Hydrobiology

# PNG LNG Project: UPSTREAM

## Hydrology and Sediment Transport

December 2008

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| **ABN** | 26 096 574 659 |
| **GST** | The company is registered for GST |
| **Head Office** | 47 Park Road<br>Milton QLD 4064 |
| **Registered Office** | Suite 309 Coolangatta Place<br>87 Griffith Street<br>Coolangatta, QLD 4225 |
| **Postal Address** | PO Box 2050<br>Milton QLD 4064 |
| **Phone** | 61 (07) 3368 2133 |
| **Fax** | 61 (07) 3367 3629 |
| **Email Contact** | info@hydrobiology.biz |
| **Website** | http://www.hydrobiology.biz |

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# EXECUTIVE SUMMARY

The Papua New Guinea (PNG) Liquefied Natural Gas (LNG) Project (PNG LNG Project) is a project proposed by Esso Highlands Limited (Esso), 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 were of relevance to this report is as follows:

- Development of the Hides Gas Conditioning Plant (HGCP) in the Hides area;
- Construction of the Juha to Hides Gas Pipeline (including RoW clearing, trenching, bridging, pipe laying and covering), particularly where the pipe crosses, or lies adjacent to, watercourses; and
- Various roads, bridging, logistics bases, construction camps, landfills, communications facilities, waste management facilities etc. associated with the upstream project.

The main objective of this study was to predict any potential project-related increases in suspended solids concentrations and bed sedimentation for a range of exceedence flows in the Baia and Tagari rivers resulting from the above project activities. To achieve this objective, hydrologic, sediment yield and sediment transport models were produced to provide baseline conditions and to assess potential impacts.

To produce a sediment transport model, several data inputs are required. The methods undertaken to produce these inputs are listed below:

- Long-term real or modelled runoff data
  - The Boughton Rainfall-Runoff model (PNG-validated) was used to produce 100-year runoff and related discharge series for the Baia and Tagari rivers, using three different synthetic rainfall series to represent catchment-wide rainfall variation. Although no long-term rainfall data were available, a 100-year synthetic rainfall series was produced for both the Baia and Tagari river catchments that matched the mean, variance and autocorrelation structure of the available regional data. An autoregressive model was used to produce the synthetics series, using the SAMS2004 stochastic hydrology package (Salas *et al*. 2000).
- Velocities / discharges for the range of flow exceedence percentiles (Mean Daily Flow, 1 %, 5 %, 10 %, 20 %, 50 % and 90 % flows)
  - Flow duration curves were produced from the output from the above model, allowing the exceedence flow discharges to be determined.
- Channel characteristics (slope, width and depth) and sediment characteristics (particle size distribution)

   - These were measured either *in situ* by the Hydrobiology biological team (width, depth) or from maps (slope).

- Evaporation;

   - Estimates for the Lake Kutubu station from McAlpine *et al.* (1975) were validated and used for this study.

- Catchment area, shape and topography

   - GIS and LANDSAT data supplied by Esso were used to create Digital Elevation Models (DEMs) of the Baia and Tagari river catchments which were used to describe the above.

Using the above information, the Yang (1973) sediment transport equation was run to determine rates of transport for the 10 %, 50 % and 90 % exceedence flows. This equation has been shown to perform reasonably well against field data (Stevens and Yang 1989) and has been used widely within PNG.

Total suspended solids (TSS) predictions for the Tagari River ranged between 736 (90 % exceedence flow), 1,095 (50 % exceedence flow) and 2,164 mg / L (10 % exceedence flow), whereas values for the Baia River ranged between 1,971 (90 %), 2,749 (50 %) and 4,709 mg / L (10 %). These values compared well with other rivers near the Baia and Tagari river catchments.

A simple sediment accounting / delivery scheme based on a number of assumed and lumped parameters was used to assess impact of the RoW clearance and HGCP on total sediment delivery to the rivers. This accounting system was initially based on the 50 % exceedence flow.

Assumptions included:

- A fixed rate of erosion for disturbed areas of 50 mm/year (500 $m^3$/ha/year);

- Delivery 'zones' that accounted for the distance of the construction activities from the Baia and Tagari rivers. Three zones were defined and sediment delivery ratios set for both coarse and fine sediment for each zone;

- Rate of progression for RoW clearance was divided into two scenarios – 250 m per day and 500 m per day;

- Following initial clearance, monthly erosion rates would diminish over ensuing months;

- A rate of 5,000 $m^3$ per kilometre of cut-to-spoil disturbance was assumed based on advice from Exxon.

- An in-situ sediment density of 1.7 t / $m^3$ ;

- A RoW width of 30 m; and
- A disturbed HGCP area of 200,000 m$^2$ based on advice from Exxon.

Total sediment delivery to the rivers was converted to 'added TSS' using similar methods to those outlined in DBA (2005) and Hydrobiology (2002) and then compared with potential TSS figures created by the sediment transport model to assess the impact. These comparisons were made for the highest predicted rates of sediment input due to disturbance, using monthly time steps, for ease of interpretation. All other months would have lower impacts on TSS of varying degrees relative to the sediment delivery to the channel during that month. Calculations for both the 250 m and 500 m progress rate scenarios were completed.

Potential impact on TSS during 90 % and 10 % exceedence flows were calculated by dividing or multiplying the 50 % exceedence flow value respectively by an 'exceedence factor' of three. A similar approach was used by DBA (2005) and Hydrobiology (2002).

A similar method was used to assess the impact of the HGCP.

Under the 250 m progress rates scenario, sediment delivery to the channels resulting from the RoW clearance and the HGCP construction was predicted to reach a peak after about 2-4 months following construction onset, then tapered to minimal impacts within 6-12 months. The rate of sediment delivery was higher, but of shorter duration using the 500 m progress rate scenario.

While greater amounts of sediment were transported to the Baia River during its month of maximum impact, relative impacts (compared with potential load) were greatest in the Tagari River. Relative impacts for the higher magnitude flows (10 % exceedence flow) were less than those for the 50 % exceedence flow due to the increased transport capacity of the rivers during the flows of higher magnitude. Impacts were greatest using the 500 m progress rate scenario.

# PNG LNG Project: UPSTREAM

## Hydrology and Sediment Transport

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

- Gas from existing fields:
  - Gas treatment at the Agogo Production Facility and a new Agogo Gas Pipeline from the Agogo Production Facility to LNG Project Gas Pipeline;
  - Gas treatment at the Gobe Production Facility and a new Gobe Gas Pipeline from the Gobe Production Facility to LNG Project Gas Pipeline;
  - 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;
  - 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:
  - Onshore: from Hides Gas Conditioning Plant to Omati River Landfall;
  - 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 Upstream Background

The proposed PNG LNG Project builds on the previously proposed PNG Gas Project, a joint venture between Chevron and South Pacific Pipeline Co. (NSR 1998; Enesar 2005). Environment impact studies for the PNG Gas Project covered the majority of the proposed pipeline route and infrastructure.

The present study represents work done in totally new project areas (namely the Hides to Juha pipeline route and the Hides Gas Conditioning Plant) and some work to provide extra data for areas that were not covered in detail in the PNG Gas Project EIS (namely the Tagari River). Therefore, this impact assessment will be made with due consideration to the following existing bodies of work:

- DBA (2005). Supporting Study 12: Onshore Aquatic Environmental Impacts. Supporting study to Enesar (2005) Environmental Impact Assessment. David Balloch and Associates;
- Enesar (2005). PNG Gas Project EIS. Report to Esso Highlands Limited; and
- NSR (1998). PNG Gas Project Environmental Plan. Existing Environment and Impact Assessment Sections. Report to Chevron Niugini Limited.

More specifically, CNS contracted Hydrobiology to undertake investigations into the existing hydrology and sediment transport regimes for the two main rivers (Baia and Tagari rivers) crossed by the proposed right-of-way (RoW) within the upstream segment and to assess project-related impacts to the sediment transport regimes of these rivers as a result of the above project components. As such, only the impacts resulting from the infrastructure within these catchments will be addressed within this report. The study area for this report is shown in Figure 1-2. Note that the study area only includes areas downstream of the proposed infrastructure.

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

- Development of the Hides Gas Conditioning Plant (HGCP) in the Hides area;

- Construction of the parts of the Juha to Hides Gas Pipeline within the Baia and Tagari river catchments (including RoW clearing, trenching, bridging, pipe laying and covering), particularly where the pipe crosses, or lies adjacent to, watercourses; and

- Various roads, bridging, logistics bases, construction camps, landfills, communications facilities, waste management facilities etc. associated with the upstream project.

The hydrology and sediment transport assessments for all other components below the Hides area were reported in DBA (2005) and NSR (1998).

Hydrobiology were commissioned to prepare a suite of reports that characterise the water resources between Hides and Juha. These reports include this report (Hydrology and Sediment Transport), Water and Sediment Quality Baseline, and Aquatic Fauna Impact Assessment. The information in this report contributes to the water and sediment quality and aquatic fauna impacts discussed in those reports.

## 1.3 Objectives

The main objective of this study was to predict project-related increases in suspended solids concentrations and bed sedimentation for a range of exceedence flows in the Baia and Tagari rivers resulting from project activities.

Tasks associated with the objective were to:

- Review project-specific technical information, the previous EIS and other project and publicly available data;

- Collect limited *in situ* soil and sediment samples for size distribution and dispersivity/erodibility analysis;

- Understand the regional rainfall and hydrology for both the Baia and Tagari rivers through either currently available data or the development of rainfall and hydrological datasets for both rivers;

- Estimate the existing and potential sediment transport capacity in the Baia and Tagari rivers;
- Assess the project-related increase in sediment load for various exceedence flows (10 %, 50 % and 90 %) during construction and post-construction periods; and
- Suggest measures to mitigate potential impact from project activities.

As the construction of the HGCP and the pipeline and associated linear infrastructure will be temporally isolated, the baseline condition and impacts resulting from both will be addressed separately throughout this report.

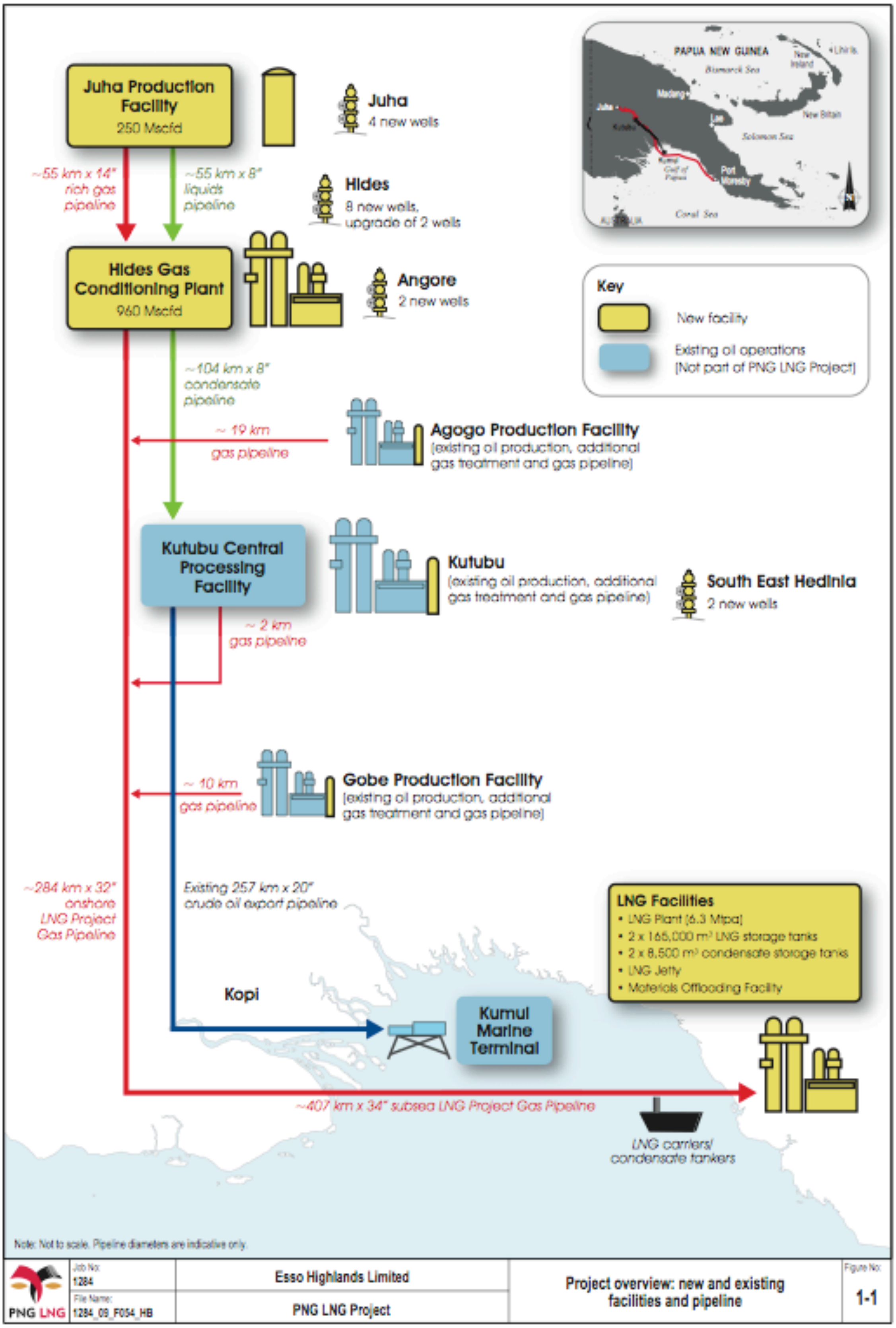



**Figure 1-1 Project overview – new and existing**

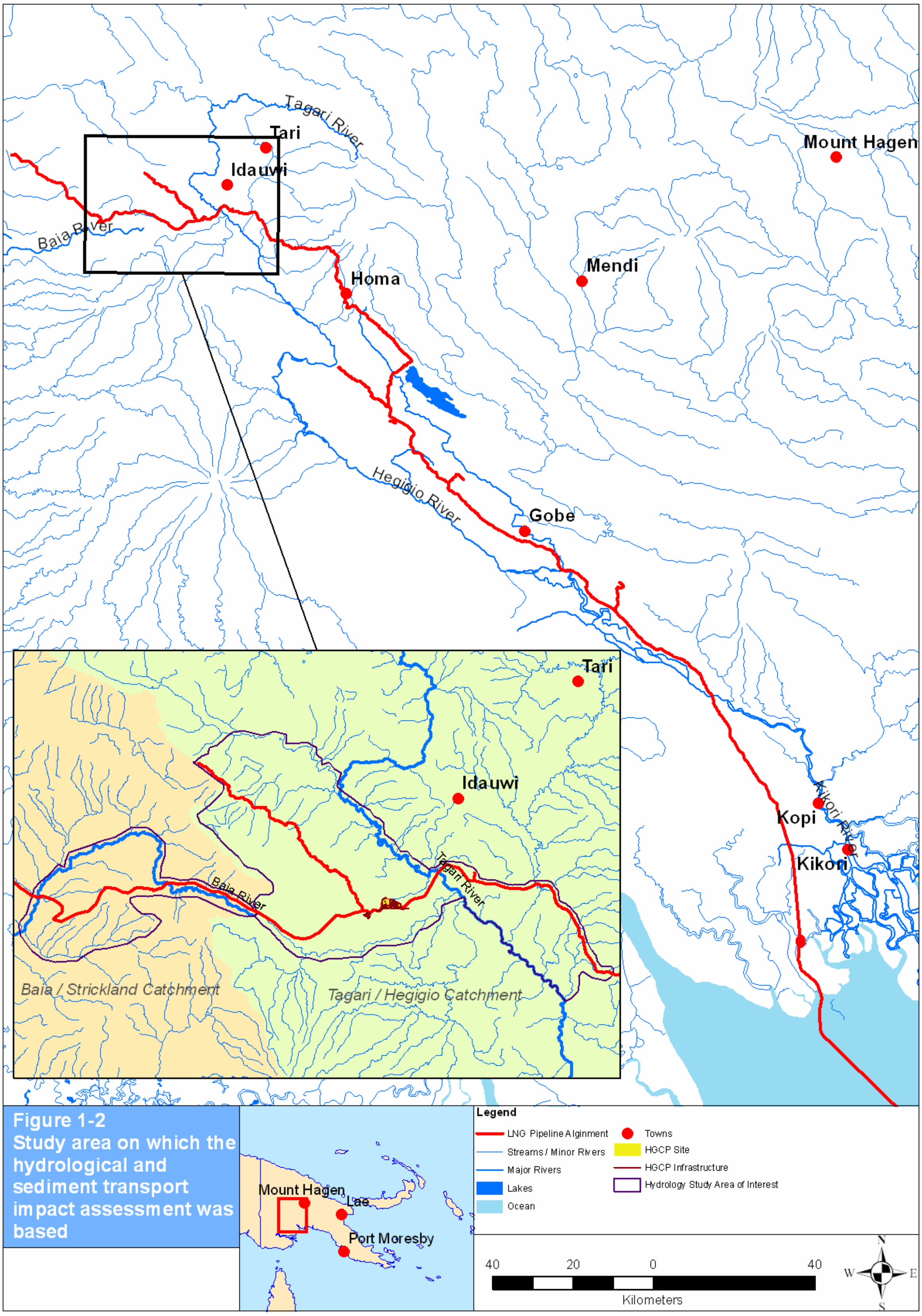



**Figure 1-2 Study area on which the hydrological and sediment transport impact assessment was based.**

# 2 BASELINE HYDROLOGY AND SEDIMENT TRANSPORT

## 2.1 Methods

### 2.1.1 Sediment transport model data requirements

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

- Long-term runoff data;
- Velocities for the range of flow exceedence percentiles (Mean Daily Flow, 1 %, 5 %, 10 %, 20 %, 50 % and 90 % flows);
- Channel characteristics (slope, width and depth);
- Sediment characteristics (particle size distribution);
- In the case of modelled runoff data used here, the following data were also required:
  - Evaporation; and
  - Catchment area, shape and topography.

The methods used to obtain these inputs are discussed in further detail below.

### 2.1.2 Real rainfall and hydrology data

Where hydrological records are of insufficient quality or quantity to produce meaningful flow statistics, synthetic data series can be created using autoregressive models based on data from adjacent gauged catchments. Regardless, long-term monitoring data from the modelled streams or from adjacent catchments are useful to supplement or validate the synthetic data.

SMEC (1990) reported that no flow gauges existed on either the Baia or Tagari rivers. However, it identified several rain gauges within the neighbouring catchments of those rivers. A further wide-ranging search of all available climatological and hydrological databases was conducted, including those controlled by the Papua New Guinea Bureau of Water Resources, the Papua New Guinea National Weather Service (NWS), the Australian Bureau of Meteorology and mine-specific databases, including those owned by Ok Tedi Mining Limited (OTML) and Porgera Joint Venture (PJV). However, no long-term data immediately adjacent to the proposed Baia and Tagari Right-of-Way (RoW) river crossings were located. Several rain gauges were found to exist in nearby catchments, as indicated in Table 2-1 and Figure 2-1. None of the other regional datasets identified were considered appropriate for the purposes of developing a hydrological model.

Table 2-1 Details of rain gauges in close vicinity to the Baia and Tagari river catchments

| Station Name | NWS Station Number | Source | Length of Record (years) | Elevation |
|---|---|---|---|---|
| Oksapmin | 85018 | NWS | 7 (patchy) | ~1830 |
| Lake Kopiago | 70018 | NWS | 9 (patchy) | ~1890 |
| Tangi | 70019 | NWS | 16 (patchy) | ~1680 |
| Nomad | 65024 | NWS | 10 (patchy) | ~110 |
| Hides Gas Plant | N/A | Exxon | 2 | ~1700 |
| Waile Creek | N/A | Porgera Joint Venture / Ecowise | 20 | 3150 |
| SG3 | N/A | Porgera Joint Venture / Ecowise | 19 (patchy) | 420 |
| SG4 | N/A | Porgera Joint Venture / Ecowise | 9 (patchy) | 70 |

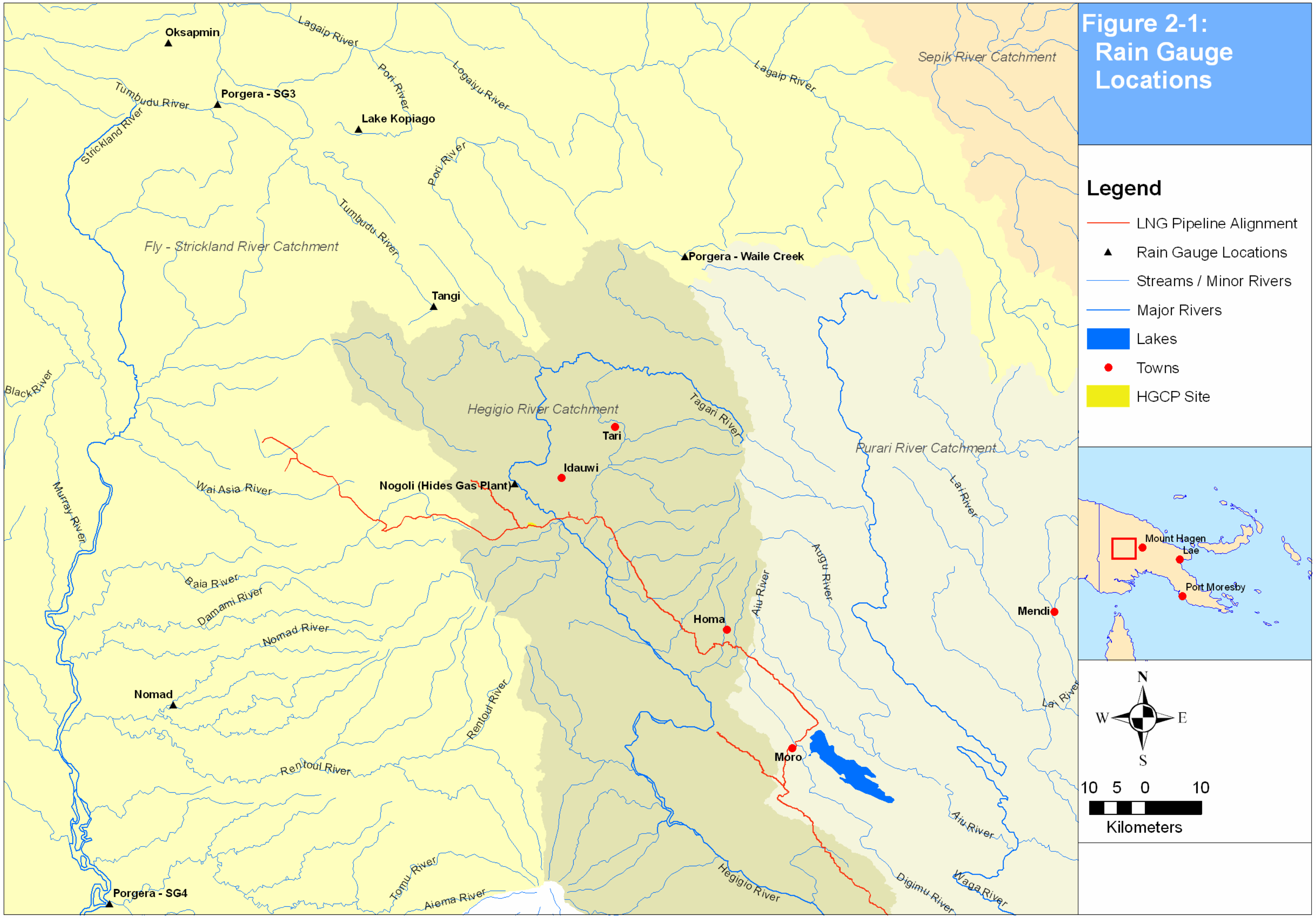



**Figure 2-1 Rain gauge locations within close vicinity of Tagari and Baia rivers**

### 2.1.3 Synthetic rainfall series

Due to the lack of a long-term and reliable rainfall data series, a 100 year synthetic rainfall series was produced for both the Baia and Tagari river catchments using the closest and most reliable rainfall records. The synthetic series was verified to ensure that the mean, variance and autocorrelation structure of the original record on which it was based was preserved.

The Hides Gas Plant data (short record) suggested an annual rainfall of 2857 mm within the vicinity of Baia and Tagari river catchments. Of the available rain gauge data, the Ok Tedi, Kiunga and Wabo rainfall data were much higher than this. The PJV data were much closer (Waile Ck – 2965 mm, SG3 – 1971 mm, SG4 – 4307 mm). Rainfall isohyet mapping done by SMEC and Nippon Koei (1977) for the Wabo Power Project showed that Central and Southern Highland areas had a substantially lower rainfall (50%) than mountain front areas that face the South Easterlies (e.g. Ok Tedi, Wabo Damsite). As such, the Waile Ck station was deemed the most appropriate dataset to generate the 100 year daily rainfall series.

A seasonal model was not used in this instance as the Waile Creek dataset that the synthetic rainfall series was based on was too short. In addition, tests with seasonal models tend to give a poorer result than a single annual model due to smaller numbers of data points in the seasonal sub-samples. Several synthetic rainfall series were created to represent the different catchments (Tagari and Baia) and rainfall variation within each catchment. The SAMS2004 stochastic hydrology package (Salas *et al*. 2000) was used to select and fit a probability distribution to the various rainfall datasets.

### 2.1.4 Rainfall-Runoff Model

Three different 100 year synthetic rainfall series were used as model input to represent rainfall variation across the catchments. Increasing the number of rainfall series from one to two caused about a 10% decrease in largest flood sizes. Increasing from two to three had only a very limited effect so three series were used to represent variation within the catchments.

These series were used as input to a modified version of the Boughton rainfall-runoff model developed for and previously tested on PNG Highland catchments (Pickup, 1976, 1977a, 1977b). Model parameters came from an optimised set derived for the Tua River (PNG Highlands) which has a similar catchment size and rainfall to the Baia and Tagari river catchments.

The Climatic Tables for PNG (McAlpine *et al.* 1975) used the Fitzpatrick method for estimating evaporation. Measured data for Wabo Damsite showed that these estimates were reasonable and, as such, estimates for the Lake Kutubu station from McAlpine *et al.* (1975) were used.

The output from this model allowed for the creation of flow duration curves to allow future sediment transport modelling for particular exceedence flows.

### 2.1.5 Channel characteristics

Channel depths and widths were measured using basic survey techniques during a Hydrobiology field trip in March and April 2008 at various survey sites along the Baia and Tagari rivers. Slope was measured using topographic maps and cross-checked with a Digital Elevation Model (DEM) created from Shuttle Radar Topography Mission (SRTM) high resolution imagery.

### 2.1.6 Sediment characteristics

Particle size distributions (PSD) were measured for the banks and bed at various sites on the Baia and Tagari rivers, the topsoil along the proposed Right of Way (RoW) alignment and at the proposed location of the HGCP. This was not a comprehensive survey, but provided some guidance to the sediment characteristics for the main areas of potential disturbance. Site selection was based on proximity to key aquatic habitats along the pipeline alignment from Juha to Hides and to watercourses draining the proposed HGCP.

The sediment types at the proposed HGCP and along the RoW were largely 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 ensure all particles sizes between fine clay and coarse gravel were accounted for. However, field observations indicated that the sediment types within the banks and on the bed of the two rivers consisted largely of three general size classes – fine clay – sand, cobbles and large boulders. Thus, additional steps were required to estimate the overall PSD of these for input into the sediment transport estimations. These steps were:

- Dry sieving and hydrometer methods to obtain PSD for the finer fraction, as outlined above;

- Digital Gravelometer method to estimate the cobble-type fraction (Graham *et al.* 2005, see www.sedimetrics.com);

- Oblique photos, with scale, to estimate the larger fraction.

These three techniques were used to estimate a final 'composite' PSD for each river.

### 2.1.7 Catchment characteristics

Catchment size, shape and topography were all measured from the Shuttle Radar Topography Mission (SRTM) DEM.

### 2.1.8 Sediment Transport Model

Total sediment load consists of washload and bed material load.

- Washload is that part of the total load which is entirely suspended in the water column by turbulence.

- Bed material load is that 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 sediment transport carrying capacity of the rivers of interest can be made using transport capacity formulae. Strictly, these 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).

A number of sediment transport equations are available to estimate 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.

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

Sediment transport rates were determined for the 10 %, 50 % and 90 % exceedence flows.

## 2.2 Baseline Environment Condition

### 2.2.1 Geomorphology

Baia River

Upstream of the RoW crossing, the Baia River was observed to be a partly confined channel. Isolated floodplain pockets existed (Figure 2-2a), but the channel's lateral position was largely dictated by the surrounding geology. Channel width varied considerably according to the degree of confinement (30 – ~100 m). Figure 2-2b shows the variability in width, with the foreground width much greater than the background due to a small floodpocket. Valley confinement also influenced sinuosity which is defined as the ratio of channel distance to downvalley distance. A sinuosity index (SI) of one is given to a straight stream, whereas meandering streams generally have SI values of more than 1.5. The sinuosity of the 10 km reach downstream of the downstream Baia River crossing was 1.13, indicating that the upstream reaches of the Baia River are straight, as dictated by the valley.

Upstream slope was 0.0033 m / m, contributing to the constant high flow velocities. However, slope and velocity markedly decreased further downstream. Bed substrate consisted of three distinct class size groupings, namely sands, gravel – cobble and large boulders (Figure 2-2c and d). The channel consisted of high banks that were highly unstable at many locations, experiencing current fluvial scour and mass failure processes. High banks were generally composed of a coarse fragment matrix surrounding non-consolidated fines, which was contributing to their instability (Figure 2-2e and f). PSD tests on the fines showed them to be sandy clay. Failure of these high banks, in addition to mass wasting of the surrounding landscape contributed high amounts of sediment to the naturally turbid river.

Floodplain pockets likely to be crossed by the RoW within the Baia River catchment were generally similar to the bank sediment composition. PSD analysis of four off-river samples within the Baia catchment indicated high clay content (>20%in three, 13% in the fourth with 32% silt) ranging between sandy clays and clayey sands.

Tagari River

At the point of the RoW crossing and immediately upstream and downstream, the Tagari River was a very wide (>100 m in parts) river that experienced high velocities and highly turbid flow (Figure 2-3a). It was situated within a narrow floodplain that was bounded by steep valley sides that restricted lateral channel movement in reaches where the channel was adjacent to the valley sides (Figure 2-3b). Sinuosity was also dictated by the surrounding geology to some degree and, as such, was variable. In the 10 km valley length upstream of the RoW crossing, sinuosity was 1.36, whereas downstream of the crossing the sinuosity was 1.3. The channel slope at the location of the RoW crossing on the Tagari River was lower than that of both Baia River crossings (0.002 m / m). The channel consisted of a similar three-tiered substrate as that of the Baia River (Figure 2-3c). Bank height was variable, dependent on the channel's adjacency to the valley sides and on sediment type. Dominant sediment type was generally silty sand or sandy clay with a matrix of cobble. As such, considerable active fluvial scour and mass bank failure was observed (Figure 2-3d), contributing large amounts of sediment to the channel (Figure 2-3e).

Velocities at the time of inspection were similar to that of the Baia River, but due to the lower slope, mean velocities were likely to be lower. More depositional features were evident in the Tagari River than the Baia (Figure 2-3f), reflecting the RoW crossing points position in the catchment.

Sediment samples from proposed RoW locations on the floodplain / adjacent to the channel suggested a highly sandy sediment type.

In summary, and from the perspective of sediment yield and transport, both rivers were observed to have high natural rates of sediment input and sediment transport.

Hides Gas Conditioning Plant

Sediment samples taken from within and adjacent to the area of the proposed HGCP were composed largely of sandy or silty clays. Most samples had > 50% fines, with one composed of > 80 % fines, suggesting that runoff of cleared and excavated land could, potentially, contribute large amounts of sediment to the TSS of the Tagari River.


Figure 2-2 Baia River Geomorphology, showing (a) small floodpocket; (b) variability in channel width; (c) sands, gravel and cobbled bed material; (d) boulder bed material; (e) and (f) bank failure and bank material.


**Figure 2-3 Tagari River Geomorphology, showing (a) high velocity flow; (b) geological channel confinement; (c) sands, gravel and cobble bed material; (d) active bank failure and boulder bed material; (e) high turbidity; and (f) within channel depositional bars.**

### 2.2.2 Hydrology

Figure 2-4 and Figure 2-5 show the long-term time series for the Baia and Tagari rivers respectively created using the model described above. From these data, flow duration curves were created to identify the duration over which certain sized flows were exceeded. These curves are shown in Figure 2-6 (Baia) and Figure 2-7 (Tagari), with drop-lines on the graphs showing the discharges for particular flow exceedence values. Those flows that were exceeded less often were obviously of greater magnitude than those exceeded more often. For example, the 10 % exceedence flows were 365 and 389 $m^3/s$ for the Baia and Tagari rivers respectively, whereas the 90 % flows were 46 and 49 $m^3/s$ respectively.

The general flow statistics for the two study rivers are shown in Table 2-2. Both rivers had similar flow statistics which reflected their similar geographic settings and catchment sizes. They both had high means and medians but the datasets both showed equally low variability, indicated by the coefficient of variations (CVs) and ranges. The low CVs indicated that there was little hydrological seasonality, but this was partly an artefact of the modelling method although the Baia and Tagari rivers are located within an area of PNG subject to little seasonality (McAlpine *et al.* 1983). This is further evidenced by Figure 2-8.

Both the Baia and Tagari rivers were perennial. While little seasonality was observed in terms of the dataset, DBA (2005) and McAlpine *et al.* (1983) noted that they were affected, to some degree, by the November to May monsoon. Surface runoff dominated the natural flow regime for both the Baia and Tagari rivers. This was reflected by the highly flashy nature of the rivers (both were seen to rise significantly following heavy overnight rainfall).

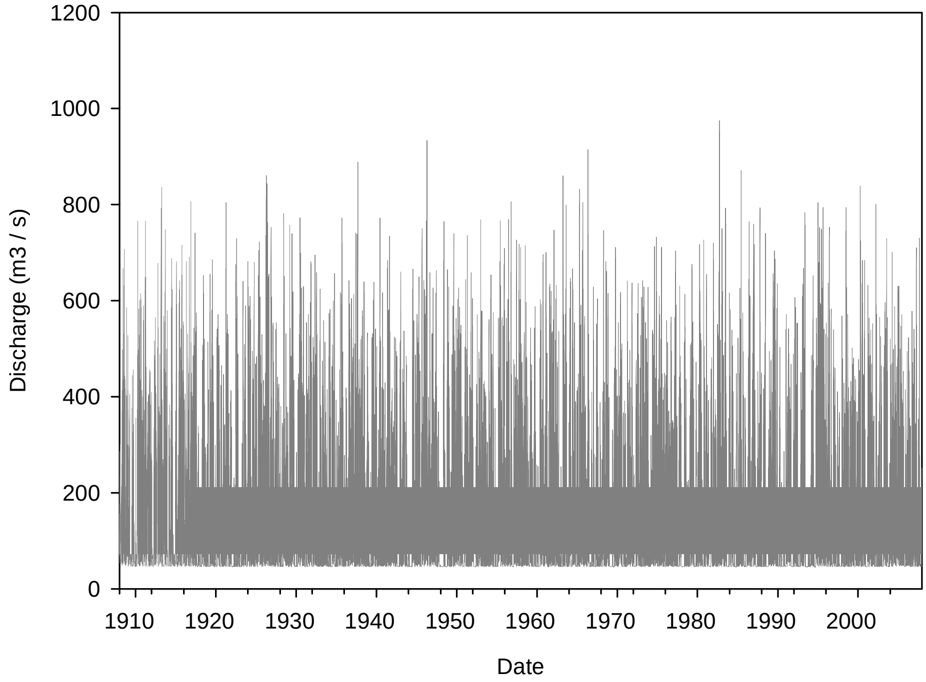



**Figure 2-4 Modelled Baia River Hydrograph**

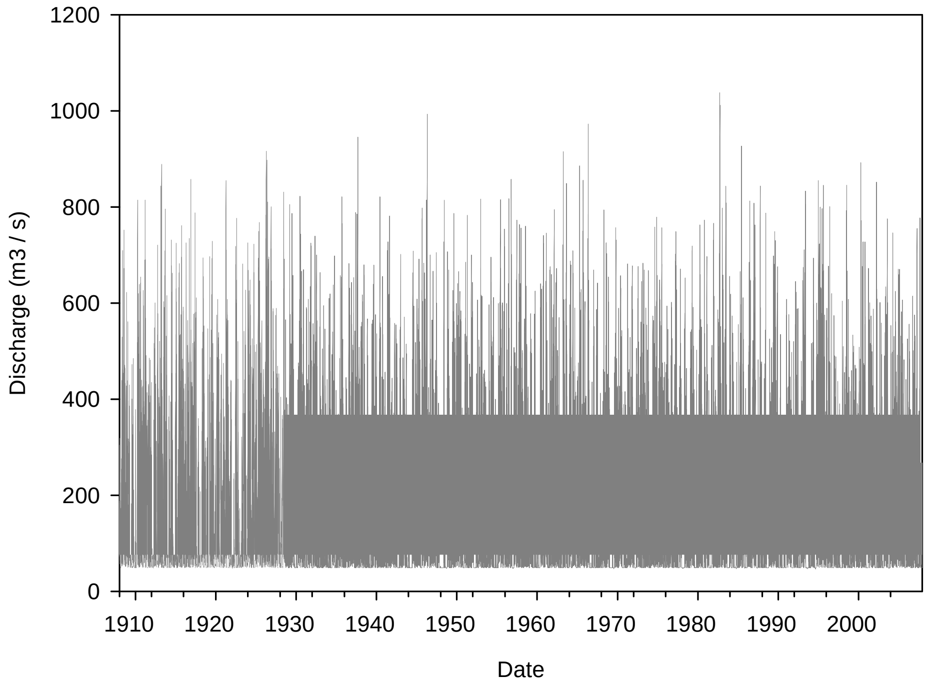



**Figure 2-5 Modelled Tagari River Hydrograph**

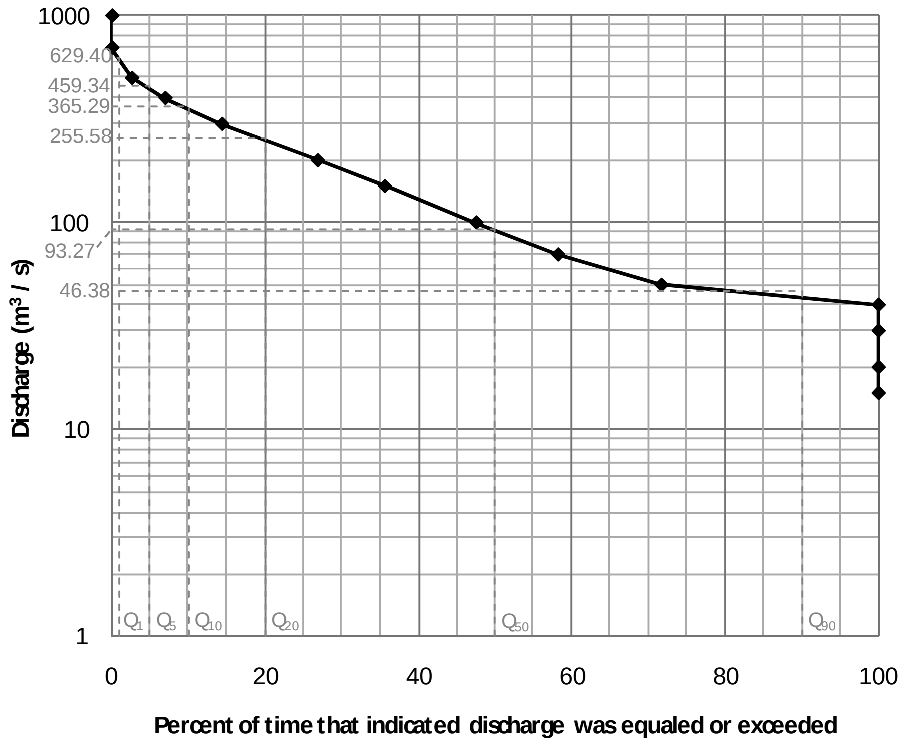



**Figure 2-6 Flow Duration Curve (Log Intervals) for Baia River, showing discharges for particular exceedence flows (red dashed lines)**

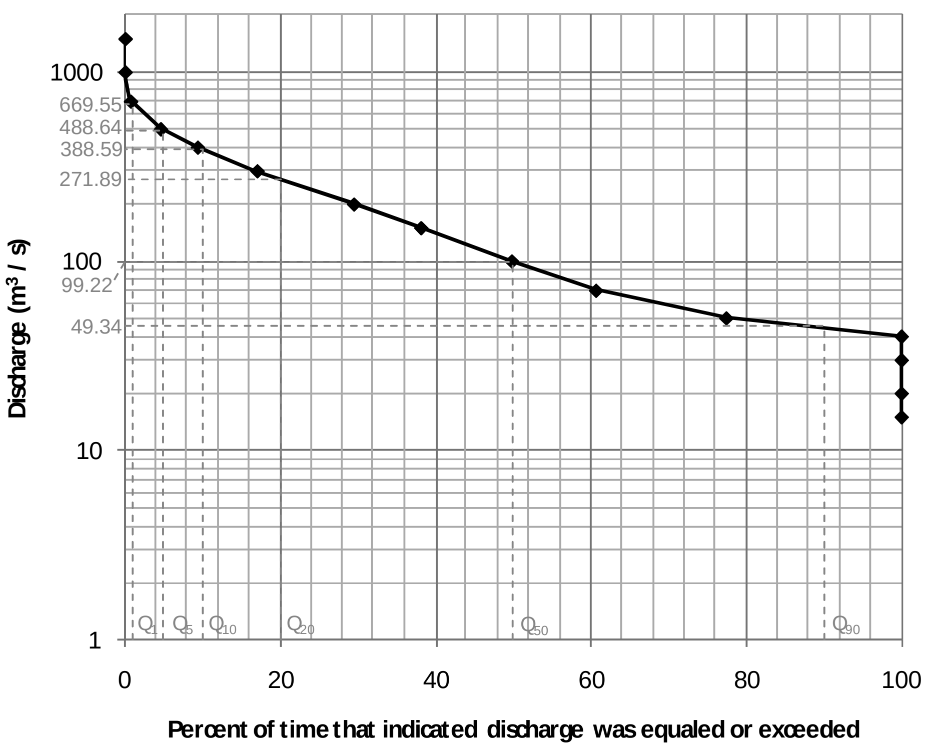



**Figure 2-7 Flow Duration Curve (Log Intervals) for Tagari River, showing discharges for particular exceedence flows (red dashed lines)**

Table 2-2 General hydrological statistics for the Baia and Tagari rivers.

| Statistic | Baia River | Tagari River |
|---|---|---|
| Mean Daily Flow ($m^3$ / s) | 155.6 | 165.5 |
| Median Daily Flow ($m^3$ / s) | 93.3 | 99.2 |
| Coefficient of Variation | 0.91 | 0.91 |
| Minimum ($m^3$ / s) | 44.0 | 46.8 |
| Maximum ($m^3$ / s) | 975.2 | 1037.5 |

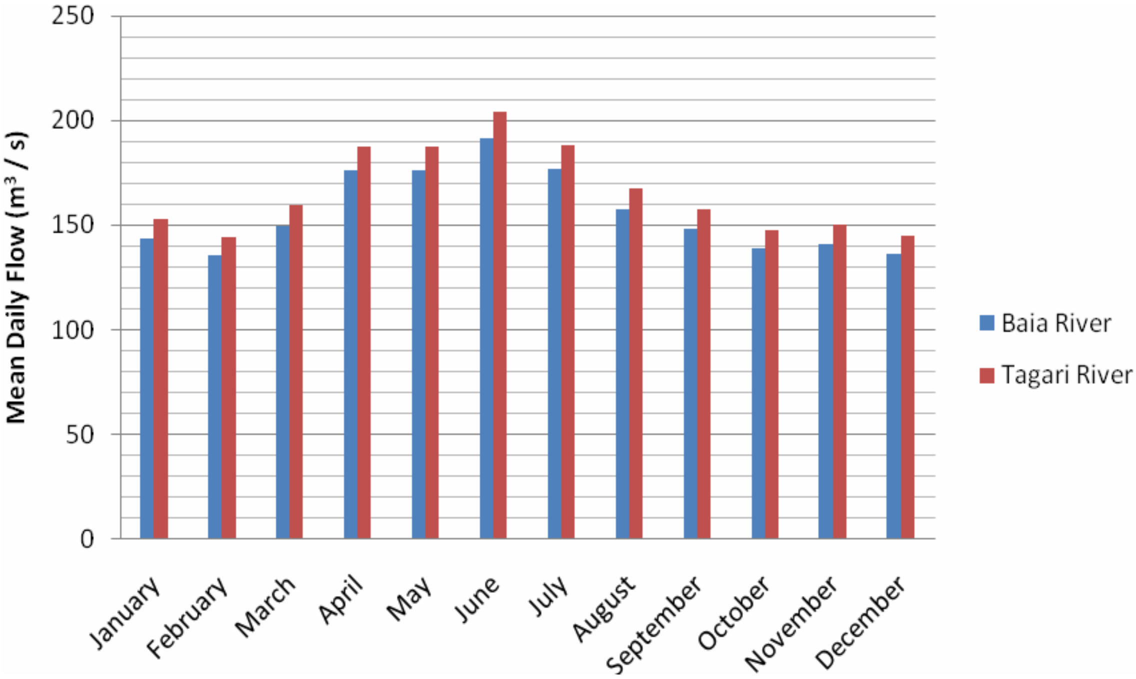



**Figure 2-8 Monthly mean daily flows for the Baia and Tagari rivers, indicating the low variability between seasons.**

### 2.2.3 Sediment Yield

Papua New Guinea has one of the highest rates of weathering anywhere in the world (Thomas 1994). In addition, landscape denudation processes in upland areas are typically influenced, and often dominated, by mass movements such as landslides that occur due to the combined effect of high rainfall, high rates of tectonic uplift, seismic activity and weak rock formations. Sediments from mass movements would typically be delivered quickly to the river system and erosion processes operate via a ubiquitous "conveyor" moving saturated colluvium from slopes to valley channels as opposed to the headward extension of stream erosion into deep residual soil profiles.

Field photographs from the Baia and Tagari rivers showed that these rivers were frequently undercutting and eroding steep river banks and cliffs of rock and colluvium which resulted in sediment inputs directly to the rivers from both fluvial erosion and mass failures.

Ongoing soil erosion also occurs and eroded sediments are transported towards the river initially by sheetwash (dislodgement of particles due to raindrop impact then removal by a sheet-like flow of water). Eventually, sediments transported in this way 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 does not reach the major streams. Accordingly it is the finer fraction of the eroded sediment that enters the watercourse. 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 and less important than processes of mass failure (Loffler 1977, PSM 2003).

### 2.2.4 Sediment Transport

The sediment transport results for selected exceedence flows are listed in Table 2-3. Irrespective of the discharge and the naturally turbid nature of both rivers, Baia River potential transport rates were generally double that of the Tagari River. This was due to the differences in slope between the two catchments (at the point of RoW crossing). It must be noted that these values were 'potential' values and not actual transport figures. Calculation of actual figures would require long-term hydrology and TSS data which were not available for, or attainable during, the study period. As such, the figures were high, but compared well with other rivers within similar climatic regions of PNG. Based on flow and TSS data, at a discharge of 25 $m^3$ / s, Porgera River transport capacity was estimated to be about 2,500 tonnes / day (Andy Markham, *pers. comm.* 2008), the Ok Om had a transport capacity of between about 27,000 and 54,000 t /day for a discharge of 125 $m^3$ / s (Andy Markham, *pers. comm.* 2008), while the Strickland River (of which, the Baia River is a tributary) had a transport capacity of between about 54,000 and 96,000 t /day for a discharge of 750 $m^3$ / s (Andy Markham, *pers. comm.* 2008).

*In situ* TSS values measured for this study ranged between about 80 and 300 mg / L for the Baia River and about 250 mg / L for the Tagari River for flows that approximated median flow conditions. These measurements were markedly lower than the predicted TSS capacities of the rivers at those flow levels, indicating that the two rivers had capacity to transport greater sediment loads than was indicated by the measured data and were thus supply limited.

**Table 2-3 Upper and lower potential sediment transport rates and TSS concentrations for the Baia and Tagari rivers for selected exceedence flows.**

| | Baia River | | | | | | Tagari River | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Flow Exceedence Percentile** | **1 %** | **5 %** | **10 %** | **20 %** | **50 %** | **90 %** | **1 %** | **5 %** | **10 %** | **20 %** | **50 %** | **90 %** |
| **Discharge ($m^3$ / s)** | 629 | 459 | 365 | 256 | 93 | 44 | 670 | 489 | 389 | 272 | 99 | 49 |
| **Sediment Transport (t / day)** | 314093 - 348084 | 205446 - 227457 | 150681 - 166731 | 92464 - 102218 | 22513 - 24839 | 7619 - 8398 | 159740 - 179777 | 101200 - 114032 | 72277 - 81453 | 42506 - 47935 | 9368 - 10575 | 3064 - 3454 |
| **TSS (mg / L)** | 5151 - 5708 | 4617 - 5112 | 4256 - 4709 | 3730 - 4124 | 2491 - 2749 | 1788 - 1971 | 2463 - 2773 | 2137 - 2408 | 1921 - 2164 | 1618 - 1825 | 971 - 1095 | 653 - 736 |

# 3 IMPACT ASSESSMENT

## 3.1 Construction Impacts

### 3.1.1 Background

The general activities of the construction phase that could potentially impact on sediment transport characteristics of the Baia and Tagari rivers are:

- The construction of the HGCP;
- Construction of the Juha to Hides Gas Pipeline (including RoW clearing, trenching, bridging, pipe laying and covering), particularly where the pipe crosses, or lies adjacent to, watercourses; and
- Infrastructure related to the above, including various roads, bridging, logistics bases, construction camps, landfills, communications facilities, waste management facilities etc.

In the Baia and Tagari river catchments, construction activities will be temporally isolated. Construction of the Juha to Hides Gas Pipeline is anticipated to occur within the last phase of the PNG LNG Project (Year 10), whereas the HGCP will be constructed within phase 1. As such, impacts were addressed separately. Specific activities associated with each of the activities are outlined below.

Pipeline Construction

Pipeline construction will involve the clearing of a RoW corridor. The corridor will be of varying widths, depending on the limitations of the environment, but will average approximately 22 m along most of the route. At watercourse crossings, the RoW will be 10 m wide for minor crossings and up to 30 m wide for crossings of larger rivers. For this report, a 'worst-case' 30 m wide RoW scenario was adopted for the entire length of RoW.

The RoW will intersect a number of watercourses of various types and will potentially lie adjacent to a number of watercourses or water bodies. The method used for crossing watercourses will be determined by a range of engineering and environmental constraints and this is not known for all crossings. However, for the Baia and Tagari river crossings, it is understood that bridge-crossing techniques will be used.

At the intersection with watercourses, pipeline construction will involve the removal of some riparian vegetation, disturbance to river banks and instream habitats. There is also likely to be at least some stockpiling of topsoil and sidecast material during construction. .

Hides Gas Conditioning Plant Construction

The footprint for the HGCP will include a large construction camp and industrial area. The HGCP and associated facilities are to be constructed at the southeast base of the Hides Ridge approximately 2 km north-northeast of the existing village of Laite. Wellpads will be located along the crest of the Hides Ridge, which rises to the northwest of the HGCP site. Well pads will be placed at intervals of hundreds of metres along this ridge line. Each well pad will require an area of approximately 2 ha to be cleared. As such, the amount of clearing required for well pad construction is considered to be minimal over and above that carried out as part of pipeline ROW and access road construction. Drilling new wells is likely to require the use of very limited quantities of foam drilling fluids for drilling fractured upper limestone in the Hides region based on past experience (Enesar 2005).

The footprint for the operations camp for the HGCP and associated infrastructure will be somewhat larger than that for the Juha Production Facility as it will encompass the upgrading of two existing airfields in the southern highlands for scheduled transportation, as well as the construction of telecommunications, residential and industrial facilities. The latter includes waste management facilities (e.g. holding ponds and landfills), maintenance workshops, stores, warehouses and a vehicle wash down station. The HGCP will only support a small number of staff during the operation phase.

In addition to the development of the above infrastructure, the construction phase will involve:

- Transport and storage of a range of compounds (mainly fuel);
- Handling and treatment of waste;
- Use of vehicles for transporting staff and goods;
- The construction of holding ponds, drains and bunds; and
- The stockpiling of sidecast and road base material.

### 3.1.2 Methods

The broad steps in the assessment of sediment impacts were:

- Estimation of background sediment load capacities and associated sediment concentrations for the Tagari and Baia rivers (Section 2.2.4) from modelled data;
- Estimation (using models) of amount and rate of coarse (> 125 μm) and fine (< 125 μm) sediment delivered to the Tagari and Baia rivers during construction and operations;
- Estimation of likely increases over background of sediment load and concentration for Tagari and Baia rivers for specific durations.

Sediment Delivery

Due to the complexity of the construction program, and its geographic nature (i.e. a progression of disturbance across an extensive and highly variable geographic area), a detailed erosion model was neither feasible nor justified.

Rather, the approach taken was to apply a simple sediment accounting/delivery scheme based on a number of assumed parameters. 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 SE Asia (Hydrobiology 2002). By way of comparison, background erosion rates for the Strickland River Basin (based on TSS measurements by Porgera Joint Venture) were estimated to be approximately 15 $m^3$/ha/year. The Strickland River Basin is largely undisturbed, but subject to high rates of natural delivery to the river system through mass movements.

- 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.

  Based on the high rainfall and well-developed drainage network, the delivery ratio of sediments was assumed to be reasonably high (i.e. a high proportion of eroded sediment would be transported quickly to either the Baia or Tagari rivers via tributaries). In order to account for the distance of the construction activities from the Baia and Tagari rivers, three zones were defined 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 3-1.

**Table 3-1 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 | 0.5 | 0.3 |
| 2 | 0.5 km – 2.0 km | 0.3 | 0.2 |
| 3 | > 2.0 km | 0.2 | 0.1 |

- Rate of progression for RoW clearance and construction progress. This was a critical parameter because it defined the rate of land disturbance. Based on advice from CNS, the rate of progress was expected to vary between 100 and 800 m per day depending (principally) on terrain and could be as low as 50 m per day for certain sections. Two scenarios were run, 250 m per day and 500 m per day. It was not thought that trenching and pipe laying activities following initial RoW clearance would necessarily add significant new quantities of sediment to the river systems.

- Establishment of revegetation. Rates of erosion are highest following initial clearance, and then decline as vegetation cover re-establishes. It was assumed that, following initial clearance, monthly erosion rates would be two-thirds of the erosion rate of the preceding month.

- Cut-to-spoil quantities. This is additional sediment that is cut and sidecast. A nominal rate of 5,000 $m^3$ per kilometre of disturbance was assumed based on advice from CNS.

Other assumptions included an *in situ* sediment density of 1.7 t / $m^3$ and a RoW width of 30 m. The proportion of total eroded sediment that was in the <125 μm range was assumed to be 50%, based on measured particle size distributions, and previous work in PNG (e.g. PSM 2003, DBA 2005).

A simple monthly sediment schedule for the HGCP construction was also developed. Advice from CNS indicated that approximately 200,000 $m^2$ of area would be disturbed. A mean earthworks depth of 0.5 m was assumed, leading to an approximate earthworks volume of 100,000 $m^3$. It was assumed that earthworks would take place over a 2-month period.

<u>Impacts on TSS</u>

For each of the clearance rates of progress, sediment delivery to the channel was added to the predicted natural loads of the Baia and Tagari rivers to assess its impact on the sediment load and TSS. The above methods dealt with sediment delivery under 'normal' (median flow) conditions. As such, total sediment delivery to the channel (t / month) calculated in the above methods was then converted initially to delivery / day (by dividing by 30) and then to TSS (mg / L) for the 50 % exceedence flow, 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 2.2.4 to determine the degree of impact. These calculations were only performed for the month of greatest impact (i.e. the predicted maximum monthly values of sediment delivery for each river), for ease of interpretation. All other months would have lower impacts on TSS of varying degrees relative to the sediment delivery to the channel during that month.

Potential impacts on TSS during 90 % and 10 % exceedence flows were calculated by dividing or multiplying the 50 % exceedence flow value respectively by an 'exceedence factor'. A similar approach was used by DBA (2005) and Hydrobiology (2002). PSM (2003) used a factor of 1.3 (divide to determine the impact of the 90 % exceedence flow and multiply to determine the impact of the 10 % exceedence flow). The rate of erosion and hence, sediment delivery to a channel, is poorly correlated with monthly rainfall depth, due to the impacts of a range of other factors, including the frequency of intense storms, duration of tributary flow and sediment types. Thus, an exceedence factor of 3 was adopted in this study as a precautionary measure. These calculations were performed using two scenarios – one assuming all sediment delivered to the channel would be entrained into suspended load and another assuming that only fines < 125 μ would be entrained. The 125 μ demarcation is usually taken to be significant for aquatic ecological impact assessment. However, within larger rivers this demarcation can be confused as larger sediment particles can be entrained by the flow.

A similar method was used to assess the impact of the HGCP.

### 3.1.3 RoW Clearance Impacts

Sediment Delivery

The estimated delivery of sediment to the Tagari and Baia rivers over a 24-month period following start of construction is presented in Figure 3-1 and Figure 3-2 respectively. The figure shows that faster rates of progress will likely result in a greater short term sediment impact due to the greater amount of bare-earth disturbance. For the month of greatest impact, the model indicated that fine (<125 μm) sediment delivery would be in the approximate range of 50,000 and 110,000 tonnes for the Tagari River, and 70,000 and 150,000 tonnes for the Baia River. Additional (>125 μm) sediment would also be delivered to both rivers. This material is expected to be predominantly bed material load that would be transported along the bed and in the lower part of the water column.

TSS Impacts

Table 3-2 and Table 3-3 show the impacts to TSS load resulting from the RoW clearance on the Tagari and Baia rivers respectively. Impacts in both rivers differ greatly between the 250 m and 500 m progress rates and for both total and fine scenarios. Regardless, it is evident that all scenarios provide some impact for the rates predicted at the month of maximum impact, with the 500 m progress rate causing the most impact to TSS.

Additions to the suspended load of the 50 % exceedence flow of the Tagari, using the < 125 μ scenario, are about 40 %of potential load under the 500 m progress rate and 20 % of the potential load under the 250 m progress rate. Additions to the suspended load using the total sediment scenario are obviously larger. While actual added sediment and TSS values within the Baia River are larger than those of the Tagari River, relative to the predicted background TSS, impacts are expected to be less significant.

Despite increased delivery of sediment to the channels during higher flow events (10 % exceedence flow), impacts to the suspended load during these events are expected to be of lower consequence, as there is relatively more water compared to added sediment, while impacts to the suspended load of the 90 % exceedence flow will be similarly low as the delivery rate of sediment to the channel will be much lower during these low flow events..

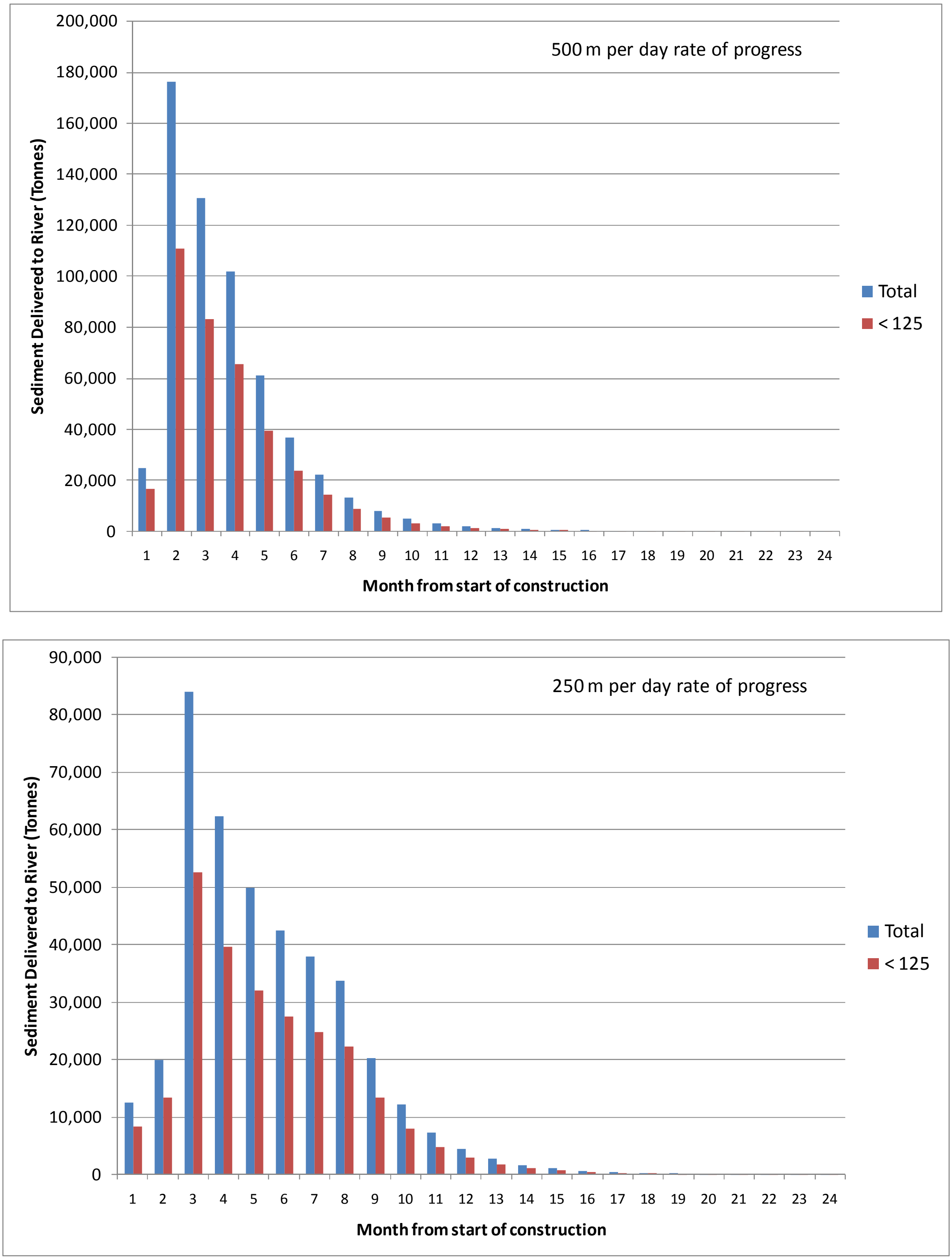
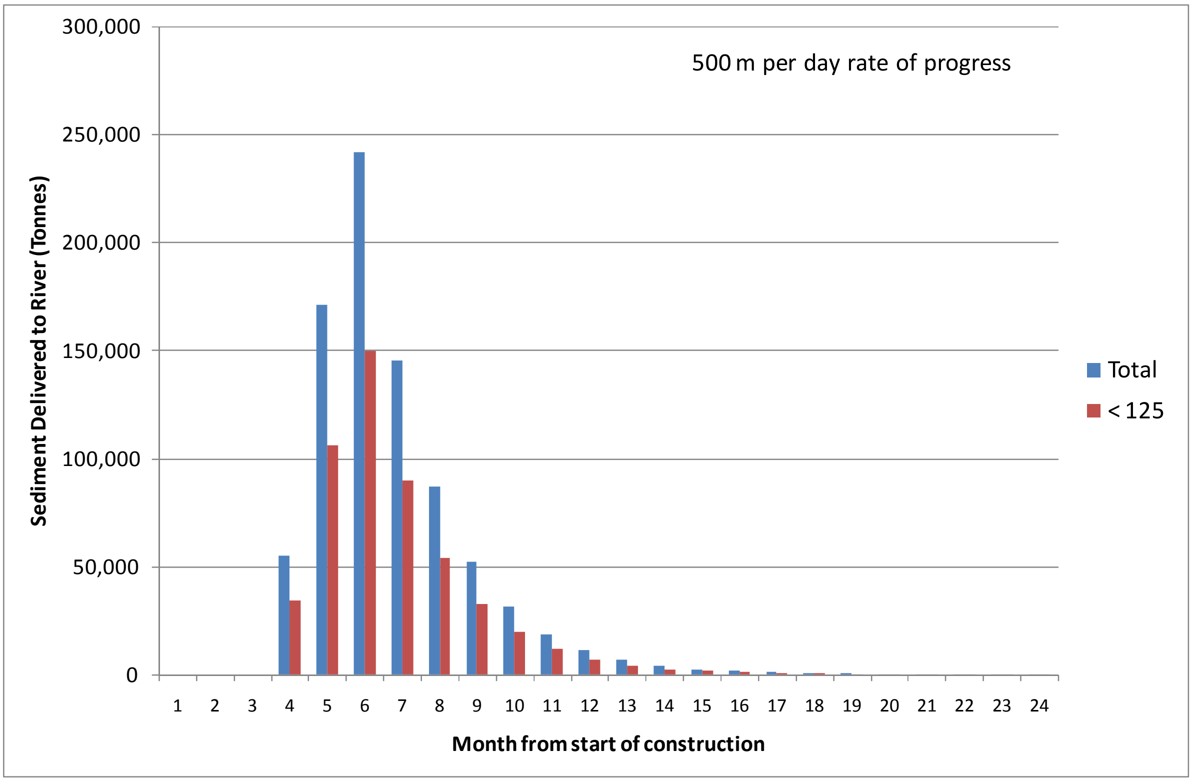



**Figure 3-1 Estimated sediment delivery to Tagari River**



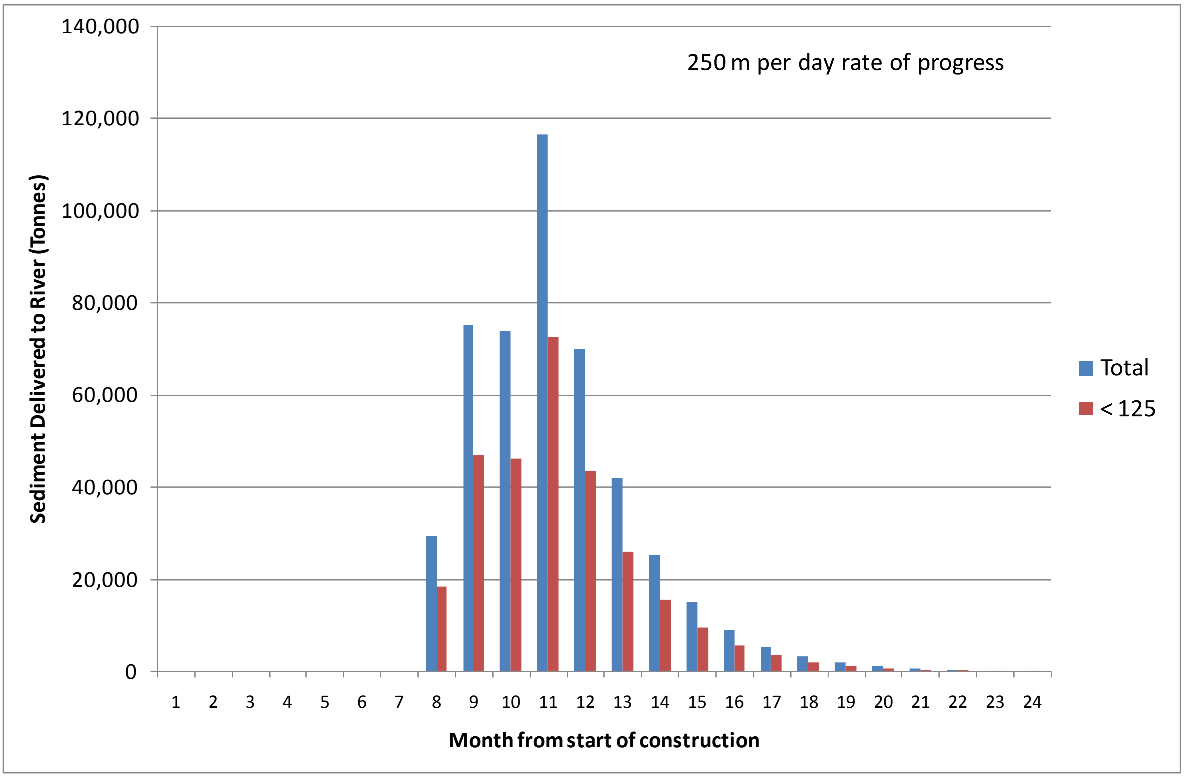




**Figure 3-2 Estimated sediment delivery to Baia River**

**Table 3-2 Impacts to the Tagari River TSS resulting from RoW clearance during the month of maximum impact. Impacts to TSS are highlighted in green.**

| | | Flow exceedence percentiles | | |
|---|---|---|---|---|
| | | 10 % | 50 % | 90 % |
| Discharge (m3 / s) | | 389 | 99 | 49 |
| Potential Transport Rate (t / day) | Upper | 81,453 | 10,575 | 3,454 |
| | Lower | 72,277 | 9,368 | 3,065 |
| Potential TSS (mg / L) | Upper | 2,164 | 1,095 | 736 |
| | Lower | 1,921 | 971 | 653 |
| **250 m Progress Rate (Month 3)** | | | | |
| Added Total Load (t / day) | | 8,396 | 2,799 | 933 |
| Added < 125 µ Load (t / day) | | 5,254 | 1,751 | 584 |
| Added Total TSS (mg / L) | | 250 | 326 | 219 |
| Added < 125 µ TSS (mg / L) | | 156 | 204 | 137 |
| Added <125 µ (% of Potential TSS) | | 7% | 19% | 19% |
| **500 m Progress Rate (Month 2)** | | | | |
| Added Total Load (t / day) | | 17,621 | 5,874 | 1,958 |
| Added < 125 µ Load (t / day) | | 11,080 | 3,693 | 1,231 |
| Added Total TSS (mg / L) | | 525 | 685 | 460 |
| Added < 125 µ TSS (mg / L) | | 330 | 431 | 289 |
| Added <125 µ (% of Potential TSS) | | 15% | 40% | 40% |

**Table 3-3 Impacts to the Baia River TSS resulting from RoW clearance during the month of maximum impact. Impacts to TSS are highlighted in green.**

| | | Flow exceedence percentiles | | |
|---|---|---|---|---|
| | | 10 % | 50 % | 90 % |
| Discharge (m3 / s) | | 365 | 93 | 44 |
| Potential Transport Rate (t / day) | Upper | 166,731 | 24,839 | 8,936 |
| | Lower | 150,681 | 22,513 | 8,106 |
| Potential TSS (mg / L) | Upper | 4,709 | 2,749 | 2,020 |
| | Lower | 4,256 | 2,491 | 1,832 |
| **250 m Progress Rate (Month 11)** | | | | |
| Added Total Load (t / day) | | 11,644 | 3,881 | 1,294 |
| Added < 125 µ Load (t / day) | | 7,241 | 2,414 | 805 |
| Added Total TSS (mg / L) | | 369 | 482 | 323 |
| Added < 125 µ TSS (mg / L) | | 229 | 300 | 201 |
| Added <125 µ (% of Potential TSS) | | 5% | 11% | 10% |
| **500 m Progress Rate (Month 6)** | | | | |
| Added Total Load (t / day) | | 24,174 | 8,058 | 2,686 |
| Added < 125 µ Load (t / day) | | 14,984 | 4,995 | 1,665 |
| Added Total TSS (mg / L) | | 766 | 1000 | 670 |
| Added < 125 µ TSS (mg / L) | | 475 | 620 | 415 |
| Added <125 µ (% of Potential TSS) | | 10% | 23% | 21% |

### 3.1.4 Hides Gas Conditioning Plant Impacts

Sediment Delivery

The estimated rate of sediment delivery from the HGCP is shown in Figure 3-3. It shows that during the first two months, sediment delivery to the Tagari main channel increases when construction activities are greatest, and then starts to subside until the 6 month point when construction impacts are assumed to stop. Delivery of fine sediment (< 125 µm) reaches a maximum of about 22,000 tonnes in Month 2, with additional coarser sediment also being delivered to the Tagari River.

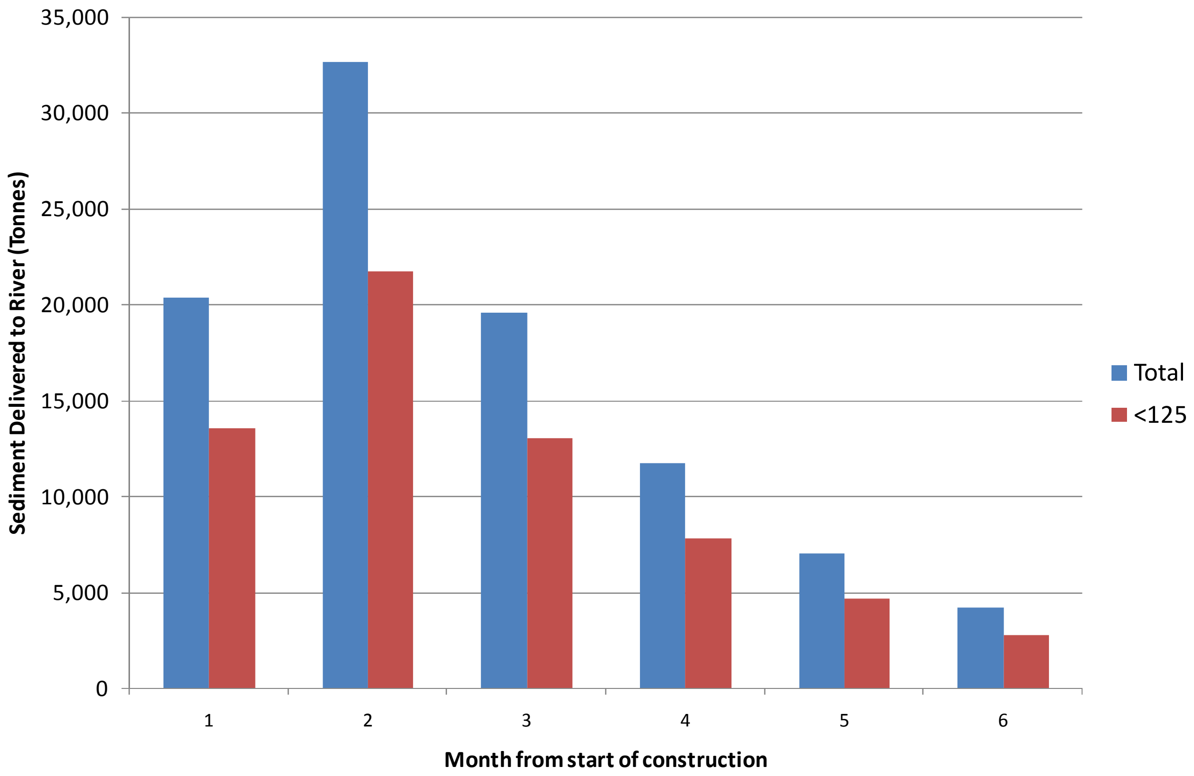



Figure 3-3 Estimated sediment delivery to Tagari River from HGCP

TSS Impacts

Using Month 2 as that of greatest impact, total additional TSS was calculated. The results are listed in Table 3-4. It is evident that while there will be some minor short-term TSS impacts, largely felt during median flows (127 mg / L cf. current values between 971 and 1095), these impacts are generally expected to be minor, with the naturally fast flowing, turbid Tagari River capable of adjusting to these minor impacts. Impacts to the suspended load during higher (10 % exceedence flow) and lower (90 % exceedence flow) magnitude events are expected to be of a lower consequence than the impacts during 50 % exceedence flow, due to the same phenomena discussed in Section 3.1.3.

**Table 3-4 Tagari River TSS impacts within the month of maximum impact (Month 2) resulting from the construction of the HGCP**

| Flow Exceedence Percentile | Discharge ($m^3$ / s) | Current Transport Rate (t / day) | | Current TSS (mg / L) | | Added Load (t / day) | Added TSS (mg / L) |
|---|---|---|---|---|---|---|---|
| | | Upper | Lower | Upper | Lower | | |
| 10 % | 389 | 81453 | 72277 | 2164 | 1921 | 3,264 | 97 |
| 50 % | 99 | 10575 | 9368 | 1095 | 971 | 1,088 | 127 |
| 90 % | 49 | 3454 | 3065 | 736 | 653 | 363 | 85 |

In summary, under the 250 m progress rate scenario, sediment delivery to the channels resulting from the RoW clearance and the HGCP construction was predicted to reach a peak after about 2-4 months following construction onset, then tapered to minimal impacts within 6-12 months. The rate of sediment delivery was higher, but of shorter duration using the 500 m progress rate scenario.

### 3.1.5 Construction Impact Summary

Sections 3.1.3 and 3.1.4 showed that sedimentological and hydrological impacts will be minimal. Although the tributary processes were not dealt with in detail in this report due to the scale of this project, the complexity of the construction process and the resulting catchment-wide approach, the types of impacts on these streams would be of a similar nature to those already discussed. Impacts may include:

- Elevated TSS in receiving watercourses;
- Bed sedimentation;
- Triggering of mass failures from construction activities;
- Elevated turbidity and erosion due to disturbance of dispersive / highly erodible soils;
- Increase in erosion (gullying) due to inadequate drainage control;
- Change in stream flow;
- Change in surface hydrology due to inadequate drainage control; and
- Loss of runoff and sedimented runoff to groundwater through karst geology (e.g. exposure of sinkholes).

## 3.2 Operation Impacts

Sedimentological and hydrological impacts relating to operation of the RoW and HGCP were expected to be minimal because it was assumed that appropriate revegetation, site stabilisation, drainage and erosion and sediment control plans would be implemented. However, impacts may include:

- Continued elevated TSS in receiving watercourses resulting from sediment-laden runoff from the RoW, HGCP and associated infrastructure;
- Associated continued bed sedimentation;
- Triggering of mass failures due to the removal of vegetation on slopes;
- Increase in erosion (gullying) due to inadequate drainage control from exposed surfaces;
- Changes in stream flow and surface hydrology due to inadequate drainage control; and
- Loss of runoff and sedimented runoff to groundwater through karst geology (e.g. exposure of sinkholes).

# 4 IMPACT SUMMARY AND MITIGATION

## 4.1 Impact significance

Table 4-1 summarises the potential impacts from the upstream component of the project with regard to sediment transport and hydrology of the Tagari and Baia rivers and their tributaries. 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 4.1.1, 4.1.2 and 4.1.3.

### 4.1.1 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.

### 4.1.2 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.

### 4.1.3 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.

## 4.2 Impacts and mitigation options

Mitigation recommendations to address the impacts on hydrology and sediment transport for all watercourses within the Baia and Tagari river catchments from the construction and operation of all infrastructure include:

- Clearing of riparian vegetation will be limited to the width required to safely accommodate pipeline ROW/access way and watercourse crossings. Also, the number of watercourse crossings will be reduced, to the extent practicable, to limit riparian soil erosion and sediment delivery to watercourses;
- Where practical, stabilise cleared banks to provide a suitable habitat for recolonisation;
- Where practicable, the pipeline ROW/access way alignment approaches to watercourses will be kept as close to right angles as possible to limit disturbances to the banks of watercourses;
- Conduct fine-scale routing of the ROW/access ways to reduce traversing particularly erosive soils on steep slopes and to limit the number of pipeline crossings of clear-water streams, sinkholes, off-channel waterbodies and other karst terrain, where practicable;

- At some watercourse crossings, where the watercourse is considered too large and fast-flowing for the use of conventional open-cut trenching methods, horizontal directional drilling may be used to install the pipeline;

- Implement good industry-practice management of in-stream activities where practicable to limit the downstream extent of turbid water created by trenching (e.g., the use of sediment-trapping devices such as silt curtains), particularly for watercourses that have either beneficial uses or flow on to sensitive habitat downstream of project works;

- The duration of construction activities at watercourse crossings will be as short as practicable;

- The construction of bridges, abutments and in-river bridge supports (where needed) will take into account the hydraulics of the watercourse in their design to provide long term stability and to limit flow disruptions;

- Develop an erosion and sediment control plan for all construction-related activities to:

    - Implement good industry practice erosion and sediment control measures at watercourse crossings, as necessary;

    - Prohibit stockpiling spoil and topsoil materials close to waterways (i.e., maintaining a minimum of 10 m from the waterline);

    - Control sediment runoff from stockpiles and cleared areas around watercourses;

    - Implement sediment control measures downstream of sidecast material where safe and practicable;

    - Limit erosion and sediment delivery to streams from new quarries;

    - Prohibit side-casting material directly into waterways where practicable;

    - Grade pipeline ROW/roadway alignments adjacent to streams away from watercourses;

    - Monitor and maintain erosion and sediment control measures until adequate soil stabilisation has been achieved;

    - Install diversion drains to intercept uncontaminated surface runoff around facilities and away from construction areas;

    - Install sediment control structures to intercept sediment-laden surface runoff to reduce sediment delivery to watercourses; and

- Monitor for and rectify areas of problematic erosion at reclaimed watercourse crossings.

- Reduce construction activities in areas prone to mass failures by fine-scale route selection during detailed design;
- Perform terrain evaluation / mapping to identify past instabilities;
- River / stream crossings will be limited in areas of high, unstable banks; and
- Develop a watercourse crossing construction management plan that addresses the sensitivities of crossings on an individual watercourse basis. Plans are to consider, where relevant:
  - Watercourse diversions requirements;
  - Disturbance limits;
  - Equipment limitations;
  - Erosion control measures;
  - Fine-scale routing at crossing sites to limit disturbance of particularly large and established riparian vegetation and complex bank habitat structure;
  - Delay the clearing of banks of watercourses for temporary vehicle crossing until the need for the crossing is imminent, where practicable.

Table 4-1 summarises the potential impacts and associated mitigation options from the upstream component of the project with regard to sediment transport and hydrology of the Tagari and Baia rivers and their tributaries. 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 4-1 Assessment of potential impacts to the sediment transport and hydrological regimes of the Tagari and Baia rivers and recommended mitigation measures to ameliorate these impacts**

| Type of Impact | Potential Impact / Consequence | Magnitude / Significance of Impact | Mitigation Measures | Residual Impact Magnitude / Significance |
|---|---|---|---|---|
| **Sediment transport / yield** | Elevated TSS in receiving watercourses – tributaries | High | Implement good industry-practice management of in-stream activities where practicable to limit the downstream extent of turbid water created by trenching.<br>Develop an erosion and sediment control plan for all construction-related activities.<br>The duration of construction activities at watercourse crossings will be as short as practicable.<br>Clearing of riparian vegetation will be limited to the width required to safely accommodate pipeline ROW/access way and watercourse crossings.<br>Where practical, stabilise cleared banks to provide a suitable habitat for recolonisation.<br>Conduct fine-scale routing of the ROW/access ways to reduce traversing particularly erosive soils on steep slopes.<br>At some watercourse crossings, where the watercourse is considered too large and fast-flowing for the use of conventional open-cut trenching methods, horizontal directional drilling may be used to install the pipeline. | Minor |
| | Elevated TSS in receiving watercourses – Tagari and Baia rivers | Medium | | Minor |
| | Bed sedimentation – tributaries | High | | Minor |
| | Bed sedimentation – Tagari and Baia rivers | Medium | | Minor |
| | Triggering of mass failures from construction activities | Medium | Reduce construction activities in areas prone to mass failures by fine-scale route selection during detailed design.<br>Perform terrain evaluation / mapping to identify past instabilities.<br>River / stream crossings will be limited in areas of high, unstable banks.<br>Develop a watercourse crossing construction management plan that addresses the sensitivities of crossings on an individual watercourse basis.<br>Clearing of riparian vegetation will be limited to the width required to safely accommodate pipeline ROW/access way and watercourse crossings.<br>Where practical, stabilise cleared banks to provide a suitable habitat for recolonisation.<br>Where practicable, the pipeline ROW/access way alignment approaches to watercourses will be kept as close to right angles as possible to limit | Minor |

| Type of Impact | Potential Impact / Consequence | Magnitude / Significance of Impact | Mitigation Measures | Residual Impact Magnitude / Significance |
|---|---|---|---|---|
| | | | disturbances to the banks of watercourses. | |
| | Elevated turbidity and erosion due to disturbance of dispersive / highly erodible soils | Medium | Implement good industry-practice management of in-stream activities where practicable to limit the downstream extent of turbid water created by trenching.<br>Develop an erosion and sediment control plan for all construction-related activities.<br>The duration of construction activities at watercourse crossings will be as short as practicable.<br>Clearing of riparian vegetation will be limited to the width required to safely accommodate pipeline ROW/access way and watercourse crossings.<br>Where practical, stabilise cleared banks to provide a suitable habitat for recolonisation.<br>Conduct fine-scale routing of the ROW/access ways to reduce traversing particularly erosive soils on steep slopes. | Minor |
| | Increase in erosion (gullying) due to inadequate drainage control | Medium | Develop an erosion and sediment control plan for all construction-related activities.<br>The duration of construction activities at watercourse crossings will be as short as practicable. | Minor |
| **Hydrology** | Change in stream flow – tributaries | Minor | The construction of bridges, abutments and in-river bridge supports (where needed) will take into account the hydraulics of the watercourse in their design to provide long term stability and to limit flow disruptions.<br>Develop a watercourse crossing construction management plan that addresses the sensitivities of crossings on an individual watercourse basis.<br>Develop an erosion and sediment control plan for all construction-related activities.<br>Conduct fine-scale routing of the ROW/access ways to limit the number of pipeline crossings of clear-water streams, sinkholes, off-channel waterbodies and other karst terrain, where practicable. | Negligible |
| | Change in stream flow – Tagari and Baia rivers | Negligible | | Negligible |
| | Change in surface hydrology due to inadequate drainage control | Minor | | Negligible |
| | Loss of runoff and sedimented runoff to groundwater through karst geology (e.g. exposure of sinkholes) | Minor | Conduct fine-scale routing of the ROW/access ways to limit the number of pipeline crossings of clear-water streams, sinkholes, off-channel waterbodies and other karst terrain, where practicable | Negligible |

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