PNG LNG Project: LNG Facilities

Hydrology and Sediment Transport

January 2009

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Document Control Information					
Date Printed	8 January 2009				
Project Title	PNG LNG Project				
Project Manager	Ben Pearson				
Job Number	CNS0802a				
Report Number	1				
Document Title	PNG LNG Project: LNG Facilities: Hydrology and Sediment Transport				
Document File Name	**Document Status**	**Originator(s)**	**Reviewed By**	**Authorised By**	**Date**
CNS0802a_R_1_v0-2.docx	Draft	BP	AM	AM	8/8/2008
CNS0802a_R_1_v1-2.docx	Reviewed Draft	BP	AM	AM	17/10/2008
CNS0802a_R_1_v2-1.docx	Reviewed Draft	BP	AM	AM	25/11/2008
CNS0802a_R_1_v3-1.docx	Reviewed Draft	MW	BP	BP	06/01/2009

Distribution

Document File Name	Description	Issued To	Issued By
CNS0802a_R_1_v2-1_BP.docx	DRAFT	Rebecca Hewlett Carmel Coyne	BP
CNS0802a_R_1_v2-0_BP.doc	FINAL DRAFT	Rebecca Hewlett	BP
CNS0802a_R_1_v3-0_BP.doc	FINAL DRAFT	Carmel Coyne Anne Maree Goldman Robert Meagher Amelia Jenkinson	BP
CNS0802a_R_1_v4-0_BP.doc	FINAL	Mike Wright	BP

EXECUTIVE SUMMARY

The Papua New Guinea (PNG) Liquefied Natural Gas (LNG) Project (PNG LNG Project) is a project proposed by ExxonMobil, to commercialise reserves in the Hides, Angore, Juha, Kutubu, Agogo, Gobe and Moran fields in the Southern Highlands and Western Province of PNG.

A summary of the project components that are of relevance to this report is as follows:

- Development of the LNG Facilities site within Portion 152 (P152);
- Development of pipelines linking these facilities to the landfall; and
- Other infrastructure and services associated with the LNG Facilities component of the project.

The main objective of this study was to predict project-related increases in sediment load for a range of flows in the Vaihua River and to assess potential impact to the discharge regimes of other watercourses within P152. For the purpose of these assessments, P152 was divided into three separate catchments: Vaihua, North Vaihua and Karuka. A tributary of the Vaihua River (named 'Vaihua Tributary') that flowed into it in the estuary was also identified. Baseline condition of this tributary and predicted impacts will be addressed with the North Vaihua catchment as they both drained the LNG Facilities site and the tributary flowed into the Vaihua River downstream of the site on which the Vaihua hydrological and sediment transport models were based.

The hydrology, sediment transport regime and other geomorphic features and processes were assessed using a bilateral field-based and model-based approach. A field reconnaissance was used to assess *in situ* features, such as bed and bank sediment type, bed and bank stability, cross-sectional shape, slope and channel type. Data from the field trip fed into the model to produce a hydrological and sediment transport baseline.

No reliable hydrological records existed within the region. As such, stochastic modelling to achieve a long-term synthetic flow series was not possible and the *Regional Flood Frequency Method* outlined in the P*apua New Guinea Flood Estimation Manual* (SMEC 1990) was used to produce "best estimates" of discharges for a variety of return periods (Q_2, Q_5, Q_{10}, Q_{20}, Q_{50}, Q_{100}) for the Vaihua River.

Using the above information, the Yang (1973) sediment transport equation was run to determine rates of transport for the above return periods. This equation has been shown to perform reasonably well against field data (Stevens and Yang 1989) and has been used widely within PNG.

The Vaihua River catchment was broken into three major sections: floodplain channels, undulating landscape channels and the steep upper reaches. Its hydrology reflected the climate, with all streams within the catchment being either intermittent or ephemeral. The discharge of Vaihua River at the most downstream survey location varied between 30 m^3 / s (Q_2 flow) and 74 m^3 / s (Q_{90} flow). It was estimated that the Vaihua River at this location would only convey flows up to the Q_2 within channel. Less frequent, higher magnitude flows would spill onto the floodplain. The sediment transport model showed that, for the Q_2 flow, an estimated 24,000 tonnes / day (approximately 5,000 mg / L) would be conveyed.

The streams within the North Vaihua River and Vaihua Tributary catchments were similar to those within the lower floodplain channels of the Vaihua River catchment, with respect to being intermittent in nature, bounded by relatively flat landscape and having small cross-sectional areas incapable of conveying larger flows.

The only impacting infrastructure within the freshwater reaches of the Vaihua River catchment were the proposed new roads. A simple sediment accounting / delivery scheme was used to assess impact of the road construction. The key elements of the sediment delivery scheme were as follows:

- A fixed rate of erosion for disturbed areas was set at 50 mm/year (500 m^3/ha/year);
- Delivery 'zones' that accounted for the distance of the construction activities from the Vaihua River. Three zones were defined and sediment delivery ratios set for both coarse and fine sediment for each zone;
- Rate of progression for road construction was considered to be 250 m / day;
- An *in situ* sediment density of 1.7 t / m^3;
- A road width of 30 m; and
- The proportion of total eroded sediment that was in the <125 μm range was assumed to be 70%, based on measured particle size distributions.

The estimated delivery of sediment to the Vaihua River from road construction would expect to be minimal compared with overall potential sediment transport capacity of the Q_2 flow (4 % of potential capacity). Impacts on Total Suspended Solids (TSS) were estimated to be of a similar magnitude.

Potential impacts on the streams of the North Vaihua River and Vaihua Tributary catchments relate to construction and operation of the LNG Facilities and may include changes to surface hydrology, related increased within-channel velocities and sediment delivery, elevated TSS values during times of flowing water and within standing pools, increased erosion (gullying) and changed drainage patterns due to diversion channel excavation. These impacts are likely to be minimal with the implementation of the recommended mitigation options.

Potential impacts within the Karuka Creek catchment would be associated with the construction of a section of road within the catchment. Impacts may include increased erosion and sediment delivery to the channel and resulting elevated TSS and bed sedimentation. With the implementation of the recommended mitigation options, these impacts are likely to be minimal.

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1 INTRODUCTION

1.1 Project Background

The Papua New Guinea Liquefied Natural Gas (PNG LNG) Project involves the development of a number of gas fields and facilities in a series of development phases to produce liquefied natural gas (LNG) for export. The development will also produce condensate. The development of the Hides, Angore, and Juha gas fields and blowdown of the gas caps at the existing Kutubu, Agogo and Gobe oil fields will supply the gas resources. An extensive onshore and offshore pipeline network will enable transportation of the gas to a new LNG Plant near Port Moresby and stabilised condensate to the existing oil processing and storage, and offloading facilities at the Kutubu Central Processing Facility and Kumul Marine Terminal respectively. Small amounts of condensate are also produced at the LNG Facilities site.

Esso Highlands Limited (Esso), a Papua New Guinea subsidiary of the Exxon Mobil Corporation (ExxonMobil), is the operator of the PNG LNG Project. The PNG LNG Project will be developed in five phases over a period of 10 years to ensure reliability and consistent quality of supply of LNG for over the 30 year life of the project.

A list of the proposed developments is provided below, and Figure 1-1 shows a schematic diagram of facilities and pipelines:

Upstream Development Components:

- Hides gas field development:
  - Seven wellpads with a total of eight new wells and re-completion of two existing wells;
  - Hides gathering system including gas flowlines from new and re-completed Hides wells;
  - Hides spineline and mono-ethylene glycol (MEG) Pipeline in the same right of way (ROW);
  - Hides Gas Conditioning Plant;
  - Hides–Kutubu Condensate Pipeline in the same ROW as the LNG Project Gas Pipeline.
- Juha gas field development:
  - Three new wellpads with four new wells;
  - Juha gathering system including gas flowlines from new Juha wells;
  - Juha spinelines and MEG Pipeline in the same ROWs;
  - Juha Production Facility;

- o Juha–Hides pipelines right of way (ROW) containing three pipelines including Juha–Hides Rich Gas Pipeline, Juha–Hides Liquids Pipeline and Hides–Juha MEG Pipeline

- Angore gas field development:
    - o Two new wellpads with two new wells;
    - o Angore gathering system including gas flowlines from new Angore wells;
    - o Angore spineline and Angore MEG Pipeline to Hides Gas Conditioning Plant, both in the same ROW.

- Gas from existing fields:
    - o Gas treatment at the Agogo Production Facility and a new Agogo Gas Pipeline from the Agogo Production Facility to LNG Project Gas Pipeline;
    - o Gas treatment at the Gobe Production Facility and a new Gobe Gas Pipeline from the Gobe Production Facility to LNG Project Gas Pipeline;
    - o Gas treatment at the Kutubu Central Processing Facility and a new Kutubu Gas Pipeline from the Kutubu Central Processing Facility to the LNG Project Gas Pipeline;
    - o South East Hedinia gas field development: one new wellpad and two new wells; new gathering system including gas flow lines from the South East Hedinia new wells to the Kutubu Central Processing Facility in the same ROW as the Kutubu Gas Pipeline.

- Kopi scraper station.

- LNG Project Gas Pipeline:
    - o Onshore: from Hides Gas Conditioning Plant to Omati River Landfall;
    - o Offshore: Omati River Landfall to Caution Bay Landfall;

LNG Facilities Development Components:

- Onshore LNG Plant including gas processing and liquefaction trains, storage tanks, flare system and utilities; and

- Marine facilities including jetty, LNG and condensate export berths, materials offloading facility and tug moorage.

Supporting Facilities and Infrastructure:

In addition to the principal gas production, processing and transport, and LNG production and export facilities, the project will involve the following permanent infrastructure and facilities:

- New roads and upgrade of existing roads;
- New bridges and upgrade of existing bridges;
- Upgrade of two existing airfields (upstream at Komo and Tari);
- New helipads (multiple);
- New wharf and an upgrade of the existing Kopi roll-on, roll-off facility;
- Water supply systems and pipelines, wastewater and waste management facilities; and
- Operations Camps (at Hides, Juha and Tari).

A series of temporary works and access roads will also be required during the construction phase, including:

- Construction camps (multiple); and
- Material/pipe laydown areas.

1.2 LNG Facilities Background

A summary of the project components that are of relevance to this report is as follows:

- Development of the LNG Facility site within Portion 152 ;
- Development of pipelines linking these facilities to the landfall; and
- Various roads, bridging, logistics bases, construction camps, landfills, communications facilities, waste management facilities etc. associated with the LNG Facilities section of the project.

The present report deals only with the LNG Facilities segment of the project. This report is designated as Hydrobiology (2008f) and the upstream segment hydrology and sediment transport report is Hydrobiology (2008e). CNS contracted Hydrobiology to undertake investigations into the existing hydrology and sediment transport regimes for the Vaihua River – the major river system within P152 – and to assess project-related impacts to the discharge and sediment transport regimes of the watercourses within P152.

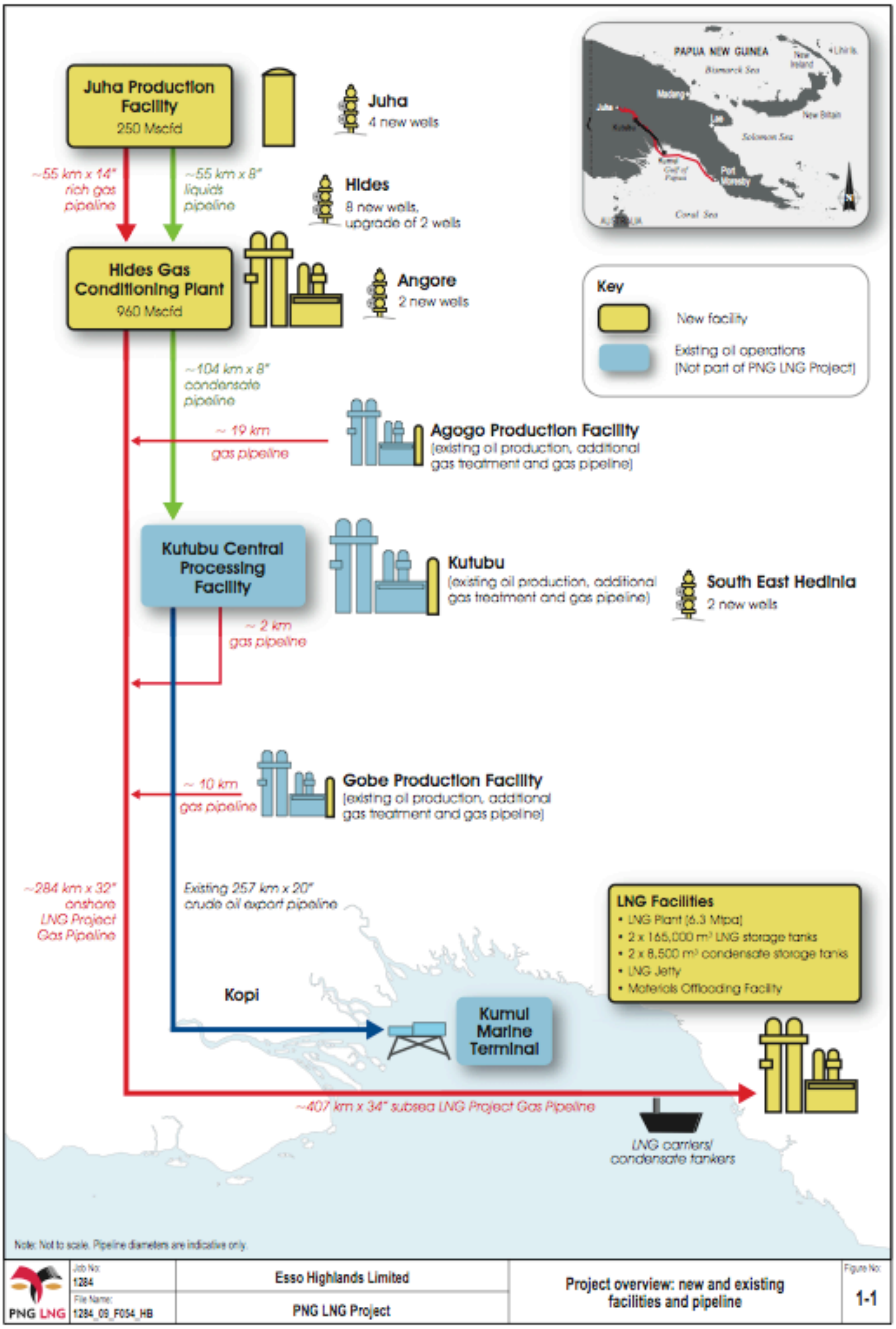

Figure 1-1 Project overview – new and existing

1.3 Objectives

The main objective of this study was to predict possible project-related increases in sediment load for a range of flows in the Vaihua River and to assess potential impact to discharge regime of other watercourses within P152.

Tasks associated with the objective were to:

- Review project-specific technical information, the previous EIS and other project and publicly available data;
- Collect *in situ* bank and bed sediment samples for further size distribution and dispersivity/erodibility analysis for the purpose of describing existing conditions and for input to sediment transport calculations;
- Perform *in situ* geomorphic / hydrological assessment, including bank and bed stability assessments, cross-sectional surveys, longitudinal surveys and visual interpretation;
- Estimate existing and potential flow exceedence percentiles and sediment transport regimes of the Vaihua River through either currently available data or the development of a hydrological dataset for the river;
- Assess the potential impact to discharge regime for all significant watercourses within P152 during construction and post-construction periods; and
- Suggest measures to mitigate potential impacts from project activities.

The objective required a far more detailed approach for the Vaihua River catchment than the remaining P152 watercourses. This involved hydrological and sediment transport modelling for a site within its freshwater reaches. The outline of this report is designed specifically to address this need with the baseline condition of the freshwater reaches of the Vaihua River (Chapter 3) described separately from that of the remaining watercourses (Chapter 4). A tributary (named 'Vaihua Tributary') and its catchment that drained the LNG Facilities and that had its confluence with the Vaihua River within the estuary (i.e. downstream of the Vaihua River modelling site) will also be dealt with in Chapter 4 (Figure 2-1).

2 STUDY AREA

2.1 Location

The study area was broadly defined as that encompassed by the P152 boundary with several additional assessment sites upstream and downstream of the boundary. The boundary and assessment sites are listed in Table 2-1 and shown in Figure 2-1. Figure 2-1 also shows the approximate delineations between the different catchments that were used to guide the baseline and impact assessment sections. Note that the downstream limit to these catchments has been taken as the most upstream point of the estuary / clay pans. Three catchments were identified: Vaihua (including the Vaihua Tributary), North Vaihua and Karuka. The Vaihua Tributary catchment has also been identified in Figure 2-1. The Vaihua and North Vaihua catchments and Vaihua Tributary subcatchment all drain into an expansive clay pan area with poorly defined drainage channels in the upper estuary prior to entering the more defined channels of the lower estuary.

2.2 Climate

As shown by McAlpine *et al*. (1983), the rainfall of the Port Moresby region is one dominated by high seasonality, with a January-April maximum (Figure 2-2) influenced by the south-easterly trade winds. On average, 80 % of rainfall falls within the wet season months of November to April. This high seasonality is further evidenced by the high intra-annual variation in rainfall between months, with a monthly coefficient of variation (CV) of 77 % and moderately high inter-annual variation of 22 %. Long-term records of Port Moresby rainfall showing mean lengths of rainy and rainless periods indicated its general dryness – mean lengths of rainy periods do not exceed 2.5 days, whereas mean rainless periods vary between 3 days in the wet season and 10 in the middle of the dry season (McAlpine *et al.* 1983).

Table 2-1 Geomorphic sampling site coordinates

NAME	X	Y
KS1	147.04545	-9.32739
KS2	147.04418	-9.33855
KS3	147.05518	-9.35829
KS4	147.04861	-9.35822
KS5	147.02706	-9.30800
KS6	147.05365	-9.35228
KS7	147.04728	-9.35386
KS8	147.04832	-9.35364
VS1	147.02044	-9.35552
VS2	147.02612	-9.36271
VS3	147.03618	-9.36585
VS4	147.04194	-9.37788
VS5	147.03003	-9.35918
VS6	147.04707	-9.38614
VS7	147.02839	-9.34757
VS8	147.01491	-9.33050
VS9	147.06433	-9.36758

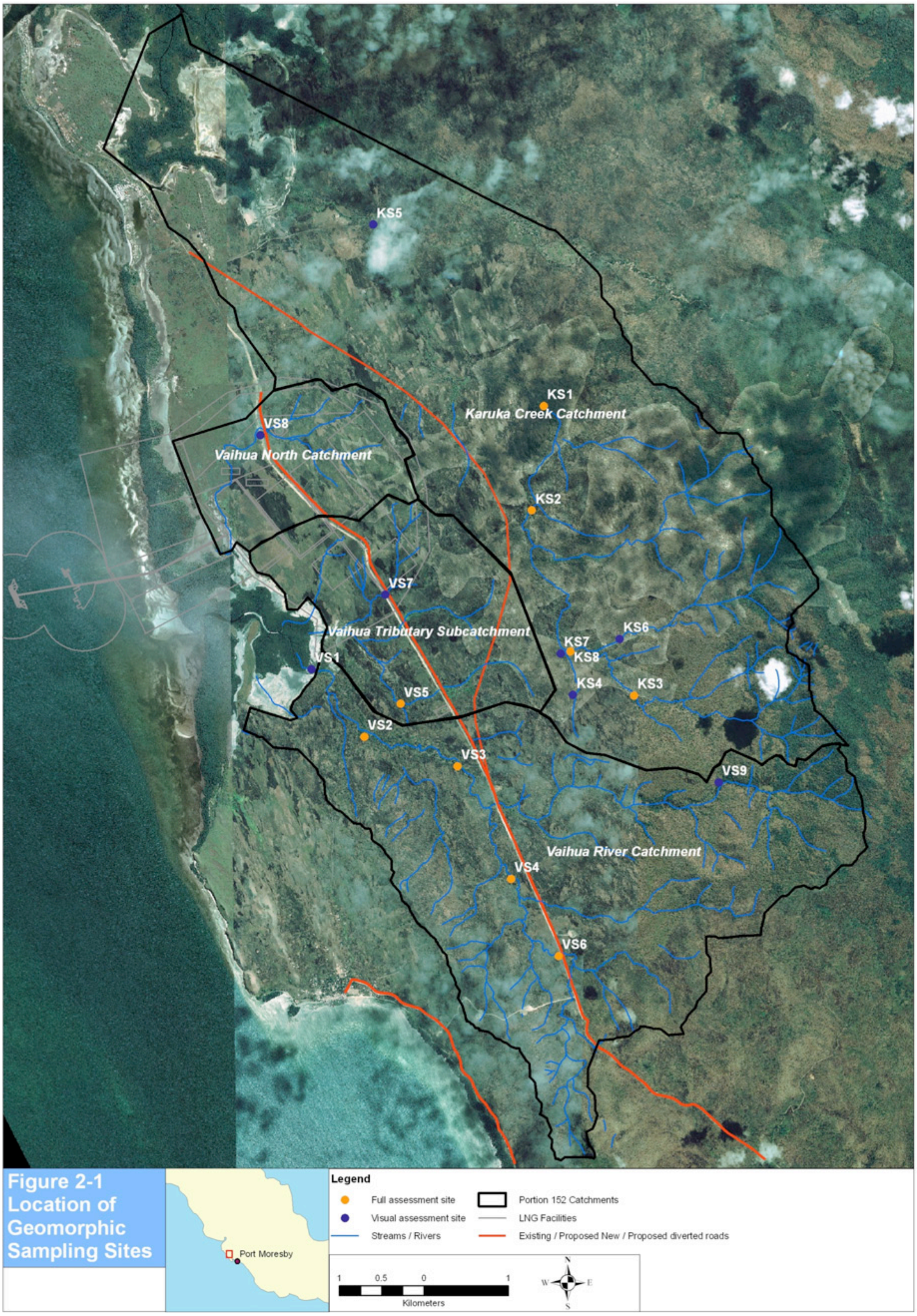

Figure 2-1 Geomorphic assessment sites, proposed LNG Facilities and catchment boundaries

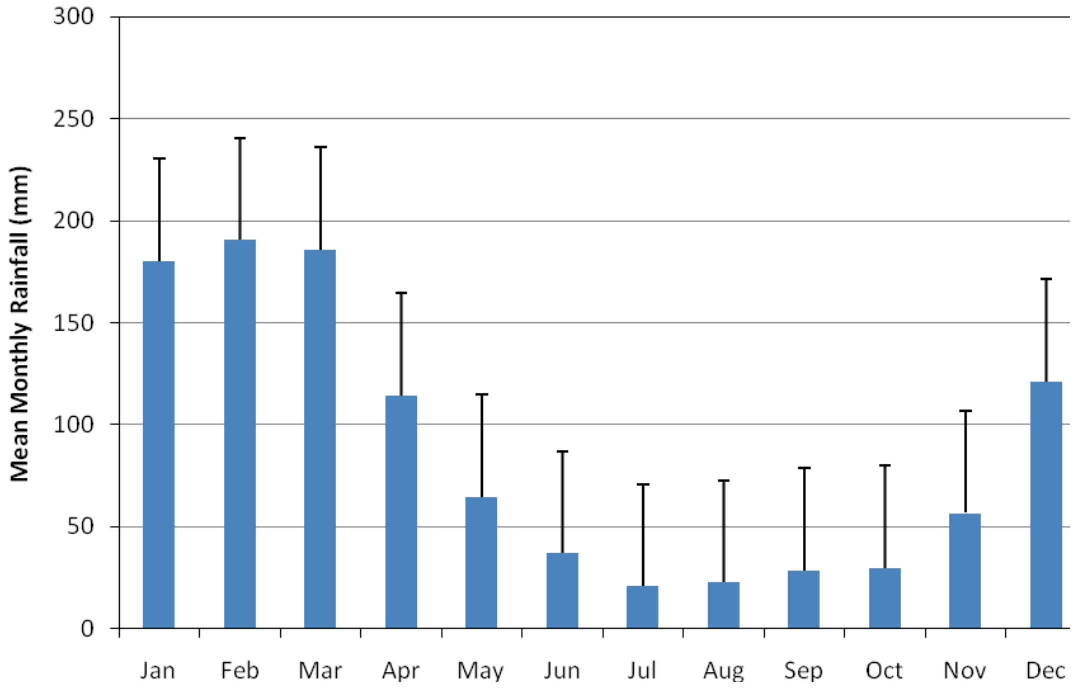

Figure 2-2 Mean monthly rainfalls for Port Moresby. Error bars indicate standard error (Source: Clewett 2003)

3 VAIHUA RIVER BASELINE HYDROLOGY & SEDIMENT TRANSPORT

This section addresses the baseline condition of the freshwater reaches of the Vaihua River and the modelled hydrology and sediment budget for the Vaihua River.

3.1 Methods

3.1.1 Field Assessment

Field assessment was undertaken within P152 between 30 May 2008 and 4 June 2008 to inform the Vaihua River hydrological and sediment transport impact assessment and to provide a baseline of the Vaihua River and the remaining area of P152. Two *in situ* assessment techniques were employed during the field assessment – a basic visual assessment and a full geomorphic assessment which was applied at selected key sites. Basic visual assessment involved the recording of brief notes on geomorphology / hydrology and a photographic record. The full geomorphic assessment included:

- A catchment-based aerial photograph interpretation;
- A review of available literature;
- A detailed visual assessment, including:
    - Bank and bed stability;
    - Riparian vegetation abundance;
    - Active geomorphic processes (infilling / incision); and
    - Channel type;
- Channel slope;
- Bed and bank sediment analysis (PSD, Emerson's Dispersion Test);
- Cross-sectional profiles; and
- A detailed photo record.

Site-by-site details are included in Appendix 1.

3.1.2 Hydrology

No reliable hydrological records existed within the region. Further, the required parameters to create a synthetic data series were also non-existent or of insufficient quality or quantity for meaningful assessment. As such, stochastic modelling to achieve a long-term synthetic flow series was not considered appropriate. Therefore, the P*apua New Guinea Flood Estimation Manual* (SMEC 1990) was used instead to select a method to produce "best estimates" of flows for specific return periods (Q_2, Q_5, Q_{10}, Q_{20}, Q_{50}, Q_{100})[1]. Methods within this manual will produce discharges for peak (design) flows and not flow exceedence percentiles. However, this was considered sufficient for assessments of potential impacts on hydrology and sediment transport within the Vaihua River.

The *Regional Flood Frequency Method* outlined in SMEC (1990) was selected as it was designed specifically for estimating peak flood discharges in rural catchments greater than 4 km^2. The area of the Vaihua River catchment is approximately 17 km^2. A full description of the method is outlined in SMEC (1990); however, data requirements are listed below:

- Catchment area;
- 2-year ARI (Average Return Interval) daily rainfall intensity index for the catchment (adapted from Port Moresby rainfall data);
- Slope index of the main channel;
- Percentage of swamp or flood-prone land along the main river channels, as defined on 1:100,000 topographic maps;
- Catchment shape index (area relative to length); and
- Percentage of karstic land within the catchment.

Two alternative sets of equations are used in the method outlined in SMEC (1990) ('normal' and 'alternative' methods). The 'normal' method is dependent on the catchment characteristics listed above falling within specific data ranges. If any characteristic does not fall within the prescribed ranges, the 'alternative' equation is used. The Vaihua River catchment had several characteristics that were right on the limit of the prescribed ranges and, as such, the model was run with both sets of equations.

This hydrology estimation was applied to the catchment upstream of Site VS2.

3.1.3 Sediment Transport Model

Total sediment load consists of washload and bed material load.

- Washload is the part of the total load which is entirely suspended in the water column by turbulence.
- Bed material load is the part of the total load which consists of grain sizes found in the bed, and generally, rolls, skips or slides along the bed. Fluid lift and drag forces dominate bedload/bed-material load processes.
- Suspended load is that part of the total load that is predominantly in suspension and is the component sampled in the field. It contains both washload and bed material load.

In the absence of measured data, estimates of the potential sediment transport carrying capacity of Vaihua River can be made using transport capacity formulae. Strictly, these

[1] Return periods refer to the likelihood of a particular 'event' (in this case a rainfall / flow event) occurring each year, as indicated in the following brackets - Q_{100} (1% chance); Q_{50} (2%); Q_{20} (5%); Q_{10} (10%); Q_5 (20%); Q_2 (50%) and Q_1 (100%).

equations apply to bed material only rather than the total sediment load (i.e. excluding washload), although many researchers equate bed material discharge to total sediment discharge (Stevens and Yang 1989) as the bed material load constitutes the majority of the total discharge.

A number of sediment transport equations are available to estimate potential bed material load. Most equations consider the fluid forces acting on bed sediments of a known size distribution, and transport rates are calculated based upon the concept that transport is a function of the excess of some flow quantity above the threshold value for initiation of transport.

Such equations are semi-empirical, and it is critically important that a relation is selected that is appropriate for the flow and sediment characteristics of the river. Guidance for appropriate selection is provided by the United States Geological Survey (Stevens and Yang 1989). Yang's (1973) equation has been shown to perform well against field data (Stevens and Yang 1989) and has been applied to other PNG rivers. Therefore, it was considered the most suitable for this study and is consistent with methods applied for the upstream project (Hydrobiology 2008e).

Size distribution of benthic sediments is required in order to evaluate the transport rate for each size fraction of sediment. A size distribution was selected as described in Section 3.1.7.

Potential sediment transport rates were determined for the Q_2 flow.

3.1.4 Sediment transport model data requirements

The sediment transport model used here to measure current potential sediment transport conditions under a variety of flows required several data inputs. These were:

- General and return-period-specific channel characteristics (slope, width, depth, cross-sectional area, roughness);
- Sediment characteristics (particle size distribution);
- Data for the hydrology model, as listed in Section 3.1.2; and
- Velocities for the range of return-period discharges (Q_2, Q_5, Q_{10}, Q_{20}, Q_{50}, Q_{100} flows as described in Section 3.1.2).

The model used the most downstream freshwater survey site (VS2) for input (Figure 2-1). The methods used to obtain the above inputs are discussed in further detail in the ensuing sections.

3.1.5 Channel characteristics

Slope was measured using topographic maps. Cross-sections were measured during a Hydrobiology field trip in May 2008 at various survey sites along the Vaihua River to understand longitudinal geomorphic change. At Site VS2, channel depths, widths and cross-sectional areas were measured at each cross-sectional survey point for input into the sediment transport model (Figure 3-1). Velocities for flows reaching the elevation of each of these survey points were calculated using Manning's equation, as listed below:

$$v = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$$

where v = velocity (m / s), R = hydraulic radius (m), S = slope and n = "Manning's *n*" roughness coefficient. The hydraulic radius is defined as the cross-sectional area of a flow divided by the wetted perimeter (the parts of the channel "wetted" by the flow). Manning's *n* was estimated in two ways to obtain an accurate estimate – with comparisons between photos of previous Manning's *n* estimations (Barnes 1967, Hicks and Mason 1991) and *in situ* observations of Vaihua River and using a Manning's *n* calculator, as described in Chow (1959). Both methods of determining Manning's *n* returned similar values which provided confidence in the accuracy of the Manning's *n* estimate.

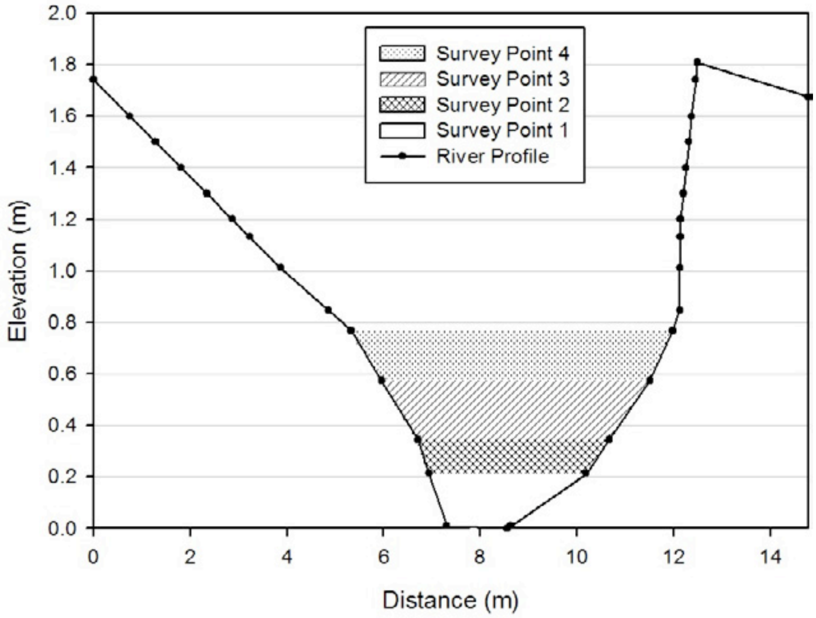

Figure 3-1 Vaihua River cross-section showing four examples of the different survey points at which channel characteristics were measured

3.1.6 Return-period velocities and characteristics

Velocities, depths, widths and other channel characteristics for return-period flows were estimated using comparisons of discharges between the return period flows and those calculated for each cross-sectional survey point, as described in Section 3.1.5. Where discharges matched or closely resembled each other, the characteristics calculated in Section 3.1.5 were adopted for the return-period flows.

3.1.7 Sediment characteristics

Particle size distributions (PSD) were measured for the banks and bed at various sites on the Vaihua River. This was not a comprehensive survey, but provided some guidance to the sediment characteristics for the main areas of potential disturbance. The sediment types within the main channel were generally finer than gravel. As such, PSD was measured using a combination of dry sieving with the hydrometer sedimentation method (see Gordon *et al.* (2004) for a method description) to account for all particles sizes between fine clay and coarse gravel.

3.1.8 Catchment characteristics

Catchment size, shape and topography were all measured from 1:100,000 topographic maps of the study area.

3.2 Geomorphic Description

As discussed in Section 2.1, the estuary of the Vaihua River also receives drainage from the Vaihua Tributary subcatchment and North Vaihua catchment. All three drain into an expansive clay pan area with poorly defined drainage channels in the upper estuary prior to entering the more defined channels of the lower estuary. The Vaihua River catchment upstream of the estuary can generally be divided into three geomorphic units – a meandering system flowing through a flat alluvial floodplain occurring mainly east of the Lea-Lea Road (e.g. VS2), a channel within undulating lowlands with lateral position in some locations dictated by the surrounding terrain (occurring in the more upstream sections of the Vaihua River – e.g. VS6) and a partly confined to confined system within low hills (observed in tributaries east of the Lea-Lea Road – e.g. VS9 and occurring in the far upstream sections of Vaihua River out of P152). A general geomorphic description of the channel in each of these units is outlined below.

3.2.1 Floodplain channels

This region was flat with cracking clays, indicating poor drainage, which is typical of Gilgai country. The Vaihua River and its tributaries within this region were generally slightly incised streams with small cross-sectional area and with high potential for overbank flows (Figure 3-2a). Bank gradients varied between very gradual (VS5) and steep (VS2). Banks were generally composed of material with high clay content (VS2 – 42% clay; upper layer at VS3 – 29% clay), typical of Gilgai country; however, some locations consisted of banks with several sedimentary units. VS3, for example, had banks with three different units – a top layer of black clay, a middle layer of black clay with gravel and a bottom layer of black clay (Figure 3-2b). This is evidence of some past channel downcutting and lateral movement. The black soils within the banks were generally not dispersive (i.e. diffusion of sediment particles into water) but underwent complete aggregate slaking (fragmentation of soil aggregates) within seconds of immersion in water, indicating some weakness when wet (Figure 3-3). This has significant implications for bank stability during rainfall events and resulting stream flows.

Longitudinal channel slope was low throughout this region (< 1° at all sites). While past incision was evident, current trends within most floodplain channels appeared to be more of infilling, with large within-channel deposition zones of coarser sediment (Figure 3-4a). This sedimentation is likely to be an artefact of the drier conditions. Wet season flows will redistribute this sediment. Similar seasonal sedimentation occurs at the mouth fed by tidal redistribution and longshore drift of sediment, with mouth re-opening occurring during larger wet season flows.

Bed sediment was composed of large amounts of sand and gravel, ranging between clayey sands (VS2), clayey gravels (VS4) and silty sands (VS3). Only scattered cobbles were observed in the reaches of streams and rivers in this region, suggesting a low energy system.

Riparian vegetation was variable and dependent on the presence of remnant standing water (suggesting the presence of some groundwater lenses). However, in general it consisted of scattered to low density trees and dense grasses (Figure 3-4b). As such, very little additional stabilising effect was offered via the root matrix.

a. Slightly incised, small floodplain channel	b. Cracking clay and clay-gravel matrix bank sedimentary units

Figure 3-2 Geomorphic condition of floodplain channels

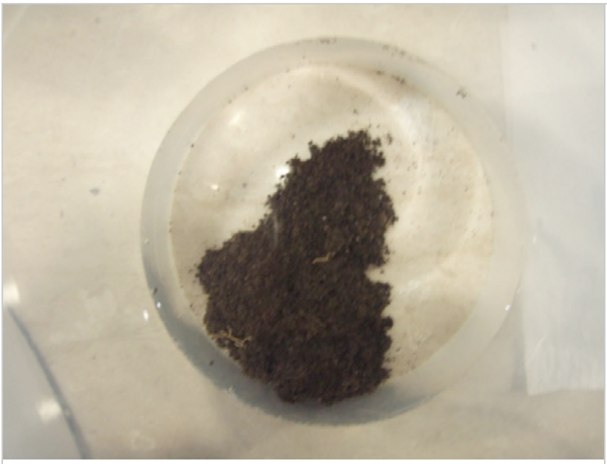

Figure 3-3 Aggregate slaking of bank sediments at VS2 (left) and VS3 (right)

	
a. Vegetated, depositional mid-channel sand bar)	b. Example of riparian vegetation

Figure 3-4 Examples of floodplain channel geomorphology and riparian condition

3.2.2 Undulating landscape channels

The Vaihua River was assessed in one location within the undulating landscape. VS6 was typical of the stream reaches within this zone. The site consisted of a much smaller channel with lower and more gradual, stable banks. The bed was largely composed of coarse gravel, with some cobble most likely sourced from eroding road-base material immediately upstream of the site. The cobble graded out quickly with distance downstream from the road. Banks were homogeneous, consisting of similar sediments as those on the floodplain, with less cracking evident and less slaking when immersed in water, indicating greater inherent stability. The plan form of the channel was one of a meandering system, partly free in the flatter sections and dictated by the surrounding undulations in others. Slight infilling was occurring within this section. Riparian vegetation was largely dense savannah grassland, although 'dense' pockets of trees were observed in sections (5-6 trees / 100 m^2 quadrat). Channel slopes were between one and two degrees.

	
a. Bed material	b. Example of riparian vegetation

Figure 3-5 Baseline condition of Site VS6

3.2.3 Upper reaches

The upper reaches of the catchment drained westward from the south-east corner of P152 and northward from outside the south west of P152. No sites were able to be observed in the south west; however, one site in a tributary was assessed (VS9), with the surrounding topography also observed. These reaches were of much higher energy, as indicated by their greater channel slope (> 3°), more confined, steeper valley sides and much larger substrate (cobble – boulder material) (Figure 3-6). Long, dry cascades interspersed by deeper scour pools were evident. The channel was completely confined at Site VS9, with meandering dictated entirely by the valley sides. Banks were composed of bedrock and, hence, stability was very high. Riparian vegetation consisted of far denser trees than any other point in the catchment (Figure 3-6). Grass density was dependent on bank slope, with steep banks consisting of little undergrowth and more gradually sloped banks consisting of dense grasses.

a. Bed material

b. Example of riparian vegetation

Figure 3-6 Baseline condition of the upper reaches of Vaihua River catchment

3.3 Hydrology

3.3.1 General characteristics

The hydrology of the Vaihua River catchment reflected its climate, with most flow occurring during January to April. The small catchments indicated that after initial wetting of the ground, the streams would be fast rising. However, all were intermittent, typical of streams within this region, where they flow for only short periods of time following rain events (Golder Associates 2007). Some longer-lasting pools remained, partially sourced by past flows and (presumed) minor groundwater influence. From site inspections and flow estimation, it was evident that, particularly in the lower reaches of the river, channels only conveyed the more frequent, lower magnitude flows (Q_2), whereas large magnitude flows spilled water and sediment onto the floodplain.

3.3.2 Modelled Hydrology

The results from the *Regional flood frequency method* are outlined in Table 3-1. The two sets of equations made little difference to the overall results and, as such, the alternative method results were used for the remainder of the analyses. The Q_2 flow approximated bankfull at Site VS2. It is important to note that these velocities were arbitrary and did not take into account channel cross-sectional area and plan form or variability of either.

Table 3-1 Results for Site VS2 from both sets of equations using the Regional Flood Frequency Method of flood estimation

Return Period (years)	Normal Method (m^3 / s)	Alternative (m^3 / s)
Q_2	30	30
Q_5	45	45
Q_{10}	52	55
Q_{20}	60	65
Q_{50}	68	76
Q_{90}	74	84

3.4 Sediment Yield

The Vaihua River was observed to be very different in terms of hydrology from the rivers affected by the upstream project components analysed in Hydrobiology (2008e). The topography of the Vaihua River catchment was far lower in elevation, relief and slope than the rivers discussed in Hydrobiology (2008e) and, as such, mass movement processes would not dominate sediment supply. Further, the erosion of sediments would be far more episodic and would only occur following temporally isolated larger flows. Site observations showed that bank undercutting and eroding led to minor sediment inputs to the channel. As such, it could be assumed that most bed sediment was sourced from upstream reaches.

Within the lower reaches, sheetwash would be minimal, due to low slopes and dense grasslands. The formation of some preferential pathways was, however, observed within the floodplain where water that had escaped the channel during a large flow would return to the channel over the fastest possible route. Exposure of sediment associated with the floodplain black soils in these pathways would add minor amounts of sediment to the channels and may explain, to some degree, the clay content within the bed sediments.

Eventually, sediments do enter the stream network. Some component of the coarser fraction of this material may be deposited on the land surface or on the beds of tributaries and therefore would not reach the major streams. Accordingly it is the finer fraction of the eroded sediment that would enter the watercourses. This fraction is quantified by the delivery ratio (DR), which is explained in later sections. Although variable, soil erosion rates under natural conditions are often low (Loffler 1977, PSM 2003).

3.5 Sediment Transport

As discussed above, all flows except the Q_2 flow were estimated to exceed the channel bankfull level and without floodplain cross-sections no sediment discharge values for out-of-bank flows could be calculated. Regardless, the floodplain in the lower reaches of the Vaihua River was very flat and would add very little to overall downstream flow and sediment transport and most likely act as a sediment sink. The sediment transport model showed that, for the Q_2 flow, an estimated potential 24,000 tonnes / day (5,000 mg / L) would be conveyed. The Q_2 flow has a low exceedence probability and, as such, these values are low for such a flow, reflecting the channel and catchment characteristics.

4 GENERAL P152 BASELINE CONDITION

This section details baseline condition of the Karuka Creek and North Vaihua River catchments. Methods followed those outlined in Section 3.1.1. Site-by-site details are included in Appendix 1.

4.1 Karuka Creek Catchment

The Karuka Creek and its tributaries were generally more confined than those in the Vaihua River catchment, with only a very narrow floodplain existing throughout most of the catchment. All streams and rivers were intermittent or ephemeral in nature, flowing for only short periods following rainfall. Some groundwater discharge was evident in the lower reaches of the main Karuka Creek channel on inspection; however, this discharge appeared to be only of a short-term nature, as indicated by its diminishing volume during the field assessment.

Eastern tributaries were generally high energy systems, draining small, but steep catchments of the NNW-SSE ranges in the east of P152 (Figure 4-1). Western tributaries were generally only minor depressions draining small, gradually sloped catchments (Figure 4-1). This was reflected in the bed sediment, with the bed of eastern tributaries generally consisting of gravel to cobble substrate and that of the western tributaries consisting of clays and silts.

The majority of the Karuka Creek was an irregular meandering system that laterally migrated within a narrow 'valley'. However, plan form and cross sections were variable. This variability was driven largely by variability in the boundary material. Most banks were stable and composed of consolidated sediments with high silt and clay content. However, banks varied between homogeneous and heterogeneous, with some reaches consisting of banks containing multiple facies of old bed material. Weathered bedrock was exposed in a few locations (including at Site KS2). Bed material was generally composed of sands, gravels and cobbles, with some downstream fining of bed sediment. Longitudinal slope was generally low (< 2°) in all reaches except the eastern tributary headwaters.

a. Eastern tributary

b. Western Tributary

Figure 4-1 Examples of stream types within the Karuka Creek catchment

4.2 North Vaihua River Catchment and Vaihua Tributary Subcatchment

4.2.1 Estuary

The upper estuarine reaches of the North Vaihua River catchment and Vaihua Tributary subcatchment were similar to those of the Vaihua River. They consisted of a very flat, expansive clay pan with shallow, wide distributary channels that would only be wetted periodically during high tides and high flow events. Little vegetation occurred on this clay pan. During high flow events, both the Vaihua River and the streams of the North Vaihua River catchment would fill this area. The lower estuarine reaches consisted of more confined channels. Longshore drift of sediment and tidal redistribution of sediment within these channels would result in gradual closing of the mouth during dry season conditions. Wet season flows would 'reopen' this mouth.

4.2.2 Freshwater Reaches

The catchment was generally flatter than the majority of the P152 area, with elevation ranging between 5 and 45 metres and landscape slopes between one and four degrees. Channel slopes were even more gradual than that of the surrounding landscape (< 2°). Both VS7 and VS8 were of similar size and shape as each other and resembled the lower reaches of the actual Vaihua River. However, channel size was smaller than the Vaihua River. The channels were moderately incised in sections, although these coincided with culvert locations, with plunge pools created downstream of the culverts. The channels were adapted to convey only small flows, with less frequent, larger magnitude flows overbanking.

The banks at both inspection sites were vegetated by dense grasses, except for the lower banks which were exposed. Banks were stable. Bank sediment was generally not dispersive but underwent aggregate slaking when immersed in water, similar to that seen in the banks of several Vaihua River sites. Bed sediment varied between silts / clays (sourced from the bank) and sand / gravel. The floodplain was expansive and flat, similar to that of the lower Vaihua River reaches; however, further upstream, the channel became slightly more confined.

5 IMPACT ASSESSMENT

5.1 Vaihua River Catchment

As the majority of the infrastructure related to the LNG Facility site is outside the freshwater reaches of the Vaihua River and its tributaries, sources of impacts on the Vaihua River hydrology and sediment transport will be limited to the construction of new and upgraded roads and associated bridging within the Vaihua River catchment.

Sedimentological and hydrological impacts relating to operation of the above were expected to be minimal because it was assumed that appropriate revegetation, site stabilisation, drainage and erosion and sediment control plans in accordance with good industry practice would be implemented. As such, they are not addressed within this report. Specific activities associated with construction of the pipeline are addressed in Hydrobiology (2008e). Construction of roads has been assumed to progress at a similar rate as pipeline construction. Worst-case scenarios of sediment delivery to the channel have been adopted.

5.1.1 Methods

The broad steps in the assessment of sediment impacts were:

- Estimation of background sediment load capacities and associated sediment concentrations for the Vaihua River (Section 3.5) from modelled data;
- Estimation (using models) of amount and rate of coarse (> 125 μm) and fine (< 125 μm) sediment delivered to the Vaihua River during construction;
- Estimation of likely increases over background of sediment load and concentration for Vaihua River for specific the Q_2 flow; and
- Use of CNS (2008) to guide assessment of the significance of predicted impacts, discussed further in Section 6.

<u>Sediment Delivery</u>

The approach taken to determine sediment delivery was to apply a simple sediment accounting/delivery scheme based on a number of assumed parameters similar to that in Hydrobiology (2008e). For the purposes of adopting a precautionary approach, the model parameters were generally set to produce higher, rather than lower, estimates of sediment yield and delivery. The key elements of the sediment delivery scheme were as follows:

- A rate of erosion for disturbed areas was set at 50 mm/year (500 m^3/ha/year). This value was based on work undertaken by PSM (2003) and compares reasonably well with estimates of erosion rates for tropical soils in South-East Asia (Hydrobiology 2002);
- The sediment delivery ratio describes the proportion of eroded material that is expected to reach the river. The delivery ratio is affected by a range of factors, including:
    - Size characteristics of sediment;

- ‘Efficiency’ and sediment transport capacity of the drainage network between the source of the sediment and the receiving rivers of interest; and
- Distance from erosion source to the point of interest on the receiving rivers.

The Vaihua River catchment is exposed to low rainfall, and is characterised by lower slopes and a poorly developed drainage network. Thus, the delivery ratio of sediments was assumed to be reasonably low, particularly in the downstream reaches. In order to account for the distance of the construction activities from the Vaihua River, three zones were defined according to distance from the main Vaihua River channel and delivery ratios set for both coarse and fine sediment for each zone. The width of these three zones was set arbitrarily. The adopted values are presented in Table 5-1;

- Rate of progression for road construction was considered to be 250 m / day; and
- It was assumed that, following initial clearance, sediment runoff controls would be established that would minimise impacts.

Other assumptions included an *in situ* sediment density of 1.7 t / m^3 and a road width of 30 m. The proportion of total eroded sediment that was in the <125 μm range was assumed to be 70%, based on measured particle size distributions.

Table 5-1 Delivery ratios for coarse and fine sediment for the three delivery zones

Zone	Distance from River	Delivery ratio (<125 μm)	Delivery ratio (> 125 μm)
1	< 0.5 km	0.3	0.2
2	0.5 km – 2.0 km	0.2	0.1
3	> 2.0 km	0.1	0.05

Impacts on Total Suspended Solids (TSS)

For each of the clearance rates of progress, sediment delivery to the channel was added to the predicted natural loads of the Vaihua River to assess its impact on the sediment load and TSS. Total sediment delivery to the channel (t / day) was then converted to TSS (mg / L) for the Q_2, using a similar method to that set out in DBA (2005). These values were then compared with the potential sediment transport figures developed in Section 3.5 to determine the degree of impact.

5.1.2 Impacts

Sediment Delivery

The entire length of new and upgraded road within the Vaihua catchment would occur within Zone 1 (<0.5 km from the Vaihua River channel). According to the above progress rates, the construction of the road would likely finish within one month.

The estimated delivery of sediment to the Vaihua River from road construction would expect to be minimal compared with overall potential sediment transport capacity of the Q_2 flow.

The model indicated that fine (<125 μm) sediment delivery would be about 535 tonnes / day under Q_2 flow conditions. An additional 153 tonnes / day of coarse sediment (>125 μm) would also be delivered to both rivers. This is compared with the potential sediment transport capacity of 23617 tonnes / day. As such, while no direct impacts on sediment transport within other flows can be measured, it can be assumed that considering the small amount of sediment added, impacts on the sediment budget will be minimal. Further, these impacts would only occur if a Q_2 flow occurred during construction. Q_2 flows are less likely to occur during the dry season.

TSS Impacts

Table 5-2 shows the predicted impacts to TSS load resulting from road construction on the Vaihua River. Impacts are predicted to be negligible for both total and fine sediment scenarios.

Table 5-2 Predicted impacts to the Vaihua River TSS resulting from road construction. Impacts to TSS are highlighted in green.

Attribute	Q_2 Return Period
Discharge (m3 / s)	30
Potential Transport Rate (t / day)	24,000
Potential TSS (mg / L)	5,000
Added Total Load (t / day)	688
Added < 125 μ Load (t / day)	535
Added Total TSS (mg / L)	266
Added < 125 μ TSS (mg / L)	207
Added <125 μ (% of Potential TSS)	4 %

Estuarine Impacts

Regardless of the minor to negligible predicted sediment delivery and TSS impacts, changes to longshore marine sediment transport processes resulting from the construction and operation of the earthen causeway may result in sedimentation/closure of the mouth of the Vaihua River. This has implications for long-term delivery of sediment to the coast (and continued longshore transport), mangrove condition within the estuary and bed levels within the upper and lower estuaries.

5.2 North Vaihua River and Vaihua Tributary

The LNG Facility site is anticipated to require an approximate area of 6.9 km^2. This is currently proposed to be located in the far north-west of P152 – an area of low slope (1-4 degrees) and low relief (Golder Associates 2007). Only two main drainage channels exist within this section with several additional small tributaries (Figure 2-1) and these sit within very small, flat catchments. Hence, potential impacts resulting from construction and operation of the LNG Facility site are likely to be of minimal consequence to overall water and sediment discharge from the either the North Vaihua River or the Vaihua River tributary. However, areas of concern relating to potential construction and operation impacts are listed below. Impacts during both periods are expected to be similar, although operation will be of a longer-lasting nature. Of importance to note is the apparent need to divert the current stream positions around the LNG Facility site to improve site drainage and to facilitate construction of the infrastructure. Potential diversion-related impacts can be postulated here, but without detailed diversion design cannot be stated decisively.

Impacts may include:

- Change in surface hydrology due to inadequate drainage control, including increased runoff volumes from catchment into the channel, due to removal of vegetation, landscaping and an increase in area of hard surfaces;
- Increased localised within-channel velocities due to the above runoff;
- Increased delivery of sediment to channel due to the increased runoff and increased exposure of sediment;
- Elevated TSS in receiving watercourses during times of flowing water;
- Elevated TSS in remnant pools of receiving watercourses, impacting on important refugia;
- Bed sedimentation, including infilling of remnant pool refugia;
- Elevated turbidity and erosion due to disturbance of dispersive / highly erodible soils;
- Increase in erosion (gullying) due to inadequate drainage control;
- Changes to drainage patterns due to the need for diversion channels / chutes to remove water from site, including changed downstream velocities, sediment delivery and duration of flows. This is particularly the case in terms of the delivery of flows and sediment to the lower North Vaihua River and greater Vaihua River estuaries, where altered sediment delivery may impact upon the mangrove community; and
- Changes to longshore marine sediment transport processes resulting from the construction and operation of the earthen causeway which could result in sedimentation/closure of the mouths of the North Vaihua and Vaihua River regardless of the absence of any changes to the hydrological or sediment transport regimes of either of these two catchments.

5.3 Karuka Creek

A 3.2 km long section of the road diversion traverses the Karuka catchment. The area concerned is of low slope and relief and no major tributaries are crossed. Those tributaries that are crossed are small headwater streams. As such, potential impacts resulting from construction of the road are likely to be of minimal consequence to overall water and sediment discharge from the Karuka Creek catchment. Operational impacts of the road were expected to be negligible because it was assumed that appropriate revegetation, site stabilisation, drainage and erosion and sediment control plans would be implemented in accordance with good industry practice. Impacts are dependent on a flow occurring during construction.

Construction impacts may include:

- Increased delivery of sediment to channel due to increased exposure of sediment;
- Elevated TSS in receiving watercourses during times of flowing water;
- Elevated TSS in remnant pools of receiving watercourses, impacting on important refugia;
- Bed sedimentation, including infilling of remnant pool refugia;
- Elevated turbidity and erosion due to disturbance of dispersive / highly erodible soils; and
- Increase in erosion (gullying) due to inadequate drainage control.

6 IMPACT SUMMARY & MITIGATION

6.1 Impact significance

Assessment of the magnitude and significance of impacts within this table was based on Section 4 and Attachment 1 of CNS (2008). Section 5 of CNS (2008) addressing resource sensitivity was not considered as impacts to hydrology / sediment transport are not dependent on resource sensitivity. Definitions of the terms negligible, minor, moderate and major are listed in Sections 6.1.1, 6.1.2 and 6.1.3.

6.1.1 Significance criteria for impacts on water yield

Four impact assessment criteria have been defined to assess project-related impacts on water yield:

- Negligible: Basically unchanged water yields (less than 10% deviation); indistinguishable from the pre-disturbance surface runoff;
- Minor: Deviation in water yields between 10% and 25% of the pre-disturbance range of fluctuations in surface runoff;
- Moderate: Deviation in water yields between 25% and 50% of the pre-disturbance range of fluctuations in surface runoff; and
- Major: Deviation in water yields greater than 50% of the pre-disturbance range of fluctuations in surface runoff.

6.1.2 Significance criteria for impacts on stream flow

Four impact assessment criteria have been defined to assess project-related streamflow impacts:

- Negligible: Basically unchanged flow volumes (less than 10% deviation); indistinguishable from the pre-disturbance range of flows;
- Minor: Deviation in flow volumes between 10% and 25% of the pre-disturbance range of flows;
- Moderate: Deviation in flow volumes between 25% and 50% of the pre-disturbance range of flows; and
- Major: Deviation in flow volumes greater than 50% of the pre-disturbance range of flows.

6.1.3 Significance criteria for impacts on bed material load

Four impact assessment criteria have been used to assess project-related impacts on bed material load:

- Negligible: Basically unchanged bed material load; indistinguishable from the estimated pre-disturbance range of bed material load, where the sediment-carrying capacity of the receiving watercourse is able to transport all delivered coarse sediments downstream;

- Minor: Deviation in bed material load not greater than 10% of the pre-disturbance range of bed material load, where the sediment-carrying capacity of the receiving watercourse is able to transport 90% of delivered coarse sediments downstream;
- Moderate: Deviation in bed material load between 10% and 50% of the pre-disturbance range of bed material load, where the sediment-carrying capacity of the receiving watercourse is able to transport between 50% and 90% of delivered coarse sediments downstream; and
- Major: Deviation in bed material load greater than 50% of the pre-disturbance range of bed material load, where the sediment-carrying capacity of the receiving watercourse is able to transport less than 50% of delivered coarse sediments downstream.

6.2 Impacts and mitigation options

Mitigation recommendations to address the impacts on hydrology and sediment transport for all watercourses within P152 resulting from the construction of all aspects of the LNG Facilities site (including new and diverted roads) include:

- Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings;
- As far as practicable, clearing of riparian vegetation should be limited to the width required to safely accommodate roads, and watercourse crossings. Construction workers will be prevented from entering areas outside the works area though the use of tape or similar to indicate boundaries;
- Limit ground disturbance and vegetation clearing for LNG facilities, camps, lay down areas to the area within the perimeter fence (plus working buffer zone). Prohibit works from exceeding the design disturbance width and enforce boundaries through use of security fencing. Where practicable revegetate promptly areas no longer required for construction or support services (e.g. the areas set aside for future LNG trains);
- At new or improved road crossings, maintain connectivity of wet season flow in watercourses to minimise impact on both hydrological and sediment transport pathways; and
- To prohibit the closure of the Vaihua and North Vaihua mouths, existing marine along shore sediment transport patterns should be maintained in the vicinity of the Vaihua River mouth by shortening the earthen causeway section of the jetty.

Table 6-1 summarises the potential impacts from the LNG Facilities component of the project with regard to sediment transport and hydrology of all P152 watercourses and expands on the above mitigation options. With the implementation of appropriate mitigation measures, all residual impacts to the sediment load (including TSS) and hydrology from construction and operation activities will be minor or negligible.

Table 6-1 Assessment of potential impacts to the sediment transport and hydrological regimes of the LNG Facilities watercourses and recommended mitigation measures to ameliorate these impacts

<table>
<tr><th>Type of Impact</th><th>Potential Impact / Consequence</th><th>Magnitude / Significance of Impact</th><th>Mitigation Measures</th><th>Residual Impact Magnitude / Significance</th></tr>
<tr><td colspan="5">Vaihua River Catchment</td></tr>
<tr><td rowspan="2">Sediment transport / yield</td><td>Elevated TSS in receiving watercourses – Vaihua River.</td><td>Moderate</td><td rowspan="2">Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on:
Good industry practice management of sediment runoff from stockpiles and cleared areas around watercourses (e.g. the use of vegetative buffers, sediment traps, bunds).
Good industry practice management of in-stream activities to limit the downstream extent of turbid water created by bridge and road construction (e.g. the use of sediment trapping devices such as silt curtains).
Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner).
As far as practicable, clearing of riparian vegetation should be limited to the width required to safely accommodate roads, and watercourse crossings.</td><td>Negligible</td></tr>
<tr><td>Bed sedimentation – Vaihua River.</td><td>Moderate</td><td>Negligible</td></tr>
<tr><td></td><td>Elevated turbidity and erosion due to disturbance of dispersive / highly erodible soils.</td><td>Moderate</td><td>Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on:
Good industry practice management of sediment runoff from stockpiles and cleared areas around watercourses (e.g. the use of vegetative buffers, sediment traps, bunds).
Good industry practice management of in-stream activities to limit the downstream extent of turbid water created by bridge and road construction (e.g. the use of sediment trapping devices such as silt curtains).</td><td>Negligible</td></tr>
</table>

Type of Impact	Potential Impact / Consequence	Magnitude / Significance of Impact	Mitigation Measures	Residual Impact Magnitude / Significance
			Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner). As far as practicable, clearing of riparian vegetation should be limited to the width required to safely accommodate roads, and watercourse crossings.	
	Increase in erosion (gullying) due to inadequate drainage control.	Moderate	Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on: Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner).	Negligible
	Sedimentation/closure of the mouths of the North Vaihua River resulting from the construction and operation of the earthen causeway	Major	Existing marine longshore sediment transport patterns should be maintained in the vicinity of the Vaihua River mouth by shortening the earthen causeway section of the jetty	Minor
Hydrology	Change in stream flow.	Negligible	Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on: Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner). At new or improved road crossings, maintain connectivity of wet season flow in watercourses to minimise impact on both hydrological and sediment transport pathways.	Negligible
	Change in surface hydrology due to inadequate drainage control.	Minor	Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on: Good industry practice management of sediment runoff from stockpiles and cleared areas around watercourses (e.g. the use of	Negligible

<table>
<tr><th>Type of Impact</th><th>Potential Impact / Consequence</th><th>Magnitude / Significance of Impact</th><th>Mitigation Measures</th><th>Residual Impact Magnitude / Significance</th></tr>
<tr><td></td><td></td><td></td><td>vegetative buffers, sediment traps, bunds).
Good industry practice management of in-stream activities to limit the downstream extent of turbid water created by bridge and road construction (e.g. the use of sediment trapping devices such as silt curtains).
Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner).</td><td></td></tr>
<tr><td colspan="5">North Vaihua River Catchment and Vaihua Tributary Subcatchment</td></tr>
<tr><td rowspan="6">Sediment transport / yield</td><td>Increased delivery of sediment to channel due to the increased runoff and increased exposure of sediment.</td><td>Minor</td><td rowspan="5">Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on:
Good industry practice management of sediment runoff from stockpiles and cleared areas around watercourses (e.g. the use of vegetative buffers, sediment traps, bunds).
Good industry practice management of in-stream activities to limit the downstream extent of turbid water created by bridge and road construction (e.g. the use of sediment trapping devices such as silt curtains).
Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner).
As far as practicable, clearing of riparian vegetation should be limited to the width required to safely accommodate roads, and watercourse crossings.
Limit ground disturbance and vegetation clearing for LNG facilities, camps, lay down areas to the area within the perimeter fence (plus working buffer zone). Where practicable revegetate promptly areas no longer required for construction or support services.</td><td>Negligible</td></tr>
<tr><td>Elevated TSS in receiving watercourses.</td><td>Minor</td><td>Negligible</td></tr>
<tr><td>Bed sedimentation.</td><td>Minor</td><td>Negligible</td></tr>
<tr><td>Elevated turbidity and erosion due to disturbance of dispersive / highly erodible soils.</td><td>Moderate</td><td>Negligible</td></tr>
<tr><td>Increase in erosion (gullying) due to inadequate drainage control.</td><td>Moderate</td><td>Minor</td></tr>
<tr><td>Sedimentation/closure of the mouths of the North Vaihua River resulting from the construction and operation of</td><td>Major</td><td>Existing marine longshore sediment transport patterns should be maintained in the vicinity of the Vaihua River mouth by shortening the earthen causeway section of the jetty</td><td>Minor</td></tr>
</table>

Type of Impact	Potential Impact / Consequence	Magnitude / Significance of Impact	Mitigation Measures	Residual Impact Magnitude / Significance
	the earthen causeway			
Hydrology	Change in surface hydrology.	Moderate	Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on: Good industry practice management of in-stream activities to limit changes to downstream flow conveyance. Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner).	Minor
	Increase localised within channel velocities due to the above runoff.	Moderate		Minor
	Changes to drainage patterns resulting from construction and operation of diversion channels.	Moderate	Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on: Good industry practice management of in-stream activities to limit the downstream extent of turbid water created by trenching (e.g. the use of sediment trapping devices such as silt curtains). Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner). Diversion channels should deliver flow and sediment to the same location within the greater North Vaihua / Vaihua estuary as the current natural channel.	Minor
Karuka Creek Catchment				
Sediment transport / yield	Increased delivery of sediment to channel due to the increased runoff and increased exposure of sediment.	Minor	Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road	Negligible

Type of Impact	Potential Impact / Consequence	Magnitude / Significance of Impact	Mitigation Measures	Residual Impact Magnitude / Significance
	Elevated TSS in receiving watercourses.	Minor	crossings. Particular attention should be focussed on: Good industry practice management of sediment runoff from stockpiles and cleared areas around watercourses (e.g. the use of vegetative buffers, sediment traps, bunds). Good industry practice management of in-stream activities to limit the downstream extent of turbid water created by bridge and road construction (e.g. the use of sediment trapping devices such as silt curtains). Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner). As far as practicable, clearing of riparian vegetation should be limited to the width required to safely accommodate roads, and watercourse crossings. Limit ground disturbance and vegetation clearing for LNG facilities, camps, lay down areas to the area within the perimeter fence (plus working buffer zone). Where practicable revegetate promptly areas no longer required for construction or support services.	Negligible
	Bed sedimentation.	Minor		Negligible
	Elevated turbidity and erosion due to disturbance of dispersive / highly erodible soils.	Moderate		Negligible
	Increase in erosion (gullying) due to inadequate drainage control.	Moderate	Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on: Good industry practice management of in-stream activities to limit the downstream extent of turbid water created by bridge and road construction (e.g. the use of sediment trapping devices such as silt curtains). Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner).	Minor
Hydrology	Change in stream flow.	Negligible	Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on:	Negligible

Type of Impact	Potential Impact / Consequence	Magnitude / Significance of Impact	Mitigation Measures	Residual Impact Magnitude / Significance
			Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner).	
	Change in surface hydrology due to inadequate drainage control.	Minor	Establish and enforce a sediment and erosion control management plan that limits the mobilisation and dispersion of sediment into freshwater and estuarine environments particularly in relation to site preparation earthworks, watercourse diversions, site drainage design and road crossings. Particular attention should be focussed on: Good industry practice management of sediment runoff from stockpiles and cleared areas around watercourses (e.g. the use of vegetative buffers, sediment traps, bunds). Good industry practice management of in-stream activities to limit the downstream extent of turbid water created by bridge and road construction (e.g. the use of sediment trapping devices such as silt curtains). Good industry practice management of runoff (e.g. employ drainage control measure to route runoff to the receiving waters in a controlled manner).	Negligible

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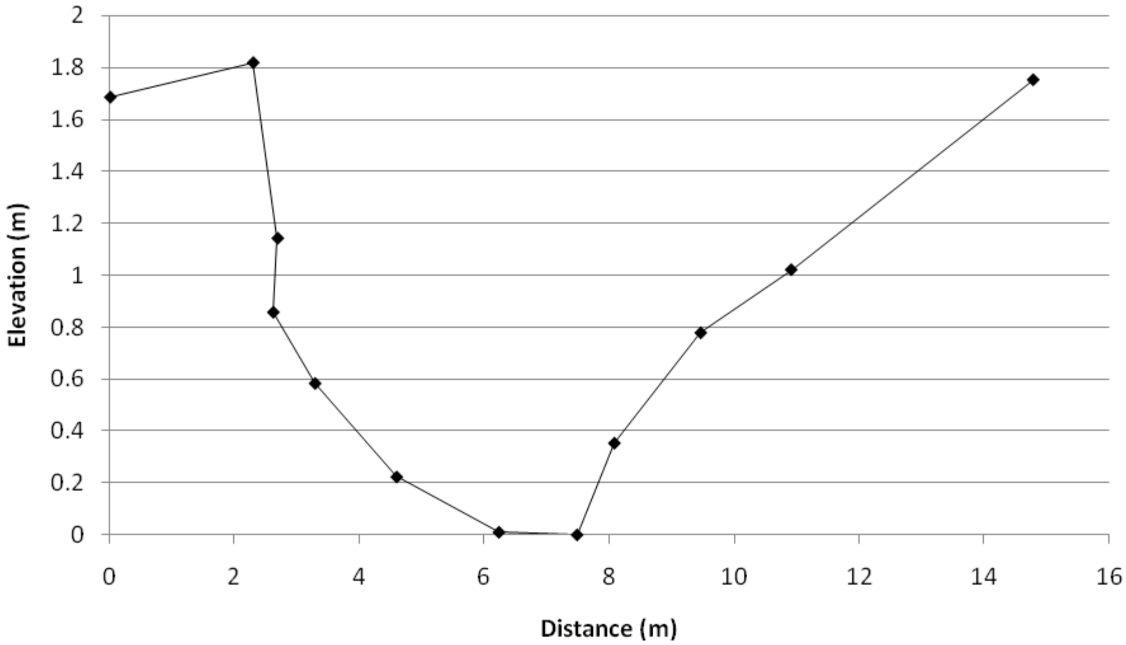
APPENDIX 1: Field Assessment Notes

VS1

- estuary / clay pans at bottom of freshwater reaches of the river.
- very wide salt pan with indistinct channels
- river appears to drain into the clay pan and anastomose / braid into very shallow, very wide channels
- very muddy black soil type substrate (clay)

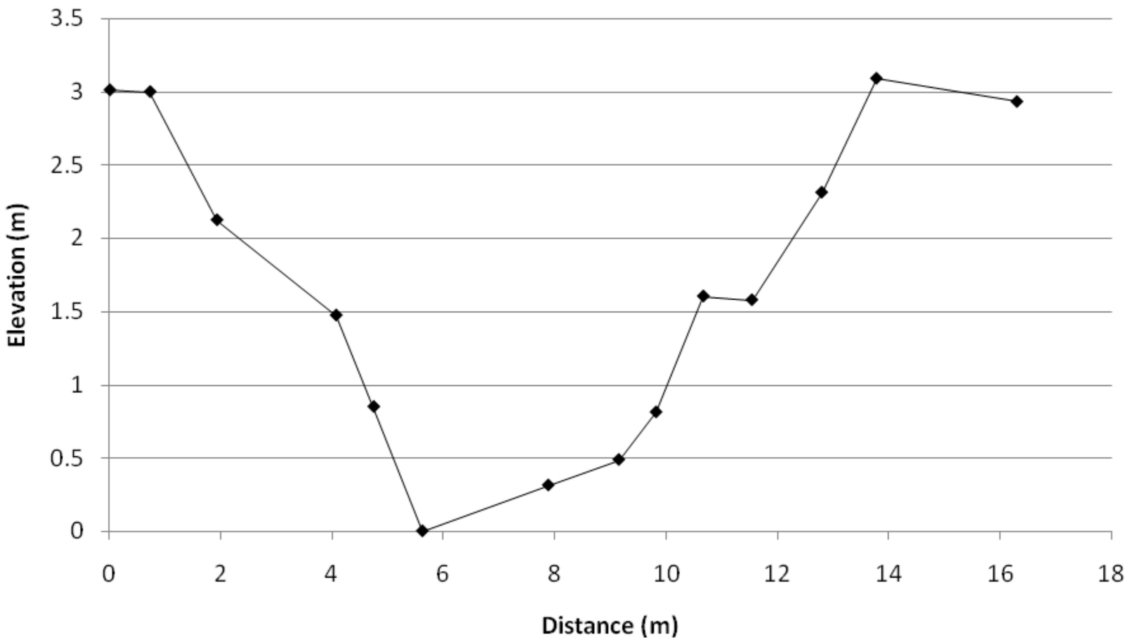
VS2

- black soil bank
  - erodible / slaking
- gravelly / sandy bed
- steep eroding banks
- meandering stream within this section
- moderately dense vegetation
  - 5-6 trees / 100 m2 quadrat on RB
- grasses on LB
- infilling sandy bed
- flat landscape
- flat slope(slope measured - 1.05 degrees)



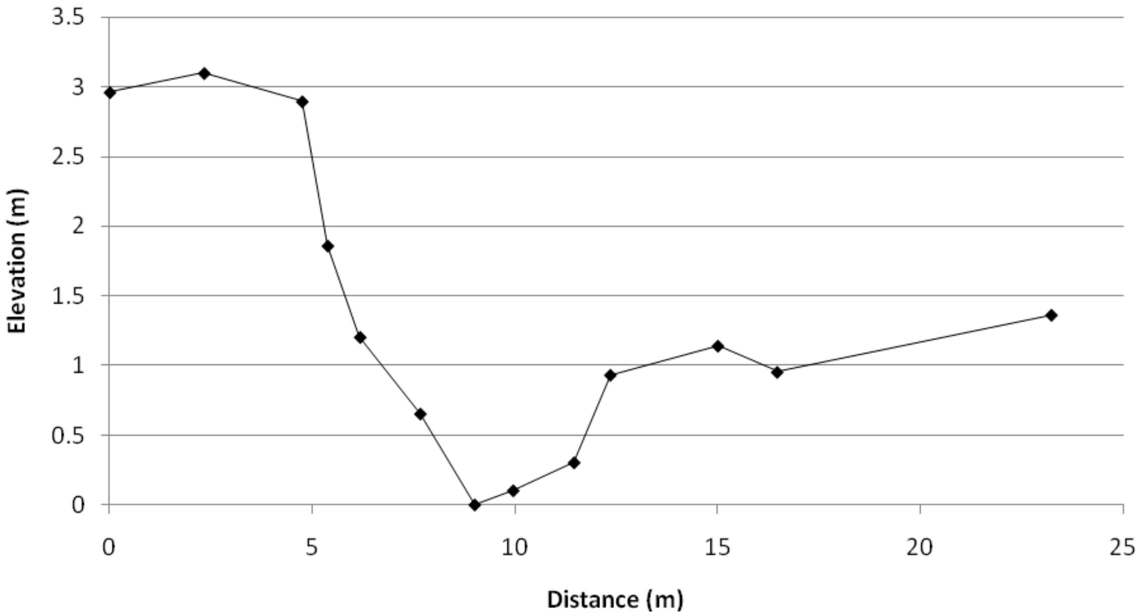
VS3

- slope = 0.9 degrees
- similar conditions as VS2
- gravelly / sandy bed
- black soil bank
- scattered trees
- dense grasses
- flat floodplain
- 3-4 m banks
- old incised channel with more recent sand deposition
- scour of lower banks
- small moist depression on RB
- bank consists of 3 facies - upper and lower black soil layers and a middle (30cm deep) black soil mixed with old bed gravel



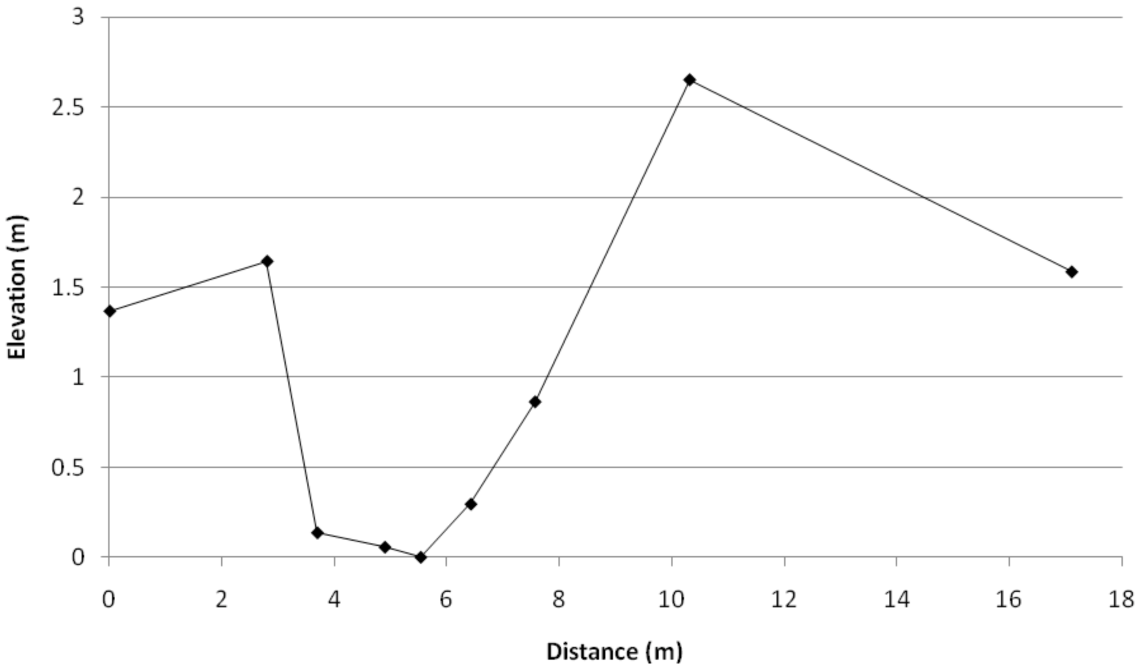
VS4

- LB - exposed erosion scarp (highly erodible)
  - scattered trees
  - dense grass
- RB - much lower floodplain
  - scattered trees
  - dense grasses
- different LB material - top facies (black soil), mid facies - old bed material (gravelly / sandy mixture)
- sandy gravel bed with scattered boulders
- intere4sting plan form - scattered pools interspersed by depositional features, causing shallower riffle type habitats
- stream levels fast to subside
- slumping of left bank - toppling slab and cantilever failure, causing slumped blocks to sit at base



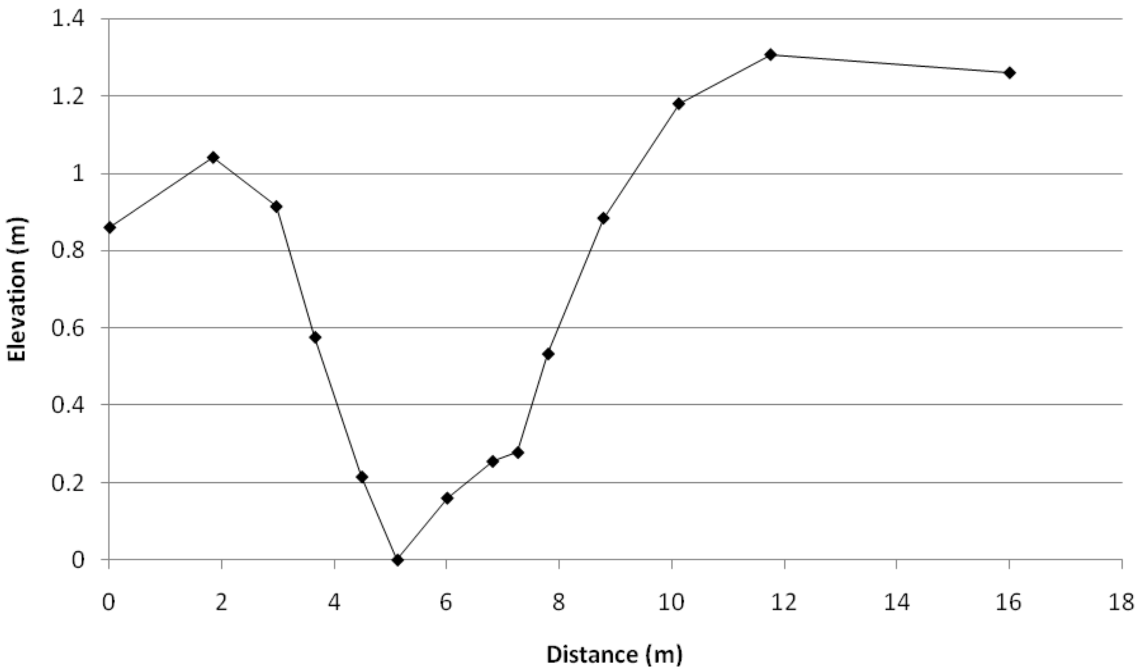
VS5

- stable stream, although slightly incised
- silty sand substrate
- small stream with very flat floodplain
- high overbank flow potential
- grass-dominated floodplain and riparian vegetation
- erodible bed (fine, non-cohesive sediment)
- very few trees
- small channel unable to convey large amounts of sediment
- black slaking soil (Emerson test 5 or 6)



VS6

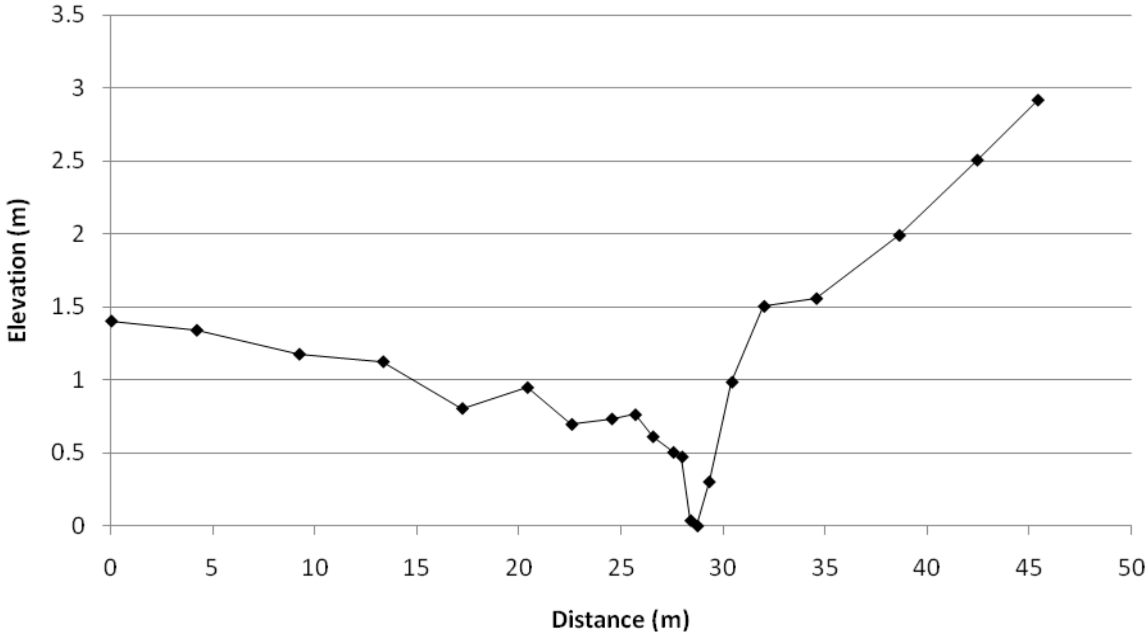
- smaller stream (US of VS4)
- lower banks with more gradual slopes
- deposition zone DS of a culvert
- rocky bed - little bit of fine gravel with coarse gravel and cobble (too big to sample)
- meandering stream
- dense vegetation (5 or 6 trees / 100m2 quadrat)
- dense grass
- trees in channel (block LWD and cause minor localised deposition and erosion of bed)
- slight infilling (culvert)
- bed material - some from US, other rocks from US culvert - road base scoured out and washed DS
- stable banks - but still consist of black soil



VS7 and VS8
- generally flat landscape surrounding channels -low channel slope - similar stream types of t Site VS2 (but smaller) - slightly incised – culvert U/S - small cross-sectional area - no trees in riparian strip – dense grasses - stable homogeneous banks (silt / clay)
VS9
- US tributary in Vaihua River catchment - gravel to boulder bed material - steep, rock RB - standing water (partially influenced by groundwater) - steeper slope - 3.5 degrees - confined valley - well vegetated with some rainfor4est species - high velocities would be expected 9higher stream power) - meandering dictated by valley walls

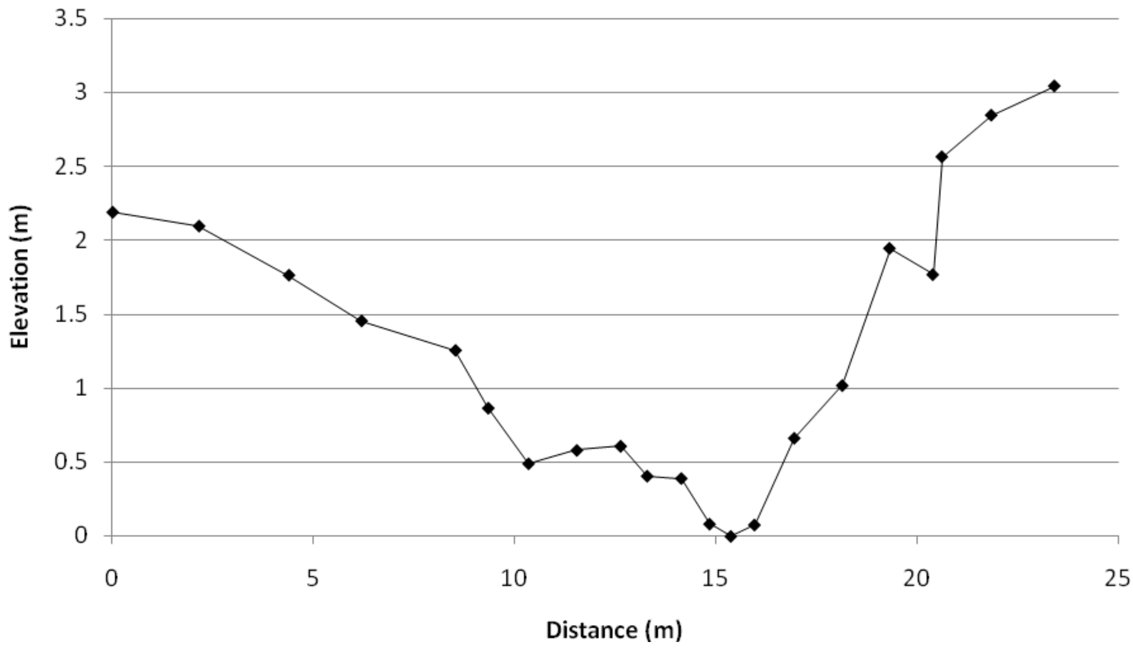
KS1

- very flat sloped channel
- minor slope at XS due to riffle
- flowing water
- less confined than previous site - still more confined than Vaihua
- interesting drop of sediment just upstream causing major pooling upstream (similar depositional feature as Vaihua)
- bed material - mixture of sand / gravel, with fine clay (from weathered bank material)
- large / wide stream with distinct habitat zones
- gradual sloping banks, although further US they are steeper
- DS - some scour at bend of RB
- bank - small black soil layer- some mixed with old bed material
- channel confined by surrounding "rolling hills"



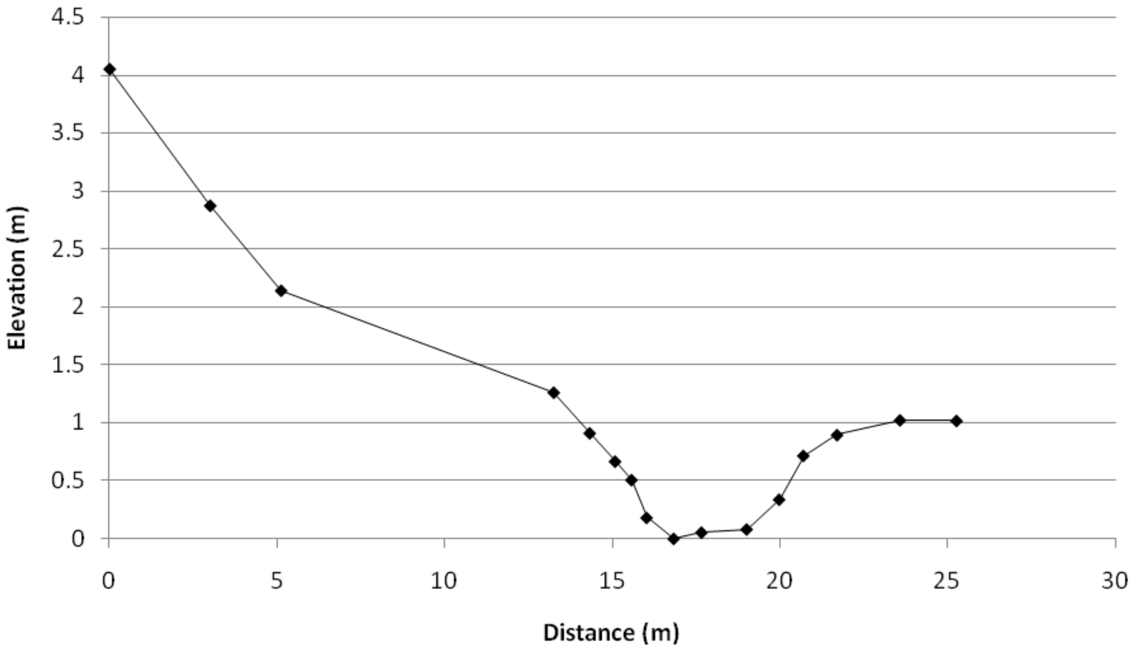
KS2

- low slope
- water pooled
- high banks (RB) - fairly stable
- minor scour / slumping
- grass dense on RB but few trees
- dense trees on gradual sloping LB
- gravelly / cobbly bed in parts, with some accumulation of silt / clay
- fine, light brown RB sediment (loamy rather than black clays)
- 'rolling hills' rather than flat floodplain
- meandering stream
- some minor infilling
- RB - top layer (30cm of black soil), mid layer (2m light brown hard, partially weathered rock), bottom layer (darker, high iron content slightly weathered rock (could be marine from mud flats)
- fine clay on bed overlays the darker less weathered bank material (~5 cm layer of clay, probably sourced from bank)
- all bank material breaks down to fine clay material



KS3

- gravelly/ cobbly bed
- upper Karuka Creek catchment
- sandy lower bank
- thin layer of darker soil above sand (different from Vaihua black soil)
- well-formed soil with aggregates
- scattered trees on both banks
- dense grass on LB
- RB - shaded by denser trees
- partly confined creek
- steeper slope than DS Vaihua River (2 degrees)
- higher sediment transport capacity (higher within channel flow, steeper slope)
- stable channel



KS4
- slightly incised very small channel in flat landscape - surrounded by very gradual sloping 'valley' sides - no distinct channel US - fine bed sediment (clays silts and fine sands)
KS5
- DS of P152 - Karuka Creek - pandanus riparian vegetation - DS of here, meets a large swamp / clay pan area - fairly incised stream in gently undulating floodplain - stable banks - gravel to sand bed
KS6
- Karuka tributary (DS section) - flows from hills in P152 area - longitudinal slope - 3 degrees - similar floodplain as KS8 - slightly more confined - narrow, shallow stream - bed - between small boulders and gravel - high bed load
KS7
- confluence of tributary with Karuka - small stream surrounded by very gradual sloping 'valley' sides - depositional zone at confluence - gravel-sized bed - stable banks, although some minor bank scour downstream of confluence

KS8

- wide, gradual sloped upper banks
- shallow active channel
- shallow bankfull, but wide
- sandy gravel bed (similar to other Karuka sites
- silty clay bank with sand / gravel
- no dispersion
- irregular meandering
- grassed on both banks
- 4 or 5 trees / 100m2 quadrat
- stable banks
- fast flowing
- fast ebbing
- relatively flat, narrow floodplain at this point (compared with other Karuka sites) with undulating surface - moderately confined by surrounding landscape