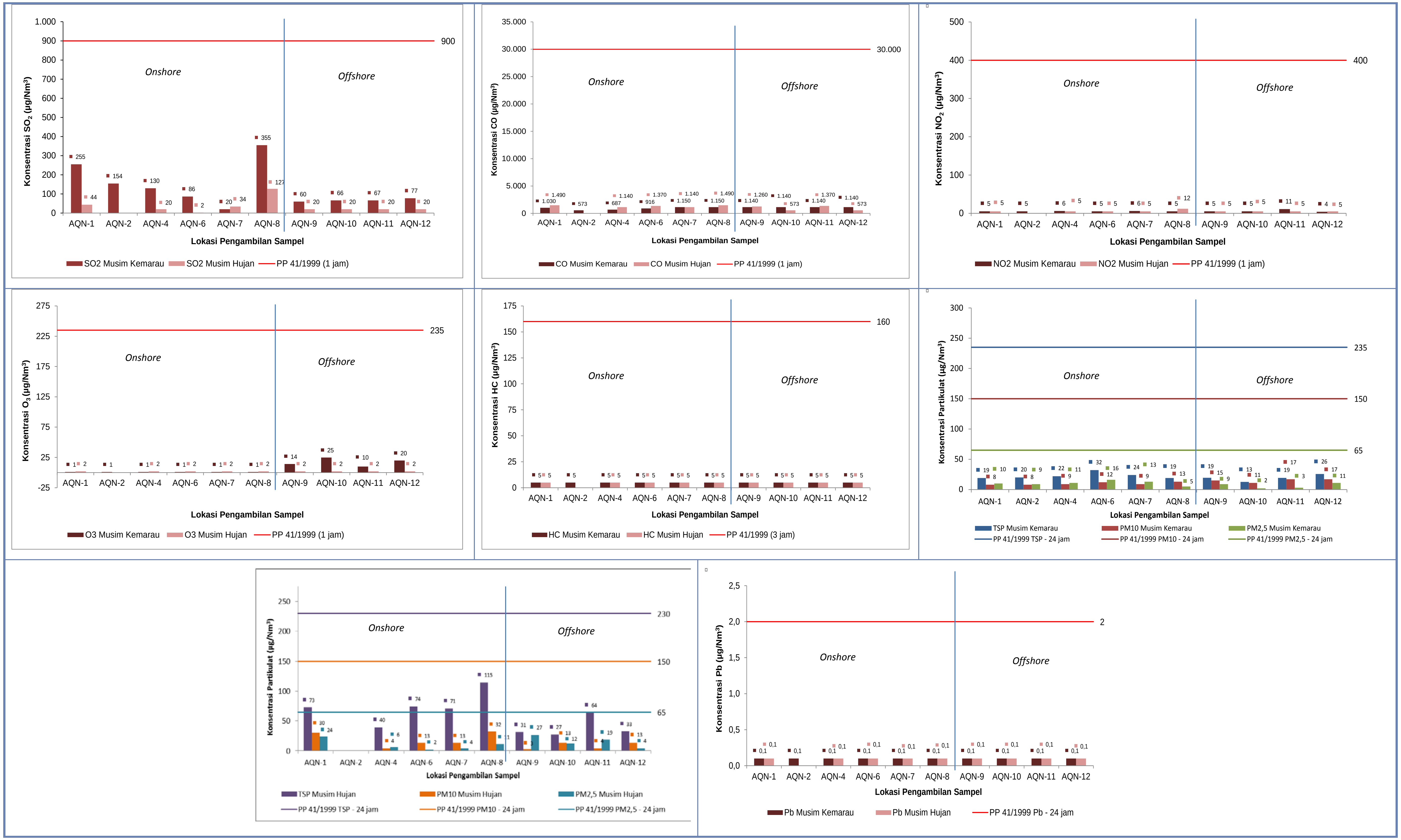


Figure II-13 Environmental Baseline of Ambient Air Quality in Tangguh LNG

2.1.3 Noise

Noise level data was obtained from onshore measurement (AQN-1, AQN-2, AQN-4, AQN-6, AQN-7 and AQN-8) and offshore (AQN-9, AQN-10, AQN-11 and AQN-12). Onshore sampling was differentiated into two locations, i.e. inside the Tangguh LNG area and nearest settlements outside the Tangguh LNG area boundary. Noise level measurements were conducted in two seasons, i.e the dry season and wet season. Noise level in the dry season was measured from August 5th to August 16th, 2012, while measurement in the wet season was conducted on October 27th and October 28th, 2012.

Noise level measurement in the Tangguh LNG was conducted using sound level meter equipped with measurement feature of Leq (equivalent energy level). Noise level was measured every 5 seconds over 10 minutes for each measurement and maximum four times measurement during daytime. The measurements were performed to obtain the equivalent noise level (Leq) for 16 hours through calculations based on MoE Decree (KepMen LH) No. 48 Year 1996 regarding Noise Level Quality Standard and Average Noise Level (L_{avg}) through arithmetic mean calculation. However, due to safety reasons, measurement of noise level at the Tangguh LNG area was only made three times during daytime at 12 selected locations. Then, calculation results were compared with the quality standard for noise level in accordance to the location classification as stated in MoE Decree (KepMen LH) No. 48 Year 1996.

Locations of noise level measurement and sampling status in the dry season and wet season are shown in **Map II-2** and **Table II-5**. Noise level as mean value of measurement in the daytime period is shown in **Figure II-14**. Detail data is presented in **Appendix II.1 and Appendix II.2 Environmental Baseline Data.**

Based on **Figure II-14**, the average noise level at offshore (41.1 dBA – 54.2 dBA) and onshore (55.3 dBA – 62.8 dBA) in the dry season overall meet the noise level quality standard. However, during the wet season, onshore noise level (45.8 dBA – 73.7 dBA) are quite fluctuative than offshore noise level (56,6 dBA – 59,7 dBA) that indicate more stable values. Offshore noise values in the wet season were observed slightly higher than those in the dry season, this is possibly due to the influence of noise caused by wind and sea waves that are higher during the wet season.

The tendency for higher noise level in the wet season compared with the dry season is due to rising air humidity and air temperature. Both physical elements of atmosphere can cause lower air density, so that will affect on reducing noise attenuation ability due to the atmospheric condition (Ahrens, 1994).

Equivalent noise level in daytime during the wet season is shown in **Figure II-15** that indicates similar tendency on average noise level in daytime during the wet season. Onshore average noise level varied between 41.1 dB and 73.3 dB. Offshore Average noise level varied between 58.2 dB and 60.6 dB.

The noise level in two measurement locations onshore during the wet season exceeds noise level standard both for settlements area (Tanah Merah Baru) and for the Tangguh LNG area (industry). Based on records of noise level sampling at measurement point of AQN-7 (Tanah Merah Baru settlements), the noise level was affected by natural conditions (wind, animals, and so forth), as well as by human activities, among others due to mower's noise during measurements of the noise level.

Noise level measurements adjacent to LNG Train 1 and 2, indicated value of 73.7 dBA. The noise level value at AQN-4 (open area proposed as a jetty for condensate tankers and LNG tankers) exceeded the quality standard for industrial area, i.e. 70 dBA. However, according to MoE Decree No. 48 Year 1996 the specified value of noise level quality standard has a tolerance of +3 dBA so that, noise level at AQN-04 can be considered to meet noise level quality standard.

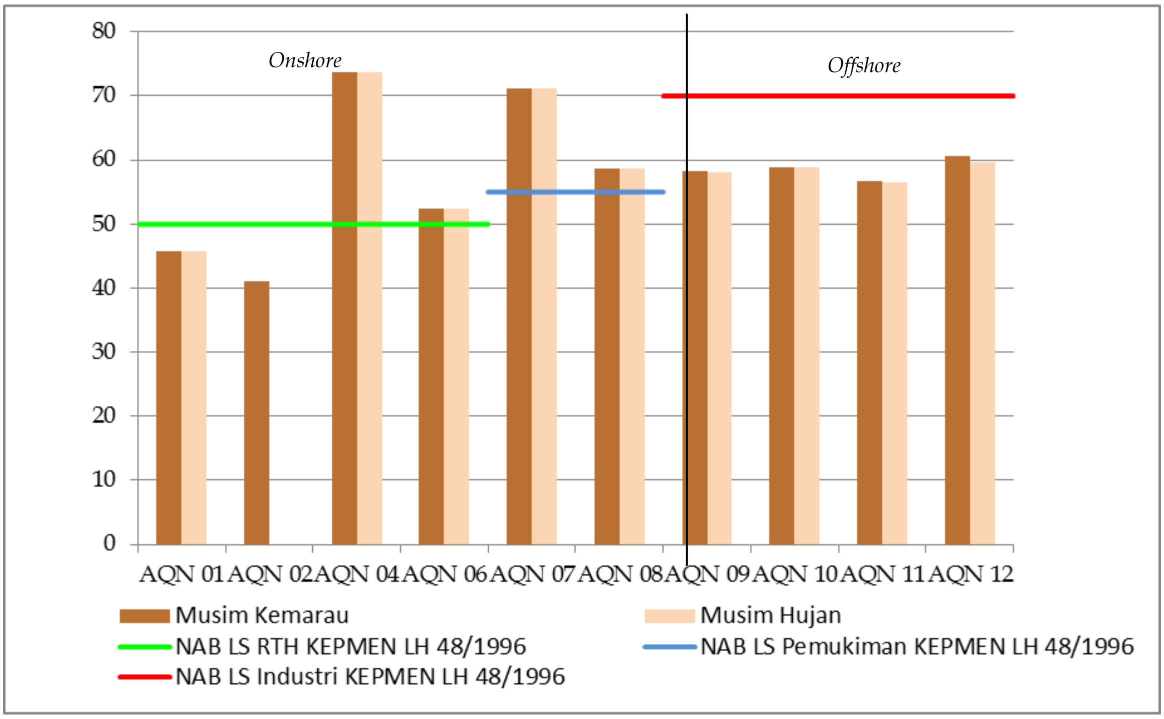


Figure II-14 Average Noise Level at Tangguh LNG

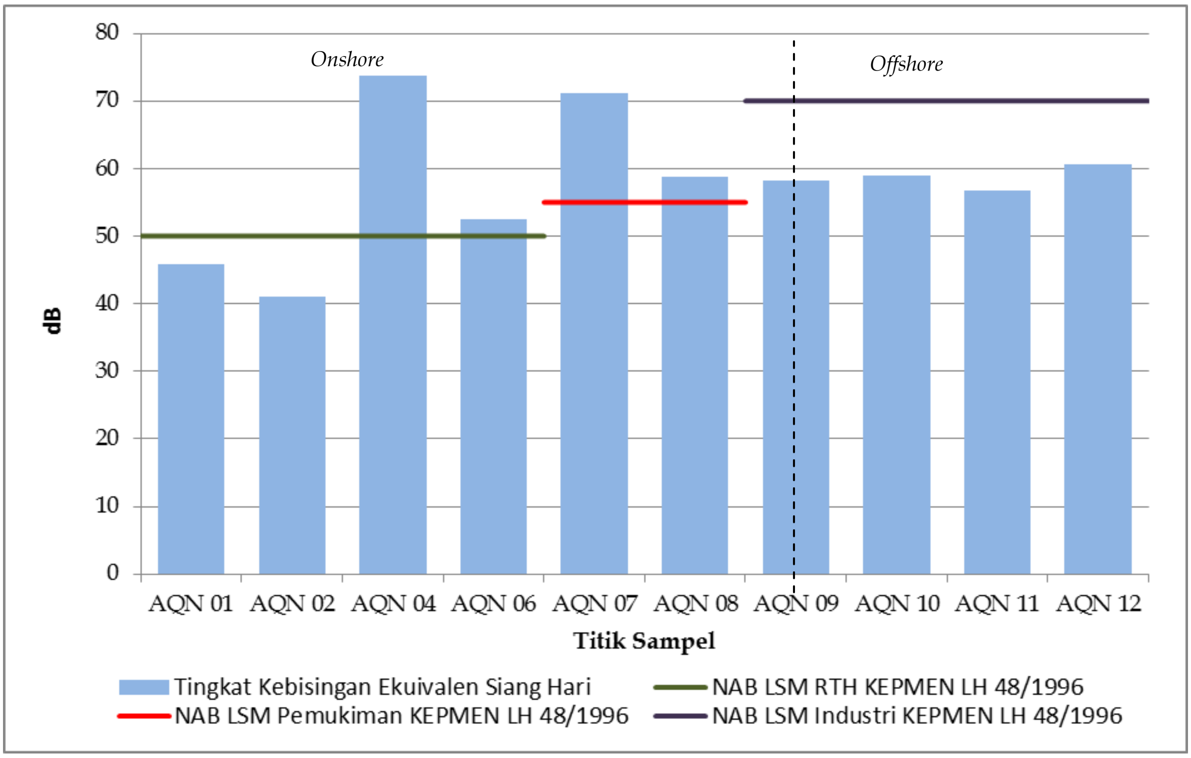


Figure II-15 Equivalent Noise Level at Daytime during Wet Season at Tangguh LNG

2.1.4 Hydrology

There are two principal watersheds (DAS) involved in the project site, namely DAS Manggosa and DAS Saengga. The Manggosa River is located on the eastern boundary of the Tangguh LNG site, while the Saengga River is located on the western boundary of the Tangguh LNG site. DAS Saengga is much larger than the DAS Manggosa.

Between the two large rivers, several creeks generally flow directly to the north coast estuaries. Thus, drainage from the Tangguh LNG location is divided into three flow directions:

- To the north through several creeks, flowing directly to the coast;
- To the west to Saengga River;
- To the east to Manggosa River.

The creeks found in the Tangguh LNG area could be considered ephermal where during extreme dry season, the creeks can dry up.

From **Figure II-16** it is estimated that around 449.6 ha of drainage area drains to the Manggosa River to the East and around 1,084.5 ha of the location drains to Saengga River to the West while drainage for the remaining areas lead to the coast in the north.

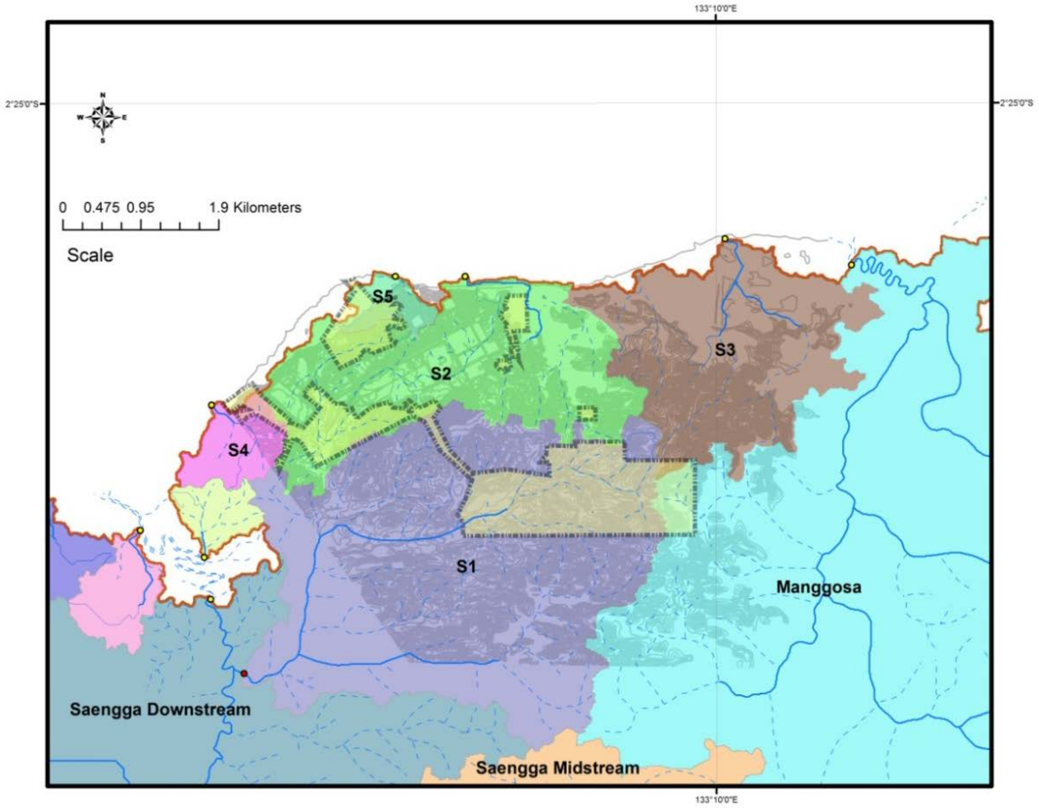


Figure II-16 Rivers and Creeks in Tangguh LNG Area

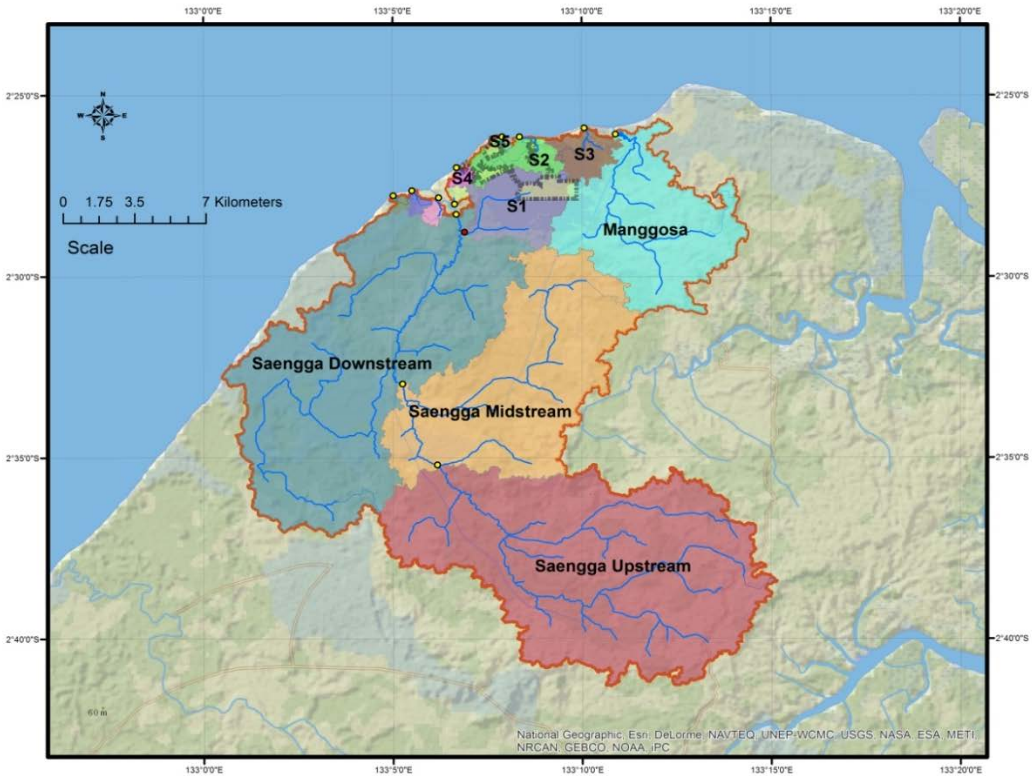


Figure II-17 Boundaries of Watersheds (DAS) for Rivers around the Tangguh LNG Area

The Manggosa River is only navigable around its estuary due to the density of Nipa Palm and other riparian vegetation. The Saengga River can be navigated further. Kampong Saengga, Onar and Tanah Merah Baru can be accessed from Bintuni Bay through the Saengga River. However, large boats can only pass river shoals during high tide. Both the Manggosa and Saengga Rivers are strongly influenced by tidal.

Figure II-18 Dominant Riparian Vegetation (Nipa Palm and Mangrove)

Saengga River is the largest river adjacent to the Tangguh LNG area where the main channel of the river is located approximately 1.5 to 2.0 km to the west of the Tangguh LNG boundary.

The slope of the Saengga River bed at downstream is relatively low, resulting in meandering mainly approaching the coast. The river depth varies between 4 to 5 m at the deepest point during high tide. The river width also varies reaching 80 m at the estuary.

The main boundaries of watersheds and creeks in the Tangguh LNG area are shown in **Figure II-19**. There are seasonal creeks/streams (ephemeral) in the Tangguh LNG area, in which several natural streams meet. The creeks are generally unnamed. For the purpose of the study, the streams watersheds area are given the code 'S' and a number. The sequence of numbering follows the watershed area measurement from the largest area (S1) to the smallest (S5).

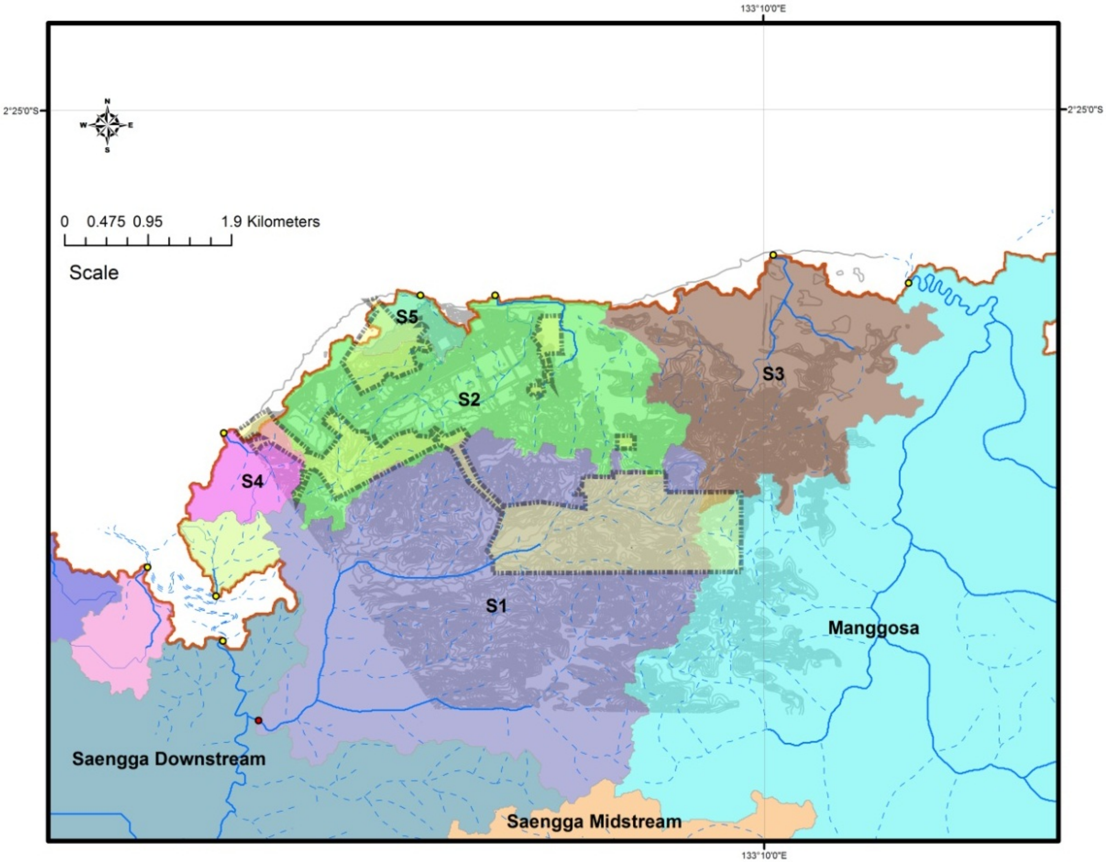


Figure II-19 **Flow Boundaries of Rivers and Creeks in the Tangguh LNG Area**

Geomorphology of the main rivers and creeks watersheds in the Tangguh LNG area is shown in **Figure II-19**.

Table II-7 **Characteristics of Principal Watersheds and Creeks around the the Tangguh LNG Expension Project Site**

Name of Watershed	Area (ha)	Average					Maximum Elevation (m)
		River Slope (%)	Length (km)	Width (m)	Depth (m)	Elevation (m)	
S1	1,482	37	8.615	6.5	0.4	21	100
S2	660	33	6.640	4.0	0.3	20	69
S3	598	31	4.829	3.8	0.3	17	72
S4	96	26	1.601	1.3	0.1	24	67
S5	53	23	1.316	0.9	0.1	20	58
Manggosa	5,070	24	18.703	13.6	0.6	17	310
Saengga Upstream	13,989	31	27.485	25.0	0.9	36	399
Saengga Midstream	8,057	23	20.003	18.0	0.8	17	225
Saengga Downstream	12,777	21	38.145	23.7	0.9	15	340

Source : Processed from the result of DEM automatic delineation using the SWAT (Soil and Water Assessment Tools) program from the US Department of Agriculture

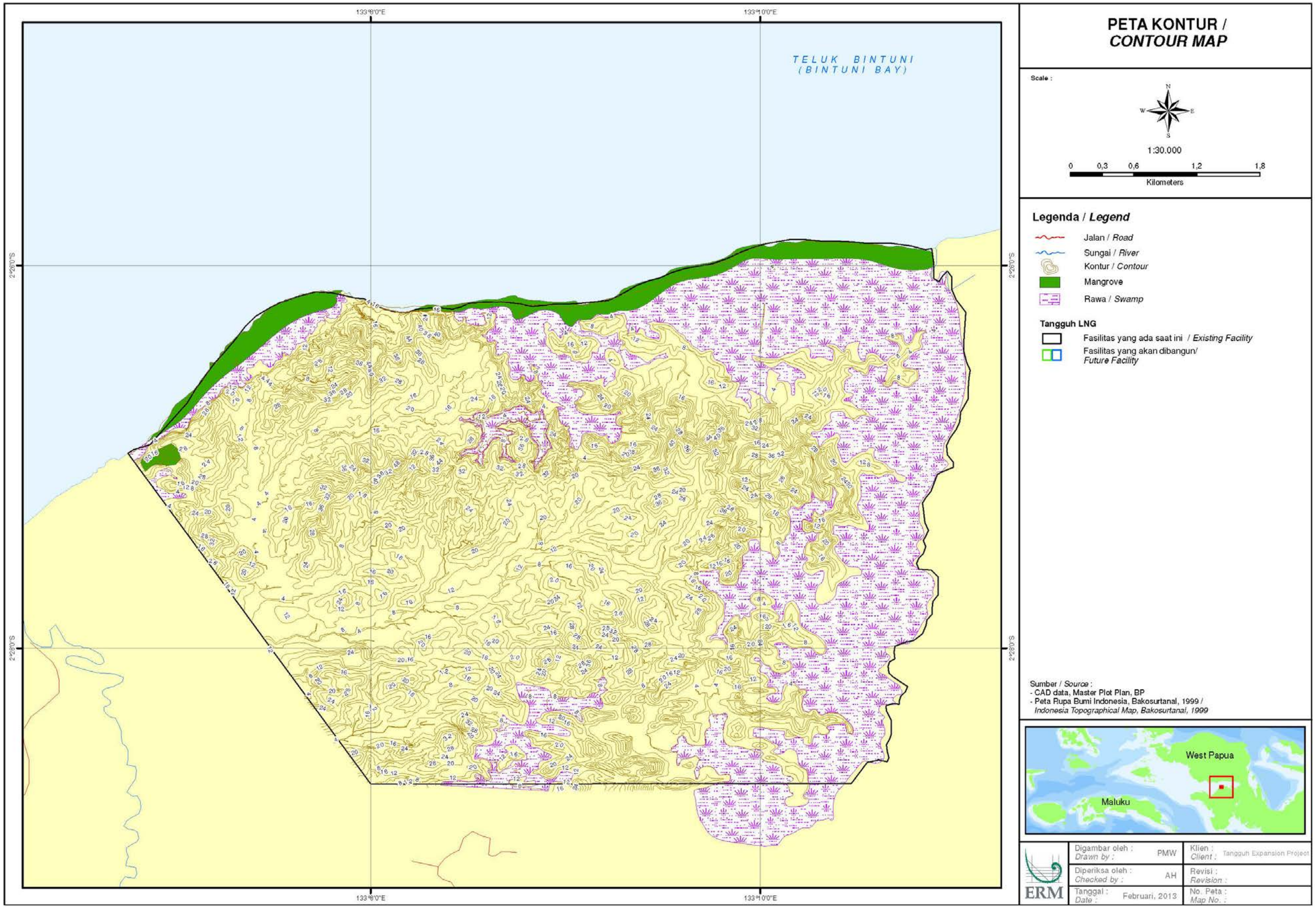


Figure II-20 Contour Map

2.1.5 Hydrogeology and Groundwater Quality

There are two aspects of hydrogeology included in the scope of the EIA for Tangguh LNG Expansion Project as described in the Terms of Reference:

a. Baseline associated with potential alternative use of groundwater; and

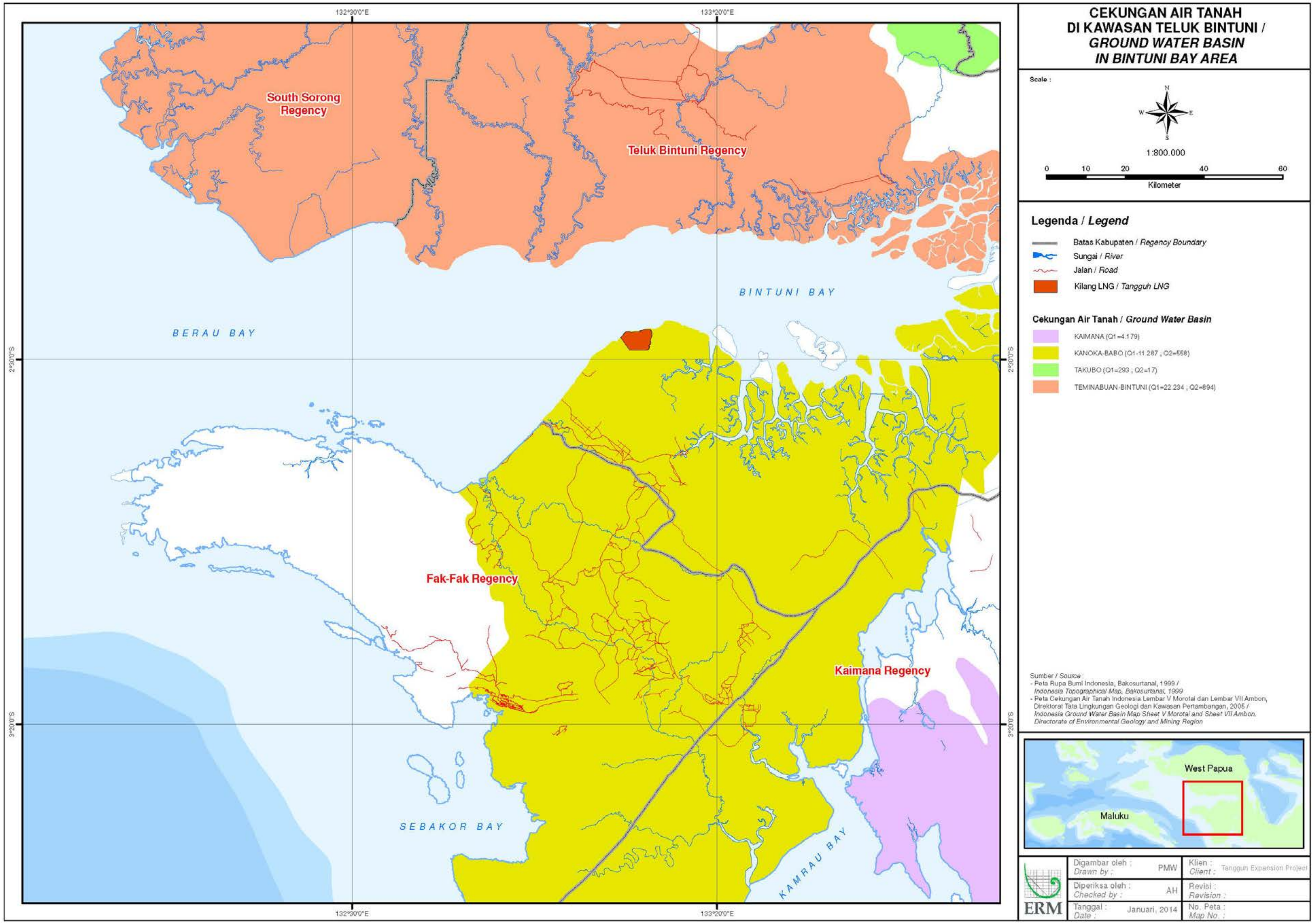
b. Baseline on quality of shallow groundwater/unconfined aquifer.

Groundwater Basin

According to Law No 7 Year 2004 regarding Water Resources, Article 12 paragraph (2) stipulates that groundwater management is based on Groundwater Basin (CAT, *Cekungan Air Tanah*), which Groundwater basins are established by Presidential Decree (Article 13 paragraph (1)). Furthermore, in Government Regulation No 43 Year 2008 regarding Groundwater, Article 4 stipulates that groundwater management is based on Goundwater Basin conducted on the basis of groundwater management policies and strategies.

Referring to Law No 7 Year 2004 and Government Regulation No. 43 Year 2008, in the discussion of hydrogeology environmental baseline, it is essential to relate the location of the Tangguh LNG Expansion Project to a Groundwater Basin. Based on Presidential Decree No. 26 Year 2011 regarding the Establishment of Groundwater Basin (CAT), Appendix 1, List of Groundwater Basins in Indonesia states that the location of the Tangguh LNG Expansion Project is part of the CAT Kanoka-Babo with coordinate boundaries 132^0 43′ 28.2″ – 134^0 07′ 55.31″ E and 02^0 13′ 36.77″ – 04^0 07′22.12″ S. The CAT Kanoka-Babo has an area of 16,870 km^2 approximately and encompasses the three regencies of Fakfak, Teluk Bintuni and Teluk Wondama.

Groundwater Basin overview of Kanoka-Babo can be seen in the Groundwater Map Sheets V Morotai and VII Ambon, published by the Directorate of Environmental Geology and Mining Region, 2005 (**Map II-3**). There is very limited data available for the CAT-Babo Kanoka and this is restricted to the immediate area to the Tangguh LNG where some investigations were undertaken over the period of 2000-2006. Threre is practically no information on potential Groundwater Basin that illustrates the geometric dimensions, aquifers distribution and aquifers characteristics and the total availability and quality of groundwater. However, theoretical estimates of groundwater flow rate for CAT Kanoka-Babo ranging between Q_1 11,267 Mm^3/year and Q_2 558 Mm^3/year.



Source: Groundwater Basin Map of Indonesia Sheet V Morotai and VII Ambon, Directorate of Geological and Mining Area Environmental Development, 2005

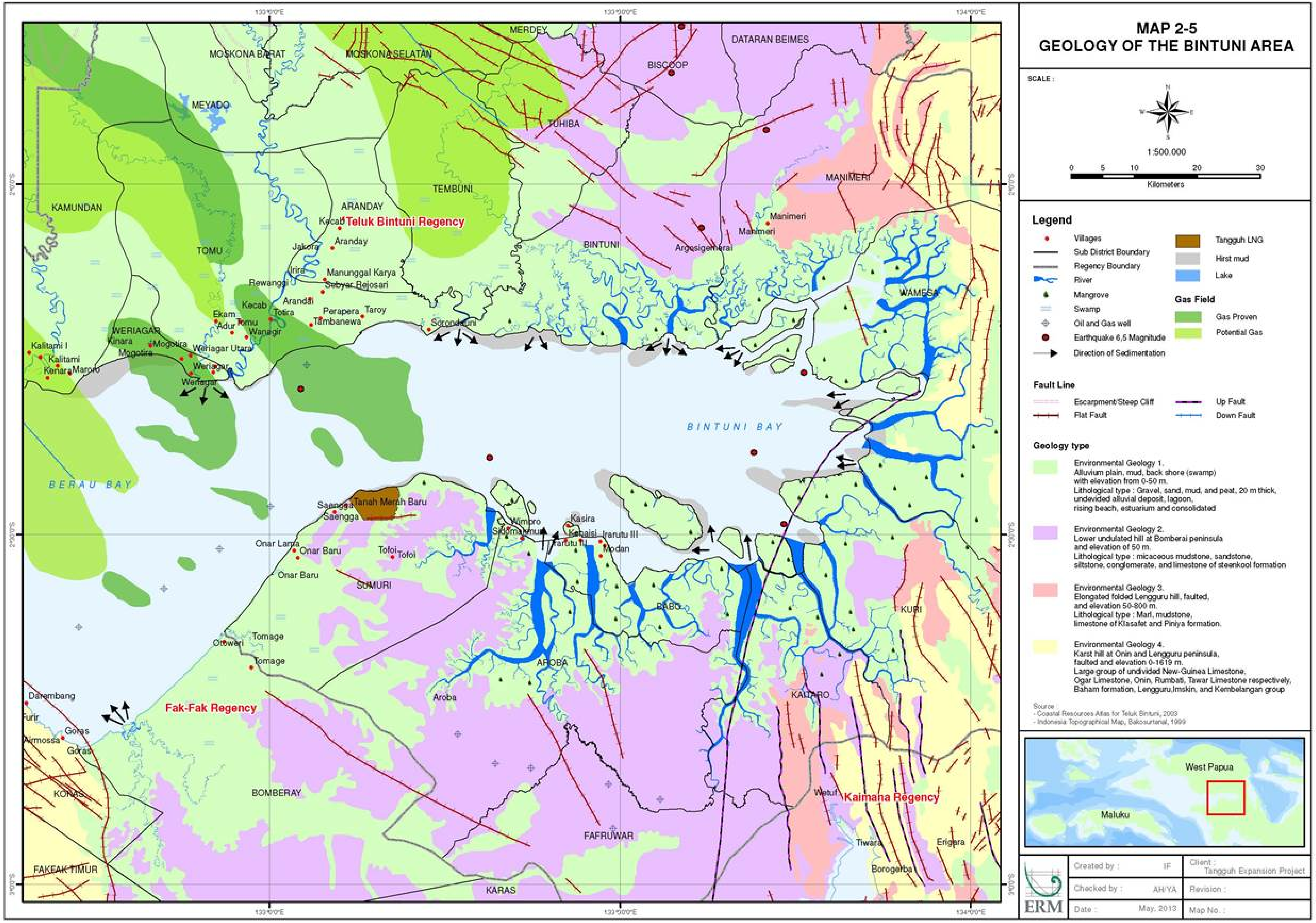
Map II-3 Location of Kanoka-Babo Groundwater Basin and Sub Basin of the Tangguh LNG Facility

Lithology and Presence of Groundwater Aquifer

The regional geological condition of the Bintuni Bay area are shown on **Map II-4** Geology of Bintuni Bay Area (Robinson et al., 1990 op.cit. LAPI-ITB, 2004). The Tangguh LNG area is underlain by the Steenkool Formation consists mainly of mudstone. Steenkool Formation outcrops are found in the south-southwest area of the Tangguh LNG, consist mostly of sandstone (TQss, indicated by yellow on the map) and are on an Antiklin structure sloping to the northeast beneath the Tangguh LNG area. This indicates the high possibility of sandstone aquifer beneath the Tangguh LNG area, recharged by rainwater infiltration and surface runoff to the southwest.

Cross section of seismic indicates that sediment layer is commonly flat to depth of around 500 m. The orientation and thickness of the Steenkool Formation in the Bintuni Basin indicate deposition of delta sediment from the south, southeast and east narrowing to the north, northwest and west. Apparently, this could be a dominant effect on the structure and orientation of the Steenkool Formation.

The Steenkool Formation was deposited in a delta area that spread westward during the Miocene to the Pleistocene, and is dominated by clay and deltaic clays and silts with sandy sediment layers and channels (Robinson et al., 1990). The dominant lithology is gray clay, very stiff to hard silty clay, generally with thin layers of silt and sand with thin layers of brown silty sand. A simple version of geological map is shown in **Map II-4** confirming that the southwest part of Steenkool Formation subcrop is predominantly sandstone, while the Tangguh LNG area is predominantly mudstone. Several anticlinal characteristics are indicated in the Figure and confirm that sandstones of the Steenkool Formation underlie the Tangguh LNG area and probably become be predominant with increasing depth.



Map II-5 Geology of Bintuni Bay Area (Robinson et al., 1990 op.cit. LAPI-ITB, 2004)

A number of oil and gas exploration wells have been drilled in the area since 1990 penetrating the full thickness of the Steenkool Formation. Their locations and the locations of seismic lines were provided by Tangguh LNG to LAPI-ITB, in 2005 to assist in preliminary evaluation of potential groundwater. The locations of wells and seismic trajectories are shown in **Figure II-21**. Seismic profiles with slope estimates of layers in the Steenkool Formation are shown in **Figure II-22**, **Figure II-23** and **Figure II-24**.

The existing data is summarized as follows:

a) Seismic

For the purpose of this analysis, six selected seismic lines that passing the Tangguh LNG area are as follows:

- Southwest–Northeast: NB97-107: 62 km; NB97-108: 32 km; NB97-109: 35.5 km
- Northwest-Southeast: NB97-103: 31 km; NB97-104: 28 km; NB97-105: 27.5 km

The seismic data indicated a correlation between the Steenkool Formation and Papua New Guinea Limestone Group and therefore can be used to evaluate the depth and structures of the Steenkool Formation.

The data are seismic lines of 104, 105 and 108 that passing the area adjacent to the proposed testing wells. The assessment was carried out in 2006 as part of potential produced water reinjection study. Further assessment on the slope of the Steenkool Formation sediment at depths of 300 m and 600 m was also carried out as part of this AMDAL study, since the purpose of the seismic survey was to observe the potential gas reservoir which data quality at depth over 500 m from the seismic profile is very limited.

Nonetheless, the seismic data indicated the following:

- There is a a potential gas just beneath the location of the Tangguh LNG at depth, associated with strike-slip fault in east-west direction;
- There are a number of faults that can be observed at depths over 500 m, which due to dominant structural system in the region, they were possibly as reactivation of left-lateral strike slip fault;
- Faults mapped at this depth were possibly of emerging or not emerging on the surface;
- Layers in and around the location at depths of less than 500 m are level;
- Slope of the layers increase at depth that could be caused by differential compaction.

The general conclusion of the data was that the faults did not emerge on the surface in the Tangguh LNG area.

Every fault that passes through claystone of the Steenkool Formation, will serve more as groundwater flow obstruction than as groundwater pathways. If the fault acts as pathway, this will cause saline groundwater flow from the lower part of Steenkool Formation to the upper Steenkool Formation. No evidence of upward vertical flow of saline groundwater was observed to a depth of 300 m during slim hole drilling or resistivity survey of ITB. However, the proposed test well for the purpose of investigating salinity to a depth of 400 m and groundwater salinity will be monitored through pumping test for 10 days. If there is a fault boundary, this will be observed from lowering of the groundwater table during the 10 days pumping test, in which the distance to the fault boundary from the test well can be calculated.

Additional interpretation of sediment dip in the Steenkool Formation at depths of 300 m and 600 m are indicated in seismic path 104, 105 and 108 (**Figure II-22**, **Figure II-23** and **Figure II-24**). Briefly, this is sediment dip measured along the section pathway (it should be noted that this is not the actual sediment dip since the direction of sediment is not known for sure) but believed to represent sediment dip in the Steenkool Formation found beneath the Tangguh LNG location. Sediment dip at depths of 300 m and 600 m are shown in **Table II-8**.

Table II-8 Sediment Dip at Depths of 300 m and 600 m in Seismic Path

Seismic Path	Sediment dip at depth 300 m	Sediment dip at depth 600 m
104	0.5^0	0.4^0
105	0.7^0	1.2^0
108	1.4^0	1.2^0

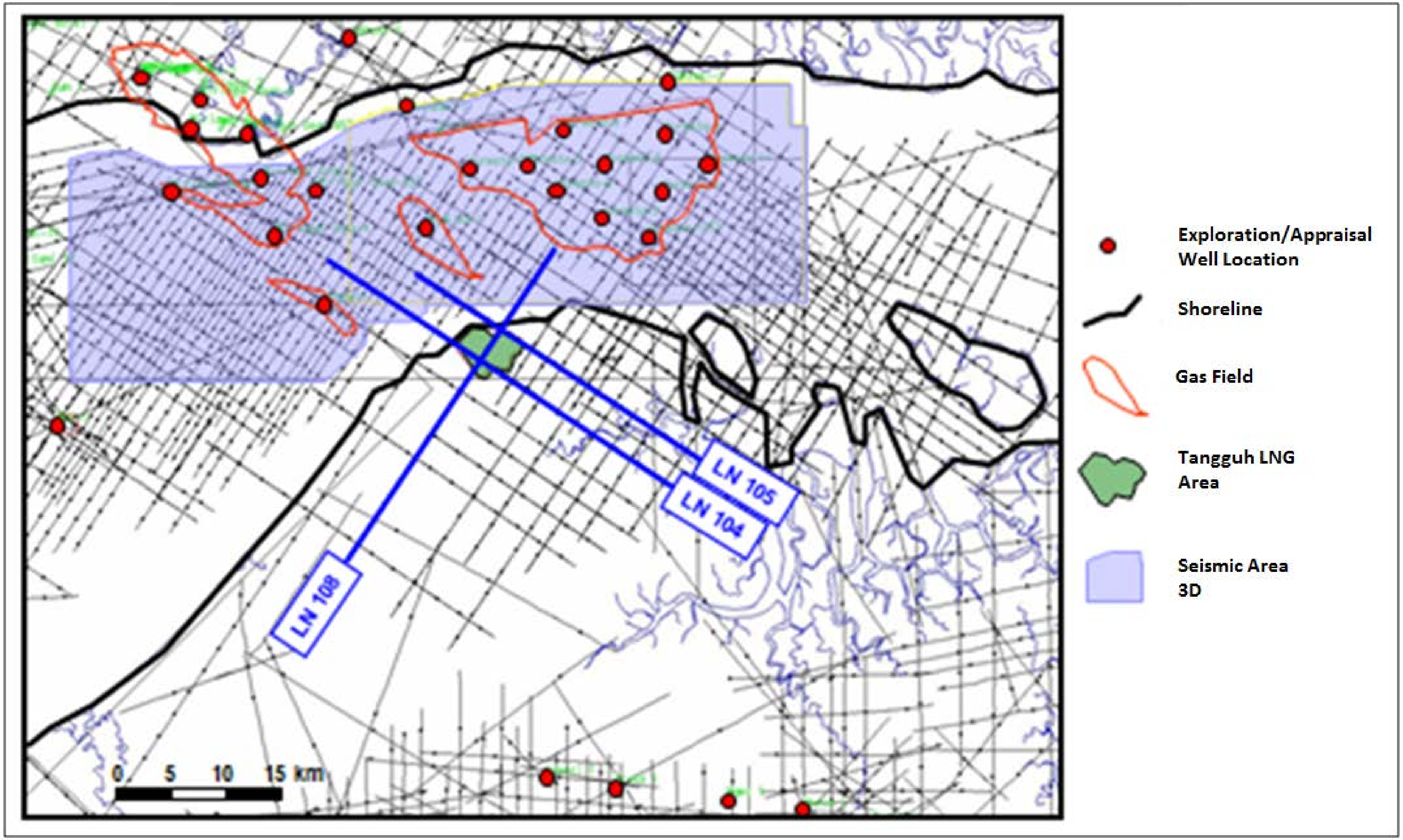


Figure II-21 Well Locations with Lithologic Logs and Seismic Path

Seismic Section LN 104

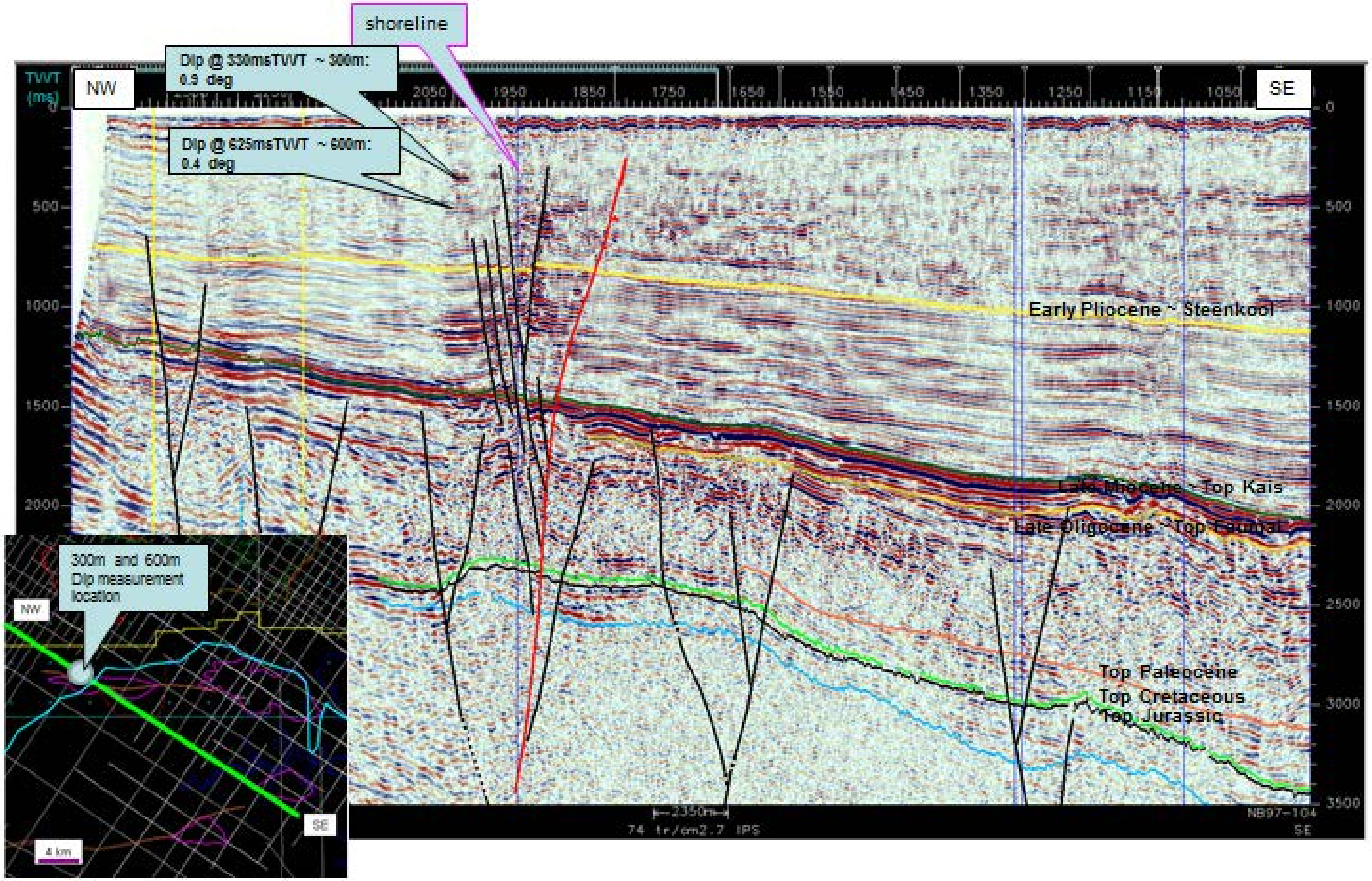


Figure II-22 **Seismic Profile for Path 104 with Estimated Sediment Dip in Steenkool Formation at Depths of 300m and 600m beneath Tangguh LNG**

Seismic Section LN 105

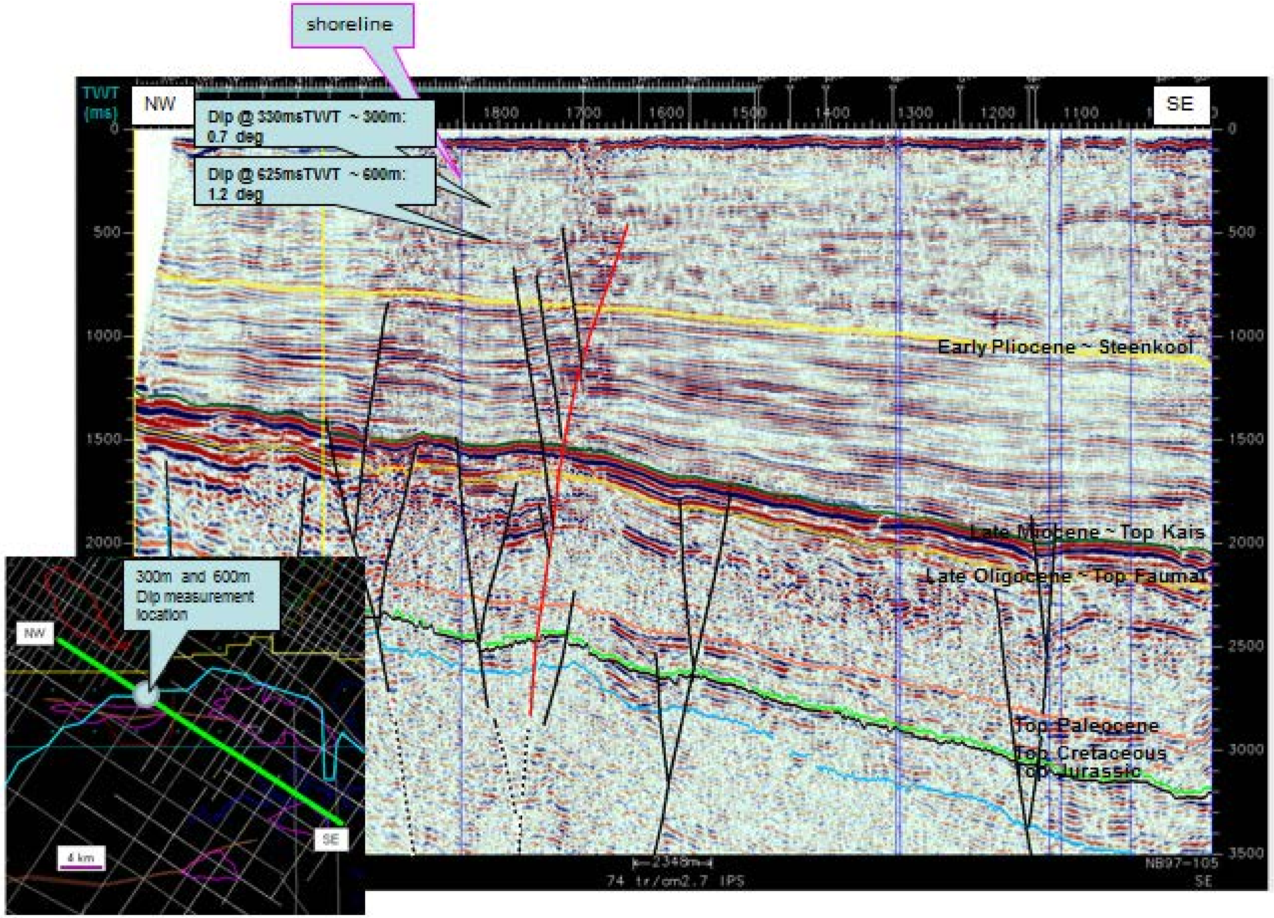


Figure II-23 Seismic Profile for Path 105 with Estimated Dip of Steenkool Layer at Depths of 300m and 600m beneath Tangguh LNG

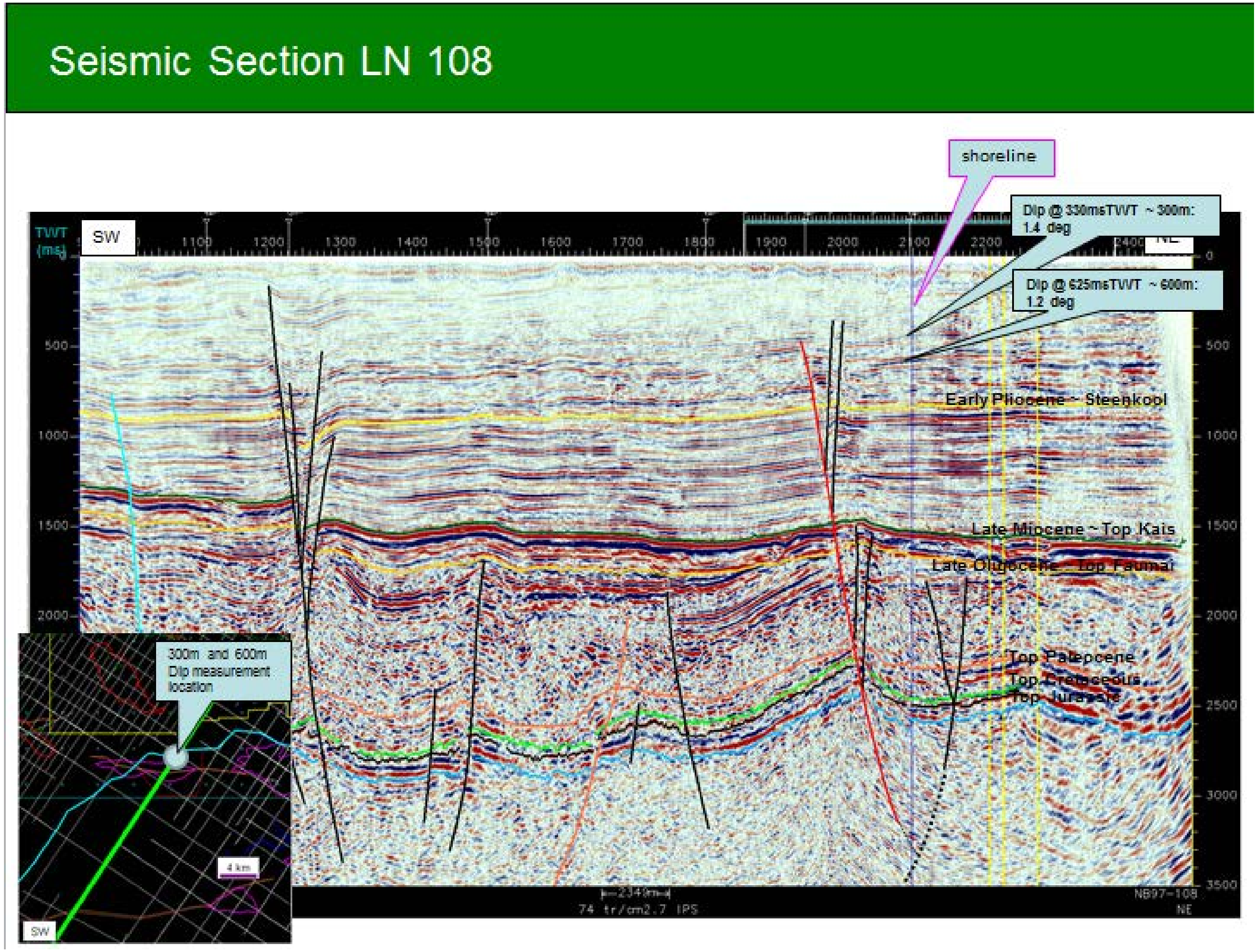


Figure II-24 **Seismic Profile for Path 108 with Estimated Dip in Steenkool Layer at Depths 300m and 600m beneath Tangguh LNG**

b) Lithology Log

Vertical and lateral rock distribution are interpreted from downhole geophysical logs and description of lithology from drill cuttings. Onshore and offshore borehole wells used in the assessment are as follows:

Onshore: Kasuri-1, Aroba-1, Terie-1, South Jarua-1, and South Monie-1

Offshore: Vorwata-1, Vorwata-2, Vorwata-3, Vorwata-4, Vorwata-5, Vorwata-6, Vorwata-7, Vorwata-8, Vorwata-9, Vorwata-10, Vorwata-11, Wiriagar Deep-1 , Wiriagar Deep-2-3 Wiriagar Deep, Wiriagar Deep-4, Wiriagar Deep-6, Wiriagar Deep-7, Ofaweri-1, Roabiba-1, Nambumbi-1, Sakauni-1, WOS-1, and Kalitami-1X Onshore North: Sebyar-1 and Aum-1.

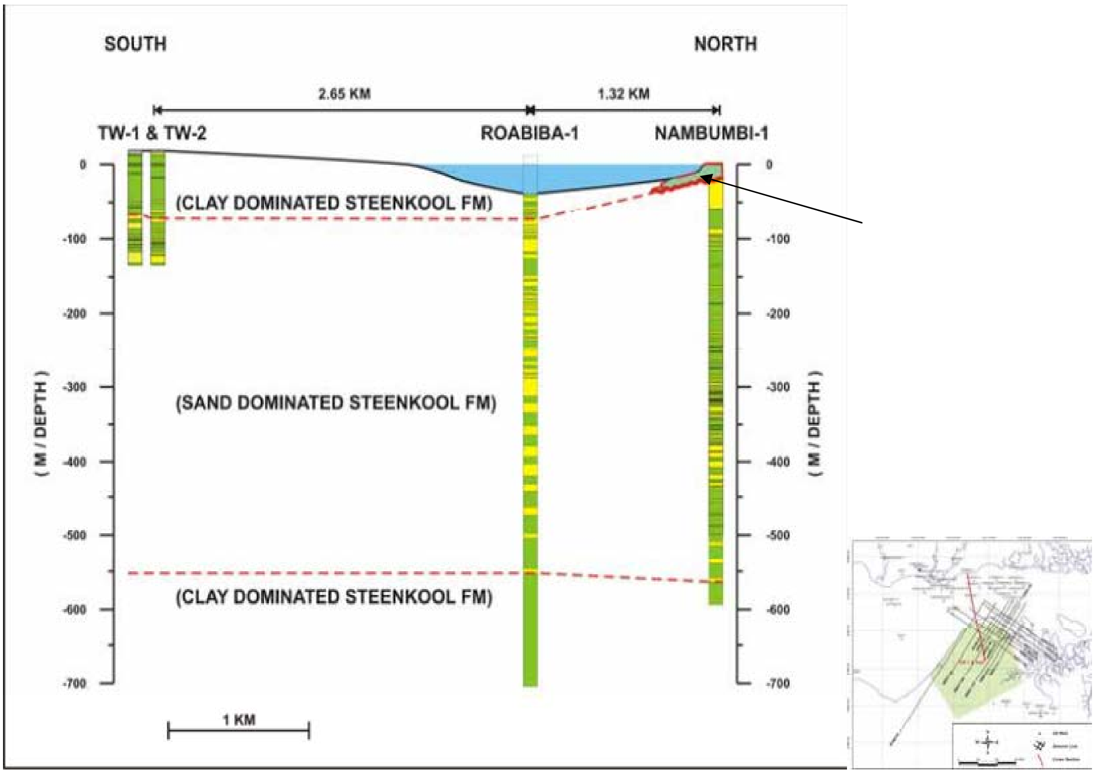


Figure II-25 Reconstruction of Cross Section of Oil Company and Well TW1-TW2

Figure II-25 shows cross section line extending from TW1-TW 2 through exploration well Roabiba-1 to exploration well Nambumbi-1.

In the Tangguh LNG area it is estimated that bottom depth of the Steenkool Formation is approximately 1,500 m. Initial drilling to a depth of 153 m (TW1 and TW2) conducted in 1999/2000, and supported by geology map interpretation confirmed the existence of sandstone layer between layers of relatively impermeable claystone. After cross section was made in 2007, another well was drilled near the shore (Slimhole Drillhole 1, SHD1) between TW1-TW22 and Roabiba-1, identifying the existence of sandstone aquifer to a depth of 310 m. This indicated that frequency and depth of sandstone may extend to a depth of 300 m.

Results of geological study of the Tangguh LNG area (Baynes Geology, 2006) indicated that the Bintuni Basin was influenced by echelon faults in the Northwest – Southwest direction and folds that were generally parallel with the faults. Slope of sediment to a depth of 500 m from the surface was relatively level (less than 0.5^0).

It is unlikely that faults will extend to the surface around the Tangguh LNG area (Baynes Geology, 2006), although the tendency of faults in the East-West direction as shown in the geology map some 5 km to the South (Robinson et al, 1990) are groundwater aquifers flowing through granular pore space.

Numeric modeling indicates that Steenkool Formation recharge is approximately 3% from rainfall.

The discharge area system in the Tangguh LNG area is not yet known, but it is likely that the subsurface flow heads to Bintuni Bay through sandstone subcrop from Anticlinal Highs or fault zones. The flow area might be located north of the Tangguh LNG area under Bintuni Bay or further to the west in the Banda Sea.

c) Groundwater Salinity

No data is available on shallow groundwater salinity in the Steenkool Formation to a depth of 30 m other than as shown in the hydrogeology cross section (**Figure II-27**) and also interpretation of groundwater salinity to a depth of 300 m based on geophysical logging in slim hole drilling SHD-1. Initial assessment made showed that ground water salinity to a depth of 600 m, which is the bottom part of numeric modeling, was less than 1,000 mg/L. Numeric modeling described in Chapter III indicated that salinity is based on groundwater flow and water balance, and this is shown in the cross section and map. Numeric modeling used the assumption that the meeting point of fresh water-saline water in the lower part of the Steenkool Formation was located some 2 km offshore.

Potential Groundwater

Potential groundwater in the Tangguh LNG area may be evaluated from the results of several surveys that were performed, drilling, geophysical log and geo-electrical survey made during 2000 through 2006, including survey toward community well installations in the Steenkool Formation in Tanah Merah and Saengga.

In and around the Tangguh LNG area a total of 11 groundwater wells have been drilled with depths ranging between 90 m to 300 m (**Table II-9**). The drilling locations are shown in **Figure II-26**, except for two bore holes in Onar Baru and Onar Lama (WWOL-1 and WWOB-1) at distance of more than 12 km to the West.

Drilling and testing of TW1 and TW2 wells were done from 1999 through 2000. TW1 was abandoned at depth 132.5 m due to drilling problems and loss of equipment into the well. Then the bore well was replaced by TW2 at distance of about 82 m from TW1. However the filter in TW2 bore well was not installed at the proper depth and the bore well was eventually abandoned after fine sand continued to enter the bore well during pumping test. However, useful data was acquired on aquifer distribution, aquifer parameter and groundwater quality.

Bore wells made in Saengga, Tanah Merah Baru, Onar Baru and Onar Lama in 2005 to 2006 were for the purpose of providing water supply to the four villages as part of the community development program conducted by the Tangguh LNG.

In 2006, further study was made of aquifer distribution in the Steenkool Formation beneath the Tangguh LNG area at depths of between 150 and 310 m with small diameter drilling (Slim hole SHD-1). Although casing and filter were not installed in the bore well, useful data was obtained on sandstone distribution and estimated water quality from the well geophysical log.

Results of drilling in TW1 and TW2 indicated the existence of confined aquifer in the Steenkool Formation to a depth of 150 m. Piezometrik groundwater table reached a depth of 2.5 m below the surface. Bore wells TW1 and TW2 are located centrally between community well in Tanah Merah Baru/Saengga and small-diameter well (Slim Hole SHD-1) at depth 310 m.

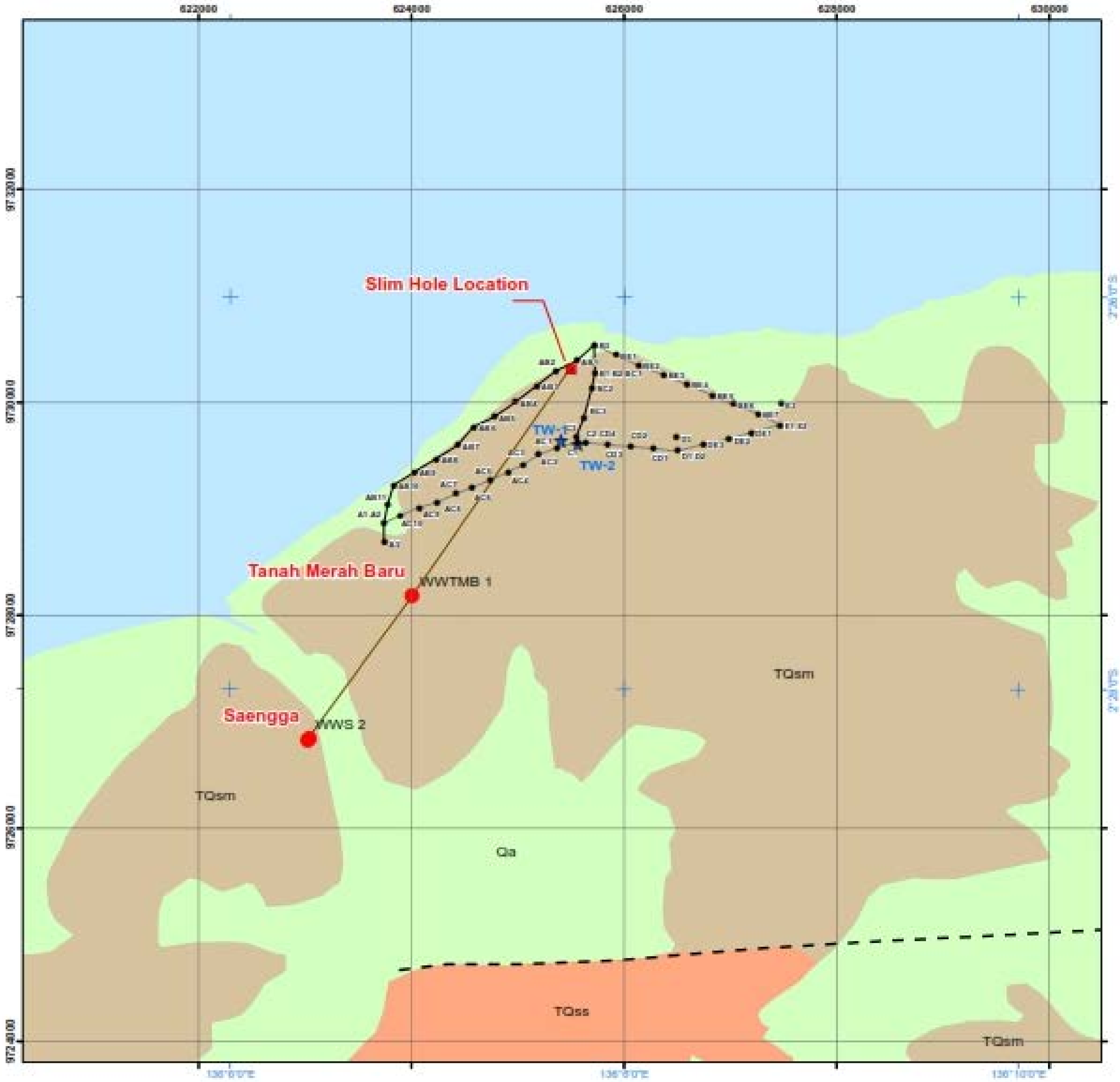


Figure II-26 Locations of Resistivity Survey

Table II-9 Construction of Groundwater Wells and Pumping Test Results and Location of VES in Path A, B and C

Drill Number	Date of Drilling/ Construction	Total Depth (m)	Depth of Filter (m)	Pumping Test			Salinity (mg/L) TDS	Note
				Discharge (L/s)	Duration (jam)	Withdraw (m)		
TW1	Jan 2000	153	-	-	-	-	-	Sand 136 - 151 m. Abandoned, drill shaft stuck in hole
TW2	Jan 2000	153	87 - 93 98,8 - 101,8 104 - 116	1,4	6,7	16,5	488	Sand 135 - 150 m. Covered by mud during construction.
WWS-3	Nov - Dec 2005	135	98 - 110	2,5	24	5,4	325	Kampong Saengga
WWS-4	Nov 2005	129	101 - 122	2,6	24	5,8	326	Kampong Saengga
WWTMB - 1	Jan - Feb 2006	151	98 - 110 122 - 125	3,2	24	12,7	321	Kampong Tanah Merah Baru
WWTMB - 2a	Jan - Mar 2006	150	106 - 118 121 - 124	-	-	-	-	Abandoned, unable to be built without sand
WWTMB - 2b	Apr - May 2006	135	-	-	-	-	-	Abandoned, drill string separated in hole
WWTMB - 2c	Aug 2006	133	-	-	-	-	-	Abandoned, unable to be completed due to swelling clay
WWOB - 1	Feb - Mar 2006	90	71 - 83,3	2,9	24	18,3	257	Kampong Onar Baru
WWOL - 1	Jun - Jul 2006	90	40 - 45,2	2,9	24	7,4	325	Kampong Onar Lama
SHD - 1	Dec 2006 - Jan 2007	310	-	-	-	-	-	Muddy sand , 266 - 275 and 283,5 and 293,5

Interpretation of geophysical log for wells TW1, TW2, SHD1 and community wells in Tanah Merah Baru and Saengga (ERM, 2007), identified several indicator layers with profiles enabling correlation of aquifer from Saengga to Tanah Merah Baru through well TW1/TW2 and SHD1 in the Tangguh LNG area (**Figure II-27**). This correlation confirmed that the sandstone layer at SHD1 became thicker and more frequently found below depth of 250 m and separated from the aquifer utilized in Saengga and Tanah Merah Baru by a relatively thick impermeable claystone horizon. Based on the geological interpretation, there is good potential for sandstone layer to be thicker and coarser at depths below 300 m based on regional geologic distribution of sandstone in the Steenkool Formation.

Geoelectrical resistivity survey was conducted in July-August 2004, along four inter-connected paths in the Tangguh LNG area. Survey was done using the Vertical Electrical Soundings (VES) method, with Wenner configuration and electrode separation until 310 m. Results of geoelectric resistivity survey along AB, were interpreted with re-calibration of bore well log TW1, TW2, WWTMB-1 and SHD-1 (**Figure II-28**). Estimated resistivity of VES survey data of 2004 may be correlated with lithology at SHD -1. Re-interpretation indicated that in general sand layer below a depth 266 m at bore well SHD-1 extended laterally at least 3 km to the southwest, and there was correlation between interpretation of VES and adjacent drilling log.

Resistivity survey and hydrogeological cross section of downhole electric and gamma logs, indicated an absence of significant vertical shift in the Steenkool Formation to a depth of 300 m. Hydrogeological cross section indicated 0.8° dip in the Steenkool Formation at depth of approximately 100 m however it should be noted that the seismic cross section path used to calculate sediment dip was not perpendicular to the true dip of sediment. This was in line with sediment dip at depths 300 m and 600 m measured from seismic profile.

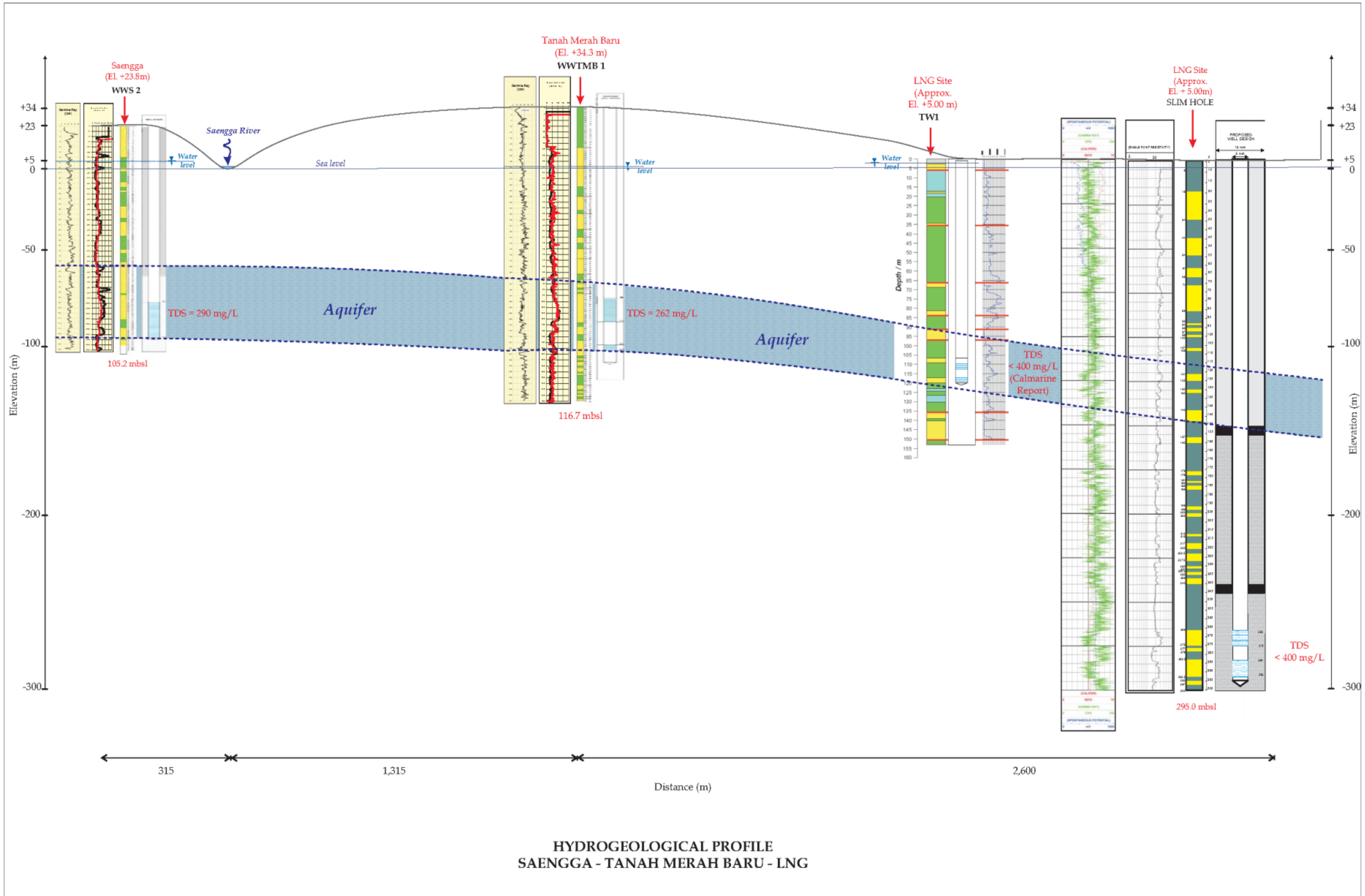


Figure II-27 Hydrologic Profile and Aquifer Correlation for Saengga – Tanah Merah Baru – Tangguh LNG (2007)

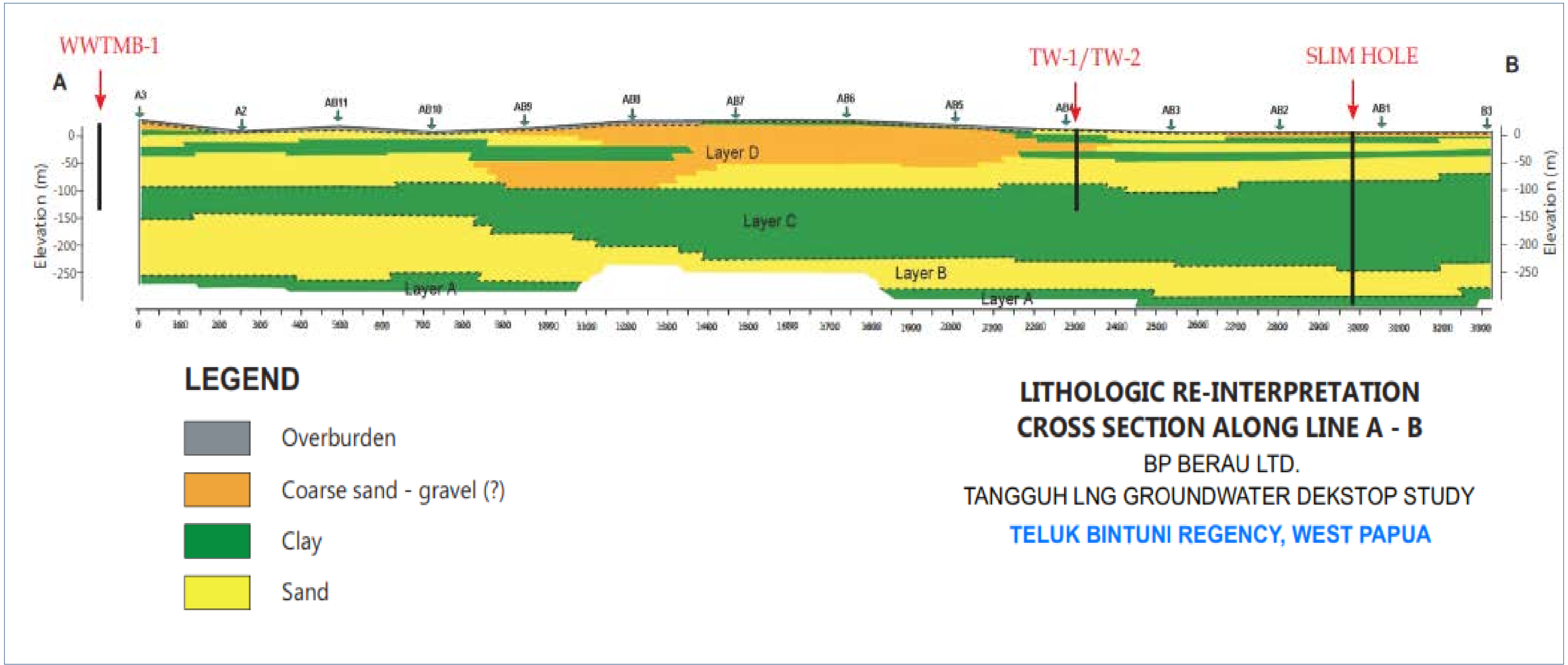


Figure II-28 Aquifer Correlation

Interpretation of geophysical resistivity log of bore well SHD-1, indicated that groundwater at depth 150 - 300 m below the surface had salinity of less than 500 mg/L. Results of lithology log (from drill cuttings) and geophysical resistivity log at bore well SHD-1 indicated the presence of ten aquifer zones between the surface to a depth of 150 m with total thickness of 83 m. Below 150 m until total depth of 310 m, groundwater aquifers were found at depths between 266 m - 275 m and 283.5 m – 293.5 m, total thickness of the two aquifers were 19 m.

Hydraulic Characteristics of Groundwater Aquifer

In the period from 1997 to 2005 Calamarine operated a base camp near Tanah Merah Lama in the Tangguh LNG area and relied on a production well 26 m deep to provide water needs of the camp. During that period, the well operated satisfactory to produce good quality groundwater for drinking water, with no indication of increased salinity despite the relative proximity from the waters of Bintuni Bay.

Exploration drilling for groundwater supply for the Tangguh LNG Project was made between 1999 to 2000, aside from the failure of the previous well bore TW1 and TW2, much information was obtained on sand dispersion to a depth of 150 m, groundwater table, groundwater salinity and aquifer parameters.

In 2006, community wells were built in Tanah Merah Baru and Saengga with respective depths of 153 m and 135 m in the Steenkool Formation, and additional data was obtained on groundwater table, groundwater quality and aquifer parameters. Sandy rock layers found in community wells may be connected to sandy rock layer at intersection of well TW1/TW2 and SHD1.

Hydraulic characteristics of groundwater aquifer in the Tangguh LNG Project area could be obtained from pumping test results in the TW2 well and community wells. Pumping test at bore well TW2 was performed for a short period, but was unsatisfactory as fine sand continued to enter the filter. Maximum groundwater discharge at bore well TW2 during the short pumping test before finally being abandoned was between 10 to 14 L/second, with drop in groundwater table of 38 to 49 m.

Head measurement from +2.55 m MSL in bore well TW2 was considered consistent with recharge zone at higher ground surface elevation to the South and head increased with increasing depth. It was concluded that with increasing depth, pressure would increase with potential artesian flow in area with low ground surface elevation.

Water surface depth measured in two community wells in Saengga (to depth of 135 m) ranged between 21.6 m and 20.7 m below ground surface, equivalent to elevation of +2.2 to 3.1 m MSL. Groundwater surface of community well in Tanah Merah was 34.52 m below ground surface, equivalent to around -0.2 m MSL, however due to its proximity to original community well in Tanah Merah Baru that was eventually abandoned, the groundwater surface experienced change with the lower groundwater surface and may be disregarded.

It should be noted that despite the five-year measurement interval, hydrostatic heads are sufficiently representative for confined aquifer to depth of 150 m in the Steenkool Formation in which the aquifers may be correlated between Saengga, Tanah Merah and well TW1/TW2. Hydrostatic pressure increased with increasing depth and with increasing distance from shore in Bintuni Bay. Apparently, the shallowest part near the surface of the Steenkool Formation was unconfined aquifer, and depended on seasonal re-charge, and higher groundwater table in relation to topography and drainage. This indicated limited hydraulic correlation between the surface of the Steenkool Formation (unconfined) and Steenkool Formation at greater depths (confined), which indicated that main recharge to the Steenkool Formation occurred in sandstone outcrops to the Southwest.

Estimated transmissivity and hydraulic conductivity, taken from pumping test data, are shown in **Table II-10**. Average hydraulic conductivity from all pumping test results was 4.4 m/day.

Groundwater Conservation Zone Map

The Groundwater Conservation Zone Map for the Tangguh LNG region and explanation have been prepared in accordance with Government Regulation No. 43 Year 2008 concerning Groundwater. According to Article 24 Paragraph 3 of the regulation (Establishment of Conservation Zone), utilization of groundwater from aquifer needs to be evaluated to determine safe, vulnerable, critical, and damaged groundwater zones .

Two Groundwater Conservation Zone Maps were made for the AMDAL study and the following explanation is used to determine the limits of groundwater conservation zone.

- Safe – groundwater source not excessively extracted or not included as vulnerable to be excessively extracted, and the groundwater quality is not affected by impact or not likely to be impacted by human activities and/or influences.
- Vulnerable – sustainable yields are estimated to be low, with current groundwater extraction approaching or likely exceeding sustainable yields capacity of the aquifer, or groundwater quality likely to be affected by impact of activities and/or indirect influences of human activities.
- Critical – groundwater extraction exceeds sustainable yields and/or groundwater quality affected by impact of activities and/or impacted by activities and/or indirect influence of human activities. Improved groundwater quality and/or groundwater source recovery is possible if groundwater resources are managed in better manner.
- Damaged – groundwater resources are in threatened condition due to groundwater extraction far exceeding capacity of sustainable yields and/or groundwater quality is significantly affected by impact of human activities. Recovery of groundwater resource able to be utilized or improvement of groundwater quality is already quite difficult.

The Tangguh LNG region encompasses a small area (approximately 32 km^2) in a sub-basin (approximate area 750 km^2) as part of Groundwater Basin (CAT) Kanoka-Babo (16,870 km^2) as shown in **Map II-3**.

Preparation of the Groundwater Conservation Zone Map should be viewed in the context of the Kanoka-Babo Groundwater Basin area, by conceptual hydrogeological modelling (**Figure II-29**), as the basis of numerical modeling with wider limits than the Tangguh LNG area.

The hydrogeological conceptual model indicates that the Tangguh LNG area consists of several layers of aquifer system, in which the aquifer in the Steenkool Formation to depth of 600 m has potential for groundwater resource with suitable quality to meet groundwater supply needs of Tangguh LNG. The Groundwater Conservation Zone Map was made on the basis of conceptual modeling and other data described in the environmental baseline section of the ANDAL document. The first Groundwater Conservation Zone Map was for aquifers from the surface to depth of 150 m below the ground surface. The second Groundwater Conservation Zone Map is for aquifers located in the lower part of the Steenkool Formation at depths from 150 m to 600 m below the ground surface.

The two Groundwater Conservation Zone Maps indicate groundwater sources at Tangguh LNG that can be utilized and are also vulnerable, to a depth of 150 m below ground surface, and which have been utilized by the population of Kampong Tanah Merah Baru and Saengga and previously used to support various surveys made by the project before the first AMDAL was approved in 2002. This zone is shown in **Map II-5** Groundwater Conservation Zone 1: Shallow Aquifer in the Steenkool Formation between 0 m bmt and 150 m bmt in the Tangguh LNG facility. The second Zone lies at depth of between 150 m and 600 m below ground surface, which is the target aquifer being studied as a potential source of groundwater for Tangguh LNG and shown in **Map II-6** Groundwater Conservation Zone 2: Confined Aquifer in the Steenkool Formation between 150 m and 600 m bmt in the Tangguh LNG Facility.

The Baynes Geological Report of 2006 was used as reference in assessing the possibility of faults existing in the Tangguh LNG location.

Bintuni Basin sediments, such as the Steenkool Formation dating to the Late Miocene – Plistocene found at the Tangguh LNG location, is the outcome of erosion of the Lengguru fold in the east and Tamru highlands in the north. The Steenkool Formation is of greatest thickness near the Lengguru fold.

The structure of the upper portion of the Kais Formation dating to the Miocene period, near the Wiriagar gas field in the Bintuni Basin illustrates compression in the northeast-southwest direction dating to the Pliocene produced faults en-echelon, small displacement left-lateral strike-slip with similar direction of orientation, and folds in the northwest- southeast direction. The compression also reactivated left-lateral strike-slip faults dating to the Oligocene in the east-west direction. The faults indicate maximum displacement of 200 m after Miocene Displacement.

Fault displacement in the northeast-southwest direction is smaller than the one occurring in the east-west direction. Folded sediments from the Pliocene period are covered by level sediments dating to the Pleistocene indicating that tectonic deformation along the northwest-southeast fold in the Wiriagar area of Bintuni Basin halted during the Pleistocene period. From interpretation, it may be concluded that every contemporary fault in the Bintuni Basin and in even wider areas of the Bird's Head, are characterized by small-displacement, left-lateral motion on east-west trending vertical strike-slip.

Table II-10 Hydraulic Parameters of Pumping Test

Drill Number	Filter Depth (m)	Pumping discharge (L/s)	Final drawdown (L/s)	Specific Capacity (m^2/day)	Calculated Transmissivity (m^2/day)			Transmissivity Value applied (m^2/day)	Hydraulic Conductivity (m/day)
					Pumping	Recovery	Specific Capacity		
TW2	87 - 93 98,8 - 101,8 104 - 116	1,4	16,5	26	-	-	32	32	1,5
WWS-1	98 - 110	2,5	5,4	40	98	50	49	50	4,2
WWS-2	101 - 122	2,6	5,8	39	54	29	48	51	2,4
WWTMB - 1	98 - 110 122 - 125	3,2	12,7	22	61	45	27	53	3,5
WWOB - 1	71 - 83,3	2,9	18,3	14	16	14	17	15	1,5
WWOL - 1	40 - 45,2	2,9	7,4	34	100	324	41	70	13,5

Source: Pumping Test Results

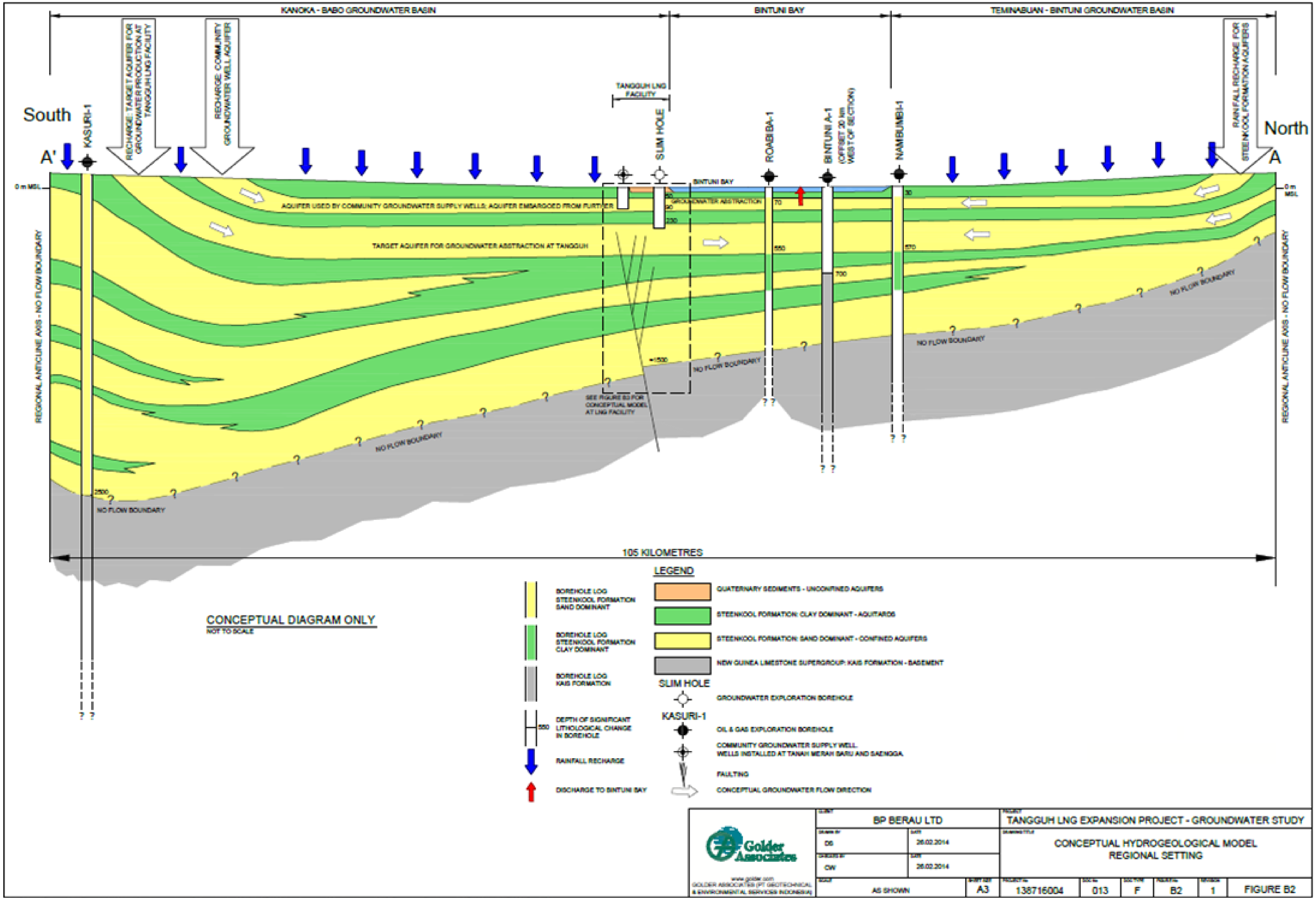


Figure II-29 Illustration of Regional Hydrogeology Conceptual Model

Map II-5 Groundwater Conservation Zone 1: Shallow Aquifer in the Steenkool Formation between 0 m and 150 m bmt in LNG Tangguh Facility

Groundwater conservation zone (groundwater recharge area) found in and located near the Tangguh LNG is divided into three groups, namely:

1. Unconfined aquifer associated with alluvial deposit along rivers and streams originating from and passing the Tangguh LNG facility, was refilled by rivers and pools, and also by direct rainwater infiltration with discharge locations in areas of lower elevation and also to the sea;
2. Shallow aquifers found at the upper 30 m of the Steenkool Formation, are recharged by rainwater infiltration along the surface outcrops and discharge locations in areas with lower elevation; and
3. Confined and semi-confined aquifers found in the upper part of the Steenkool Formation, are recharged through areas where sandstone outcrops at higher elevation to the south and southwest of the Tangguh LNG location are found and also recharged by flow of water from the aquifer above it. Outflow locations are found in Bintuni Bay.

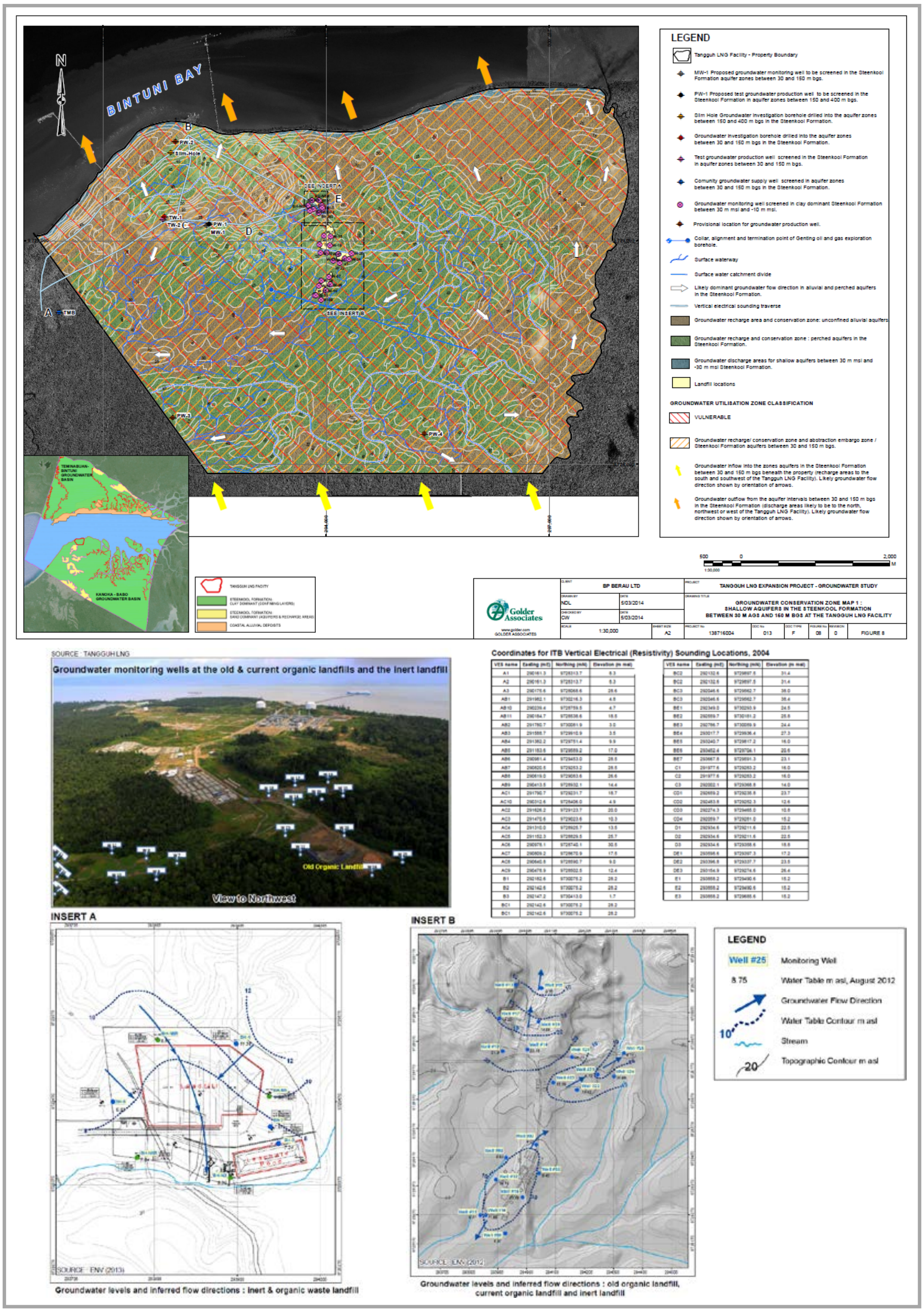
Safe Zone – unidentified.

Vulnerable Zone – four vulnerable zones of groundwater utilization consist of :

1. Facility area located on alluvial deposit,
2. Facility area on soils dominated by clays of the upper part of the Steenkool Formation, which are shallow aquifers and/or sufficiently large semi-confined aquifers,
3. Groundwater on lower part and downstream (down gradient) of the organic waste disposal site, inerts landfill and organic landfills, with potential for pollution.
4. Sandstone aquifer in the upper part of the Steenkool Formation, from the surface to a depth of 150 m below the ground surface with potential as a source of groundwater for the local community.

Critical Zone – unidentified.

Damaged Zone – unidentified.



Map II-6 Groundwater Conservation Zone 1: Shallow Aquifer in the Steenkool Formation between 0 m and 150 m bmt in LNG Tangguh Facility

Map II-6 Groundwater Conservation Zone 2: Confined Aquifer in the Steenkool Formation between 150 m and 600 m bmt in LNG Tangguh Facility

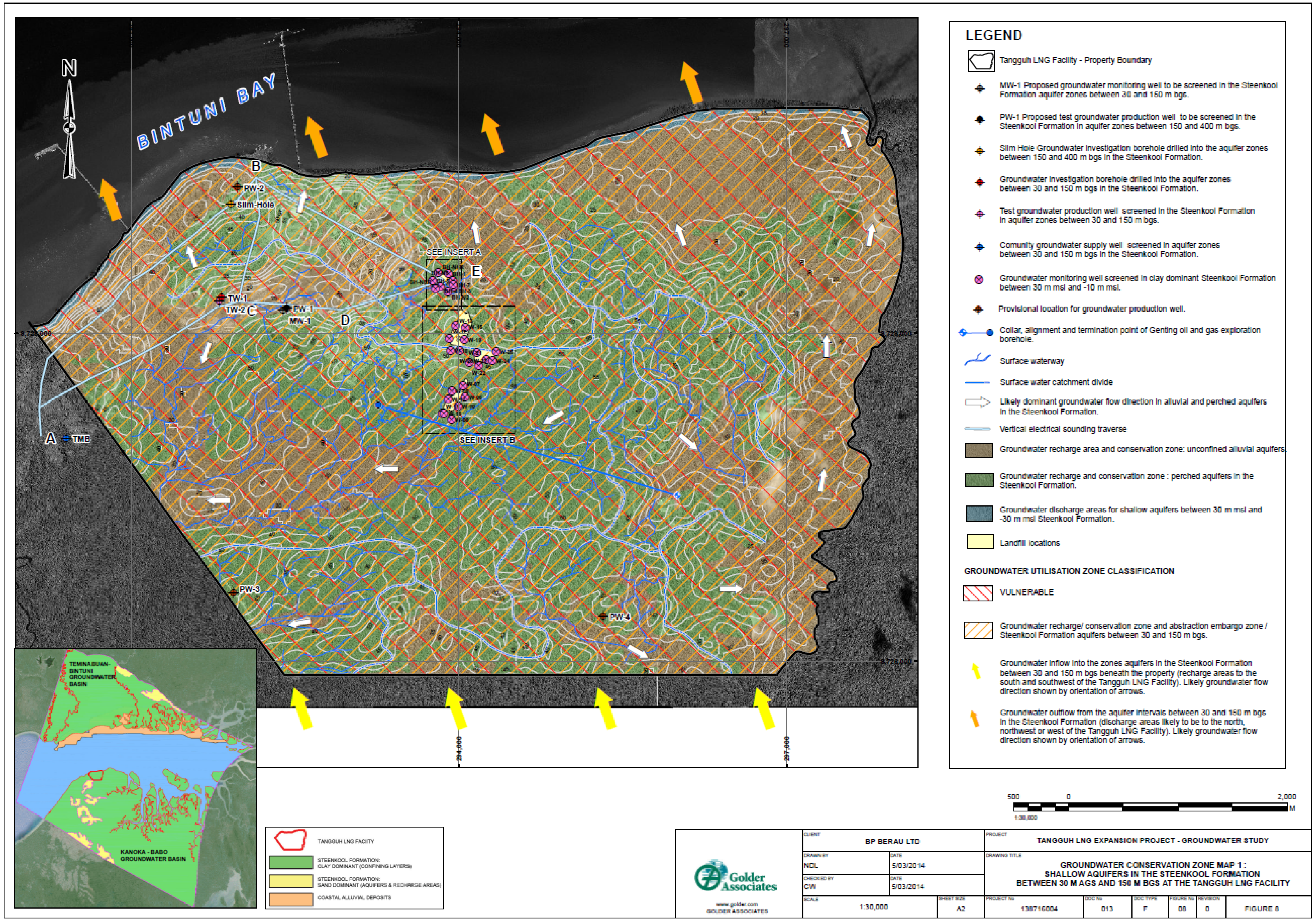
Due to the hydrogeological condition in an overall area larger than Tangguh LNG area, there are no recharge locations for confined aquifer zone in Map 2 Groundwater Conservation Zone in the Tangguh LNG location. Groundwater in confined aquifer is estimated to flow beneath the Tangguh LNG location from the recharge areas in the south and southwest to the discharge area in the north and/or northwest of the LNG facility. This mechanism is shown by inflow along the south side of the Tangguh LNG facility.

Safe Zone – unidentified.

Vulnerable Zone – exploitation of groundwater resources in the lower part of the Steenkool Formation aquifer if not well-managed and monitored has the potential to cause lowering of the groundwater table in community wells, soil subsidence, and seawater intrusion

Critical Zone – unidentified.

Damaged Zone – unidentified.



Map II-7 **Groundwater Conservation Zone 2: Confined Aquifer in the Steenkool Formation between 150 m and 600 m bmt in LNG Tangguh Facility**

Groundwater Quality

Evaluation of groundwater quality analysis was made to assess groundwater quality, with regard to the option to use groundwater in place of seawater desalination.

Groundwater samples obtained from TW2 well in July and August 2000 (*Calmarine* Indonesia, 2001) indicated that groundwater quality was dominated by sodium and bicarbonate, that together constitute nearly 90% of weight (in miliequivalent) as principal ion.

Groundwater analysis of community wells indicated similar chemical parameters as those of groundwater from TW2 well, with slightly lower salinity of TDS 163-296 mg/L in community wells compared with TDS 353-387 mg/L in well TW2. Analysis of fluoride parameter was also conducted on groundwater originating from bore wells, in which the value was still below the threshold limit of Class I water quality standard according to Regional Regulation No. 82 of 2001 concerning Water Quality Management and Water Pollution Control. Groundwater is generally alkaline with pH ranging from 7.9 to 8.4, except for well WWOL-1 in which groundwater quality is influenced by the presence of marshes in the absorption area with pH anomaly 6.9.

Groundwater quality in Tanah Merah and Saengga met Class I water quality standard specified in Government of Indonesia Regulation No. 82 Year 2001. Monitoring of groundwater quality in March and August 2012 confirmed that groundwater quality in Saengga was very good (TDS 89-179 mg/L) or one half of the groundwater salinity of Tanah Merah (TDS 344-381 mg/L). The difference in salinity between wet season and dry season indicated there was significant recharge, however it is not yet ascertained at this stage whether the recharge originated from sandstone outcrops in the Steenkool Formation or was local in nature.

Unconfined Aquifer

Community Wells

Groundwater quality samples were taken from community wells in kampong Saengga and Tanah Merah at the time of the environmental baseline survey for the AMDAL study in 2002 as shown in **Table II-11**.

Table II-11 Groundwater Sampling – Field Survey for AMDAL 2002

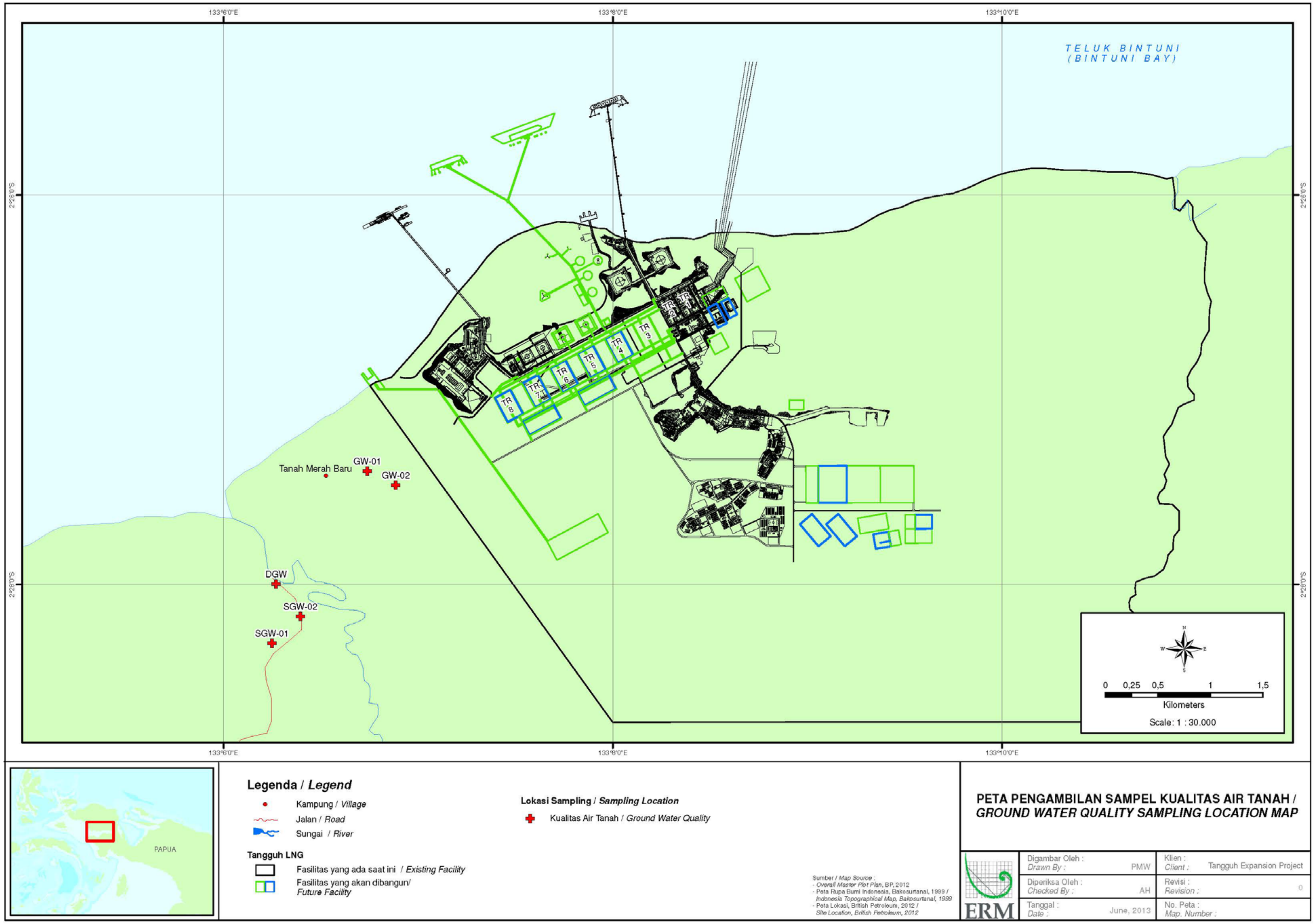
Sampling Location Code	Location	Coordinates		Dry season	Wet season
		South	East		
GW-100	Simuri (Saengga) Base Camp – old well	2^0 27′ 41.22″	133^0 6′ 17.76″	√	√
GW-105	Simuri (Saengga) - new well	-	-		√
GW-200	Simuri (Saengga) Village; Well 1	2^0 28′ 9.9″	133^0 6′ 23.7″	√	√
GW-250	Simuri (Saengga) Village; Well 2	2^0 28′ 8,.58″	133^0 6′ 20.28″	√	√
GW-260	Simuri (Saengga) Village; Well 2A	-	-		√
GW-300	Tanah Merah Village (old village); Well 1	2^0 26′12.18″	133^0 6′ 54.42″	√	√
GW-350	Tanah Merah Village (old village); Well 2	2^0 26′ 14.22″	133^0 7′ 51.66″	√	√
GW-400	Japanese Air strip				√

Source: ANDAL 2002

Monitoring results based on AMDAL 2002 are summarized in **Table II-14**.

As part of the Environmental Baseline Study for the AMDAL study of the proposed Tangguh LNG Development Project, samples were also taken in community shallow wells in kampong Saengga and Tanah Merah Baru. The wells generally were of less than 5 m depth, so that the water originated from the unconfined aquifer layer near the ground surface. Many community members also installed simple roofs to catch rainwater for additional supply besides the water from shallow wells. The locations of SGW-01 and SGW-02 are shown in **Figure II-30** and **Figure II-31**.

It is possbible that the water from shallow wells and rainwater will decrease during the dry season, particularly for drought during prolonged El Nino, so that the community will have to depend on the water network supply from deeper well built by Tangguh LNG to groundwater depth in the confined aquifer in the Steenkool Formation.



Map II-8 Sampling Locations of Groundwater

Figure II-30 SGW01 Community Well in Saengga

Figure II-31 SGW02 Community Well in Saengga

Groundwater samples were taken during the dry season in August 2012 and wet season in March 2013. Laboratory analysis results are presented in **Table II-12**. Low pH values (5.24, lower than quality standard of >6) and other parameters such as nitrite and coliform indicate local groundwater recharge.

Table II-12 Results of Groundwater Quality Analysis, Survey 2012-2013

No.	Parameter	Unit	Quality Standard*	Location							
				DGW 01		SGW 01		SGW 02		GW 01	
				Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Physical Properties											
1	pH	-	6 - 9	8.32	7.93	5.39	5.51	5.95	5.24	7.14	5.75
2	Temperature	°C	± 3	26.9	25.0	27.3	26.1	26.9	25.8	26.4	24.6
3	Total Dissolved Solids , TDS	mg/L	1.000	381	344	23	25	17	20	179	89
Nutrients											
1	Nitrate, NO_3-N	mg/L	10	0.045	0.463	0.170	<0.005	<0.005	0.010	0.223	8.63
2	Nitrite, NO_2-N	mg/L	0.06	0.765	1.37	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Microbiology											
1	E.Coli	MPN/100ml	100	2	ND	7	1	128	13	ND	ND
2	Total Coliform	MPN/100ml	1,000	187	179	548	99	>2420	225	14	4
Dissolved Metals											
1	Arsenic, As	mg/L	0.05	0.0010	<0.0005	0.0014	0.0006	0.0005	0.0007	0.0010	<0.0005
2	Cadmium, Cd	mg/L	0.01	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	0.0002
3	Chromium Hexavalent, Cr^{6+}	mg/L	0.05	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
4	Copper, Cu	mg/L	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
5	Iron, Fe	mg/L	0.3	0.10	<0.05	0.26	0.170	0.16	0.060	<0.05	<0.05
6	Lead, Pb	mg/L	0.03	0.004	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.002
7	Selenium, Se	mg/L	0.01	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005

* Quality standard based on PP 82 Year 2001, Class I (as Drinking Water Standard)

Tangguh LNG Area

In the Tangguh LNG area, there are 19 monitoring wells to observe the groundwater condition around the existing landfill area. The wells are regularly monitored by Tangguh LNG as part of the AMDAL 2002 commitment and reported to Ministry of the Environment (KLH) every six months. The data below originates from monitoring made by Tangguh LNG between October – December 2010 to January - September 2011.

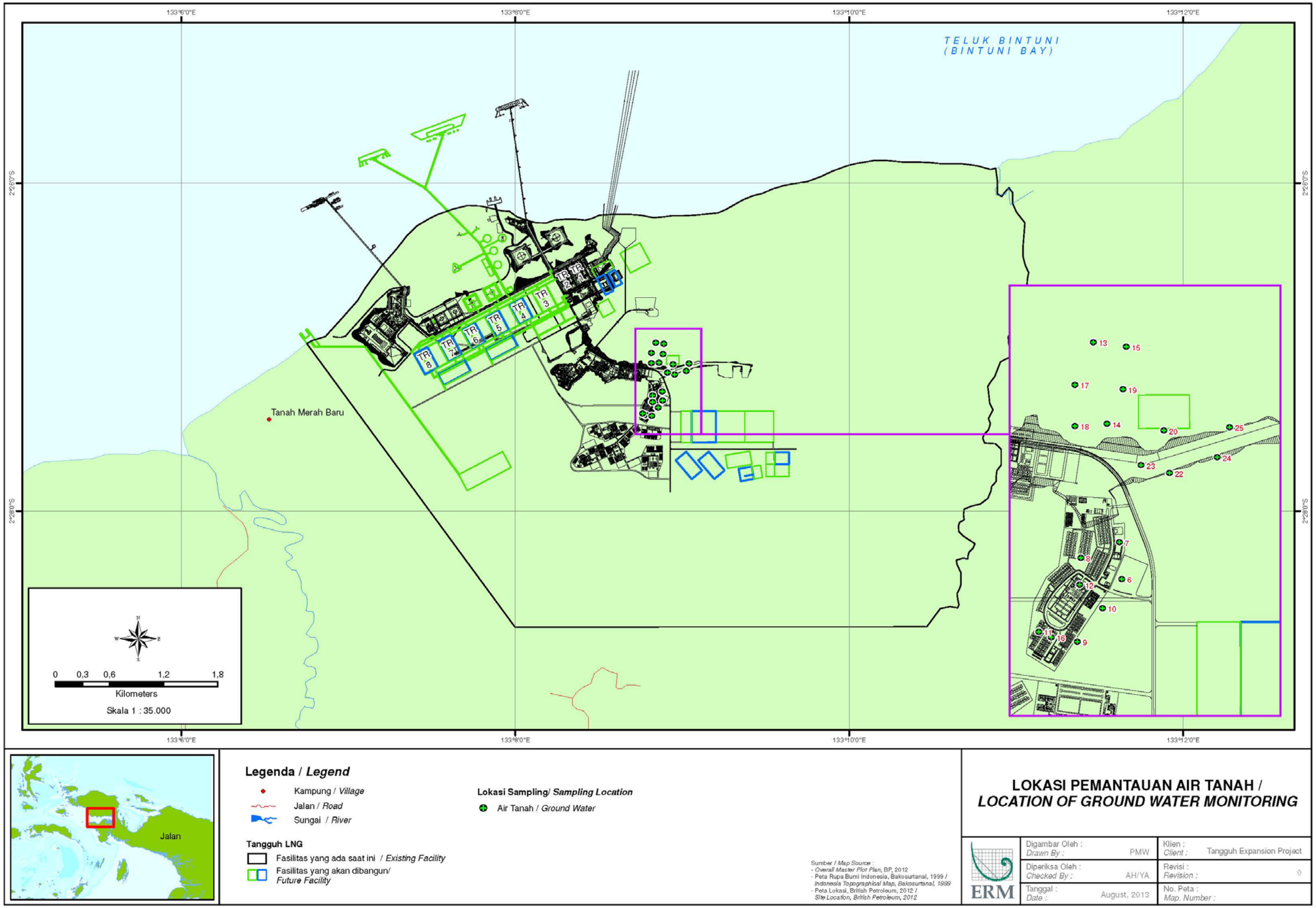
Table II-13 Coordinates of Sampling Locations for Groundwater Monitoring

Well #	Coordinates	
	South Latitude	East Longitude
Well #6	02º 27′ 19.6″	133º 08′ 52.9″
Well #7	02º 27′ 16.3″	133º 08′ 52.7″
Well #8	02º 27′ 17.7″	133º 08′ 49.3″
Well #9	02º 27′ 26.3″	133º 08′ 49.0″
Well #10	02º 27′ 22.2″	133º 08′ 51.2″
Well #11	02º 27′ 24.3″	133º 08′ 46.4″
Well #12	02º 27′ 20.1″	133º 08′ 47.9″
Well #13	02º 26′ 58.4″	133º 08′ 50.4″
Well #14	02º 27′ 05.7″	133º 08′ 51.6″
Well #15	02º 26′ 58.8″	133º 08′ 53.3″
Well #16	02º 27′ 24.8″	133º 08′ 46.7″
Well #17	02º 27′ 02.2″	133º 08′ 48.8″
Well #18	02º 27′ 05.9″	133º 08′ 48.8″
Well #19	02º 27′ 02.6″	133º 08′ 53.0″
Well #20	02º 27′ 06.3″	133º 08′ 56.6″
Well #22	02º 27′ 10.1″	133º 08′ 57.1″
Well #23	02º 27′ 09.4″	133º 08′ 54.6″
Well #24	02º 27′ 08.7″	133º 09′ 01.3″
Well #25	02º 27′ 06.0″	133º 09′ 02.4″

Monitoring wells are located around the solid waste management facility area or near the present landfill facility, as shown in **Figure II-32** and also in **Map II-8**. Monitoring wells are further added to the new landfill area. The groundwater monitoring wells are built in the uppermost part near the surface of the Steenkool Formation dominated by dark grey claystone interspersed with sand. The wells were periodically monitored every six months to detect the depth of the groundwater table and samples were taken for analysis of physical and chemical properties of groundwater. In general, monitoring of shallow groundwater provided water quality baseline data, in which several natural heavy metals were recorded as exceeding quality standard (Government Regulation No 82 Year 2001) as shown in **Table II-14**. COD and BOD values were recorded slightly higher (elevated) during operation of the organic waste disposal site used by EPC contractor during phase I Tangguh LNG construction period. The organic waste disposal site was re-excavated and reclaimed. Organic waste was moved to the organic landfill built near the area with suitable design. The improvement made succeeded in restoring groundwater quality and upon further monitoring in which the outcomes were consistently good, the groundwater monitoring program around the former organic waste disposal pits during the construction period became less intensive.

The groundwater table in the Steenkool Formation near the surface reflects surface topography with numerous drainage outlets leading to water bodies and Bintuni Bay.

Figure II-32 Location of Groundwater Monitoring Wells



Map II-9 Location of Groundwater Monitoring Wells – Tangguh LNG Construction Phase

The majority of water quality parameters in samples taken met Class I water quality standard according to Government of Indonesia Regulation No. 82 Year 2001, except for several parameters such as pH, Total Coliform, chromium hexavalent, iron, lead, manganese, as shown in **Table II-14**.

Table II-14 Groundwater Parameters Exceeding Clean Water Quality Standard

			AMDAL 2002		2010		2011	
Parameter	**Unit**	**PP No. 82/2001**	**Min**	**Max**	**Min**	**Max**	**Mi n**	**Max**
Physical								
pH	-	6 - 9	3.99	7.89	6.35	10.9	6.3 4	8.91
Microbiology								
Dissolved Metals								
Chromium Hexavalent, (Cr_{6+})	mg/L	0.,05	0.001	0.22 9	-	-	-	-
Iron, Fe	mg/L	0.3	0.1	29.2	0.02	1.42	0.0 2	4
Lead, Pb	mg/L	0.03	<0.00 1	0.08 2	-	-	-	-
Manganese, Mn	mg/L	1	<0.01	13.1	-	-	-	-

2.1.6 Soils

2.1.6.1 Soil Map Units

Locations of soil observation are in the Tangguh LNG area boundary. Based on landform, the project area is classified into three Soil Map Units (SPT). Four soil orders are found in the SPTs, namely Entisols, Inceptisols, Ultisols and Spodosols. The soil types are encountered in associations. Distribution of SPT is shown in **Map II-9**, while characteristics of each SPT are presented in **Table II-15**.

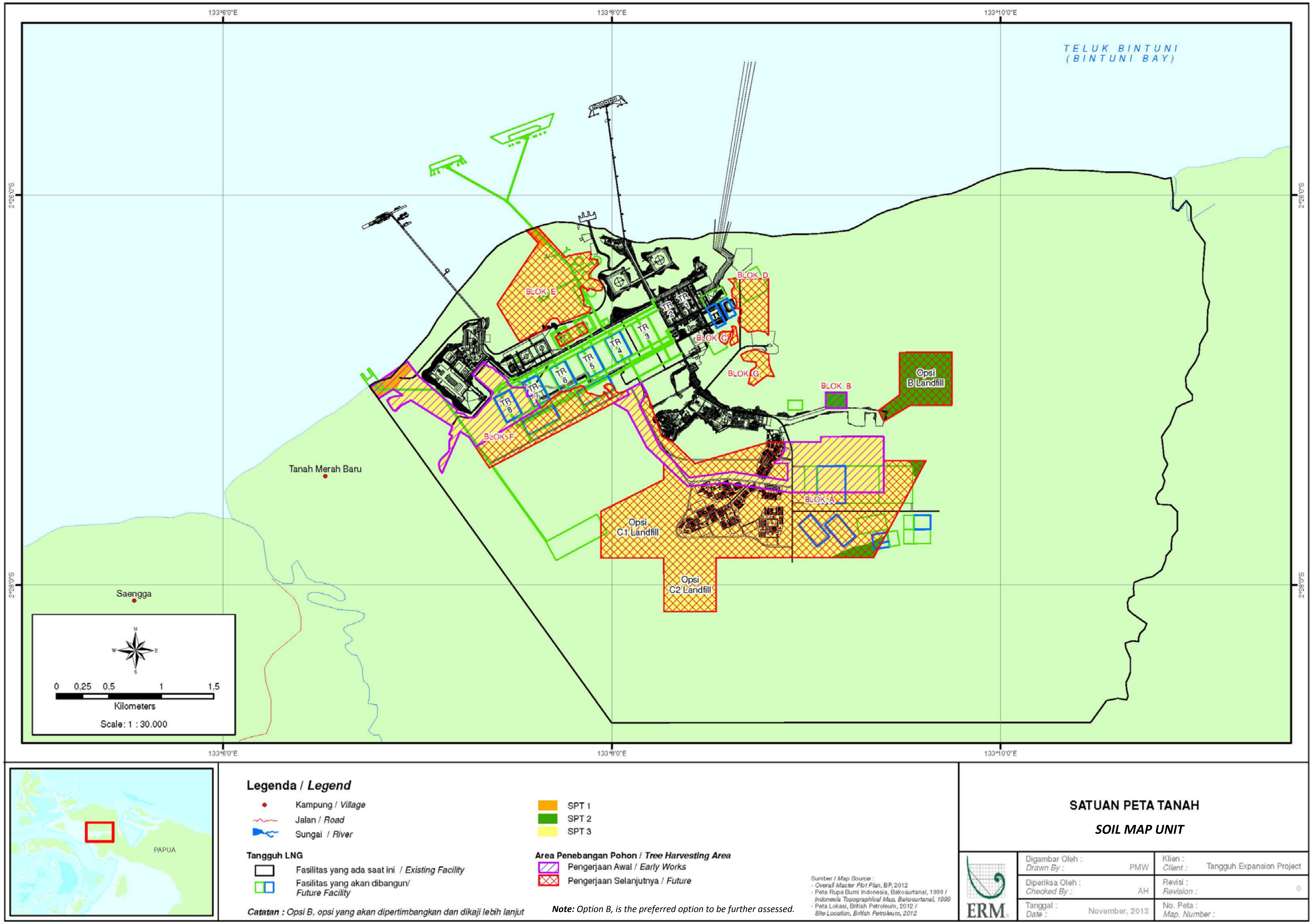
Soil Map Unit (SPT) 1 (Entisols)

SPT-1 Entisols are located on the north shoreline of the project area. The landform of the SPT consists of coastal shoal and tidal swamp (mangrove swamp) that are intermittently found along the shores. Mangrove swamp of Kajapah (KJP) land unit are found in a narrow area. Mangrove swamp are directly influenced by tides. In some places they are permanently inundated while in other areas far from the shoreline they are tidal swamps. No other vegetation is found in the area other than mangrove. In other places, the areas approaching fresh water (brackish water) mangrove gives way to other nipa palm vegetation. Based on the block map (**Map II-10**), the mangrove swamp belongs to Block E. Soils in the mangrove swamp are very poorly drained, unstructured (massive) and are of fine texture. In the USDA (United States Department of Agriculture) classification in great group level, soils with properties as described above are in the category of Hydraquents.

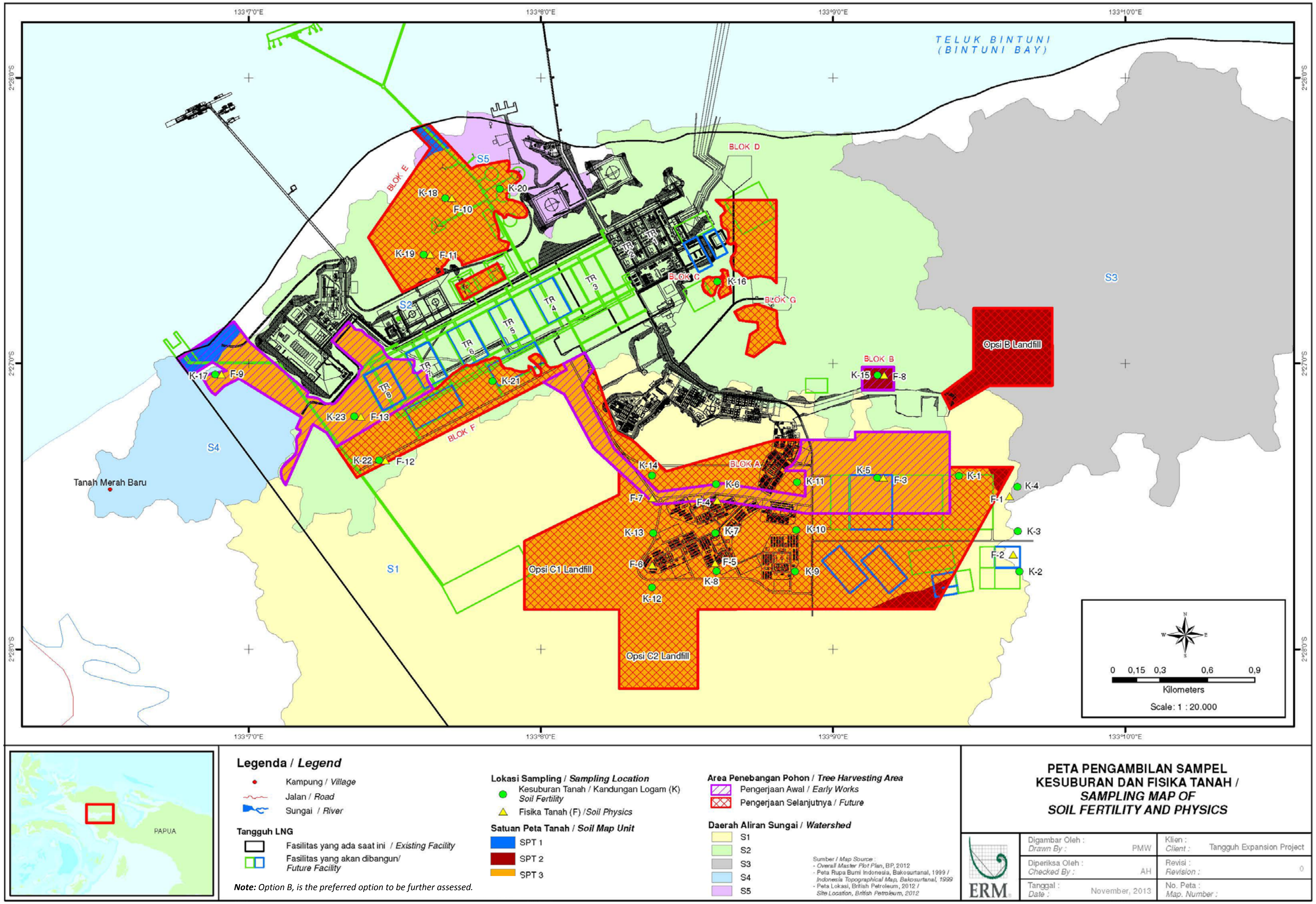
Along the shoreline, besides tidal landforms of mangrove swamp, other coastal shoal landforms of *Putting* (PTG) land unit with secondary forest land cover are found. The coastal shoals have undeveloped soil, good drainage to very well drained, deep solum and generally soil texture of sandy clay or clayey sand. The soil is relatively newly formed (recent soil). In the USDA soil classification the great group level is known as Quartzipsamment.

Soil Map Unit 2 (Association of Ultisols and Inceptisols)

SPT-2 The Ultisols and Inceptisols association are soils found in mild slopes (hillock complex), alluvial folds with undulating or hilly landform at elevation <50 meter above sea level. The area is characterized by lowland forest and appears to be untouched by the local population.



Map II-10 Soil Map Unit (SPT) in Land Area to be Cleared for the Tangguh LNG Expansion Project



Map II-11 Locations of Blocks and Soil Sampling

At eastern of the Tangguh LNG, there is land with low hills. Blocks included in the landform are Block B and a small portion of Block A in the east. The Soil Map Unit (SPT) is association between ultisols and inceptisols which ultisols are represented by hapludults while inceptisols are represented by dystropepts.

Ultisols are soils with deep to very deep effective depth. Argillic horizon , namely the clay accumulation horizon (horizon B) containing 1.2 times clay content in the upper layer. Base saturation is less than 35% (low) and acidic in nature. Hapludults are reddish yellow clays with deep solum, medium drainage, acidic soil reaction and are widely-dispersed in hilly areas. These soils are never dry for 90 cumulative days in a year (udic moisture).

Besides ultisols, inceptisol soil type was also found in association. This soil type is developing soil or recently developing soil characterized by weak structure, less horizonation and displacement of fine particles so that clay content in fine fractions is below 8%. Thus each horizon will be bright colored. The soil type is classified as dystropepts, i.e. greyish colored sandy clay soil with somewhat blockage in drainage, deep solum and slightly acidic reaction. The soil type is frequently encountered at the base of hill valleys.

Soil Map Unit 3 (Association of Ultisols and Spodosols)

SPT-3 The Ultisols and Spodosols association are found in incised terrace landforms. Those are formed from many incised, low and undulating land forms, encompassing undulating and hilly land. The ultisols and spodosols association occupy an undulating to hilly landscape with 8-30% slope. This landform is most dominant in the Tangguh LNG area.

Between both types of soils, the ultisols order are dominant in the Tangguh LNG area. The effective depth is deep to very deep. There is an argillic horizon, i.e. clay accumulation horizon (horizon B) containing 1.2 times clay content above it. Base saturation is less than 35% (low) and acidic. The soils are never dry for 90 cumulative days a year (udic moisture). In USDA's soil classification, the sub-order level is known as Udult. Ultisols are dominated by grey color (gley) indicating much blockage in drainage encountered in hilly land or in basins. At edges of hills the soil is reddish yellow since it is moderately well drained. Clay accumulation occurs in the lower horizon, effective depth is very deep and slightly acidic. Ultisols encountered in Block F are characterized by upper layer containing organic materials to a depth of 10-15 cm. In USDA's soil classification, the sub-order level is known as Humults.

Spodosols occupy a small and sporadic part of flat valleys and are associated with ultisols. The main characteristic of this soil type is advanced leaching until the remaining bright colored quartz sand fraction. The upper layer is dark colored due to high level of organic materials. In the USDA's soil classification, the sub-order level is known as Ortdods.

Table II-15 Soil Map Unit Characteristics in Area to be Cleared

SPT	Soil Type		Landform	Slope (%)	Main Material	Area	
	Order	Representative Great Group				ha	%
1	Entisols	Hydraquent and Quartzipsamment	Tidal swamp and coastal shoal	<2	Aluvium marin	5	2
2	Ultisols and Inceptisols association	Hapludults and Dystropepts	Mildly-sloping hills	8-25	Conglomerate complex and mudstone	62	19
3	Ultisols and Spodosols association	Hapludult, Humuldt and Ortods	Incised terrace	3 -16	Conglomerate complex and mudstone	255	79
Total land area to be cleared						**321**	**100**

2.1.6.2 Soil Physical Properties

The soil physical properties was observed in the field and laboratory consist of: texture, structure, surface rock and effective depth, color, Bulk Density (BD) and Particle Density (PD) as well as permeability. Sampling locations of soil physical properties are shown in **Map II-10.** Laboratory analysis results of soil physical properties are shown in **Appendix II-5**. Observation of land physical parameters is required to determine the potential erosion.

Soil Texture

The soil texture refers to the relative ratio of sand, silt and clay fractions. Soil texture is related to soil infiltration rate, water status in soil (groundwater content), soil permeability and soil porosity. Laboratory analysis results of soil fractions are shown in **Table II-16** and **Figure II-33**. Based on experience in other places, such SPT-1 soils have slightly different texture variation in between mangrove swamp and coastal shoal landforms. Mangrove swamp area generally has fine soil texture (clay loam) on the surface and coarse texture (sand-clay sand) is encountered several cm below, whereas SPT-1 with coastal shoal of the soil surface has coarse texture (sandy sand–loam). SPT-2 and SPT-3 have finer textures than SPT-1. Ultisols in SPT-2 and SPT-3 have higher clay content (silty loam-silty clay) compared to inceptisols and spodosols in the same SPT (sandy loam-loam). Soils containing much clay are more resistant to erosion. In general the texture class range in each SPT indicates varying water holding capacity. Water holding capacity is lowest in SPT-1, medium in SPT-3 and high in SPT-2.

Table II-16 Fractions of Soil Texture in Soil Map Unit at the Tangguh LNG Site

Sampling location		Texture of 10 Fractions (%)									
		Sand Fraction					Silt Fraction			Clay Fraction	
		>1.000 µ	500-1.000 µ	200-500 µ	100-200 µ	50-100 µ	20-50 µ	10-20 µ	2-10 µ	0,05-2 µ	<0,05 µ
SPT-1	F-9	0.9	0.6	5.9	24.8	19.8	19.1	3.8	2.1	18.2	4.8
SPT-2	F-1	0.4	0.2	2.3	13.7	25.4	24.2	13.5	4.3	12.2	3.8
	F-2	0.1	0.3	6.5	6.4	13.7	32.2	20	0.8	14.8	6.2
	F-8	0.1	0.7	8.3	11.8	28.1	29.9	17.9	2.2	0.8	0.2
SPT-3	F-3	0.7	4.8	24.8	22.5	16.2	15.7	8.1	3.2	2.9	1.1
	F-4	21.1	0.3	1.2	5.5	14.9	30.5	19.8	1.7	3.2	1.8
	F-5	0.1	0.8	0.9	5.4	21.8	37.8	12.5	3.7	11.2	5.8
	F-6	0.2	0.6	9.6	17.4	31.2	22.4	7.2	2.4	6.7	2.3
	F-7	0.1	0.8	1.6	2.3	6.2	29.8	15.1	4.1	32.8	7.2
	F-10	0.1	0.3	1.2	5.5	14.9	39.4	23.2	9.4	4.1	1.9
	F-13	0.4	3.9	51.2	14.9	5.6	6.8	3.2	2	8.2	3.8
	F-11	0.5	0.1	29.6	23.1	16.7	17.8	6.6	1.6	2.1	1.9
	F-12	0.1	0.7	25.6	9.9	8.7	26.3	18.7	4	3.8	2.2

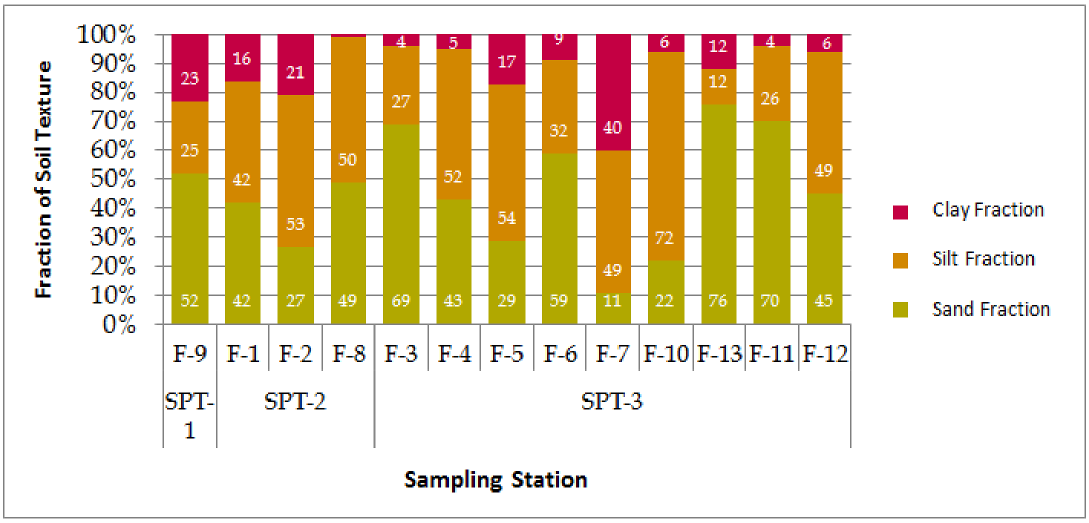


Figure II-33 **Percentage of Sand, Silt, and Clay Fractions for Soil Texture in Each SPT at the Tangguh LNG Site**

Soil Structure

Soil structure is directly observed in the field, i.e. form, size and level of development. Soil structure in SPT-1 is unformed (sand) since the soil in this SPT is recent soil. SPT-2 and SPT-3 generally are of flakey structure on the upper layer (between 0-5 cm), and clumps in the bottom layer (between 5-20 cm) except for lower layer spodosols (5-20 cm) are generally flakes-unstructured (loose). Firmness of structure is generally in the lower layer. Soils with firm structure such as ultisols in SPT-2 and SPT-3 are more resilient to erosion compared with inceptisols and spodosols.

Surface Rock and Effective Depth

Surface rocks are not encountered in all SPT except for spodosols that has lost its upper layer (organic material). Surface rock in spodosols are encountered in small number (<5%). Effective depth in all SPT is over 100 cm except for inceptisols in Block E, with effective depth of about 30 cm due to the presence of pan layer in the form of clay fraction and iron accumulation.

Soil Color

Soil color in each block varies from brown, yellowish brown, reddish yellow and gley. Soils in SPT-2 and SPT-3 on slopes or terraces and on mildly sloping hilltops are brown-colored on the surface layer (10 YR 3/4) and the layer below is reddish colored (7.5 YR 6/8). Soils in valleys are generally gley colored (7.5 YR 7/2) in the lower layer. Soil color indicates the drainage condition in soils . Brown to reddish or yellowish colored soils generally indicate good drainage, while gley colored soils indicate poor drainage. Drainage is one of the soil properties observed based on the velocity of water flow from a soil plot, both as run off and absorption into the soil. Drainage can also signify as frequency and duration of the soil to be free from water saturation.

Bulk Density (BD) and Particle Density (PD)

Bulk density indicates soil density per unit volume of soil (with soil pores) while Particle Density refers to soil density per unit soil volume (without soil pores). Values of BD and PD are directly proportional to the coarseness level of soil particles, the finer of soil particles will be heavier in the weight. Values of BD and PD are associated with ease of plant root penetration into the soil, soil drainage and aeration and other physical properties. Weighted value of soil varies from one soil location to another, depending on variations in organic matter content, texture, structure and surface vegetation.

Table II-17 Analysis of Soil Physical Properties in Soil Map Unit in the Tangguh LNG Location

Location of Sampling		Water Content (% vol)	BD (g/cc)	PD (g/cc)	Total Pores Space	Permeability (cm/hour)
SMU 1	F-9	33.5	1.22	2.43	49.9	2.42
SMU 2	F-1	36.5	1.25	2.35	46.7	1.96
	F-2	36.5	1.22	2.38	48.6	0.71
	F-8	49.7	1.08	2.4	55.3	0.19
SMU 3	F-3	36.1	1.43	2.5	43.0	8.52
	F-4	27.2	1.37	2.56	46.5	7.82
	F-5	39.6	1.37	2.54	46.0	2.49
	F-6	39.4	1.21	2.37	49.0	5.87
	F-7	38.9	1.29	2.51	49.6	1.24
	F-10	24.9	1.17	2.37	50.9	0.17
	F-13	26.2	1.13	2.13	46.8	8.88
	F-11	30.3	1.56	2.18	28.4	3.75
	F-12	29.8	1.59	2.64	39.9	2.22

Note: Pore diameter (pF): (1) 296μ, (2) 28.6μ, (2.54) 8.6μ, and (4.2) 0.2μ
Source: Primary data, Soil Physics Laboratory Analysis, Soil Research Center-Bogor, July 2013

Analysis results as shown in **Table II-17** indicate values of BD and PD in coastal shoal of SPT-1 where BD = 1.22 g/cc and PD = 2.43 g/cc. In SPT-2 average BD is 1.18 gram/cc and average PD is 2,38 gram/cc, while in SPT-3 average BD is 1.35 g/cc and average PD is 2,42 g/cc. Values of BD and PD obtained in SPT-2 and SPT-3 tends to be high due to the soil samples were taken at 7-15 cm from the soil surface. In this layer, organic matter content has decreased so that the soil is more compact than the overlying layers.

Soil Permeability

Soil permeability refers to soil capacity to allow water to pass through it. Soil permeability is one of the soil properties that greatly affect soil infiltration rate, surface runoff and soil sensitivity to erosion. In permeable soils, soil infiltration rate is high so that surface flow rate is low, the soil surface can avoid erosion hazard. Soil permeability in SPT-1 was generally in the category of high due to the dominant sand which water can pass through it easily. In SPT-2 and SPT-3, the permeabilities were categorized as slow to rapid. In *ultisols* with high clay content, permeability was categorized as slow (average 2.0 cm/hour). S*podosols* with high sand content, had permeability of medium category (5.87-8.52 cm/hour). Permeability was in line with soil texture found in each SPT.

2.1.6.3 Soil Chemical Properties

Sampling locations for the analysis of soil chemical properties are shown in **Map II-10**. Descriptions of soil chemical properties were based on the analysis of soil samples in the laboratory, as shown in **Appendix II-5**. Main soil fertility components encompassed soil reaction; organic materials; N total and C/N ratio; total and available phosphor as well as potassium; cation exchange capacity; base saturation; and Al saturation. Assessment of soil chemical properties referred to criteria of Soil Research Center Staff (PPT, 1983) as shown in **Table II-18**. Results of the assessment are presented in **Table II-18.**

Table II-18 Assessment Criterias of Soil Chemical Properties Based on Soil Research Center Staff, 1983

Soil Parameter	Unit	Very Low (VL)	Low (L)	Medium (M)	High (H)	Very High (VH)
C – Org	%	< 1	1– 2	2.01 – 3.00	3.01 – 5.0	> 5.0
N	%	<0.1	0.1-0.2	0.21-0.5	0.51-0.75	>0.75
C/N	-	<0.1	0.1 – 0.2	0.21 – 0.5	0.51 – 0.75	> 0.75
P_2O_5 HCl	mg/100g	<10	10-20	21-40	41-60	>60
P_2O_5 Bray-1	ppm	<10	10-15	16-25	26-35	>35
P_2O_5 Olsen	ppm	<10	10-25	26-45	46-60	>60
K_2O HCl 25%	mg/100g	<10	10-20	21-40	41-60	>60
KTK	me/100g	<5	5-16	17-24	25-40	>40
Ca	me/100g	< 2	2 – 5	6 – 10	11 – 20	>20
Mg	me/100g	<0.4	0.4 – 1	1.1 – 2	2.1 – 8.0	>8
K	me/100g	<0.10	0.10 – 0.2	0.3 – 0.5	0.6 – 1.0	>1
Na	me/100g	<0.1	0.1 – 0.3	0.4 – 0.7	0.8 – 1.0	>1,0
Base Saturation (KB)	%	<20	20-35	36-50	51-70	>70
Aluminum	%	<10	10-20	21-30	31-60	>60

Source: Soil Research Center, 1983

Soil Reaction

The pH-H_2O values of soil in all sampling locations (SPT-1 to SPT-3) are acidic, ranging between 3.6-5.0; while pH-KCl ranges between 3.3 – 5.9. Soil acidity commonly occurs in areas of high rainfall. This conforms to the very high rainfall in the vicinity of the Tangguh LNG site with average annual rainfall reaching 2,938 mm. High rainfall causes leaching of bases from adsorption (*jerapan*) complex and loss through drainage water. In condition where bases are fully leached, only Al and H cations remain as dominant cations causing soil to have acidic reaction (*Coleman* and *Thomas*, 1967).

Acidic soil reaction (pH) results in very low availability of nutrients (Hardjowigeno, 2006). Aluminum element is both toxic and binds phosphor, which thus cannot be absorbed by plants. In acidic soils, micro elements easily dissolve so that micro elements such as Fe, Zn, Mn and Cu are found in extremely large quantities, thus are toxic for plants.

Organic Materials

The higher of the soil organic materials will be the better or more fertile soil. Organic materials content of soil is stated in percent C-organic. Value of soil C-organic around the Tangguh LNG is shown in **Table II-19**. In SPT-1 (1.56%) at coastal shoal, C-organic is very low while in mangrove swamp the upper layer is high and the lower layer is low. In SPT-2, all C-organic values are low (1.22-1.72%) while in SPT-3 C-organic content is low to high (1.0-3.52%). The low C- organic in SPT-1 is due to coarse soil texture (sand dominance) so that organic material can easily experience leaching, supported by high rainfall. Sloping areas with small hills in SPT-2 causing organic matter from decomposition of plant organic matter easily eroded to valleys, so that organic matter of the soil on hillside slopes is generally low.

Total N and C/N Ratio

Nitrogen is a main nutrient element of plants that will rapidly react and real. N as nutrient will stimulate the growth of vegetation (on the ground), provide green color, enlarge cereal grains, raise protein content of plants. Thus N content of soil is an essential component in soil fertility. N-total reflects potential nitrogen content in soils enable to be absorbed by plants. The higher total N content, the soils tend to make good influence to the plant growth. N content in all SPTs are categorized very low to medium (0.09-0.25%), with dominantly low category as shown in **Table II-19**.

The C/N ratio is defined as relative amount of the both elements in fresh organic matter, humus or in soils. The C/N ratio also provides understanding of decomposition of organic matter and release or immobilization of N-soil. High ratios of C/N indicate that organic matter is not completely decomposed or indicate high microorganism activities and vice versa, i.e. if the C/N ratio low, it indicates nearly complete decomposition that signifies the microorganism activity has decreased. According to *Tisdale et al*. (1985), organic matter with C/N ratio more than 30:1, immobilisation of N in soil will occur, C/N between 20 and 30 signifies no release or immobilization of N, while if C/N of less than 20, N will be released into the soil. Thus, high ratios of C/N do not ensure higher soil fertility. Soil analyses results indicate that the C/N ratios in all SPTs are categorized low-medium (10-14).

Total and Available of Phosphor (P) and Potassium (K)

Phosphor content in soil has significant meaning for plants and its presence is highly critical. Lack of this element in soils prevents plants from absorbing other elements (Guswono, 1985). Phosphor plays a role in cell division activities, formation of protein, albumin, formation of plant generative system, and resiliency against disease. The total form indicates the P and K content or reserve in soil or known as potential, while the available form is a form that able to be absorbed by plant roots or actual.

In all SPTs, total content of Phosphor (P_2O_5) or P is categorized very low to high (3-46 mg/100g soil) and available P content is categorized very low to high (3.1-33.5 ppm) with very low to low dominance.

The element of Potassium (K) in plants will aid in accelerating and facilitating formation of complex compounds, mainly compounds with Cl and Mg. K functions to accelerate carbohydrate formation, strengthen cell walls, improve seed quality mainly paddy and tubers.

In SPT-2 and SPT-3 total Potassium (K_2O) concentration is categorized very low to low (1-18 mg/100g soil). Similarly, available Potassium content is categorized very low to low (17 - 78 ppm).

Table II-19 Analysis of Soil Physical Properties in Soil Map Unit at Tangguh LNG (1)

Parameter		Unit	SPT-1	SPT-2				SPT-3						
			KSB XVII Block G	KSB II Block A	KSB III Block A	KSB IV Block A	KSB XV Block B	KSB I Block A	KSB V Block A	KSB VI Block A	KSB VII Block A	KSB VIII Block A	KSB IX Block A	KSB X Block A
Extract	pH H_2O	-	4,2	4.0	5.0	4.3	4.5	3.8	4.3	4.0	4.0	3.7	3.9	3.6
	pH KCl	-	3.4	3.5	4.2	3.5	3.7	3.4	3.1	3.7	3.6	3.4	3.5	3.3
Organic Matter	*Walkley & Black ©*	%	1.56	1.63	1.72	1.22	1.3	3.52	1.84	2.23	2.05	2.93	2.41	2.7
	N-Kjeldahl		0.15	0.13	0.12	0.09	0.13	0.25	0.15	0.21	0.21	0.25	0.23	0.25
	C/N	-	10	13	14	14	10	14	12	11	10	12	10	11
HCL 25%	P_2O_5	mg/100g	19	6	17	8	46	13	5	6	3	12	14	11
	K_2O		7	3	10	3	18	7	2	3	4	5	8	8
Bray 1 P_2O_5		ppm	7.5	7	11.1	10.9	3.1	20.7	11.6	6.8	9.3	12.6	8.2	8.2
Morgan K_2O			31	21	53	27	78	37	17	23	37	31	72	78
Cation Exchange Value (NH_4-Acetate 1N, pH7)	Ca	$cmol_c/kg$	0.82	0.28	5.07	1.76	6.47	0.33	0.32	0.38	0.22	0.84	0.58	0.3
	Mg		0.22	0.19	1.6	0.48	0.91	0.38	0.22	0.24	0.22	0.31	0.38	0.26
	K		0.06	0.04	0.1	0.05	0.15	0.07	0.03	0.04	0.07	0.06	0.14	0.15
	Na		0.04	0.01	0.03	0.01	0.04	0.05	0.02	0.19	0.32	0	0.01	0.01
	Total		1.14	0.52	6.8	2.3	7.57	0.83	0.59	0.85	0.83	1.21	1.11	0.72
	KTK		6.85	5.85	9.94	5.9	17.04	14.75	2.29	3.85	5.16	10.22	9.08	12
	KB	%	17	9	68	39	44	6	26	22	16	12	12	9
KCL 1N	Al^{3+}	$cmol_c/kg$	1.15	3.15	0.04	3.19	3.73	6.66	0.23	1.87	2.06	4.75	4.56	5.57
	H^+		0.33	0.48	0.17	0.4	0.55	0.86	0.25	0.22	0.35	0.72	0.51	0.77
Fe		%	0.47	5.63	6.12	3.72	1.06	9.94	0.10	3.51	1.07	4.72	8.02	6.27
Mn		ppm	2.10	5.00	1.319.00	61.00	104.70	21.00	5.00	13.00	4.00	55.00	23.00	7.00
Cu		ppm	0.70	td	4.30	0.30	1.50	td	td	td	td	td	td	td
Zn		ppm	3.30	66.30	142.80	15.00	20.50	43.20	td	11.50	9.30	66.20	41.30	11.60
Pb		ppm	td	td	Td	td	td	td	td	0.20	td	td	td	td
Cd		ppm	0.90	1.38	0.81	0.71	1.69	0.71	0.01	0.03	0.15	0.63	0.74	0.22
Ni		ppm	td	3.30	10.10	11.70	10.00	1.20	0.70	1.10	1.70	5.90	4.70	0.40
Cr		ppm	23.20	25.90	26.80	20.20	25.90	32.40	6.80	14.80	13.40	19.90	24.40	21.60
As		ppm	4.50	1.30	1.20	2.30	3.70	0.40	0.80	0.50	0.60	1.60	1.80	1.10
Se		ppm	td	td	td	td	td	td	td	td	td	td	td	td
Hg		ppm	0.09	td	td	td	td	td	td	td	td	td	td	td

Source: Primary data, Soil Physics Laboratory Analysis, Soil Research Center-Bogor, July 2013

Table II-20 Analysis of Soil Physical properties in Soil Map Unit at Tangguh LNG (2)

Parameter		Unit	SPT-3											
			KSB XI Block A	KSB XII Block A	KSB XII Block A	KSB XIII Block A	KSB XIV Block A	KSB XVI Block C	KSB XVIII Block E	KSB XIX Block E	KSB XX Block E	KSB XXI Block F	KSB XXII Block F	KSB XXIII Block F
Extract	pH H_2O	-	3.6	4.1	4.1	3.9	4.2	4.4	4.4	4.1	4.4	3.8	4.1	3.9
	pH KCl	-	3.3	5.9	5.9	3.6	3.1	3.7	3.9	3.8	3.6	3.4	3.5	3.4
Organic Materials	Walkley & Black ©	%	1.79	1.52	1.52	2.48	1.43	2.62	1.25	1.05	1.32	2.31	1.73	1
	N-Kjeldahl		0.15	0.15	0.15	0.23	0.13	0.25	0.11	0.1	0.11	0.19	0.15	0.09
	C/N	-	12	10	10	11	11	11	11	11	12	12	12	11
HCL 25%	P_2O_5	mg/100g	7	23	23	17	19	21	21	16	19	15	16	17
	K_2O		1	9	9	8	13	11	9	5	8	4	4	4
Bray 1 P_2O_5		ppm	29.8	5.1	5.1	9.1	3.3	33.5	3.9	5.8	3.9	3.4	7.8	6.3
Morgan K_2O			36	63	63	71	47	67	33	53	42	41	17	27
Cation Exchange Value (NH_4-Acetat 1N. pH7)	Ca	$cmol_c/kg$	0.52	1.17	1.17	0.9	0.98	3.17	3.43	1.1	1.76	0.72	0.72	0.84
	Mg		0.32	0.43	0.43	0.38	0.31	0.61	0.42	0.25	0.4	0.28	0.25	0.2
	K		0.07	0.12	0.12	0.14	0.09	0.13	0.06	0.1	0.08	0.08	0.03	0.05
	Na		0.01	0.12	0.12	0.05	0.03	0.06	0.03	0.03	0.07	0.07	0.07	0.06
	Total		0.92	1.84	1.84	1.47	1.41	3.97	3.94	1.48	2.31	1.15	1.07	1.15
	KTK		4.56	12.8	12.8	8.4	11.74	12.31	10.53	4.75	11.72	9.52	7.53	7.22
	KB	%	22	14	14	18	12	32	37	31	20	12	14	16
KCL 1N	Al^{3+}	$cmol_c/kg$	1.53	3.88	3.88	0.26	3.12	0.1	1.43	0.26	2.81	0.58	1.49	1.63
	H^+		0.51	0.57	0.57	0.83	0.52	0.41	0.35	0.4	0.5	1.03	0.49	0.62
Fe		%	0.51	1.02	1.02	0.02	0.72	0.03	0.52	0.02	0.05	0.02	0.06	0.06
Mn		ppm	18.00	27.30	27.30	2.40	5.70	5.60	11.50	2.00	5.80	1.10	1.10	2.40
Cu		ppm	td	td	td	0.20	td	0.50	td	0.40	0.50	0.20	0.10	0.10
Zn		ppm	11.40	12.50	12.50	td	11.70	1.00	0.20	5.60	1.30	0.00	0.90	0.60
Pb		ppm	td	td	td	td	td	td	td	td	td	td	td	td
Cd		ppm	0.64	1.74	1.74	0.01	1.23	0.03	0.91	0.02	0.87	0.02	0.03	0.03
Ni		ppm	1.30	3.20	3.20	td	1.50	td	0.50	td	3.60	1.50	td	td
Cr		ppm		28.00	28.00	19.10	26.50	10.00	33.60	10.10	30.30	5.30	8.10	13.70
As		ppm	3.00	3.50	3.50	0.60	4.00	0.70	3.50	0.50	4.50	0.10	0.60	0.40
Se		ppm	td	td	td	td	td	td	td	td	td	td	td	td
Hg		ppm	td	td	td	td	0.12	td	td	td	td	0.07	td	0.09

Source: Primary data, Soil Physics Laboratory Analysis , Soil Research Center-Bogor, July 2013

Cation Exchange Capacity

One of soil chemical properties closely related to nutrient availability for plants and as an indicator of soil fertility is Cation Exchange Capacity (CEC or KTK). KTK is the total number of exchangeable cations on the surface of negatively charged colloids. The unit of KTK measurement is milliequivalent cation in 100 gram soil (me/100 g) or centimole charge per kg soil ($cmol_c$/kg). Soils with high KTK when are dominated by base cations such as Ca, Mg, K and Na this may increase soil fertility, however when cations in soil are dominated by acid cations , namely Al, H cations, this may reduce soil fertility due to their toxic nature for plants (Hanafiah, 2006). The obtained KTK values are averagelt categorized very low-medium (2.29-17.04), only at block B that the KTK is categorozed medium (17.04) due to clay content as a source of colloids is higher than that of other lands. Soils with criteria of very low-low KTK , means poor capacity of soils to absorb and provide nutrient elements.

Base Saturation

Base saturation (BS) indicates the ratio between number of base cations to total cations (total base cation and acid cation) found in soil adsorption complex. The maximum amount of cations able to be adsorbed by soil indicates the cation exchange capacity value of the soil. Base cations (Ca^{++}, Mg^{++}, K+, Na+) are generally nutrient elements required by plants. Base cations are generally easily leached , so that soils with low leaching BS are infertile soils. Soils found in all SPT-3 generally have very low-medium base saturation (6-37%). In SPT-2 it is very low to high (9-68%). The presence of calcium and magnesium of higher value in SPT-2 contributes to high base saturation value. As the base saturation value of SPT-2 is higher compared to SPT-3, soil fertility in SPT-2 is higher than in SPT-3.

Active Aluminum

Aluminum in the form of (Al^{+++}) ions is toxic for plants. The presence of Aluminum in soils will generally cause soils to be acidic that will lower soil fertility level. In very small amounts, aluminum in plants will aid the metabolism process, however if the soil indicates large amounts this will become toxic, stunt growth and cause abnormal leaf growth. Active Aluminum content in soils is expressed as Aluminum saturation (%), i.e. the amount of Al^{+++} concentration toward KTK. Al saturation in all SPTs is very low (0.04-6.66 $cmol_C$/kg or me/100g). Thus the possibility of toxicity by Aluminum in all SPTs in the proposed Tangguh LNG Expansion Project location is low.

Table II-21 Analysis of Soil Physical Properties Assessment Criteria * (1)

Parameter		Unit	SPT 1	SPT 2				SPT 3						
			K-17 Block G	K-2 Block A	K-3 Block A	K-4 Block A	K-15 Block B	K-1 Block A	K-5 Block A	K-6 Block A	K-7 Block A	K-8 Block A	K-9 Block A	K-10 Block A
Extract	pH-H_2O	-	Very acidic	Very Acidic	Acidic	Very acidic	Acidic	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic
Organic Matter	Walkley & Black (C)	%	L	L	L	L	L	H	L	M	M	M	M	M
	N-Kejldahl	%	L	L	L	VL	L	M	L	M	M	M	M	M
	C/N	-	L	M	M	M	L	M	M	M	L	M	L	M
HCL 25%	P_2O_5	mg/100g	L	VL	L	VL	H	L	VL	VL	VL	L	L	L
Bray 1	P_2O_5		VL	VL	L	L	VL	M	L	VL	VL	L	VL	VL
K_2O	HCl 25%	mg/100g	VL	VL	L	VL	L	VL	VL	VL	VL	VL	VL	VL
Cation Exchange Capacity (NH_4-Acetat 1N, pH7)	KTK	$cmol_c/kg$	L	L	L	L	M	L	VL	VL	L	L	L	L
	Ca		VL	VL	M	VL	M	VL	VL	VL	VL	VL	VL	VL
	Mg		VL	VL	M	L	L	VL	VL	VL	VL	VL	VL	VL
	K		VL	VL	L	VL	L	VL	VL	VL	VL	VL	L	L
	Na		VL	VL	VL	VL	VL	VL	VL	L	M	VL	VL	VL
	KB	%	VL	VL	H	M	M	VL	L	L	VL	VL	VL	VL
Aluminum		%	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
Mn			Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural
Zn			Natural	Natural	Natural	Natural	Natural	Natural	-	Natural	Natural	Natural	Natural	Natural
Cd			Natural	Natural	-	-	-	Natural	Natural	Natural	Natural	Natural	Natural	Natural
Ni			-	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural
Cr			Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural

* Based on the results of soil chemistry analysis in **Table II-21**

Note:

VL : Very Low
L : Low
M : Medium
H : High
VH : Very High

More detailed criteria are shown in **Table II-18**

Table II-22 Analysis of Soil Chemical Properties Assessment Criteria * (2)

Parameter		Unit	SPT 3										
			K-6 Block A	K-12 Block A	K-13 Block A	K-14 Block A	K-16 Block C	K-18 Block E	K-19 Block E	K-20 Block E	K-21 Block F	K-22 Block F	K-23 Block F
Extract	pH-H_2O	-	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic	Very acidic
Organic matter	Walkley & Black (C)	%	L	L	M	L	M	L	L	L	M	L	L
	N-Kejldahl	%	L	L	M	L	M	L	L	L	L	L	VL
	C/N	-	M	L	M	M	M	M	M	M	M	M	M
HCL 25%	P_2O_5	mg/100g	VL	M	L	L	M	M	L	L	L	L	L
Bray 1	P_2O_5		H	VL	VL	VL	H	VL	VL	VL	VL	VL	VL
HCl 25%	K_2O	mg/100g	VL	VL	VL	L	L	VL	VL	VL	VL	VL	VL
Cation Exchange Capacity (NH_4-Acetat 1N, pH7)	KTK	$cmol_c/kg$	VL	L	L	L	L	L	VL	L	L	L	L
	Ca		VL	VL	VL	VL	L	L	VL	VL	VL	VL	VL
	Mg		VL	L	VL	VL	L	L	VL	L	VL	VL	VL
	K		VL	L	L	VL	L	VL	L	VL	VL	VL	VL
	Na		VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL
	KB	%	L	VL	VL	VL	L	M	L	L	VL	VL	VL
Aluminum		%	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
Mn			Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural
Zn			Natural	Natural	-	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural
Cd			Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural
Ni			Natural	Natural	-	Natural	-	Natural	-	Natural	Natural	-	-
Cr			Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural

* Based on the results of soil chemistry analysis in **Table II-22**

Note:

VL : Very Low

L : Low

M : Medium

H : High

VH : Very High

More detailed criteria is shown in **Table II-18**

2.1.6.4 Soil Erosion Sensitivity

Determination of soil erosion sensitivity can be seen from soil erosion rate with the general equation of Universal Soil Loss Equation – USLE. In the equation, rate of erosion is determined by rainfall erosivity index (R), soil erodibility (K), length and gradient of slope (LS) and soil cover and cropping management factors . The form of equation is as follows:

$$A = R * K * L * S * C * P$$

Where :

A = Soil loss in ton/ha/year

R = Rainfall erosivity factor

K = Soil erodibility factor

L = Slope length factor

S = Slope gradient factor

C = Cropping management factor

P = Soil conservation factor

The rainfall erosivity index used to calculate erosion rate was based on monthly rainfall data in the Tangguh LNG. Data used was from January 2011 to June 2013. Rainfall erosivity index values were calculated using the Bols (1978) equation where $EI30=6.119\ (CH)^{1.21}(HH)^{-0.47}(maxp)^{0.53}$. In which EI30 is rain erosivity, CH (rainfall), HH (rain days), maxp (maximum daily rainfall in one month). The rainfall erosivity indexes at the representative stations are presented in **Table II-23**.

Table II-23 Average Monthly Rainfall and Rainfall Index Value (R)

Month	Average Rainfall	R Value
January	292.3	17,449
February	244.0	8.013
March	272.7	10,106
April	272.7	11,869
May	250.3	10,091
June	289.3	9,020
July	95.0	2,130
August	89.0	2,394
September	199.0	6,597
October	65.5	2,171
November	137.5	6,502
December	292.3	9,024
Total	**244.0**	**95,367**

Source: Results of data analysis, 2013

Soil erodibility value (K) was calculated from the *Wischmeier* and *Smith* (1978) equation in Arsyad (2000) where $100K=2.713M^{1.14}(10)^{-4}(12-a)+3.25(b-2)+(c-3)$. In which M=parameter of particle size, i.e. (%silt+% very fine sand)(100-%clay), a=organic matter (%Cx1.724), b=soil value, c=permeability value. Values of soil erodibility index in the study area are presented in **Table II-24**.

Table II-24 Soil Erodibility Values

Soil Map Unit	Dominant soil type	Soil Texture	Soil Structure	Permeability	Organic Material Content (%)	K index value
SPT1	Hydraquents and Quartzipsamment	Coarse (sand-sandy clay)	Non-structured	Rapid (coastal shoal) and slow (mangrove swamp)	Low	0.11
SPT2	Hapludults	Fine (Silty clay)	Lumpy	Moderate-hindered	Medium	0.74
SPT3	Hapludult	Slightly coarse (sandy clay)	Lumpy	Moderate	Medium	0.55

Source: Results of data analysis, 2013

Slope length and gradient (LS) Index Values

Slope gradient on land to be cleared was quite varied, thus in order to facilitate computation, the slope length and gradient used in calculating erosion rate was the magnitude or value of the dominant slope length and gradient in each soil map unit. Values of slope length and gradient (LS) are presented in **Table II-25**.

Table II-25 Average Slope Length and Gradient Index of Each SPT (LS)

SPT	Gradient	Slope Length	LS Index
1	0	0	1
2	8	15	3.21
3	3	10	1.3

Index values of soil cover and cropping management factors (CP)

Index value CP used to calculate erosion rate was based on land cover data.

Table II-26 Values of Land Cover Factor Index (C)

Type of Soil Cover	C Index Value
Natural forest (primary forest)	0.001
Production forest (secondary forest)	0.005
Shrub	0.020

Source : Arsyad, 2000

The value of soil management factor (P) in calculating soil erosion rate was based on soil conservation technique applied in a landscape. Soil conservation techniques were not applied yet or considered to have a value of one. Conservation technique will be applied according to the purpose of land to be utilized. Erosion rates for each geomorphology landform and land use is according to soil map unit in the area to be cleared for the proposed Tangguh LNG Expansion Project are shown in **Table II-27**.

Table II-27 Calculation of Soil Erosion Rate in Each Soil Map Unit in the Area to be Cleared for the Proposed Tangguh LNG Development Project

Environmental Baseline		Natural Factor			Land Cover (C)			Conservation (P)			Potential Erosion (ton/ha/year)			Erosion Hazard Level		
Soil Map Unit	**Dominant Soil Type**	**R**	**K**	**LS**	**Primary forest**	**Shrub**	**Secondary forest**	**Without**	**Without**	**Without**	**Primary forest**	**Shrub**	**Secondary forest**	**Primary forest**	**Shrub**	**Secondary forest**
SMU1	Hydraquents and Quartzipsamment	953.67	0.21	1	0.001	0.02	0.005	0.001	0.001	0.001	0.02	0.40	0.10	**S**	**S**	**S**
SMU2	Hapludults and Dystropepts	95.367	0.74	3.21	0.001	0.02	0.005	0.001	0.001	0.001	0.23	4.53	1.13	**S**	**S**	**S**
SMU3	Hapludult, Humuldt and Ortods	95.367	0.55	1.30	0.001	0.02	0.005	0.001	0.001	0.001	0.07	1.44	0.36	**S**	**S**	**S**

After soil erosion was calculated from the USLE equation shown in **Table II-27**, the results were compared with class of erosion hazard level as shown in **Table II-28**.

Table II-28 Erosion Hazard Level Based on Solum Thickness and Total Erosion Hazard (Total Maximum Erosion)

Solum thickness (cm)	Maximum erosion (ton/ha/year)				
	< 15	15 – 60	60 – 180	180– 480	> 480
> 90	SR	S	S	B	SB
60 – 90	R	B	B	SB	SB
30 – 60	S	SB	SB	SB	SB
< 30	B	SB	SB	SB	SB

Note: SR = Very Low, R = Low, S = Medium, B = Heavy, SB = Very Heavy
Source : Ministry of Forestry, 1986

Based on the criteria shown in **Table II-28**, it was concluded that erosion hazard level in each soil map unit (SPT) in the study location with thickness of solum 30-60 cm was in the medium category.

2.1.7 Geology

2.1.7.1 Geology and Stratigraphy

Regional Geology

The Papua region is located on the edge of the Australian continental lithospheric plate, which is currently moving west-northwest at a rate of 120 mm/year relative to the Caroline and Philippine oceanic plates (McCaffrey, 1996). The oblique collision between these plates has resulted in a broad zone of crustal deformation, the Melanesian orogeny (Simandjuntak and Barber, 1996). As a consequence of this oblique collision, a complex pattern of both compressional deformation, including folding and thrust faulting, and strike-slip faulting has developed.

Berau/Bintuni Bay is located in one of the most tectonically active regions of the world, within the collision zone between the northward moving Australian plate and the southward moving Philippine and Caroline plates. The collision zone is very complicated mainly caused by the presence of a series of smallmicroplates that have been caught up in the collision process. The region is prone to earthquakes (tectonic) and associated tsunamis. Bedrock consists of Tertiary carbonates, Quaternary siliclastic rocks and sediments that covering embedded Mesozoic sediments layers. The structure of the area is essentially an east-west trending fold and thrust belt flanked by foreland basin to the north and east (North Plain, Bomberai Plain, and Berau/Bintuni Bay) as shown in **Figure II-34**.

On the eastern side of Papua, collision of the Australian continental plate and the Philippine Sea oceanic plate began in latest Paleogene or early Neogene age (approximately 24 million years ago). The northern promontory of the Australian continent collided with an oceanic island volcanic arc located along the southern margin of the Philippine Sea plate. The remnants of the volcanic arc are now dispersed as a series of ophiolithic rocks found in the northern part of Papua New

Guinea and Papua. Progressive collision of the two plates has resulted in the remnants of the former island arc being thrust back over the Australian plate, as well as the southward subduction of the Caroline/Philippine plate beneath the Australian plate, forming the New Guinea trench. The complex and ongoing plate collision has resulted in a broad zone of folding and faulting called the Highlands fold and thrust belt, which parallels the New Guinea trench. Ongoing deformation across this collisional belt is evidenced by the numerous (tectonic) earthquakes that occured in this region (Abers and McCaffrey, 1988).

On the western side of Papua, the complex interaction between several microplates in the region of the Banda Sea has formed an arcuate, west-dipping subduction zone, the Ceram-Timor trough (McCaffrey, 1996). Again, contemporary deformation in this region is highlighted by an abundance of seismic activity.

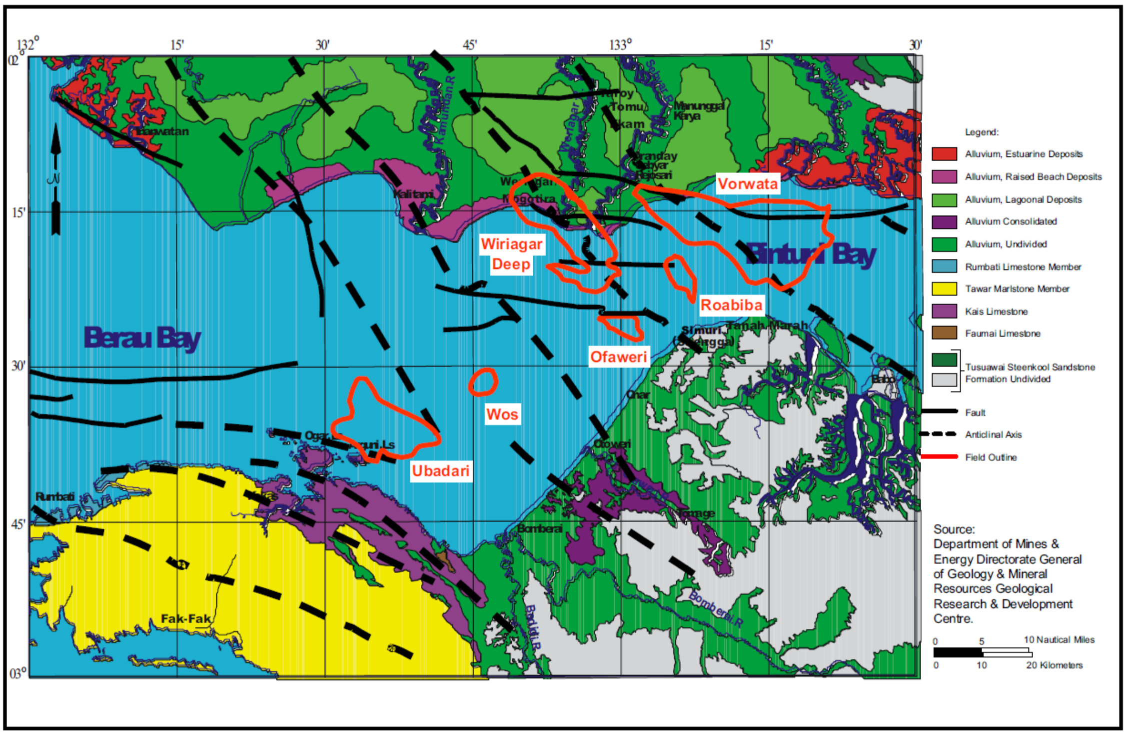


Figure II-34 **Geology of Study Area (from the EBLS Study of PT. Geobis Woodward Clyde Indonesia, 1998)**

2.1.7.2 Morphology and Slope

Based on the topographic forms and slopes, features in the Berau/Bintuni Bay area and its surroundings can be classified into four morphological units:

- ***Plains Morphology.*** The plains morphology encompass most of the Berau/Bintuni Bay region including the North Plains. The slope ranges between 0° to 5°. In general, the area consists of alluvial channel deposits, floodplain deposits and littoral marine deposits.

- ***Undulating Topography.*** The morphological unit is mainly found in isolated pockets located in alluvial plains, particularly formed from riverine deposition. The slope is from 5° to 10° with average elevation of relief around 30 m.
- ***Low Hill Topography.*** This topography can be found in the western part of the Bomberai Plain, the northern part of the North Plain, and the edge of Onin Peninsula. The slope ranges between 10° to 20° with elevation of relief up to 100 m.
- ***Hill Topography.*** The morphological unit may be encountered in part of the Onin Peninsula area with slope gradient over 20°.

2.1.7.3 Local Stratigraphy

Most of the study area in Teluk Berau/Bintuni consist of unconsolidated Quaternary alluvial and littoral deposits, particularly in physiography area. The Bomberai Plains and North Plains. On the other hand, the uplands of Onin Peninsula expose Cenozoic age carbonate and terrigenous clastic rocks of the New Guinea Limestone Supergroup. Older stratigraphic units, at least upper Paleozoic in age, have been detected by measurement tools in the region are Permian age coal-bearing lagoonal siliclastic rocks of the Aifam Group. These rocks are unconformably overlain by Mesozoic carbonate and siliclastic rocks.

The younger rocks in this succession probably belong to the Jass Formation, a sequence of shales and claystones that become more calcareous towards the top of the sequence. Rock types exposed in the study area include rocks belonging to the Tertiary New Guinea Limestone Supergroup (Baham and Onin Formations) and the Upper Miocene - Pleistocene Steenkool Formation and Pleistocene Tusuawai Sandstone. The rock formations, from oldest to most recent, are as follows:

- **New Guinea Supergroup – Baham Formation.** The Paleocene age Baham Formation comprises marine sedimentary rocks, primary sandstone, glauconite, biomycrite, and bicalcarenite (predominantly carbonate and glauconite rock). These rocks outcrop on the east-central portion of Onin Peninsula, within the hanging wall of the Onin thrust.

- **New Guinea Supergroup – Onin Formation.** This formation comprises predominantly marine limestones, marls, calcareous siltstone, and sabkha carbonates (dolomite). This formation outcrops over the majority of Onin Peninsula.

- **Steenkool Formation**. This formation consists of siltstones, mudstones, and sandstones. These rocks are fluvial, deltaic, swamp, lagoonal, and estuarine deposits containing minor amounts of conglomerate and lignite. The Steenkool Formation is located on the southern side of Berau/Bintuni Bay.

- **Tusuawai Sandstone.** This formation consists of sandstone and shale, with only minor occurance in the eastern part of the North Plain physiography.

- **Weriagar Plains Group.** This group comprises sands, clays, and silts, deposited in swamp, floodplain, fluvial, estuarine, and littoral environments from the quarter period. Deposits of this formation cover much of the North Plain and Bomberai Plain physiography.

2.1.7.4 Local Geological Structure

Berau/Bintuni Bay is separated from Cenderawasih Bay (also known as Geelvink Bay) on the eastern part of North Papua by the Jakati-Jamur fault zone as shown in **Figure II-35**. The fault zone extends in the north-south direction through the region connecting the Bird's Head (known as "Bird's Neck"), to the Masikeri Highlands in the Lenggoru Fault Belt (commonly spelled "Lengguru"). More detailed description on this fault and other primary faults accompanying lateral movement are shown in section 5.2 ("Tectonic Regions of Papua") of the report on Seismic Hazard Assessment in the Tangguh LNG Project (EQE International, 1999). The report discusses the Sorong, Ransiki, Yapen, and Tarera-Aiduna faults in the western part of Papua, all of which are identified as active faults in a study made in 1978. This report also discusses collision zones and uplift of earth's crust in the Lenggoru Fold Belt and Seram Trench and New Guinea trench fault.

The oldest Stilata in the Berau/Bintuni Bay region is'Permian' age (290 – 251 million years old) coal-bearing lagoonal siliclastic rock. .

This Stilata is founded on carbonate rocks and siliclastic from the Mesozoik period. Drilling in Berau/Bintuni bay indicates that the age of the Mesozoik strata is highly varied along a series of fault blocks. The age of the strata varies between the Early to middle Jurassic (208 to 160 million years ago) to Late Cretaceous (97-66 million years ago). Overall, this discussion conforms to the assessment result using radar satellite imagery above the Bird's Head region conducted by Koopmans (1986). Using remote sensing technique, Koopmans was able to describe four main structural units of geological regions of northern Papua, namely:

a. Paleozoic age igneous – metamorphic complex (known as the Kemoem Formation);

b. Mesozoic age central vogelklop monocline;

c. Late Mesozoic age Lengguru folded belt; and

d. Berau-Bintuni Basin (classified by Koopmans as part of the large Bomberai Basin, and classified in Mesozoic period).

In summary, it may be concluded that the Berau/Bintuni Bay region is located in a relatively stable block of the earth's crust in the bay area. To the north, the bay is bordered by W-NW striking and Sorong lateral-right fault zone; to the east by fold and Lenggoru thrust belt heading north; to the south by the Tarera-Aiduna fault; and to the west by the Seram-Timor Trench (PT Geobis Woodward-Clyde Indonesia, 1998).

2.1.7.5 Earthquake and Tsunami

As the Berau/Bintuni Bay study area is located in one of the most active tectonic regions in the world, although actually Berau/Bintuni bay itself extends in a relatively stable block of the earth's crust, the study area may generally be categorized as an earthquake vulnerable area. The study area is located between New Guinea fault-trench to the north and the Seram-Timor Trench to the south. The folds and trench zone is a collision and subduction zone, both of which are historical sources of destructive earthquakes. Global seismology database belonging to the National Earthquake Information Center (NEIC), U.S. Geological Survey, presents information on earthquakes occurring in the Papua region during the past 170 years (1830 to the present). The files combined with data from the International Seismological Center (ISC), indicate that between the year 1830 to 1998 there were 3,951 earthquake incidents with strength above 2.0 in the rectangular area measuring 10° x 7° around the Tangguh LNG project site (EQE International, 1999). Coordinates used for the data base search were 128°E - 138°E and 1°N - 6°S. As the acceptable limit for earthquake strength for engineered structures commonly used is scale 5.0, the number of earthquake events occurring in the scale is around 1,052 events that may potentially destroy engineered struct ures in the rectangular area 10° x 7° (*EQE International*, 1999).

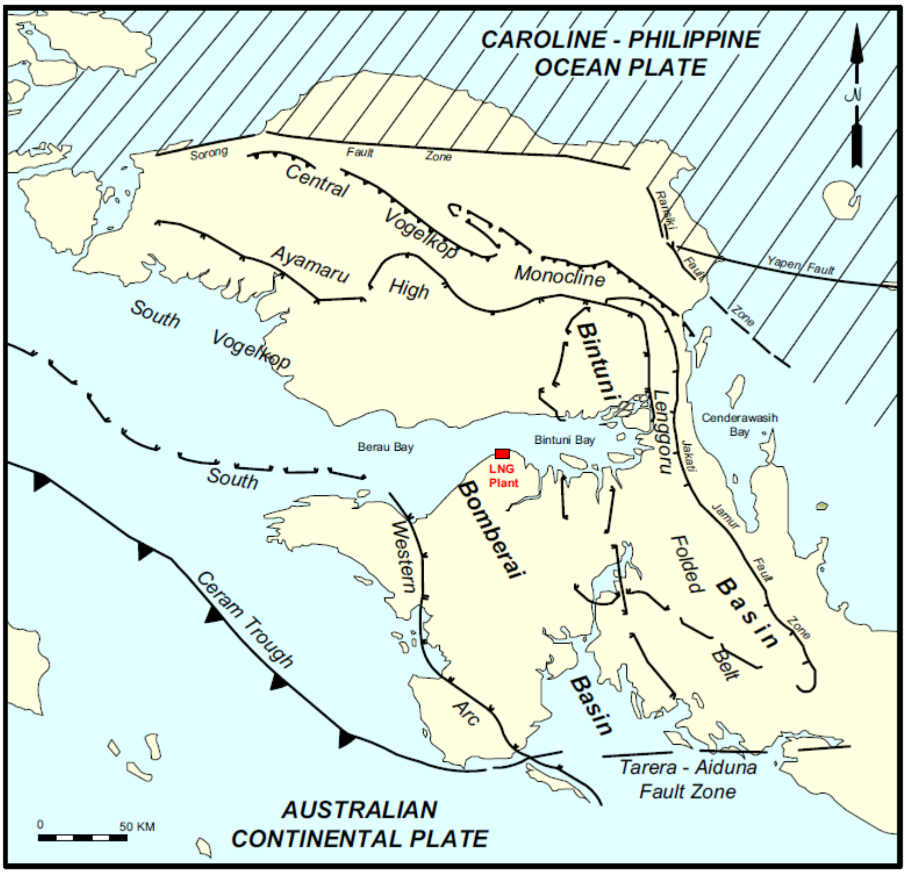


Figure II-35 Geological Sketch Map of the Bird's Head Region, Irian Jaya (Papua) (Redrawn from *Erftemeijer et al.* [1989] After *Audretsch et al.* [1966]

Figure II-36 plots the centers of earthquake events recorded only in the rectangular area 5° x 3° in the vicinity of the Tangguh LNG project site (PT. Calmarine/Emcon, 1999). It may be observed from this plot that several earthquake events of strength 5.0 have occurred near the project site, although earthquakes of strength 6.0 or over are known not to have happened in a radius of less than 100 km from the planned project site. Based on this information and various other data, computer simulation by EQE International (1999) indicated that the rectangular area is characterized by rather steep gradient of peak ground acceleration (PGA) hazard, namely above 0.4 g at return period of 475 years, east of Berau/Bintuni Bay at position of approximately 133°20' E. The results show that the Tangguh LNG project site is in Zone 3 classification for buildings with ordinary structure according to the 1994 U.S. Uniform Building Code. Zone coefficient is roughly equivalent to ground acceleration with median probability of 10% to be exceeded in a 50 year period. The risk level is related to median return period of 475 years. **Figure II-37** shows values of PGA calculation for structures built on soft rock; the Figure shows that calculated values for structures built on hard soil will be slightly higher.

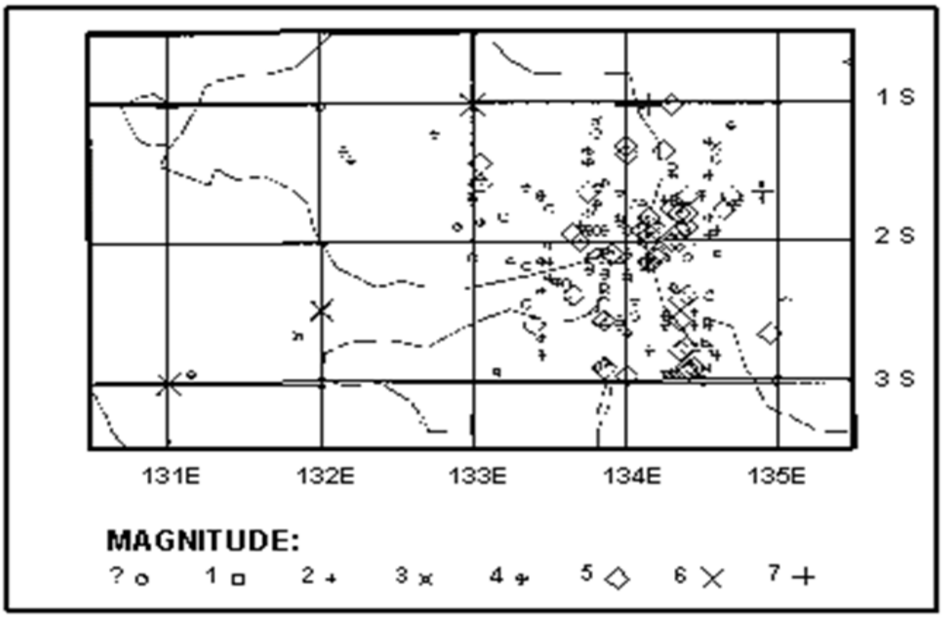


Figure II-36 **Locations of Earthquake in Irian Jaya (Papua) Recorded by the U.S./Geological Survey, National Earthquake Information Center (From: PT. Calmarine/Emcon, 1977)**

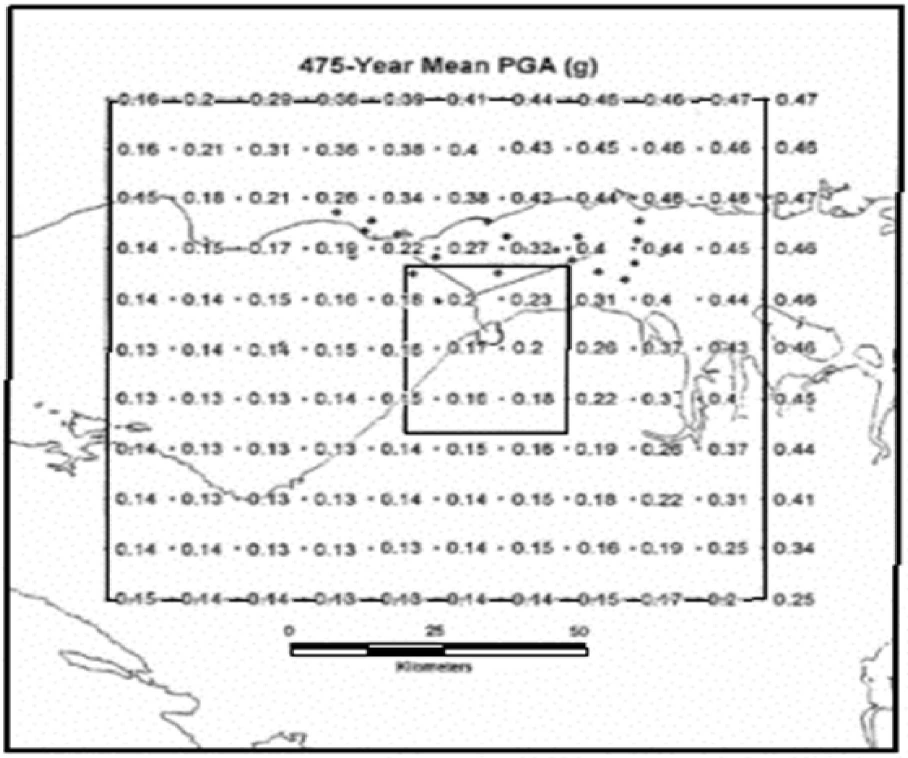


Figure II-37 **Grid Map of Median Value of 475 Years Peak Ground Acceleration (PGA) of Soft Rock in One Square Degree Around the LNG Site (From: EQE International, 1999)**

In a supplementary report (*EQE International*, 2000), it was described that the site for construction of LNG jetty was estimated to be vulnerable to the danger of soil movement, with ground acceleration value of 0.27 g in return period of 475 years.

A further report presented horizontal and vertical ground acceleration movement for the proposed facility site plan of LNG Plant and also for points at 2 km intervals along the proposed pipeline installation from the offshore construction site of Wiriagar and Vorwata to the site of the LNG jetty.

Deep sea seismic activities that can potentially affect the project site consist of the Seram and New Guinea subduction zones. Furthermore, four offshore shallow faults in Simuri (Saengga) waters will have an influence on the project site. All the faults extend a distance of 1 km to the Northeast. Not even one of the four faults disturb the sea bed, although one of them has apparently penetrated the surface of the sea bed. It is estimated that the fault is not seismogenic and limited to shallow ground column. With regard to the factor of earth crust dimension required for an active seismogenic fault, the length of surface fracture is generally greater than 1 km (*EQE International,* 2000).

In the region around the Bird's Head, West Papua, based on NEIC-USGS records the number of earthquake incidents recorded from 1973 to August 2007 was 18,504 incidents with strength interval ranging from 2.9 – 8.3 SR. In this year's interval , two earthquakes occurred in very strong category, i.e. over 8 SR as shown in **Figure II-38**.

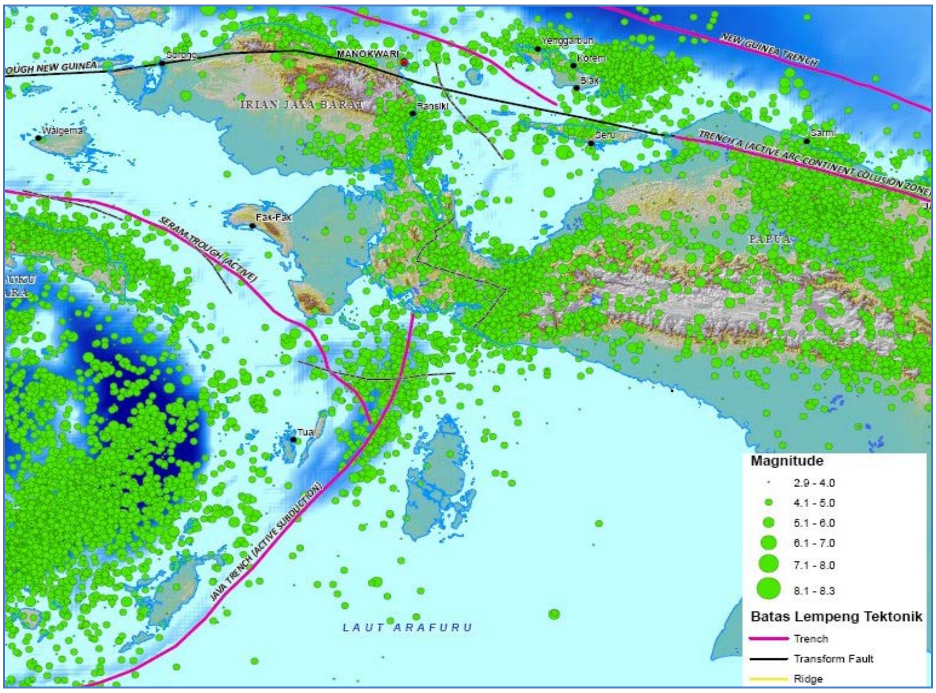


Figure II-38 Earthquake Distribution from 1973 – 2007

From USGS records, four earthquakes occurred in 2012. On May 31st, 2012, a 5.5 SR earthquake struck at depth of 17.5 km. Then, on June 1st, another earthquake was recorded of 5.7 SR at depth 14.3 km. On June 5th, 2012, yet another earthquake of 4.7 SR at depth 20.9 km, and finally on June 7th, 2012, a 4.7 SR earthquake at depth 41 km. The earthquake epicenters were in close proximity to one another. The four earthquakes were in the zone at distance of 80 – 100 km west of Manokwari city.

Tsunamigenic sources in the study area are limited to earthquakes occurring along the Ceram subduction zone. Most tsunamis, which could affect the project site, would arise from the Ceram-Banda Seas, however there is the potential for tsunamigenic events to be occured from closer sources. Risk associated with tsunamis include the following:

- Srended boat during low water elevations is associated with the retreating phase of the tsunamic wave;
- Reverse dynamic interaction between floating structures and fixed structures over a short period so that waves strike with extremely high energy;
- Failure to establish a safe non-operating configuration, and/or evacuate personnel from lower elevations and platforms.

Calculations results of a study on the probability of tsunami hazard at specific sites in Berau/Bintuni Bay (*EQE International*, 2001) indicated the possibility and potential impact of tsunami on the Tangguh LNG project site, so it should be essential to conduct an investigation on early warning system of local tsunami hazards.

2.1.8 Water Quality

Environmental baseline data collecting of water quality within the study area boundaries is performed for three types of waters, namely River, Nearshore, and Offshore.

2.1.8.1 River Water Quality

River water sampling was performed during the dry season (July – August 2012) and wet season (March – April 2013). Samples were taken from the Saengga River on the western boundary of the Tangguh LNG (SW-1) with coordinates 02° 27′ 59.8″ S - 133° 06′ 16.2 " E and from Senindara River, east of the Tangguh LNG location (SW-3) with coordinates 02° 31′ 54.8″ S - 132° 16′ 29.3 " E (**Map II-11**). Tidal condition during sampling is shown in **Figure II-39** – **Figure II-40**. River water sampling during the dry season at SW-1 coincided with the period approaching high tide, while at SW-3 it coincided with the period approaching lowest tide.

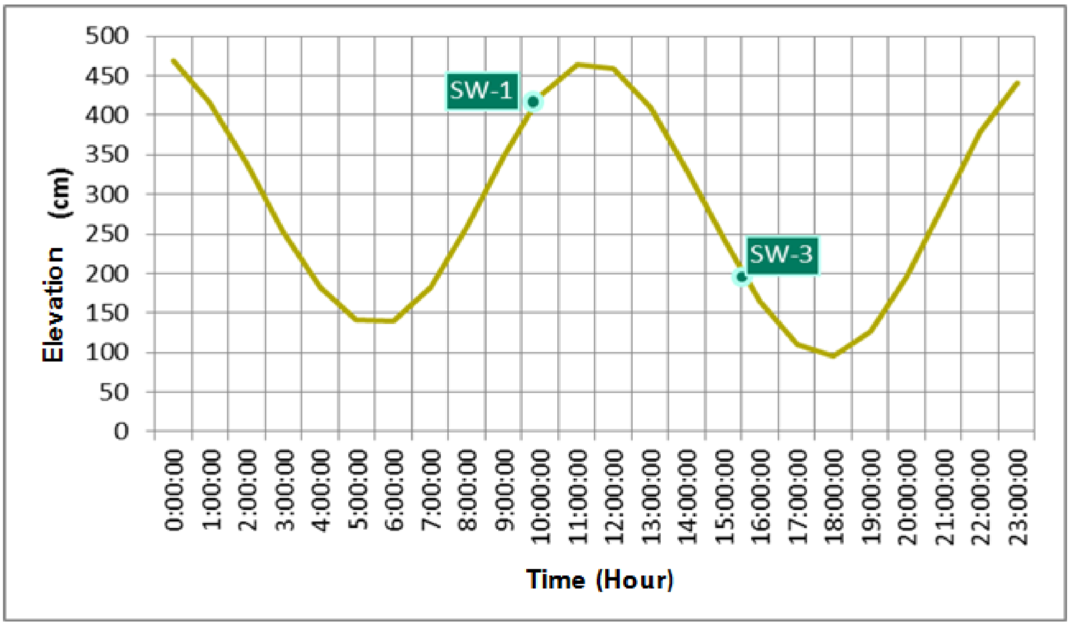


Figure II-39 Tidal Condition during Dry Season Sampling (August 9th, 2012)

Wet season sampling at SW-1 coincided with the period of lowest tide, while at SW-3 it coincided with the period approaching highest tide.