Pre-Feasibility Study for Run of the River Hydroelectric Power project

Site Analysis and Selection Report

25th October 2012

ATKINS

Plan Design Enable

Notice

This document and its contents have been prepared and are intended solely for the Power Department, Government of Sindh's information and use in relation to Pre-Feasibility Study for Run of the River Hydroelectric Power project.

WS Atkins International Ltd assumes no responsibility to any other party in respect of or arising out of or in connection with this document and/or its contents.

This document has 53 pages including the cover.

Document history

Job number: 5109913			**Document ref: Site Analysis and Selection Report**			
Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
Rev 1.0	For Comment/Discussion	NT/SK	MJW	MJW	MJW	11/09/12
Rev. 2.0	For issue	NT/SK	SK	MJW	MJW	25/10/12

Client signoff

Client	Power Department, Government of Sindh
Project	Pre-Feasibility Study for Run of the River Hydroelectric Power project
Document title	Site Analysis and Selection Report
Job no.	5109913
Copy no.	
Document reference	Site Analysis and Selection Report

Table of contents

Tables

Figures

Executive summary

The Sindh Province is the third largest province of Pakistan, with a population of 42.4million and current annual electricity demand of 15,600 GWh.   Temperatures can rise sharply in May and August leading toelectricity demand peaking;this can lead to load shedding due to shortages in generation capacity of the region and of Pakistan in general.

Hydropower offers an environmentally sound, reliable and economic source of electricity. The Sindh Province has over 42,000 watercourses, with 13,234 miles of canals and 3 major barrages with significant flows– meaning there ispotential for hydropower in the province.

The Sindh Province Power and Irrigation Department commissioned a Consortium of specialists to undertake a Feasibility Study for a Run-of-River Hydroelectricity Generation Project. The initial stage of this was a preliminary feasibility study designed to produce a shortlist of potential sites. .

An initial 29 sites were identified from desk based analysis of hydraulic structures within the Sindh Province; this analysis relied on a high level assessment of the head and flow regimes at the sites, an outline assessment of the power which could be generated therefrom, a view of the likely difficulties of installing a plant at the site, ease of connectivity of the plant to an electrical system . These 29 sites were quickly reduced to 8 sites due to either availability of data or suitability of water resource. For each of the 8 sites a power duration curve and a power availability graph were produced, which identified the hydropower resource at each site.

The likely installed plant at each site from this analysis is summarised in the table below;

Guddu Barrage	42.4 MW	
Sukkur Barrage	30.0 MW	
Pinyari Feeder Lower, regulator at RD 36	0.2 MW	
Rohri Canal, regulator at RD 118	2.50 MW	
Rohri Canal, head regulator	5.30 MW	
Rohri Canal, regulator at RD 15	2.70 MW	
KB Link Canal RD 19.5	1.4	
Nara Canal, fall regulator RD 26[1]	1.3-2.2	

It was concluded that the Guddu and Sukkur Barrages and Rohri Canal RD118 and RD15 offer the greatest potential for hydropower in the Sindh Province taking into account the available power as well as site constraints affecting the economic viability of the proposals. In principle the potential is higher at the barrage sites. However, at these sites a number of other constraints have to be considered. The table below presents the principal constraints and opportunities for barrage sites and the canal sites.

[1] Note, no records of upstream and downstream head were available at this site. The values are based on a sensitivity analysis based on a one day spot measurement of the head difference at this site. For this reason a range is quoted rather than an absolute figure.

	Hydropower at barrages	Hydropower at canal fall structures
Sites currently considered (list is not exclusive)	Sukkur, Guddu	Nara RD25, Rohri RD15, Rohri RD118, KB Link 19.5, Rohri head regulator
Opportunities	Power potential of approximately 20 to 60 MW Grid connection likely available in the vicinity Good road access available O&M Staff available	Power potential up to approximately 6 MW Can be developed quickly in comparison to barrage sites due to fewer risks Often located in less populated areas, therefore less resettlement required and land acquisition likely to be less costly Sediment management at the site is unlikely to be affected significantly by the hydropower. Water availability at the site is unlikely to change in the short to medium term. Flows are relatively constant throughout the year with slightly lower flows in Nov to Mar during the dry season. (Jan closure period applies to all structures on the network) Limited construction duration so any risk to obstruction to flow may be limited. Part of the existing structure may be retained which will ensure continuity of water supply during construction or construction can be undertaken in two sections to ensure continuity of flow.
Risks	Presence of canals on either side of barrages requires canal crossings for ‘through-bank’ options – **high cost** Usually located in more densely populated areas (particularly Sukkur) resulting in significant resettlement and land acquisition requirements – **high cost, longer lead in time** Sediment management is a key issue at all barrages (particularly Sukkur). Any hydropower option could significantly affect the sediment management at the site. Prior to preparing a tender extensive numerical and physical modelling would be required – additional cost, long lead in time. The **studies may not be able to identify a solution** acceptable to the Irrigation Department. For on-barrage options (Hydromatrix© type turbines) detailed structural assessment of existing structure is required to assess whether the additional loads can be accommodated	Grid connection may not be available in the immediate vicinity (although all currently identified sites are near villages or cities). Access roads may not be in suitable condition and new roads may be required – **additional cost, extended construction programme**. Limited information on structure available. Topographic survey required – **additional cost, limited impact on lead in time**. Limited information on ground conditions. Ground investigation may be required/beneficial – additional cost, limited impact on lead in time. Water availability may change in the long term when more efficient irrigation practices may be implemented. However, population is increasing and agricultural production is likely to increase rather than decrease.

	Hydropower at barrages	Hydropower at canal fall structures
	in the existing structure – **additional cost, longer lead in time** Construction in river channel requires significant temporary works and is programme constrained by the requirement to provide flood capacity (this issue only applies to options installed downstream of existing pockets) – **high cost** Water availability at the site may reduce due to additional water use upstream (population increase). This may result in less flow in the river channel since irrigation requirements are unlikely to reduce – **risk of power production reducing over time/being less than anticipated**. Water availability at the site may reduce due to climate change. This may result in less flow in the river channel since irrigation requirements are unlikely to reduce – **risk of power production reducing over time/being less than anticipated.** High flows during May to Sept, significantly lower flows during dry season. Low and medium flows coincide with good head difference. High floods can result in limited head difference and high flow conditions are therefore not necessarily ideal for power generation. **High uncertainties**. Any risk related to grid connection – large volatility of flows into the grid can cause it to collapse	
Further studies/reports required:	Numerical and physical modelling (approx 6 months) Detailed structural analysis (for on barrage options, approx 4 months, can be undertaken in parallel to modelling)	Topographic survey Geotechnical investigation Water level monitoring and velocity measurements (not required at all sites)
Approximate cost of further studies above (per site)	Numerical and physical modelling GBP 100,000 or Pak Rup 15,000,000 (at current rate) (consultancy fees for local and international consultants) Pak Rup 1-3,000,000 (physical modelling lab) Detailed structural analysis Pak Rup 1,000,000 (local consultancy fees)	Topographic survey Pak Rup 100,000 Geotechnical investigation Pak Rup 500,000 (survey) Pak Rup 450,000(supervision and interpretative report) Water level monitoring and velocity measurements Pak Rup 200,000

	Hydropower at barrages	Hydropower at canal fall structures
Approximate costs for construction (preliminary)	US$ 1.5 Million/MW (estimate based on Guddu Barrage Feasibility Study, MMI, 2012)	US$ 2.2 Million/MW (estimate based on costs for comparable projects elsewhere) Where the site is a significant distance from a suitable grid connection point this can increase costs.

The decision criteria for determining the preferred site are

1. The power potential of the site (low, medium or high)
2. Programme to commissioning (short, medium or long)
3. Level of risk (high, medium or low)
4. Costs/MW (low, medium or high)
5. Operability of the site (high, medium, low)

The assessment of these criteria for the four most suitable sites is presented in the table below. **Site**	**Power potential**	**Programme**	**Risk**	**Costs**	**Operability**
Guddu	High	Long	High	Low	High
Sukkur	Medium	Long	High	Low	High
Rohri RD15	Low	Short	Low	Medium	High
Rohri RD118	Low	Short	Low	High	Low

On the basis of the site selection assessment the Rohri RD15 site has been confirmed as the preferred site for development as the project has a low risk and short programme to completion. Skilled staff is available in the vicinity at Sukkur Barrage which would be available to assist in the operation and maintenance of the new equipment. There is potential to improve the head difference by adjusting the operation of the head regulator to allow a higher pond level in the reach upstream of the fall regulator. This should be further investigated in the next phase.

It should also be noted that the two barrage sites are currently being investigated under the ongoing rehabilitation projects. The feasibility assessment for Guddu Barrage has been completed and a decision is currently awaited from the client on the required further studies. The feasibility for Sukkur Barrage is under way and the assessment has not yet been completed.

1. The Project

1.1. Introduction

The advisory consortium comprising Ernst & Young Ford Rhodes Sidat Hyder, WS Atkins International Ltd, Techno-Consult International, Rizvi Isa Afridi Angell and Norton Rose LLP (the consortium) has been appointed by the Government of Sindh (GoS) to assess the feasibility of implementing run-of-river hydropower projects on a Public Private Partnership (PPP) basis in Sindh Province to address current and growing power shortages. This report presents the findings of the site selection process and on the basis of information received recommends the four most suitable sites. Of these sites one will be chosen initially for development as part of this ongoing assignment. Others may be developed at a later date.

1.2. Background to the Project

Given the context of an acute shortage of electricity in Pakistan in general and in the Province of Sindh in particular, and realizing the need for adequate power availability for economic development, the Power Department, GoS decided to explore the possibility of generating electricity, tapping the vast network of barrages and canals in Sindh. The power shortfall is hindering the economic growth of the country on the one hand and causes inconvenience for the people.

Power generation and distribution has historically been handled by the Federal Government of Pakistan. The 2002 Power Policy, issued by the Federal Government, was intended to attract new investment into the generation sector. The Private Power and Infrastructure Board (PPIB), under the oversight of the Ministry of Water & Power, was established to implement the 2002 Power Policy. Under the provisions of the 2002 Power Policy, Independent Power Projects (IPPs) above 50 MW could only be initiated at the Federal level whereas those of 50 MW or below could be initiated at the provincial level. However, the constitution also gives the right to provinces to implement projects of any size if the provinces are themselves involved in the projects. Therefore, a province can process and implement a project bigger than 50 MW, if it owns the project entirely or it develops a project in a Public Private Partnership mode.

GoS intends to explore the hydropower resources available in Sindh and initiate Run of the River (RoR) Hydro Power Projects under Public Private Partnership mode.

The GoS intends to achieve following objectives from the RoR Power Generation Project:

a) Bridge, as far as possible, the demand supply gap of electricity in the province;
b) Provide, as far as possible, the least expensive and most environmentally friendly electricity to the people of the province;
c) Share the responsibility with Federal Government of finding new avenues of power generation, thereby releasing some pressure on the Federal Government;
d) Optimally utilize the water resources of the province while maintaining the ecological and environmental balances.

1.3. Data Availability

Following the project kickoff meeting an initial list of data requests was submitted to the Client and the data requirements were discussed during a short follow up meeting. It was anticipated that the data gathering would be completed within 2 weeks. The consultants endeavoured to obtain the required data from a number of sources including the Irrigation Department with assistance from the client. However, not all data was made available to the consultants in a timely fashion.

To focus the data gathering on the sites which are more likely to have significant potential a long list of sites was prepared. This long list was based on available information of design head- and tailwater levels and design discharges for the fall structures on the canals. Design information, while not appropriate for the assessment of the overall feasibility, was considered sufficient to provide a ranking of the priority sites for data collection. It was agreed that a minimum of six sites should be available for the site selection process. Following further endeavours to gather the required data 7 sites were identified as having the highest potential based on these design levels. These were chosen as the priority sites for further data collection.

Following further enquiries on these priority sites, one of the sites, KB Feeder Lower head regulator, was discounted as the gates at this site are reportedly now permanently closed and water distribution is via the Link Canal. This left 6 sites from the original list. However, since the issue of the draft Site Analysis and Selection Report some data on two additional sites has become available and these sites have now been included in this report, leaving 8 sites for more detailed assessment.

Table 1 below summarises the data now available for the eight remaining sites:

Site	Available water level data	Available flow data	Available drawings	Other available data
Guddu Barrage	Daily 1988-2011	Daily 1988-2011	Location plan Cross Section through main weir gates	Guddu Barrage Feasibility Study – Annex N - Hydropower
Sukkur Barrage	Daily 1988-2011	Daily 1988-2011	Location plan Plan Cross section through main weir Cross section through undersluices	Sukkur Barrage Hydropower, Technical Assessment by China International Water and Electric Corporation Sukkur Barrage Hydropower, Site Investigation Preliminary Report by China International Water and Electric Corporation
Pinyari Feeder Lower, regulator at RD 36	Daily Feb 2010-May 2012	Daily Feb 2010- May 2012	Plan Cross section	None
Rohri Canal, regulator at RD 118	Daily Jan 2010-May 2012	Daily Jan 2010-May 2012	Plan Cross Section	Sukkur Barrage Hydropower, Technical Assessment by China International Water and Electric Corporation Sukkur Barrage Hydropower, Site Investigation Preliminary Report by China International Water and Electric Corporation
Rohri Canal, head regulator	Daily Jan 2006 – Dec 2010	Daily Jan 2006 – Dec 2010	Plan Cross section	None
Rohri Canal, regulator at RD 15	Daily Jul 2006 – Dec 2010	Daily Jan 2006 – Dec 2010	Cross section	Sukkur Barrage Hydropower, Technical Assessment by China International Water and

				Electric Corporation Sukkur Barrage Hydropower, Site Investigation Preliminary Report by China International Water and Electric Corporation
Nara Canal RD 25	1 day spot measurement in September 2012	Daily Jan 2006 - Dec 2010	Plan Cross Section	None
KB Link Canal Cross Regulator	Daily Jan 2007 – 26th Sep 2012	Daily Jan 2007 – 26th Sep 2012	None	None

Table 1. Data availability

1.4. Methodology

The **first stage** of the assessment was the collection of available data for sites on the irrigation network and the River Indus. Other sites were to be considered if sufficient data could be obtained.

As a **second stage** a long list of options was developed. This was undertaken primarily based on design flows and design head- and tailwater levels as more detailed information could not be easily obtained (see Section 1.2).

At the **third stage**, from this long list a number of sites were identified to prioritise the collection of further, more detailed data. Using the more detailed data obtained for these priority sites power duration curves were prepared for each of the sites making an assumption of 55% efficiency to account for inlet energy and transmission losses in addition to assumed turbine efficiency. The efficiency of the turbine will vary dependant on flow. The inlet losses include hydraulic losses through trash screens, inlets/contractions in the turbine approach and any other potential hydraulic energy losses. This assumption has been based on recommendations by the US Department of Energy (Ref 1).

Power potential against time over the year was also evaluated to identify whether the potential for generation matches likely demand peaks and whether potential at the sites shows a large variation over the year.

No on-site surveys were undertaken at this stage.

The potential power generated is next used to assess the viability of the possible scheme sites, based on consideration of:

- Scale of the potential energy available
- Scale of risks associated with the site – including geotechnical, sediment, construction complexity, susceptibility of flow to climate change induced volatility
- Scale of costs associated with the site – including a qualitative allowance for risks above
- Programme until commissioning – including need for additional studies/surveys, need for approvals and construction/installation period
- Operability of the site – is it near to a grid connection, are there skilled O&M staff in close proximity, is operation of the plant likely to require modification to suit flow regime changes

From this consideration preferred sites can be selected.

2. Demand and Supply

The per capita energy consumption per annum in Pakistan in 2003 was estimated at 0.46 tons oil equivalent (TOE) (Ref 2) and commercial energy consumption in 2005 was estimated at 55.5 MTOE (Ref 3). The per capita consumption is low in comparison to other countries. Figure 1 compares the annual per capita consumption worldwide and shows that the average consumption in Pakistan is 17% of the world average per capita consumption.

In addition to the abovementioned commercial energy use approximately 21 MTOE of traditional fuels are used annually by households and industry in Pakistan. This includes fuel wood, crop residues and animal waste. In 2005 an estimated 30% of the population had no access to electricity at all.

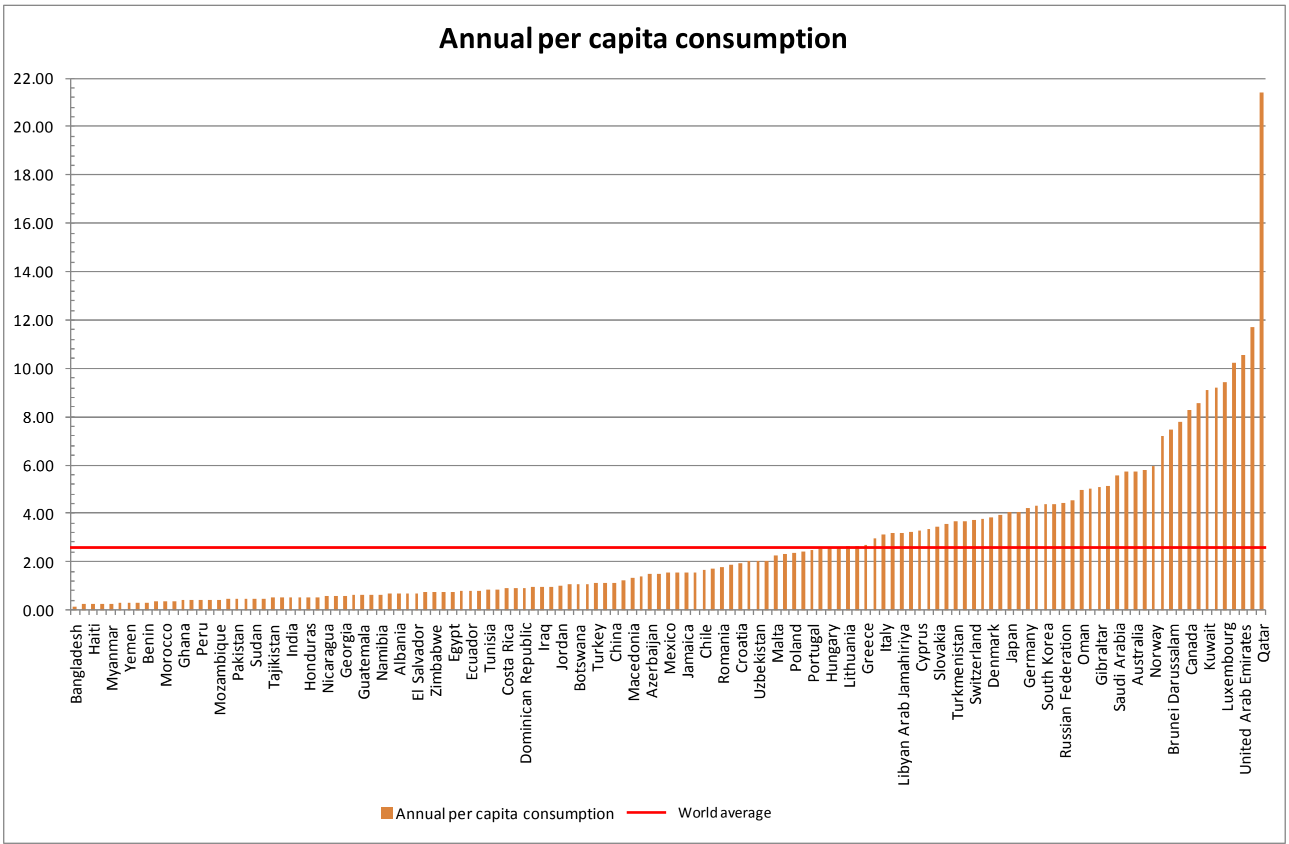

Figure 1. Annual per capita energy consumption for different countries in TOE per capita per annum in 2003 (based on information provided by the World Resource Institute, Ref 2)

The electricity generation capacity in 2005 was 19,400 MW (Ref 3) while other reports mention a total generation capacity of 14,000 MW (Ref 4). The majority of this generation capacity is provided by gas fired plants (50.8%) and about 30% by hydropower (6,500 MW) (see also Figure 2 below). Total energy generation in 2004-05 was reported to be 88,000 GWh while system losses were estimated at 26.5% of total generation.

WAPDA (Ref 6) states that the current maximum electricity shortages vary between 6150 MW in summer and 2470 MW in winter. It is not known how these values have been determined, but it is known that load shedding frequently occurs in most areas in Pakistan and increases in frequency during the summer months.

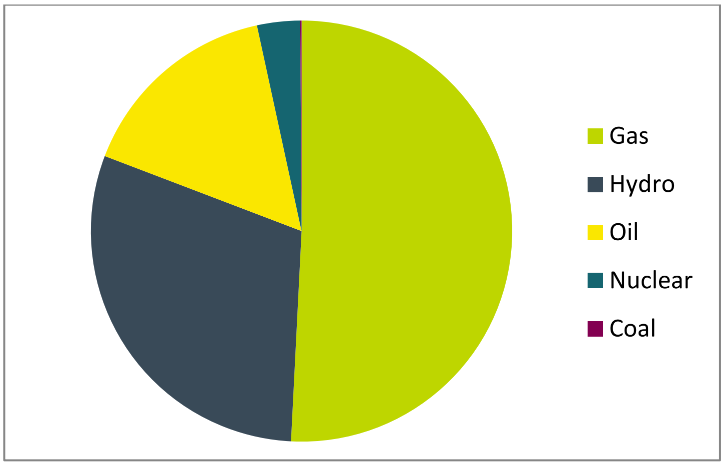

Figure 2. Electricity generation capacity by type in 2004-05 (based on data provided in Ref 3)

During the period of 2001-2005, the ratio of growth rate of primary commercial energy to growth rate in GDP was 1.02. This suggests that in the past the primary commercial energy demand has increased at a faster rate than the overall GDP growth. We expect this trend will continue unless energy efficiency in the commercial sector is addressed through focussed government policy. Projected GDP Growth for Pakistan until 2022 is 5% per annum and annual growth rate of energy demand is estimated to be between 7% (Ref 3) to 8% (Ref 6).

The use of traditional fuels in households and industry is expected to decline with increased availability of commercial fuels putting additional pressure on the generation requirements.

It is estimated that the total generation capacity requirement by 2022 is 50,000 MW (Ref 4). The Pakistani Government has decided that the development of further hydropower generation capacity will play an important part in developing this capacity. The targeted increase in capacity of various different sources is shown in Figure 3. The total estimated viable hydropower capacity has been stated as 46,000 MW (Ref 4). Other reports state a potential of around 59,200 (Ref 6) to 59,800 MW (Ref 5). Large hydropower projects tend to have a long lead in time and currently typically require financing assistance by development banks. The location of the majority of the large hydropower projects is in the mountainous regions of Pakistan and grid connection can be difficult and be a significant cost factor.

The Integrated Energy Plan recommends that a hydropower capacity of approximately 17,400 MW should be installed by 2022. This proposed increase in capacity takes account of the implementation of eight major hydropower plants. However, under the 2002 Power Policy the provinces are able to develop their own hydropower resources. Small scale hydropower projects can contribute to the overall power capacity if developed as part of an overall plan to increase the operating power capacity of Sindh Province.

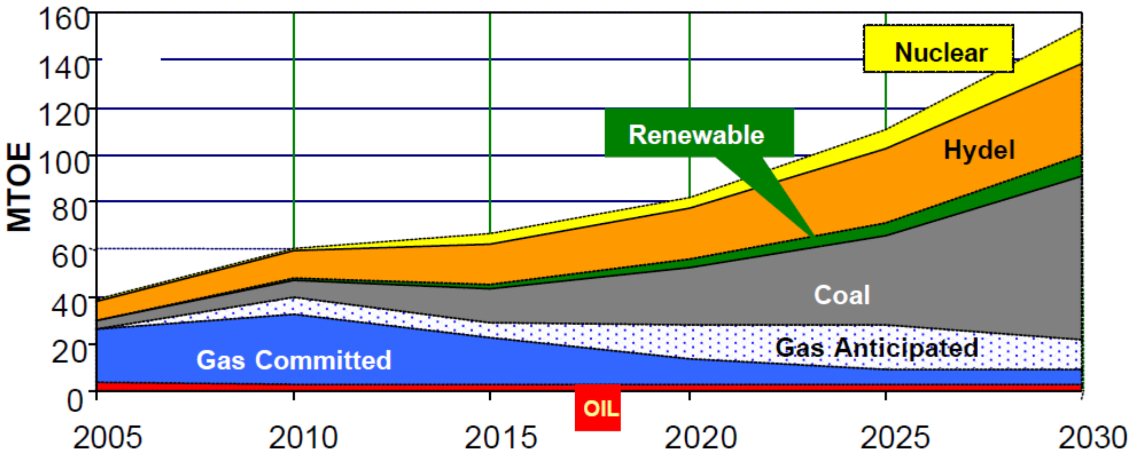

Figure 3. Indigenous supply projections (Ref 3)

No detailed supply and demand studies for Sindh Province were available for review to by consortium. However, it is known that there is currently a significant power shortage in the province. Development of small to medium hydropower plants offers an opportunity to increase the overall generating capacity in the short to medium term while larger projects in Sindh or elsewhere are under development.

Based on the available information we conclude that there is currently a significant gap between demand and supply in Sindh Province and Pakistan in general. This gap is expected to remain or widen in the future as the population and the economy continue to grow. This may be exacerbated by a reduction in the use of traditional fuels as the population without access to electricity decreases. The supply gap is significant and will be required to be addressed through a strategic national approach. Power development can contribute to this overarching approach through development at a provincial level. Whilst it is recommended that this is undertaken in the context of a strategic approach taking account of all potential resources, development of power projects at existing irrigation infrastructure offers a cost effective opportunity to add power capacity in Sindh Province.

3. Review of Previous Reports

The potential of hydropower in the Sindh province of Pakistan has been long considered and several reports have been commissioned previously. Some of these reports have been made available to the consortium by the client or have been obtained from other sources. This section presents a review of the previous reports available to us.

3.1. Hydro Potential in Pakistan, Private Power and Infrastructure Board

In February 2011 the Private Power and Infrastructure Board published a report in the Hydro Potential in Pakistan (Ref 5). The report summarises all identified potential hydropower sites within Pakistan by region. Within the Sindh province the report identifies 18 potential sites, with an estimated total capacity of 193MW of which 67MW are solicited projects. In the context of the report the term ‘solicited’ refers to sites where a feasibility study has already been completed.

The following two tables record the identified sites and their stated hydropower potential.

Site No.	Project Name	Location	Capacity (MW)
1	Kotri HPP	Kotri Barrage	29.00
2	Sukkur HPP	Sukkur Barrage	15.50
3	Rohri Canal HPP	Rohri Canal RD 328+256	2.29
4	Rohri Canal HPP	Rohri Canal RD 578+522	1.47
5	Nara Canal HPP	Nara Canal RD 0+000	2.69
6	Nara Canal HPP	Nara Canal RD 25+000	13.02
7	Nara Canal HPP	Nara Canal RD 135+000	7.63
8	Nara Canal HPP	Nara Canal RD 139+000	14.00
9	Nara Canal HPP	Nara Canal RD 335+000	9.93
10	Nara Canal HPP	Nara Canal RD 395+000	7.31
11	Nara Canal HPP	Nara Canal RD 472+000	9.61
12	Nara Canal HPP	Nara Canal RD 560+000	9.52
13	Nai Gaj Fall HPP	Nai River, Kirther Mountain	4.20
		Total	**126.17**

Table 2. Unsolicited Sites in Sindh – Hydro Power Resources of Pakistan (Ref 5)

Site No.	Project Name	Location	Capacity (MW)
1	Guddu Barrage HPP	Guddu Barrage	33.00
2	Rohri HPP	Rohri Canal RD 15+000	16.00
3	Rohri HPP	Rohri Canal RD 205+160	5.75
4	Rohri HPP	Rohri Canal RD 696+500	7.80
5	Rohri HPP	Rohri Canal RD 705+000	4.31
		Total	**66.86**

Table 3. Solicited Sites in Sindh – Hydro Power Resources of Pakistan (Ref 5)

The study refers to previous feasibility studies undertaken for Guddu Barrage and for the Rohri Canal, but no detailed reference is given for the reports. It is assumed that the Guddu Barrage study referred to in the report is the study undertaken by the Gesellschaft fur Technische Zusammenarbeit (GTZ). This has recently been reviewed by the consultants for rehabilitation of Guddu Barrage and the results of the study are reviewed in Section 2.3. A report on feasibility of hydropower on the Rohri Canal undertaken by Andritz Hydro was available to the consultants for this project. It is unclear whether the PPIB study refers to the same report or another study previously undertaken.

The report does not comment on the feasibility of implementation of hydropower at the sites with regards to economic costs and benefits, technical feasibility, grid connection or environmental impacts.

The Nai Gaj site is currently under development and is expected to be completed in April 2015.

3.2. Hydro Potential in Pakistan, Water and Power Development Authority (WAPDA)

This study published by WAPDA in November 2011 (Ref 6) summarises the status of hydropower projects in Pakistan including existing operational schemes, schemes under construction, schemes which can be implemented in the immediate future (next 5 years) and other future schemes. The report makes reference to plans for two projects in Sindh Province, Naj Gaj Dam and Darawat Dam. These are reportedly to be developed between 2009 and 2013. No further detail on the proposed works is provided in the report. During a second phase between 2010 and 2014 the following dams are expected to be implemented: Salari Dam, Nali Dam, Khenji Dam, Naing Dam, Sita Dam and Upper Makhi Dam.

The Darawat site is located on the Nai Baran River approximately 70km (44 miles) west of Hyderabad. The proposed dam is a 35m (118 ft) high, 250m (820 ft) long concrete faced rockfill dam with an installed capacity of 0.45 MW. The reservoir will have a live storage capacity of 107,313,000 m^3 (87,000 acre feet) and will be used primarily for irrigation and in addition to the power generation. The cost is estimated at Rupees 13.6 billion (US$ 144 million) at exchange rate of time of the report) and the contract was awarded to the Sinohydro-MAJ JV in 2010. Recent news suggests that there has been a delay in implementation due to insufficient available funds but that funding has now been approved by the government (Ref 7).

The Naj Gaj Dam project is located on the Gaj River in the district of Dadu and serves the purpose of storage of flood waters for irrigation as well as hydropower generation. The proposed dam is 59 m (194 ft) high and will impound a reservoir with a live storage of 197,357,000 m^3 (160,000 acre feet). The installed capacity is 4.2 MW at a total project cost of Rupees 59.4 billion (US$ 627 million at exchange rate of time of the report). The contract for the project was signed in April 2011 with NEIE-SMADB JV.

The report does not provide any further detail on the other proposed sites in Sindh Province.

There is no reference made to any further hydropower potential in Sindh Province which may suggest that WAPDA is likely to prioritise sites in other provinces due to the higher potential of the sites and may not intend to pursue the development of run-of-river hydropower in Sindh.

3.3. Guddu Barrage Rehabilitation, Mott MacDonald Ltd

The feasibility study undertaken as part of the Guddu Barrage Rehabilitation Project (Ref 8) was based upon a report undertaken by GTZ in 1990. Six options were identified by the report for hydropower based at Guddu Barrage – these are as described below and were considered in the context of the existing upstream pond level being maintained and also with the upstream pond level being raised by 4 ft;

- Option 1 Right Bank Powerhouse
- Option 2 Left Bank Powerhouse
- Option 3 Turbines in barrage gate openings
- Option 4 Powerhouse on bypass channel
- Option 5 Powerhouse Intake on BS Feeder Canal
- Option 6 In-river Powerhouse

After assessment of the options, Mott MacDonald concluded that Options 4, 5 and 6 were either inappropriate or too expensive and therefore were rejected. The Consortium supports these findings.

After further study, it was concluded by the report that Options 1 and 2 represented the most favourable arrangements and that these should be considered for further technical and economic appraisal including additional modelling.

Modelling was completed for Options 1 and 2 by Mott MacDonald, for total installed capacities ranging from 42.42MW to 69.24MW. This is significantly greater than the potential identified by the Private Power & Infrastructure Board's report, discussed above.

Key criteria used by Mott MacDonald to assess the energy potential are summarized as follows:

- Existing (normal) pond level 77.9m (256.00ft)
- Future (proposed) pond level 79.3m (260.00ft)
- Minimum tailwater level 72.5m (237.86ft)
- Average tailwater level 76.1m (249.67ft)

A tailwater rating curve is included in the Mott MacDonald report and Mott MacDonald concluded that a minimum net head of 1.8m (5.90ft) should be adopted for operation of the power plant – at net heads less than 1.8m there is a likelihood that suspended sediment concentrations will be too high for operational purposes. This minimum net head is equivalent to a tailwater level of 76.1m (250.1ft) with a pond level of 77.9m (256.0ft).

Mott MacDonald reviewed the annual recorded flows in the Indus at the barrage since 1977 and in comparing these with the demands from the off-taking canals, an "average annual flow of excess water" was derived. This is flow available for power generation – depending on the arrangement of the powerhouse and its intake and on the number of barrage gates operated in an open position.

The average annual flow of excess water derived was 2,821m^3/s (99,623 ft^3/s). However, the available excess water appears to be significantly lower in the years since 1999 and over this period a figure of 2,000 m^3/s (70,630 ft^3/s) appears more appropriate.

Assuming 50% of this "excess water" is available for power generation – that is 1000 m^3/s (35,315 ft^3/s) and assuming an overall efficiency of 80% the total output will be:

Existing pond level (256.00ft)	At maximum head of 5.4m	42MW
Future proposed pond level (260.00ft)	At minimum head of 1.8m	14MW
	At maximum head of 6.8m	53MW
	At average head of 3.2m	25MW

This assessment is rather coarse and would need to be refined by behavioural modelling, taking due account of the efficiencies of the selected electro-mechanical equipment and the timing and duration of the excess flows and tailwater levels

Mott MacDonald undertook modelling for Options 1 and 2, for total installed capacities ranging from 42.42MW to 69.24MW. The model results gave average annual energy productions of 220.81GWh and 303.25GWh respectively with the existing pond level and 281.22GWh and 384.60GWh respectively with an increased pond level, both results assuming double regulated turbines.

Having reviewed the conclusions and workings of the Mott MacDonald report it is the Consortium's view that Options 1 and 3 only merit further consideration as discussed below.

Option 1

This option consists of the construction of a powerhouse downstream of the right pocket located approximately 130m downstream of the right undersluices and partly in the right bank (see Figure 4). A new gated weir would be constructed from the powerhouse to meet an extension of the downstream guide wall. The gates in this weir would allow regulation and maintenance of water levels immediately upstream to be the same as upstream pond levels thus creating a head differential at the powerhouse for power generation.

This arrangement would render the right undersluice gates redundant for normal operational purposes. They would be kept open and the periodic flushing of the right pocket would be achieved by opening of the gates in the new “hydropower” weir.

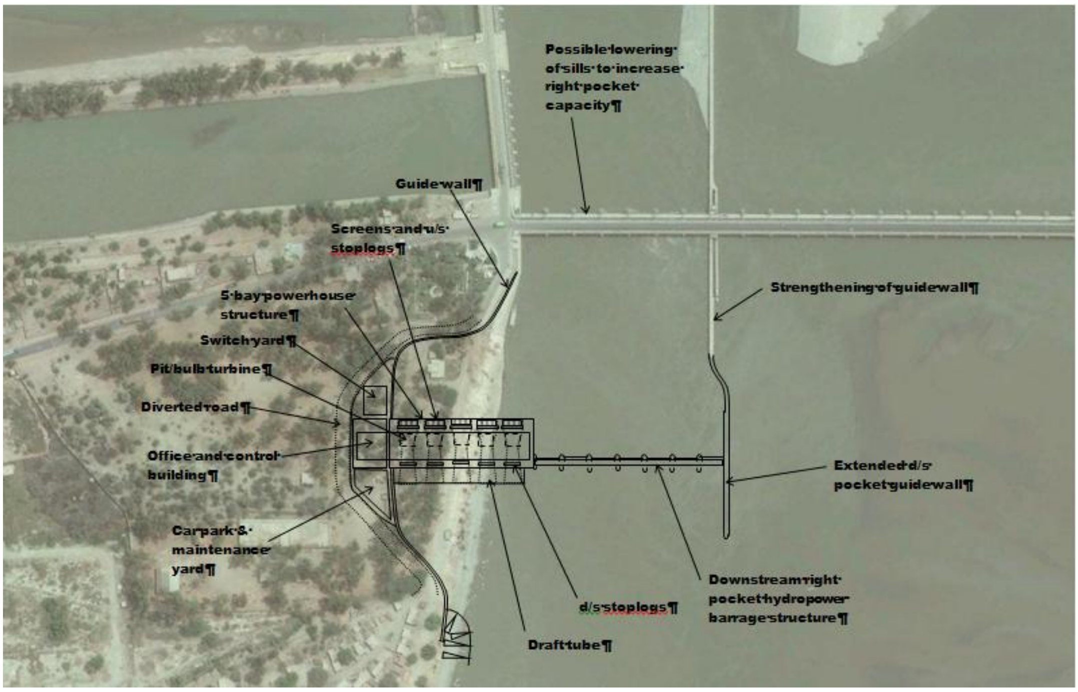

Figure 4. Guddu Barrage right bank proposals (Ref 4).

Option 3

This option involves installation of turbo-generators within the gated bays of the barrage. The units would be the “Hydromatrix™” or “Straflomatrix™” types manufactured by Andritz AG of Austria. Mott MacDonald suggested that these can either be “embedded” units installed downstream of the existing barrage gates or modular units installed within the existing gate slots.

Option 2

Option 2 comprises construction of the turbines in the left bank of the barrage and requires a settling basin just downstream of the existing head regulators, extension of the existing regulator structures, construction of new regulators downstream of the settling basin and repositioning of the guide wall (see Figure 5). This option was rejected because it is the Consortium’s view that;

- Although construction access would be relatively easy from the right bank, construction costs are likely to be relatively high due to the deep excavation required for the settling basin, the construction of new regulators and repositioning of the guide wall
- There are already concerns about the asymmetric flow approach to the barrage and there are doubts whether sufficient water will be available in the left pocket to meet the needs of the powerhouse and the off-taking canals
- Although it is proposed to relocate the guide wall, to enlarge the pocket, unless alterations are made to the undersluices and adjacent barrage bays, it is unlikely that a practical method of flushing of the pocket will be available. This will lead to sedimentation not only in the settling basin but also in the pocket itself which will be difficult, if not impossible, to rectify

- The settling basin will require mechanical de-silting and because this will require isolation of the canals and powerhouse and will be costly there are doubts about sustainability, generally, of this option.

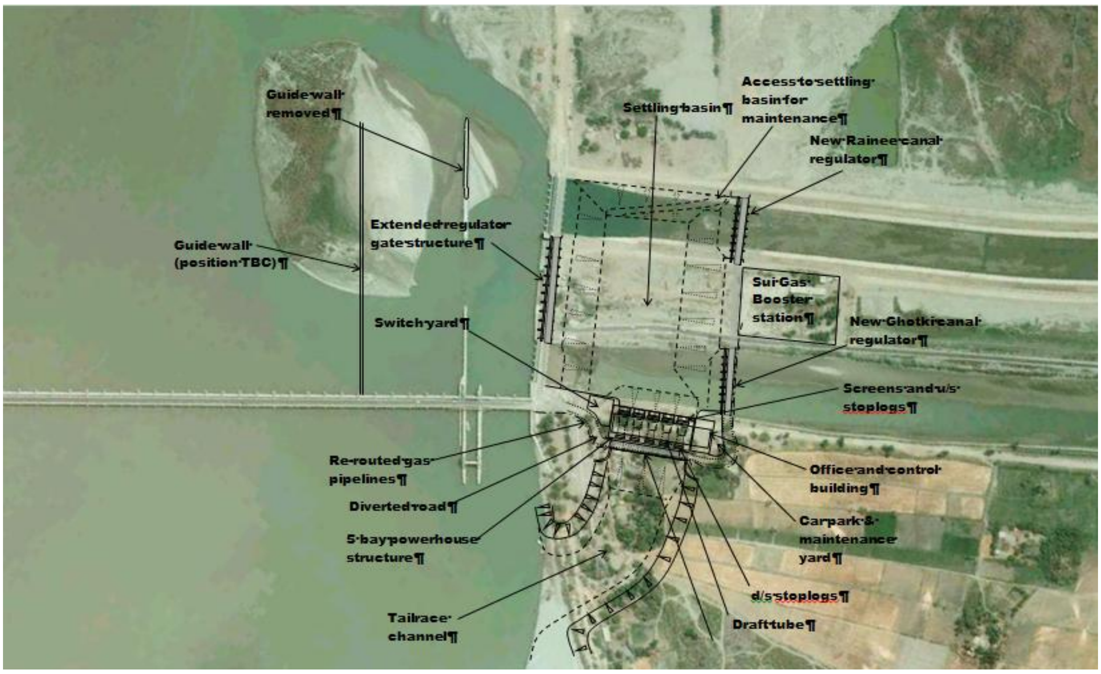

Figure 5. Guddu Barrage left bank proposals (Ref 3)

A key concern identified in the study for all three options is the impact of the options on sedimentation patterns in the canals off-taking from Guddu Barrage and the morphology of the main river channel.

The Consortium agrees with this concern in particular with regards to Option 1. The pockets are a key element of the sediment management at the barrage. For the pockets to work effectively as a sediment management structure the flow patterns should remain such that slower velocities are maintained along the divide walls and higher velocities at the entrance of the canals. Flushing is undertaken at regular intervals to remove any sediment that has accumulated in the pockets. If hydropower was incorporated in the pocket there would be a significant flow through the right pocket resulting in higher flow velocities here. There is a risk that the sediment intake into the canals would increase as a result of this option. Further detailed modelling is required to confirm the impact on sediment management and to optimise the arrangement.

3.4. Sukkur Barrage

China International Water and Electric Corporation (CIWEC), headed by the director of the 3 Gorges Dam, visited Pakistan in April 2011 with view to developing a hydropower scheme at the Sukkur Barrage. The delegation summarised their findings in two short reports, published in June and August 2011 – Sukkur Hydropower Project – Site Investigation Preliminary Report and Technical Assessment (Refs 9a and b)

The team identified four potential sites, those being;

- Option 1 – Right Bank
- Option 2 – Left Bank
- Option 3 – River Bed
- Option 4 – Irrigation Canal

Option 1 comprises a bypass channel on the right bank with the power station located some distance upstream of the barrage. This option would require a relatively long bypass channel, aqueducts for three canal crossings and a road crossing for the road across the Sukkur Barrage. The upstream right bank is heavily populated and this option was therefore discounted. The Consortium agrees with this assessment.

Option 2 is similar but would be through the left bank. In this location four canals are required to be crossed with aqueducts in addition to the road crossing, and the area on this bank is also heavily populated. The option was therefore discounted and we agree with this conclusion.

Options 3 and 4 were recommended as being suitable for further investigation.

Option 3 involves construction of the power station on the island upstream of gates 6 to 14 which have been permanently closed to create flow training works. The report highlights concerns of further silting in the channel and a need to take account of the recommendations of the current rehabilitation project when pursuing hydropower options at the barrage or the head regulators. On this basis the report discounts options to implement hydropower at the barrage at this stage. The report did not consider any alternative turbine types like Hydromatrix™ or Straflomatrix™ which do not require a separate power station building.

The team agrees with the conclusion that the findings of the rehabilitation study need to be taken into account and that the impact of any proposals for hydropower in the river channel on sediment need to be considered carefully. However, options for Hydromatrix type turbines could be investigated further. We agree with the assessment that options on the right and left bank would be costly to implement due to the built up areas adjacent to the barrage.

The assessment concluded that an overall potential of 15 MW is available if the concerns regarding the location of the power station and the sedimentation could be resolved.

Following the assessment of hydropower feasibility at Sukkur and conclusion that remained some significant concerns over the feasibility at the barrage CIWEC investigated options to implement hydropower on some of the Rohri Canal Structures. The review of this assessment is provided below

3.5. Rohri Canal

Options at Rohri Canal were investigated by CIWEC (Ref 9) and Andritz Hydro Ltd (Ref 10), both in 2011. CIWEC identified two water drops on the Rhori Irrigation Canal, the fall regulator at RD-15,000 and the fall regulator at Tando Masti Khan (RD-118,000). The technical assessment states that the canal has a discharge of 308 m^3/s (10,877 ft^3/s), but that this flow could be increased to 464 m^3/s (16,386 ft^3/s). Based on information available to the Consortium, these values appear to be original design discharge of the canal and the maximum actual discharge of the canal.

China International Water & Electric Company calculated that drop RD-15,000 could support a 6.6MW development based on a design discharge of 424 m^3/s (14,973 ft^3/s) and a head difference of 2.1m (6.9 ft). The Tando Masti Khan drop, based on a design flow of 326 m^3/s (11,510 ft^3/s) and a head difference of 1.5m (5 ft), is suitable for a 3.9MW installation. The assessment concludes that the Tando Masti Khan fall regulator may not be economically viable due to the low available head at the site.

Based on the actual discharge and head data between 2008 and 2010 the discharge of 424 m^3/s (14,973 ft^3/s) quoted by CIWEC for Rohri RD15 is rarely achieved, The data suggests an average discharge of 250 m^3/s (8,800 ft^3/s) during this period with a discharge of 410 m^3/s (14,500 ft^3/s) only being exceeded for short periods of time during July and August. The estimated average discharge for Rohri RD118 is 240 m^3/s (8,400 ft^3/s) which is also below the values quoted by CIWEC.

Further to this Andritz Hydro produced a technical offer for a hydropower development on the Rohri Canal. This adds little to the discussion as to site location but provides good technical criteria for consideration.

4. Long list of Potential Sites

With the Province of Sindh there are many potential sites at which a hydropower development may be suitable. The following table is a summary of sites identified as being of interest by the Consortium.

Of these potential sites only six were added to the long list of options for further consideration; the reasons that the other sites were discounted have been recorded in the table in the hope that future work can build upon the initial investigation completed.

RD	Canal	Name of Structure	Head difference (ft)	Design Discharge (ft^3/s)	Power potential (MW)	Comment
-	-	Kotri Barrage				Flows in dry season too low
-	-	Sukkur Barrage				Consider
-	-	Guddu Barrage				Consider
25	Nara	Nara Fall	9.2	19978	8.6	Insufficient data, included with some assumptions based on a one day spot measurement of the head difference
0	KB Feeder Lower	Head Regulator	16.93	7456	5.9	No longer in operation
36	Pinyari lower/Old Fuleli	---	8.0	12077	4.5	Consider
118	Rohri	Tando Masti Khan Fall	8.1	10595	4.0	Consider
0	Rohri	Head Regulator	6.5	10887	3.3	Consider
15	Rohri	Fall Structure	6.0	10887	3.0	Consider
19.5	KB Link	Cross Regulator	7.1	8055	2.7	Consider
497	Rohri	Usuf Dahri X-Regulator	6.5	6495	2.0	Insufficient data
231	Rice	Mohatta X-Regulator	3.3	12133	1.8	Insufficient data, non-perennial site
314	Rainee	X-Regulator at E	9.3	4213	1.8	Insufficient data, non-perennial site
205	Rohri	Naulakhi X-Regulator	3.3	10465	1.6	Insufficient data
523	Rohri	Duro Fall	4.5	6070	1.3	Insufficient data
704	Rohri	Kumblima Regulator	5.0	5390	1.3	Insufficient data
182	Rainee	X-Regulator at A	4.9	5000	1.1	Insufficient data, non-perennial site
255	Rice	Lahori X-Regulator	3.2	7342	1.1	Insufficient data, non-perennial site
590	Rohri	Mirza Baig Fall	3.4	5870	0.9	Insufficient data
433	Rohri	Phul Fall	3.5	5576	0.9	Insufficient data
340	Rice	Mondar X-Regulator	3.4	5339	0.8	Insufficient data, non-perennial site
332	Dadu	Sonahri X-Regulator	3.8	4497	0.8	Insufficient data
647	Rohri	Sakrand Regulator	3.0	5624	0.8	Insufficient data
214	Akram Wah	Alipur Syphon @ Rd 214.0	5.3	2931	0.7	Insufficient data, very limited potential
0	KF East	Head Regulator	7.0	2094	0.7	Insufficient data, very limited potential
0	KF East	Head Regulator	7.0	2094	0.7	Insufficient data, very limited potential
280	Akram Wah	Talhar Syphon @ RD 280.0	3.8	2931	0.5	Insufficient data, very limited potential
0	KF West	Head Regulator	5.5	1940	0.5	Insufficient data, very limited potential
0	KF West	Head Regulator	5.5	1940	0.5	Insufficient data, very limited potential
148	Akram Wah	Road Bridge @ 147.5	3.5	2942	0.5	Insufficient data, very limited potential

Table 4. Long list of sites

The following sites are considered in Sections 3.1 to 3.9 for further consideration

1. Sukkur Barrage:
2. Rohri Canal head regulator
3. Rohri Canal fall regulator RD 15
4. Rohri Canal fall regulator RD 118
5. Pinyari Feeder Lower fall regulator RD 36
6. Guddu Barrage:
7. KB Link Canal RD 19.5
8. Nara Canal fall regulator RD 25

The map provided below shows the location of the above sites.

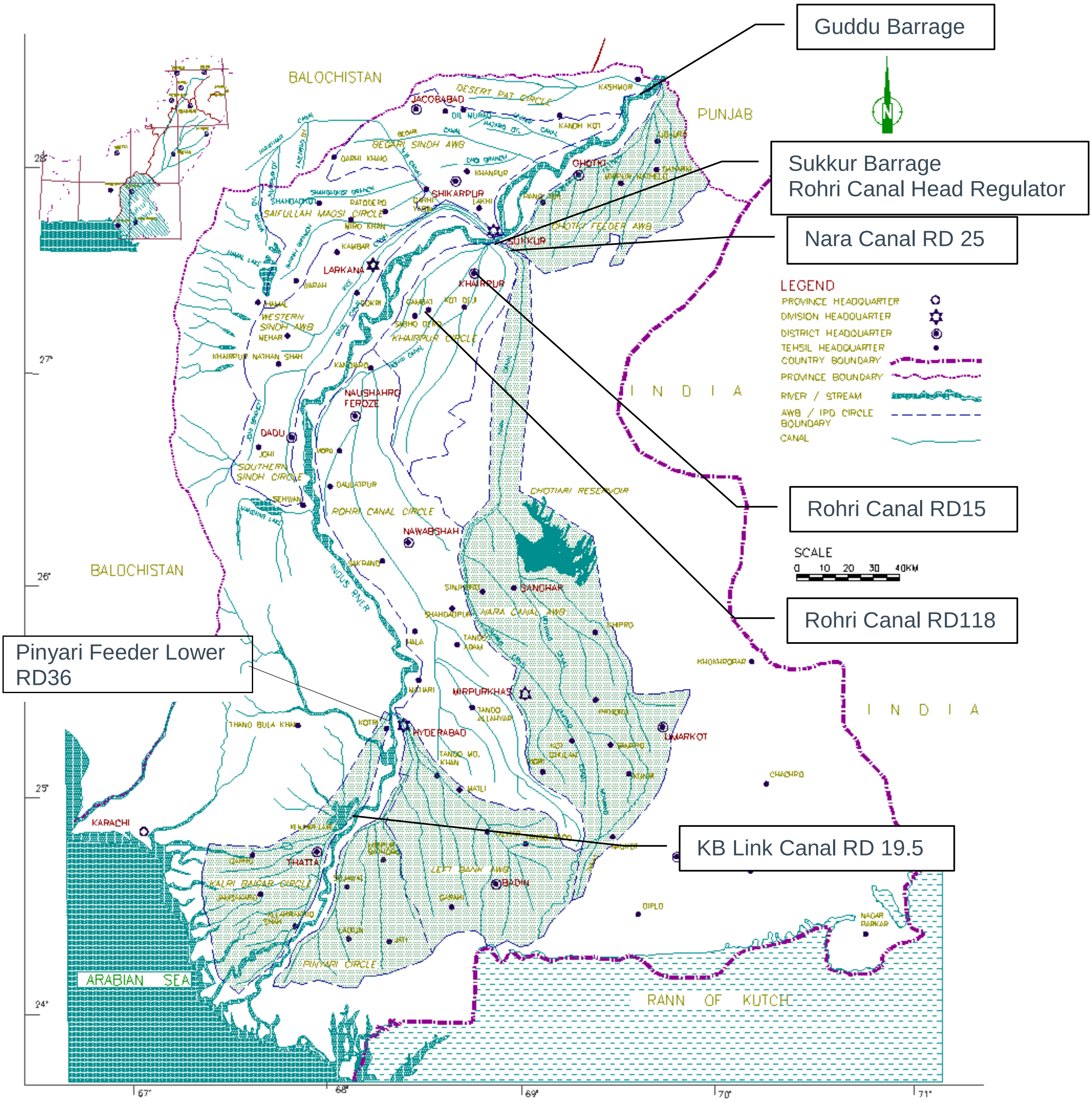

Figure 6. Sindh Province Map with locations of potential hydropower schemes shown.

4.1. Energy supply gap

In assessing the viability and feasibility of generation options it is necessary to consider the extent, timing and scale of the problem – in this case the energy gap – so as to be able to set the objectives of generating absorbable power at a suitable time. The timing of the gaps may also affect the sale price of any energy generated or used in substitution of grid energy.

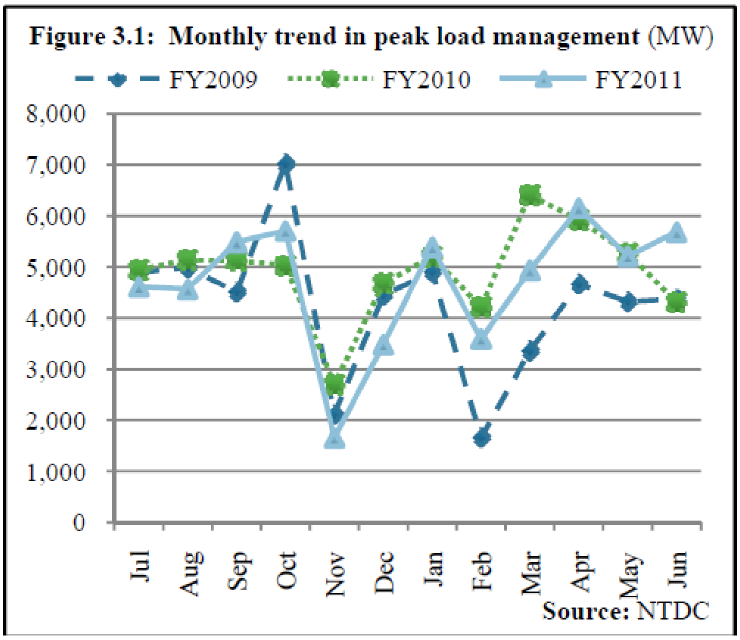

Figure 7. Graph showing energy demand per month between 2009 and 2011

Figure 7 demonstrates that energy demand fluctuates significantly throughout the year. Insofar that a three year period can illustrate it, the general trend for 2009, 2010 and 2011 is for demand to reduce during November and February whilst peaking in October and March. The fluctuations in power demand over the year as well as daily fluctuations have to be taken into account in the planning of how the current supply gap can be addressed. The supply gaps will need to be addressed by a combination of different energy sources to ensure that adequate power can be supplied for peak as well as base loads.

4.2. Sukkur Barrage

Sukkur Barrage is located about 225 miles north east of Karachi (68° 33'E, 27° 41'N). It is located about 3 miles downstream of Lansdowne Railway Bridge, and the twin cities of Sukkur and Rohri are located on the right and left banks of the river, respectively. The Barrage is situated 100 miles downstream of Guddu Barrage and about 300 miles upstream of Kotri Barrage.

The overall width of the Sukkur Barrage is 1.4 km (4725 ft) and it consists of 66 sluiceways of 18.3m (60 ft) width each, five sluiceways in the right pocket, 54 sluiceways in the main weir section and 7 sluiceways in the left pocket. Ten sluiceways of the main weir section remain permanently closed. The structure is a masonry structure with two bridges, an upper deck used for operating the gates and a lower road deck.

The following canals are off-takes from the Indus, upstream of the barrage:

Right bank:

- Dadu Canal
- Rice Canal
- North West Canal

Left Bank:

- Khaipur Feeder East
- Rohri Canal
- Khaipur Feeder West
- Nara Canal

These are shown in Figure 8 below.

Figure 8. Layout of Sukkur Barrage and Off-take Canals

In addition to supporting the off-take at the Rohri canal, on which 3 potential sites have been identified, Sukkur Barrage itself has been identified as having a hydropower potential of 30 MW by the Consortium. This is an increase from the 15.50MW identified in February 2011by PPIB (Ref 5). The assumptions for the figure quoted by PPIB are unknown. The power potential of the Sukkur Barrage has been calculated assuming a 50% reduction in discharge compared to recorded discharges. This is because any development, with the possible exception of Hydromatrix™ units, is unlikely to use 100% of the flow since not all the flow could be bypassed or channelled through the pockets. It is also important to ensure that head water levels at the barrage can be maintained for the operation of the canals. At an early appraisal stage this coarse assumption is acceptable subject to a sensitivity assessment of power around this figure; more detailed behavioural modelling will be needed for a more refined cost benefit assessment. This assumption also provides the basis of comparison between Guddu and Sukkur as the same assumption has been applied to both.

Three years only of discharge records and head measurements have been used to generate a power curve and graph of power against calendar time. The data covered the years 2008-2010.

Both the power curve and graph of power against calendar month are crucial to the understanding of a site's potential for hydropower.

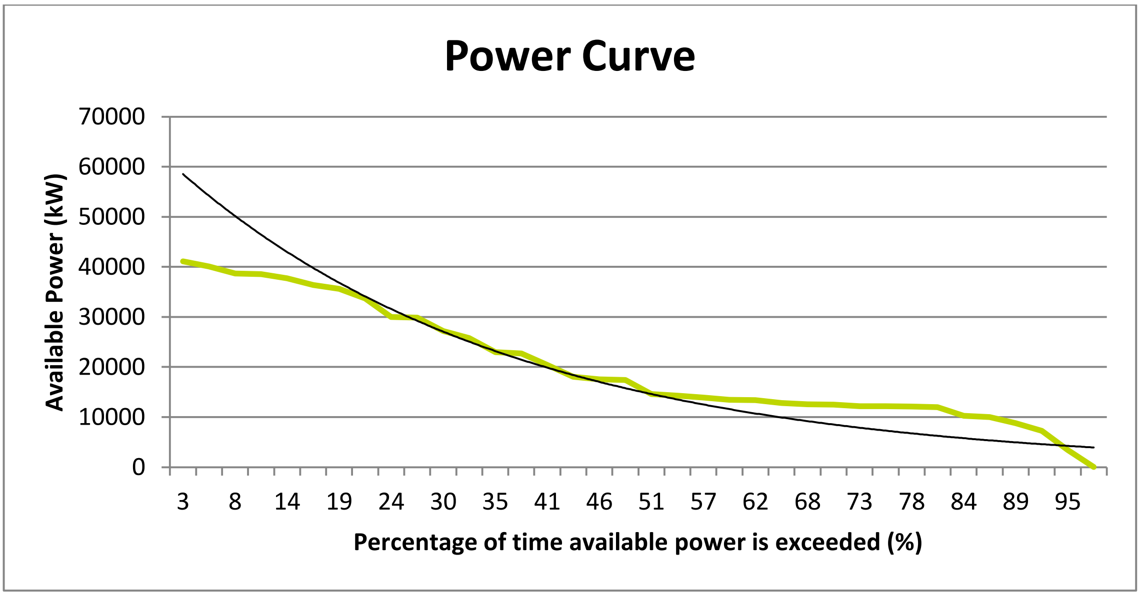

Figure 9. Sukkur Barrage Power Curve

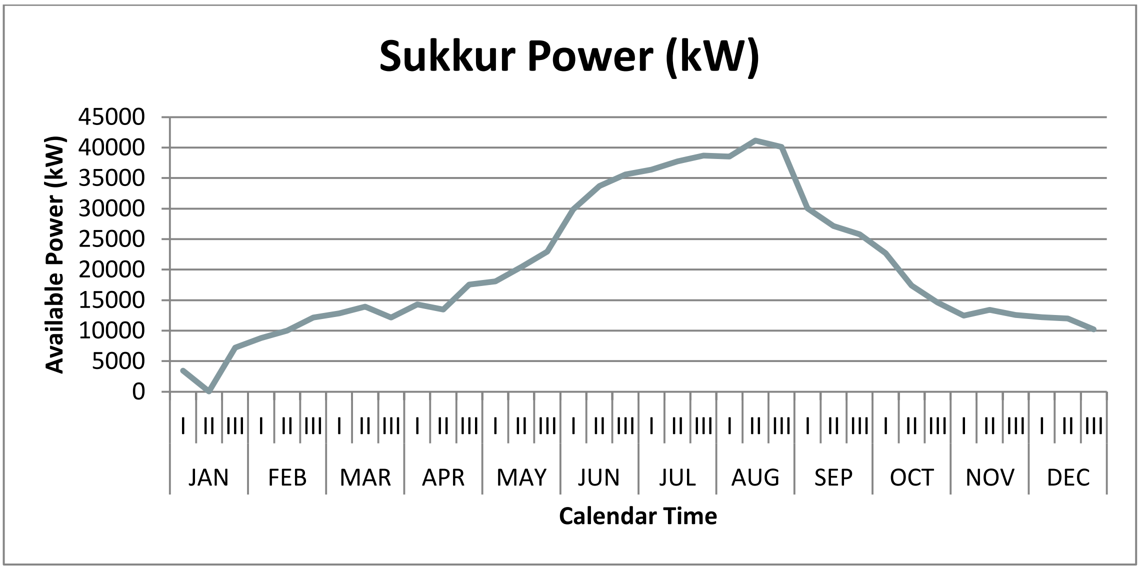

Figure 10. Available Power against Time

Figure 10 demonstrates that, should Sukkur barrage be selected as a hydropower location, on the assumptions made, power is available throughout most of the year, with over 15 MW being available for more than half of the year.

However, as Section 3.4 summarizes there are several problems with locating a hydropower development at Sukkur Barrage, meaning all options other than on-barrage development are likely to not be practical. Similar solutions as the option described for the right pocket at Guddu, where the divide wall is extended downstream of the barrage and the hydropower station is installed into the bank with sluice gates maintaining sufficient head upstream of the turbines, are constrained by the presence of the bridge downstream and buildings on either bank between the barrage and the bridge. The barrage suffers from significant sediment accumulation downstream of the right pocket and, to some extent, also downstream of the left pocket. There are also problems with sediment intake, in particular into the right bank canals. Installation of the hydropower station downstream of the barrage in the left or right pocket would likely exacerbate the sedimentation problems at the barrage as this would affect the operation of the pockets and as a result the effectiveness of the pockets as a sediment management measure. Flow patterns in the pocket should be such that the flow velocities are higher near the canals and lower along the divide walls.

Should a hydropower proposal be implemented downstream of the barrage it is likely that this will affect the sediment management and may exacerbate the problems which occur at the barrage.

Technology such as the Hydromatrix™ unit allows existing hydraulic structures to be modified such that hydropower can be retro-fitted without requiring major structural works. However, such a system would have a lower efficiency than an enclosed system and a change in the head conditions of the barrage would directly affect output power. In addition it would need to be confirmed whether the existing concrete masonry structure would be able to withstand the loads from the Hydromatrix™ units. Significant strengthening works may be required. This may result in significant costs.

The required changes to incorporate the Hydromatrix™ turbines into the structure may include:

- Since there are no stop log slots currently provided at Sukkur Barrage these could not be adapted to take the Hydromatrix™ units. Therefore either piers need to be extended to create slots for installation of the gates upstream of the existing gates or provision of new gates downstream of the existing gates would be required and the Hydromatrix™ units would be installed in the existing gate slots.
- Strengthening of O&M bridge
- Strengthening of piers
- May require larger cranes for lifting of Hydromatrix™ units
- Construction of upstream or downstream steel platform for switchgear and associated control and protection system.

Advantages and Disadvantages of Barrage and Canal Sites

Principally the development of the Sukkur Barrage site presents the following advantages in comparison to the canal sites:

- Grid connection likely available in the vicinity
- Good road access available
- O&M Staff with experience of operating major hydraulic structures is available near the site. Some additional training will be required.

Principal risks of developing the Sukkur Barrage site in comparison to developing canal sites are:

- Sediment management is a key issue at Sukkur. Any hydropower option would significantly affect the sediment management at the site. Prior to preparing a tender extensive numerical and physical modelling would be required – additional cost, long lead in time. The studies may not be able to identify a solution acceptable to the Irrigation Department.
- For on-barrage options (Hydromatrix© type turbines) detailed structural assessment of existing structure is required to assess whether the additional loads can be accommodated in the existing structure – additional cost, longer lead in time
- Water availability at the site may reduce due to additional water use upstream (population increase). This may result in less flow in the river channel since irrigation requirements are unlikely to reduce – risk of power production reducing over time/being less than anticipated.
- Water availability at the site may reduce due to climate change. This may result in less flow in the river channel since irrigation requirements are unlikely to reduce – risk of power production reducing over time/being less than anticipated.

- High flows during May to Sept, significantly lower flows during dry season. Low and medium flows coincide with good head difference. High floods can result in limited head difference and high flow conditions are therefore not necessarily ideal for power generation. High uncertainties.
- Risk related to grid connection – large volatility of flows into the grid can cause it to collapse
- The design life of the turbines with respect to the sediment concentration in the river would need to be confirmed.

The hydropower potential at Sukkur is currently being investigated as part of the Sukkur Barrage Rehabilitation and Modernisation Project. It is recommended that the outcome of this investigation is awaited before further action is taken on development of power at Sukkur Barrage. Liaison with the Irrigation Department is required should Sukkur Barrage be taken forward for further investigations.

4.3. Rohri Canal Head Regulator

The Rohri Canal is one of the canals off-taking from the River Indus just upstream of Sukkur Barrage. The head regulator is located on the left bank of the River Indus between the Khaipur Feeder West (closest to the barrage) and the Khaipur Feeder East. The head regulator comprises 12 gates.

A cross section through the head regulator is provided in Figure 11 below and an aerial photograph of the regulator is shown in Figure 12.

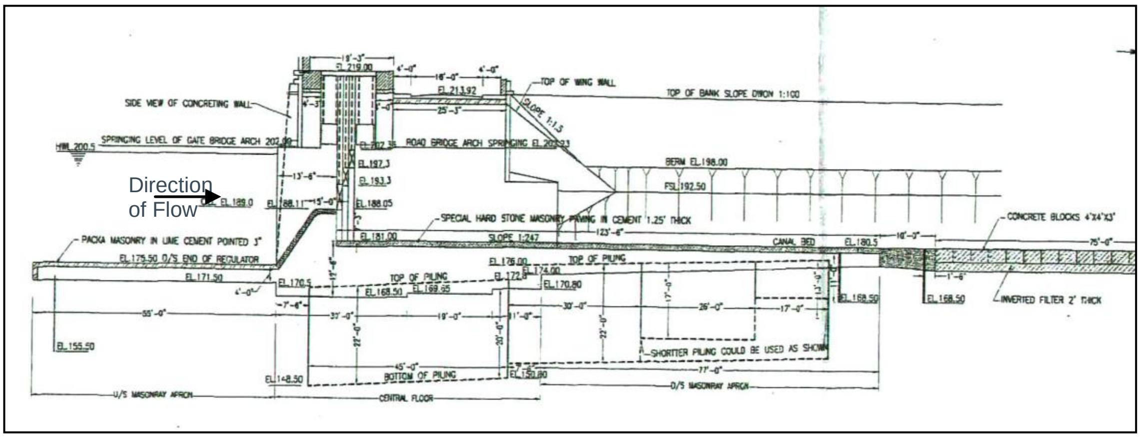

Figure 11. Cross Section through Rohri Canal Head Regulator (Historic Records, Sindh Government)

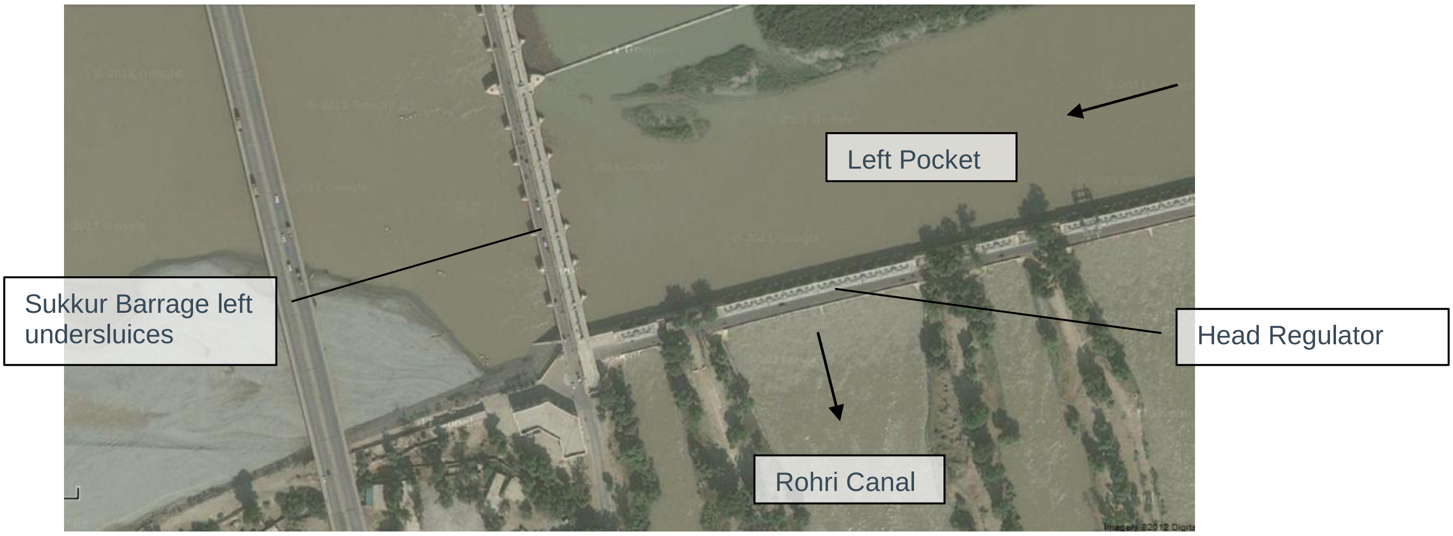

Figure 12. Aerial photograph of Rohri Canal head regulator

Source © 2011 Google

Water level records and discharge records were obtained from The Irrigation & Power Department for the period between 2008 and 2010 and a power duration curve has been prepared and is presented in Figure 13 below.

The Power Duration Curve was compiled using daily readings for discharge and up and downstream levels that have been averaged into 10 daily averages, giving 3 readings per month for discharge and head. Three years of data would not be considered sufficient to finalise a scheme, however on the assumption of accurate data then three years is acceptable at the preliminary assessment stage of a project. The power calculation is based on an assumed system efficiency of 55% to account for energy losses, turbine efficiency and transmission efficiency and accounts for the units of the input data being feet and feet.

At Sukkur barrage not all flow can be utilised for hydropower, however at the smaller control structures on irrigation canals, such as the Rohri Canal Head Regulator this assumption does not apply and therefore 100% of available flow is used to calculate power potential.

A hydropower development of 5.3 MW would potentially be viable at this site. Figure 14 shows the available power throughout the year based on the assumptions made above and that all available flow can be utilised.

It is felt that a suitable target exceedance value for a run-of-river hydropower scheme would be 25% i.e. the schemes rated capacity is available 25% of the year.

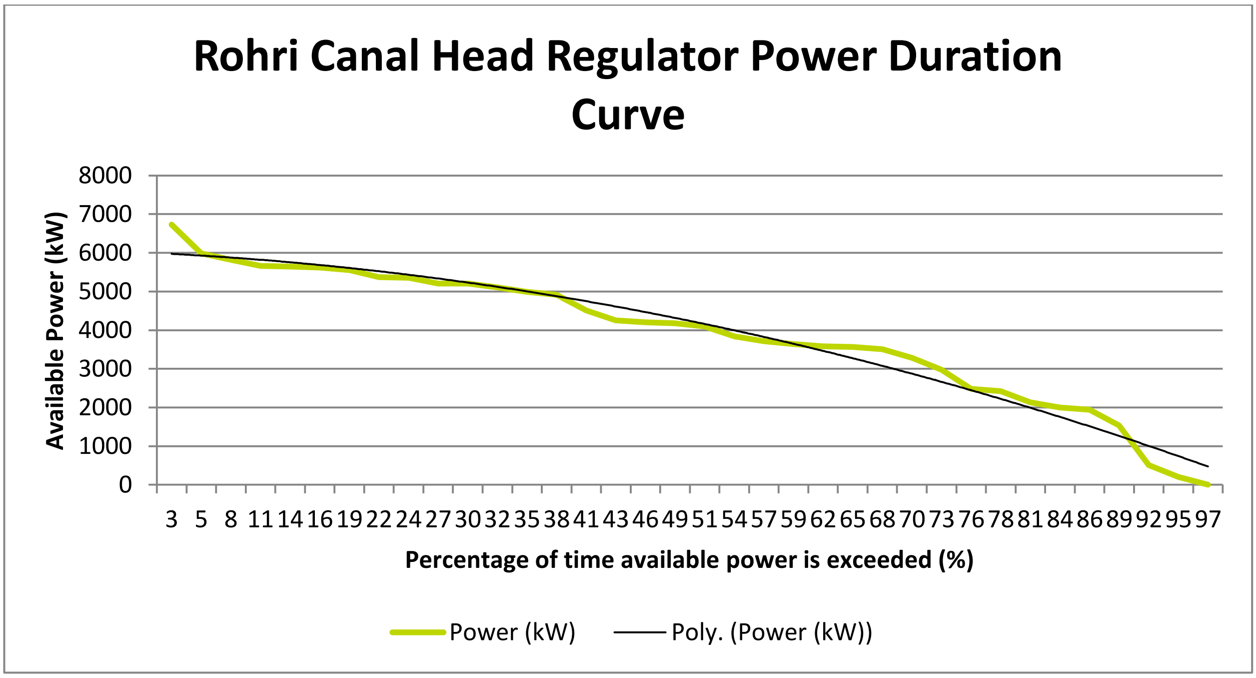

Figure 13. Power duration curve at Rohri Head Regulator

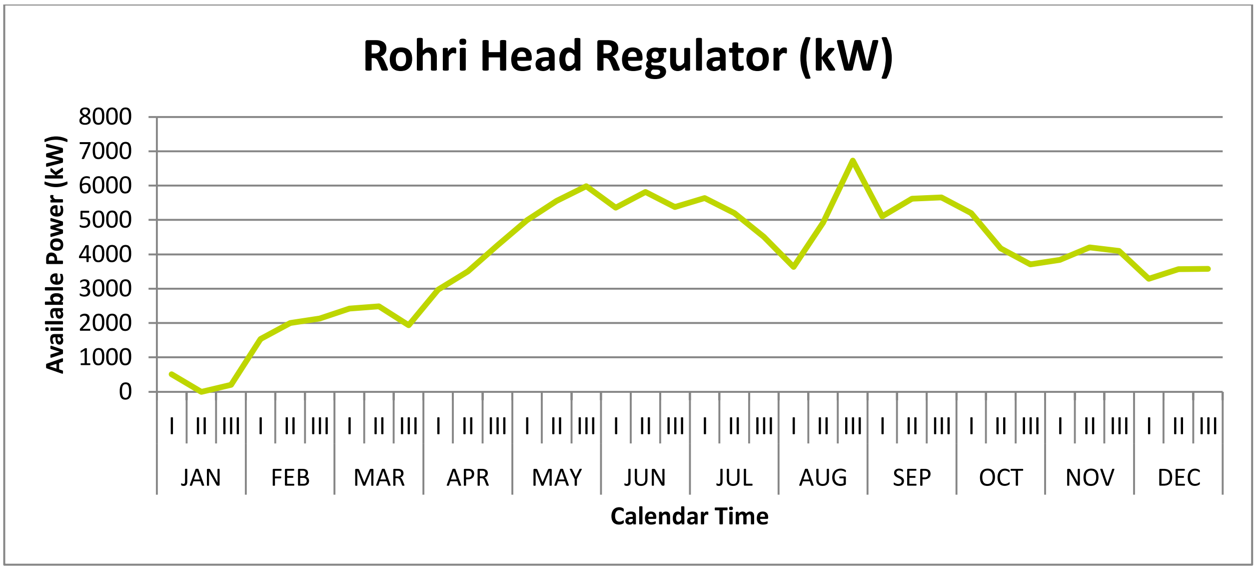

Figure 14. Available power against time at Rohri Head Regulator

It is unlikely that this site can be developed due to the limited space available in the vicinity of the head regulator to construct a power station adjacent to the new turbines and to accommodate the required changes to the structure.

Hydromatrix™ turbines are also unlikely to be feasible in this case as significant works may be required to strengthen the existing masonry structure to take the additional vertical loads. The following works may be required to incorporate the Hydromatrix™ units into the structure:

- Since there are no stop log slots currently provided at the regulator these could not be adapted to take the Hydromatrix™ units. Therefore either the piers need to be extended to create slots for installation of the gates upstream of the existing gates or provision of new gates downstream of the existing gates would be required and the Hydromatrix™ units would be installed in the existing gate slots. This would affect the road bridge and the maintenance access bridge.

- Strengthening of O&M bridge
- Strengthening of piers
- May require larger cranes for lifting of Hydromatrix™ units
- Construction of upstream or downstream steel platform for switchgear and associated control and protection system.

It is unlikely that any development at this site would be feasible given the limited space available. An extension of the piers upstream would negatively affect the flow in the pocket and the flow into the downstream canal and the O&M bridge has limited space to accommodate the switchgear and associated control and protection system as well as a larger crane for maintenance of the turbine units.

4.4. Rohri Canal Fall Regulator RD 15

The Rohri Canal fall regulator RD 15 is located approximately 4.6km downstream of the Rohri Canal head regulator (27˚38'00.41"N 68˚51'08.94"E). The regulator comprises 10 gates;a cross section through the regulator structure is provided in Figure 15 below and an aerial view in Figure 16.

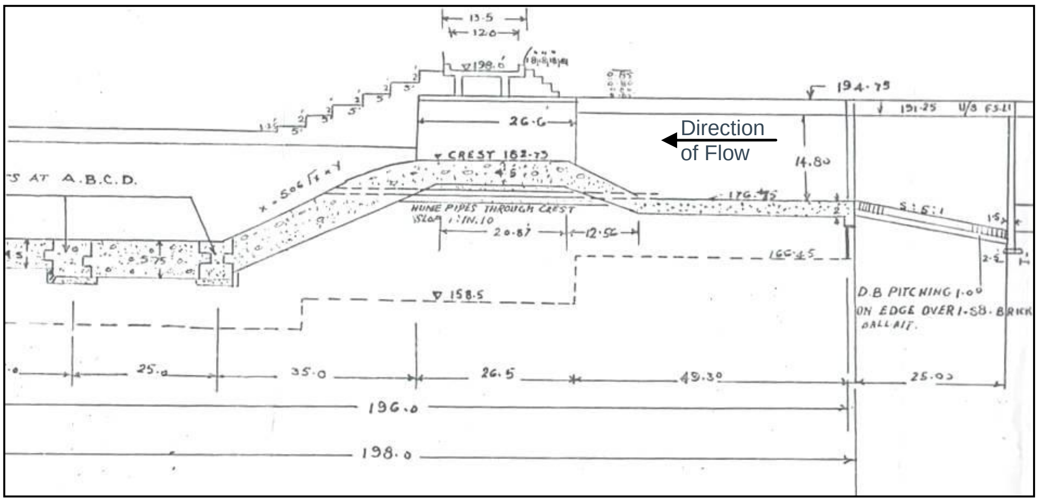

Figure 15. Cross section through Rohri RD 15 fall regulator (Source; Historic Records)

Water level records and discharge records were obtained from the Irrigation & Power Department of Sindh for the period between 2008 and 2010 and a power duration curve has been prepared and is presented in Figure 16 below.

The Power Duration Curve was compiled using daily readings for discharge and up and downstream levels that have been averaged into 10 daily averages, giving 3 readings per month for discharge and head. Three years of data would not be considered sufficient to finalise a scheme, however, based on the assumption of accurate data then three years is acceptable at the preliminary assessment stage of a project. The power calculation is based on an assumed system efficiency of 55% to account for energy losses, turbine efficiency and transmission efficiency as described in Section 1.4 above.

100% of available flow has been used to calculate power potential, as in principle all available flow at the regulator could be used to generate power

This demonstrates that installation of a 2.7MW capacity plant would be feasible. It may be possible to achieve higher potential output if efficiencies of the system can be optimised.

Figure 16. Aerial photograph of Rohri RD15 fall regulator

Source © 2011 Google

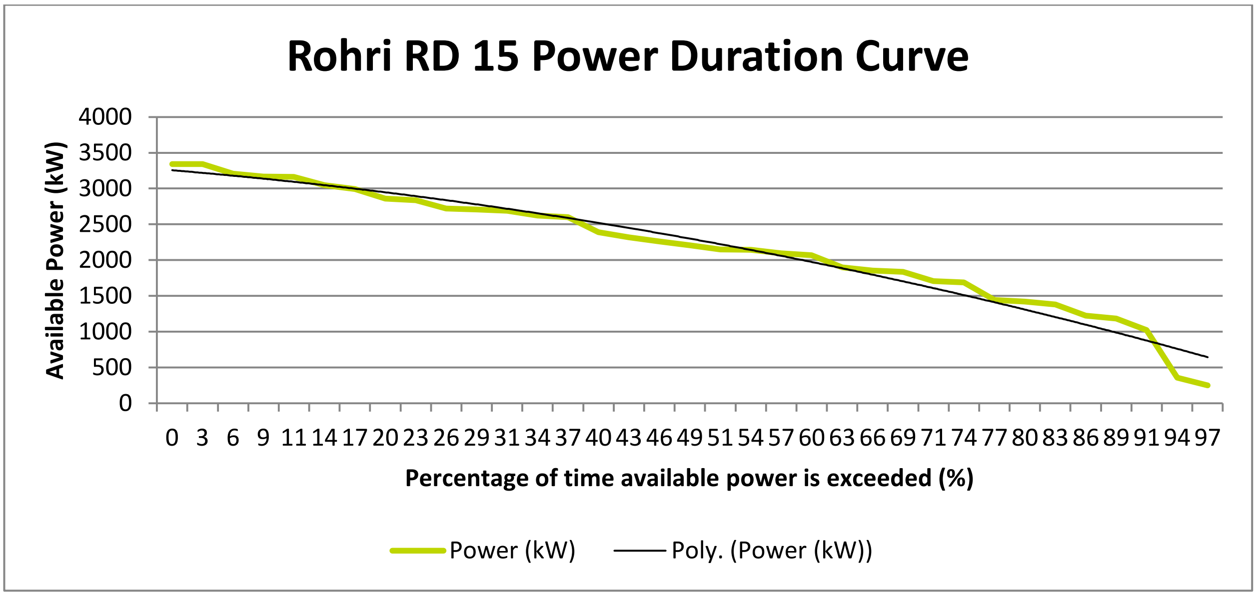

Figure 17. Power duration curve Rohri Canal fall regulator RD15

Figure 18 below shows the available power over the year based on the assumptions and available data. Available power varies between 1.5MW to 3.3 MW between the middle of April and November. Slightly less power is available between December and the middle of April. All regulators and barrages observe currently a closure period for approximately 10 days during the low flow season. During this period the regulator is inspected and any necessary maintenance is carried out. This procedure is also undertaken at the Rohri Canal fall regulator RD15 in January and no power would be supplied during this time. Given that this is the low flow season where the least power would be generated this practice is seen as a reasonable one. This period of time could be used for inspection of the turbines and any maintenance works required.

The head water level at the site varies between 0.3 to 2.14 m (1ft and 7 ft). It may be possible to reduce the variation in headwater level and increase the average headwater level by changing the operating regime and Rohri Canal head regulator and the gate opening regime at the fall regulator to maximise the power output of the turbines. This option should be discussed with the Irrigation Department.

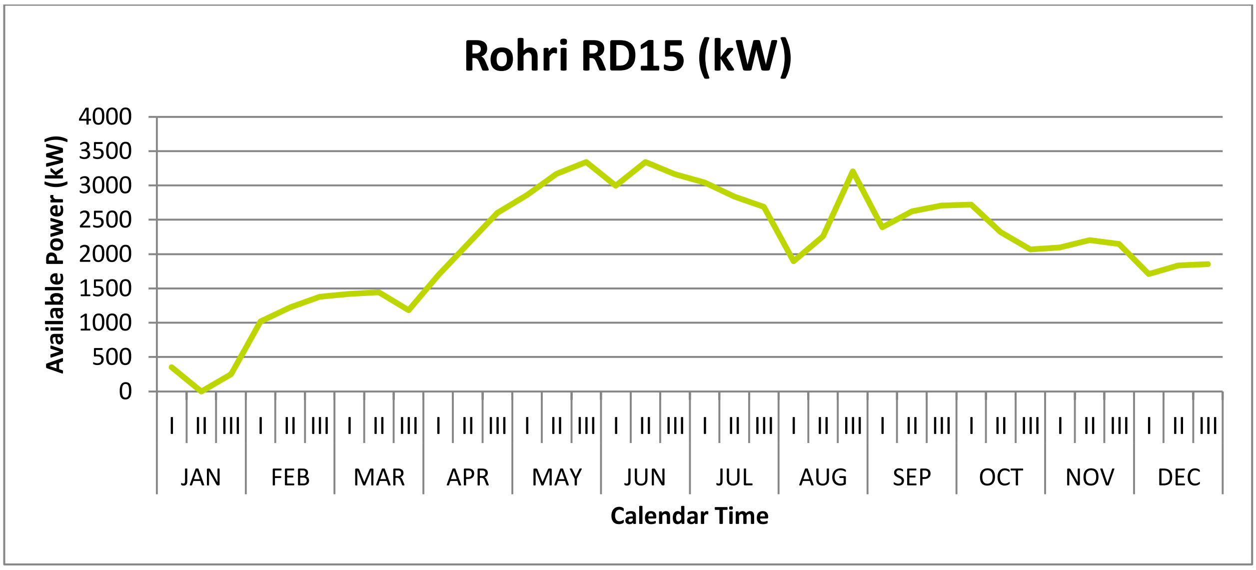

Figure 18. Available power against time at Rohri Canal RD15 fall regulator

Options for turbine type have not been evaluated in detail at this stage and a more detailed assessment will be undertaken at the next stage of the project to determine the most suitable turbine type. An access road to the site is available on the left bank of the canal. The assessment undertaken by CIWEC concluded that the access road was not in sufficiently good condition to allow construction to progress and a new road along the same alignment may be required. This assessment has not been confirmed at this stage by the Consortium.

The land on the right bank is mostly agricultural land and it is anticipated that any required land for the development of hydropower at this site could be purchased or leased from the relevant landowners. Ownership of the land adjacent to the structure would need to be confirmed as part of the next stage of the project.

It is likely that the grid connection could be established in the vicinity of Sukkur/Rohri although the grid connection requirements would need to be confirmed during the next stage of the project by a qualified transmission engineer.

Sediment concentrations at the site would need to be established through a campaign of sampling over a range of flow rates to confirm whether these will affect turbine design life.

The option of changing the operating regime of the head regulator and the fall regulator should be investigated further including confirmation of bank levels between the head regulator and the fall regulator and discussions with the Irrigation Department.

4.5. Rohri Canal Fall Regulator RD118

The Rohri Canal fall regulator (27˚26'03.4 1"N 68˚39'03.1 3"E) is located approximately 36 km downstream of the Rohri Canal Head Regulator. The regulator consists of 5 gates, each of which is 30 feet (9m) wide. An aerial view in Figure 19 below shows that the Rohri Canal fall regulator is located in an area of sparse development and with an apparently suitable access road. The condition of the access road has not been verified by the consortium at this stage.

Figure 19. RD-118 aerial view

Source © 2011 Google

In addition there is a settlement nearby meaning connection to the grid and required worker facilities may be obtained.

Records of previously experienced flows and head differentials at RD118 were obtained from The Irrigation & Power Department of Sindh and were used to generate a power curve, Figure 20, which shows that a development of 2.5 MW would be viable at the site, based on information received and taken from the derived Power Curve.

The Power Duration Curve was compiled using daily readings for discharge and up and downstream levels that have been averaged into 10 daily averages, giving 3 readings per month for discharge and head. Three years of data would not be considered sufficient to finalise a scheme, however on the assumption of accurate data then three years is acceptable at the preliminary assessment stage of a project. The power calculation is based on an assumed system efficiency of 55% to account for energy losses, turbine efficiency and transmission efficiency. It is assumed that 100% of available flow can be used for hydropower.

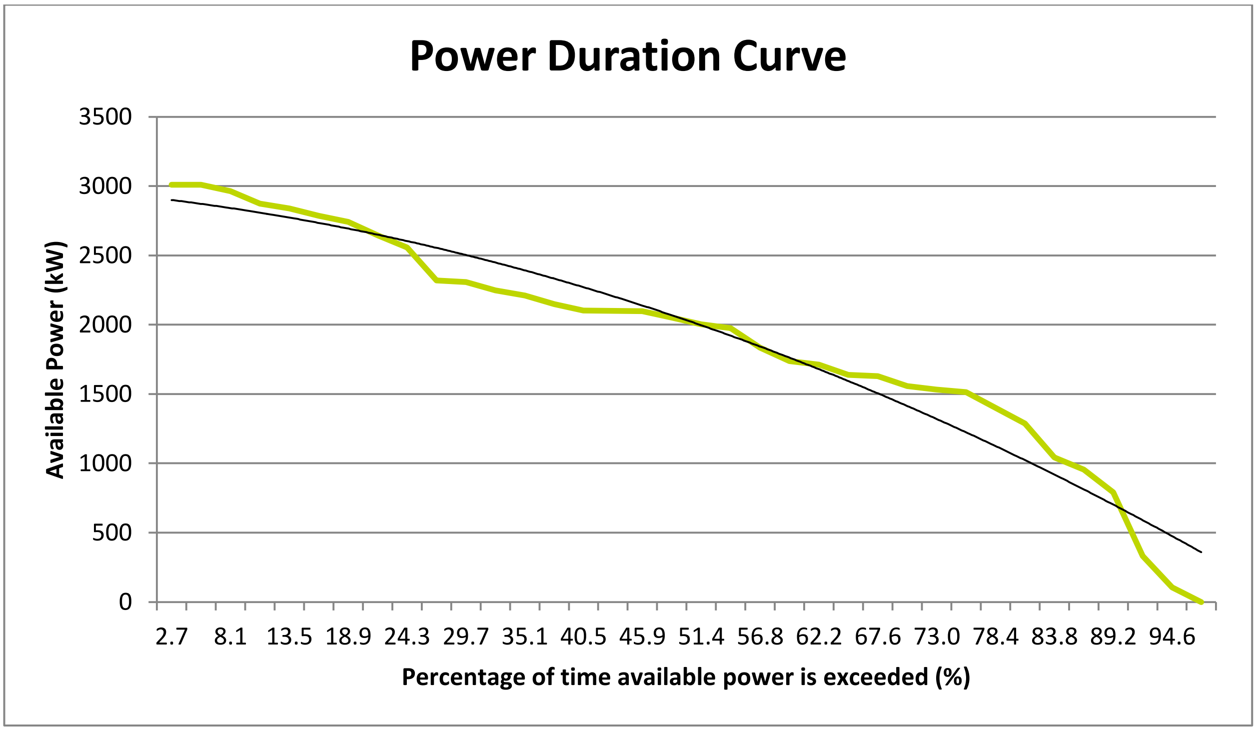

Figure 20. **Rohri Canal Drop Regulator RD-118 Power Curve**

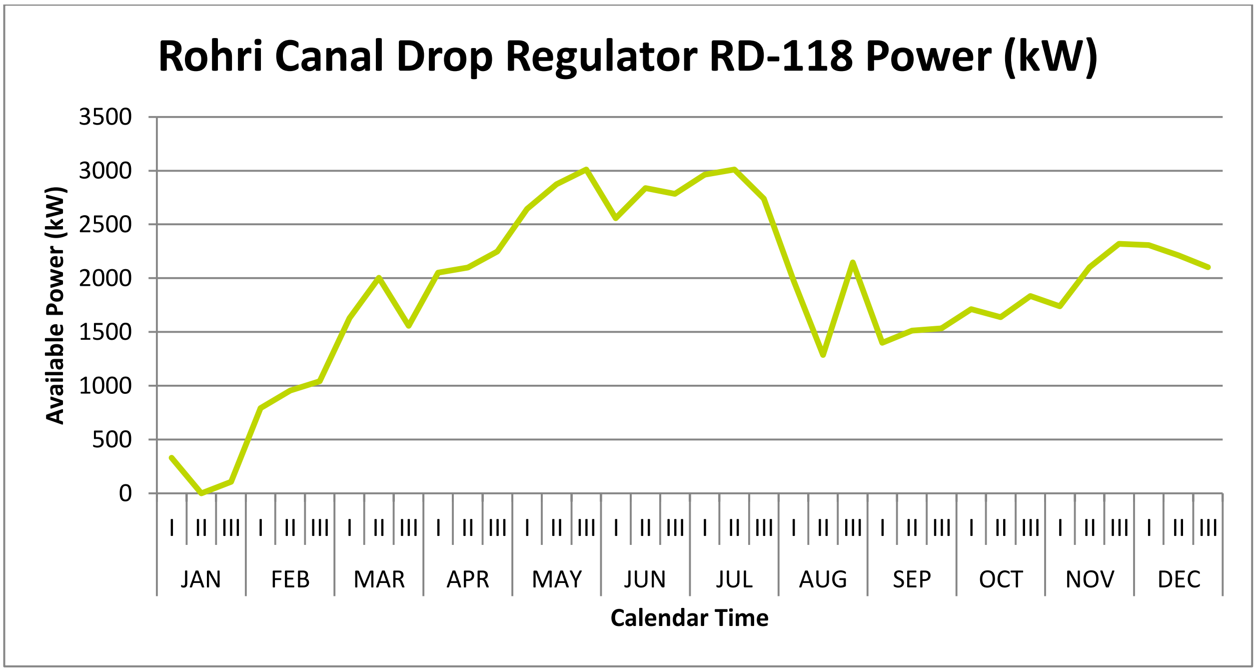

Figure 21. **RD-118 Power Availability Graph**

Figure 21 shows that for the period of record we obtained there is a significant reduction in available power in September. This is due to the canal being closed during the month of September 2011; due to the limited availability of data for this site (2010, 2011) this may not accurately reflect normal operating procedure. However, were a month long closure to occur regularly then the impact of this upon the economics of the development would have to be considered, the impact of this could be mitigated by combining annual maintenance of the hydropower units with this down period and the record does imply that available flow is reduced during the period of closure.

Options for turbine type have not been evaluated in detail at this stage and a more detailed assessment will be undertaken at the next stage of the project to determine the most suitable turbine type should this site be taken forward.

The surrounding land is mostly agricultural land and it is anticipated that any required land for the development of hydropower at this site could be purchased or leased from the relevant landowners. Ownership of the land adjacent to the structure would need to be confirmed as part of the next stage of the project.

It is not known whether grid connection is available in the vicinity of the site. It is likely that grid connection would be possible in the vicinity of Sukkur/Rohri about 36km from the site. Grid connection requirements would need to be confirmed during the next stage of the project by a qualified transmission engineer.

Sediment concentrations at the site would need to be established through a campaign of sampling over a range of flow rates to confirm whether these will affect turbine design life.

4.6. Guddu Barrage

Guddu Barrage is located near the border between Sindh Province and Punjab Province approximately 160 km (100 miles) upstream of Sukkur Barrage. The barrage is 1.3 km (4,445 ft) wide and comprises 64 gates of 18.3m (60 ft) width each. The structure also has a navigation lock of 15.24m (50ft) width.

Four canals off-take from the barrage – Rainee Canal and Gothki Feeder from the left bank, and Desert Pat Feeder and Beghari Sindh Feeder from the right bank as shown on the schematic in Figure 22 below.

Figure 22. Aerial view of Guddu Barrage and off-taking canals.

Source © 2011 Google

The options for development of hydropower are Guddu Barrage have been described in Section 2.3 above. Of the options investigated Options 1 and 3 are recommended for further investigation in particular with regards to the sediment management at the structure.

4.7. Pinyari Feeder Lower RD36

Old Fuleli Canal discharges from the left bank of the Kotri Barrage complex, the most downstream barrage on the River Indus. The Old Fuleli Canal is fed from a combined channel head regulator and has a design discharge of 405 m^3/s (14,350 ft^3/s) and previously has been operated in a non-perennial manner; however the flow records now indicate that it is operating perennially. The Old Fuleli canal discharges into the Pinyari Feeder Lower downstream of the bridge at RD 114. The fall regulator is shown below in Figures 23 and 24, and is located approximately 11km downstream at 25˚05'52.07"N 68˚25'03.79"E:

Figure 23. Pinyari Feeder Lower RD36 position relative to Kotri Barrage

Source © 2011 Google

Pinyari Canal fall regulator consists of 12 bays approximately 3.65m (12 feet) wide each.

Figure 24. Pinyari Feeder Lower RD36

Source © 2011 Google

The identified potential hydropower at the site is 0.2 MW, as shown in Figure 25. The power capacity of the site was calculated by consideration of the Power Duration Curve. This was compiled using daily readings for discharge and up and downstream levels that have been averaged into 10 daily averages, giving 3 readings per month for discharge and head. Three years of data would not be considered sufficient to finalise a scheme, however on the assumption of accurate data then three years is acceptable at the preliminary assessment stage of a project. The power calculation is based on an assumed system efficiency of 55% to account for energy losses, turbine efficiency and transmission efficiency. It is assumed that 100% of available flow can be used for hydropower.

The low available power combined with the variability of available power throughout the year, Figure 26 means Pinyari Lower Feeder is not a suitable site for a hydropower development. The small level of available power at the site means that the fixed costs associated with a hydropower development would be greater than the available revenue and therefore the site was considered not viable.

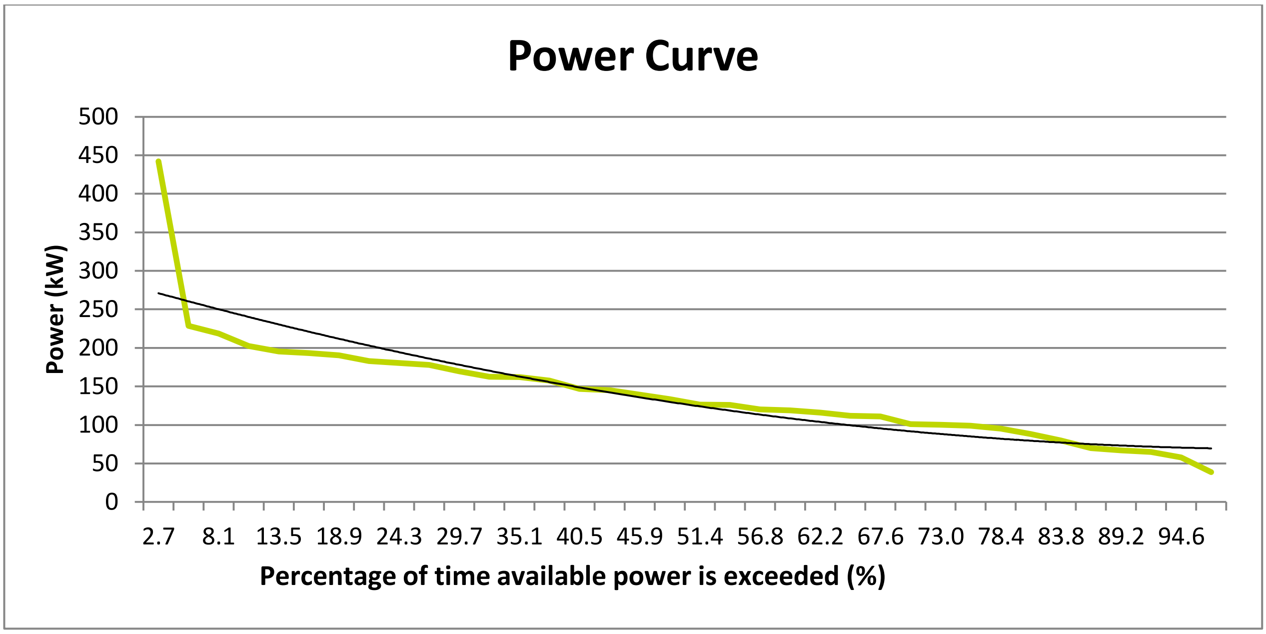

Figure 25. Power Curve Pinyari Feeder Lower

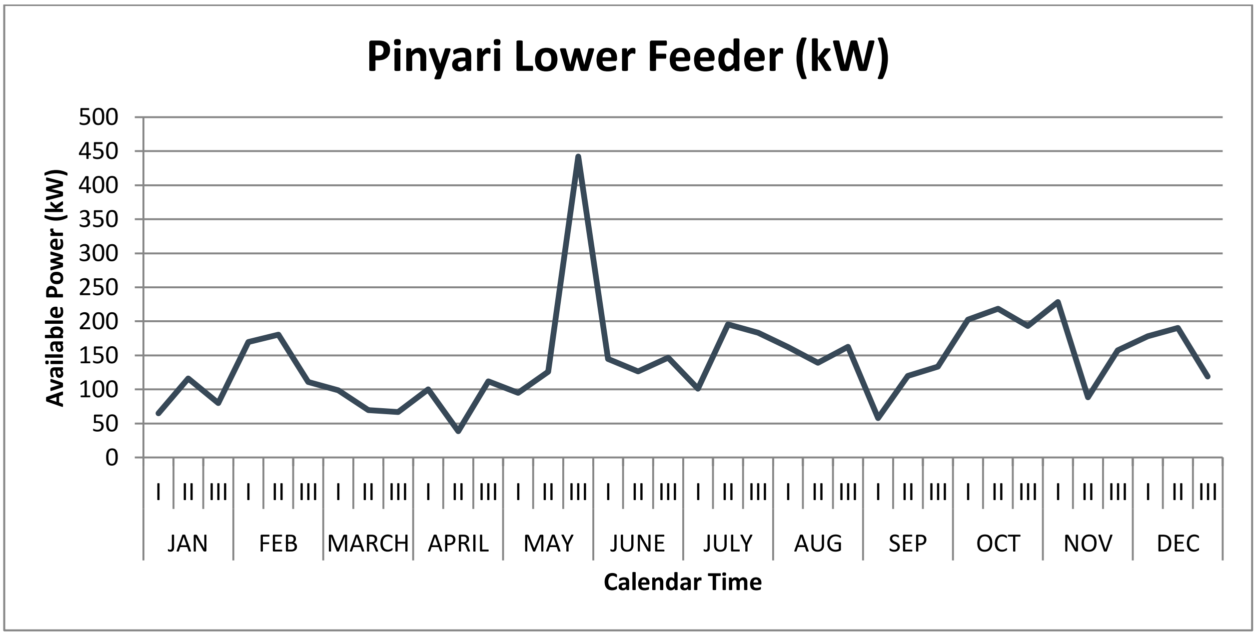

Figure 26. Pinyari Feeder Lower

4.8. KB Link Canal RD 19.5

K.B. Link Canal RD 19.5 regulator is located adjacent to Kalri Lake approximately 50km southwest of Hyderabad (24˚59'56''N 68˚08'38"E). The regulator consists of 5 gates. An aerial view in Figure 27 below shows that the fall regulator is located in an area of relatively sparse development. Condition of any access roads is unknown and would need to be confirmed during the next stage should this site be taken forward for development.

Figure 27. Location of the KB Link Canal 19.5 Structure

The identified potential hydropower at the site is 1.4 MW, as shown in Figure 28. The power capacity of the site was calculated by consideration of the power duration curve. This was compiled using daily readings for discharge and up and downstream levels that have been averaged into 10 daily averages, giving 3 readings per month for discharge and head. Three years of data would not be considered sufficient to finalise a scheme, however on the assumption of accurate data then three years is acceptable at the preliminary assessment stage of a project. The power calculation is based on an assumed system efficiency of 55% to account for energy losses, turbine efficiency and transmission efficiency. It is assumed that 100% of available flow can be used for hydropower.

Figure 28. View showing immediate vicinity of KB link canal, RD 19.5.

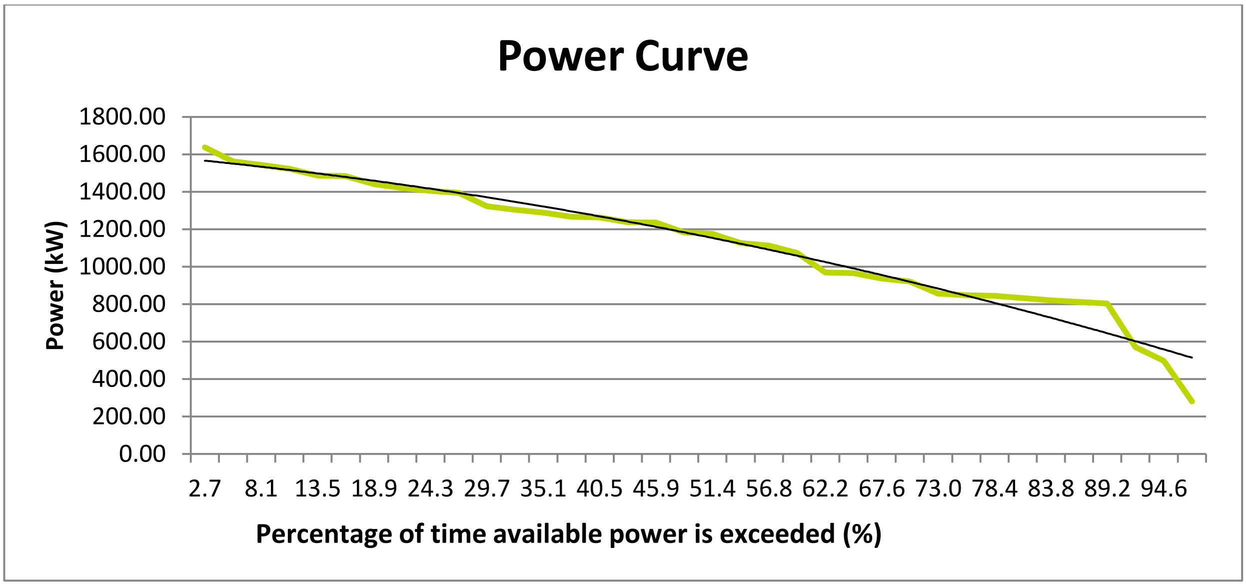

Figure 29. Power Duration Curve

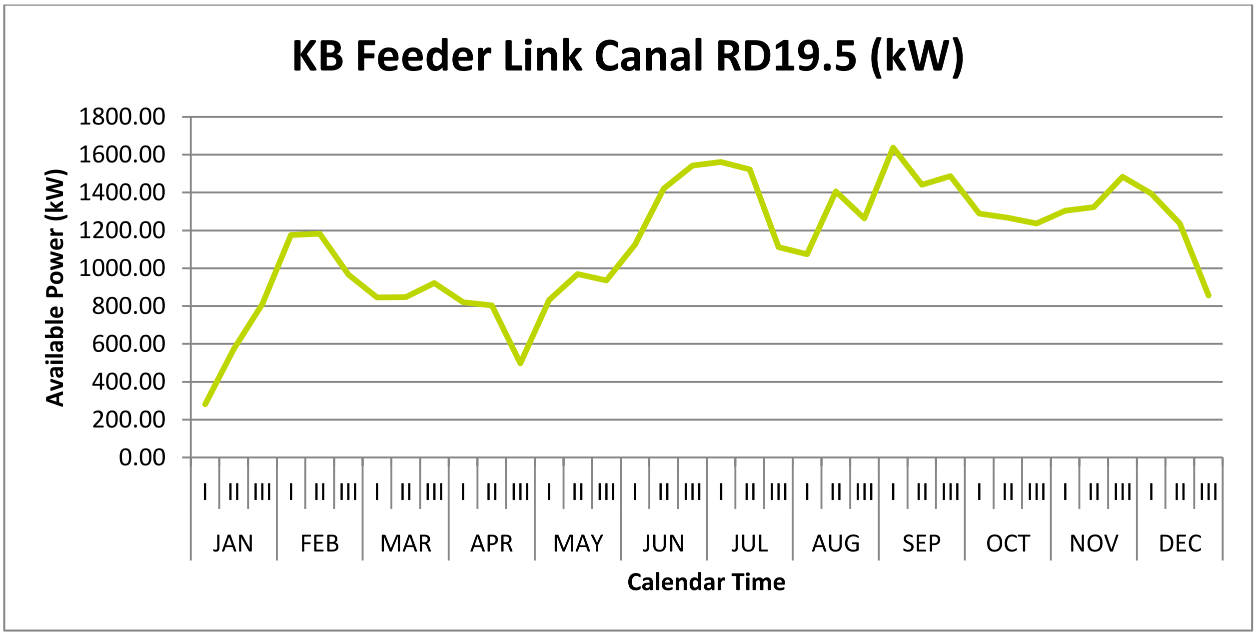

Figure 30. KB Feeder Canal available power

Figure 30 shows the available power over the year and demonstrates that greater than 1MW generation capacity would be available between June and middle of December.

4.9. Nara Canal RD 26

Structure RD 26 is located on the Nara canal approximately 7.6km downstream of Sukkur Barrage, where the Nara canal off takes; it feeds the largest canal in Pakistan and has an original discharge capacity of 400 m^3/s (14,145 ft^3/s).

The structure was constructed in the 1980s and the diversion channel used is still evident, meaning temporary works would be greatly simplified for the required works.

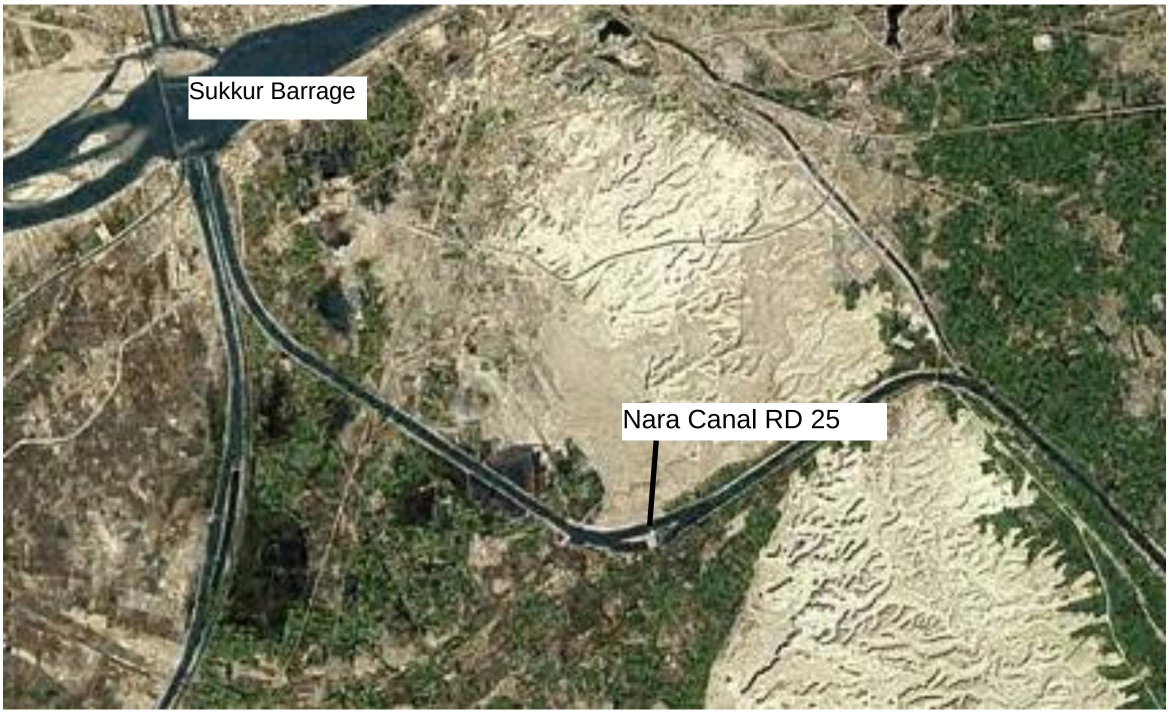

Figure 31. Fall Regulator RD 25's position in relation to Sukkur Barrage.

The surrounding area is suitable for construction, being sparsely populated. There is a vehicular access road on the left bank of the canal which is not in good condition and would require works to allow it to be used for construction access. Connection to the electrical grid are likely possible in the vicinity of Rohri/Sukkur but this would need to be confirmed in the next stage of the project should this site be taken forward.

Figure 32. Structure RD 26 on the Nara Canal, with previous diversion channel showing.

The power curve for RD 26 has been calculated utilising the design head as accurate head level data is not available, because of this error bars of +/- 25% shall be used to give a range of potentials. This design head was confirmed by a spot reading undertaken on one day in 2012. Should this site be shortlisted, more accurate data for the head values should be collected and used.

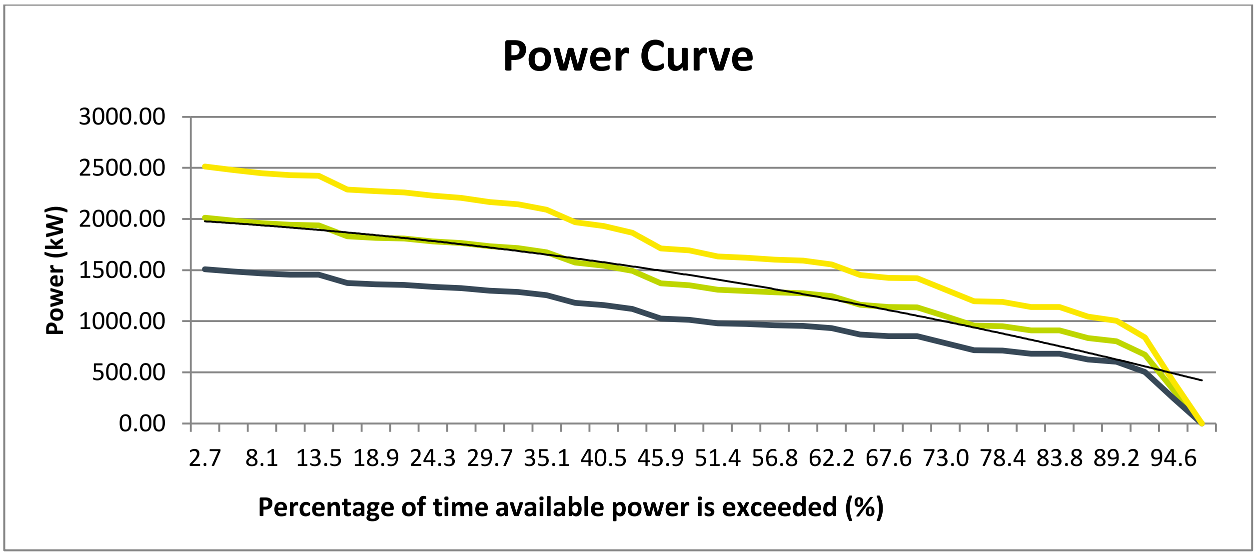

Figure 33. RD 26 power curve

Figure 33 shows that the site has a power potential 1.8MW with recorded flows at design head. Dependant on actual head the power potential may be between 1.3 and 2.2 MW.

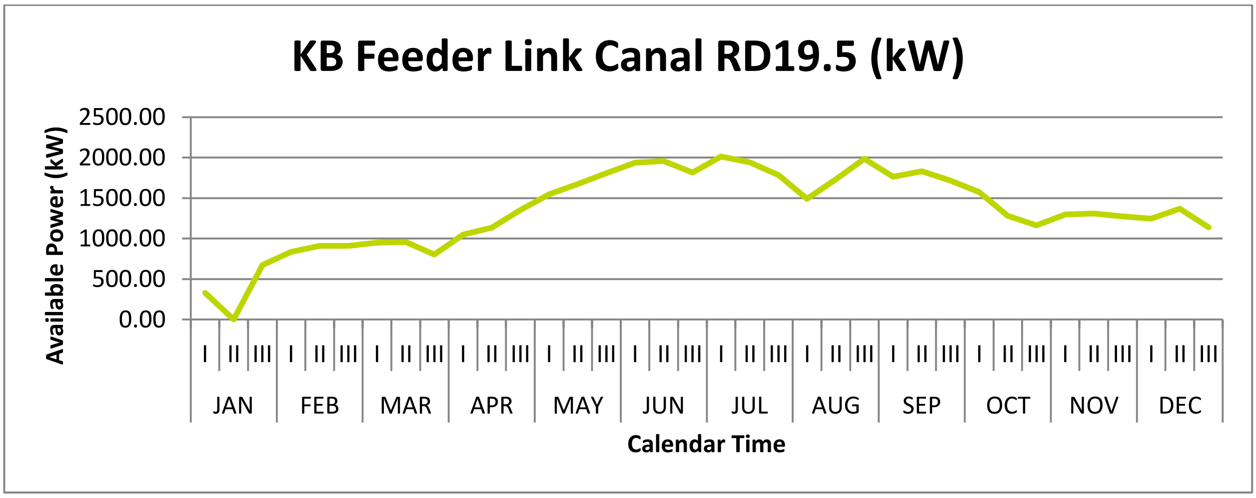

Figure 34. Annual power distribution

The power capacity of the structure is relatively evenly distributed throughout the year, with more power available in the months June to October. A closure period is observed in January which could be used for inspection of turbines if required.

5. 4.0 Conclusions & Recommendations

5.1. Conclusions

Based on the available information including flow and water levels records as well as previous studies our outline assessment indicates that the following four sites are most suitable for the development of hydropower:

1. Rohri Canal RD15
2. Rohri Canal RD118
3. Guddu Barrage; and
4. Sukkur Barrage

Table 5 presents a comparison of the sites with regards to the potential power and significant factors affecting the viability of the sites. The assessment will be presented to the client during a meeting on the 17th September to enable a decision with regards to the site to be taken forward for further development.

Site	Power potential	Constraints	Opportunities
Rohri Canal RD15	2.7 MW	New access road may be required Sediment concentrations unknown. Additional data required. Structure condition to be confirmed More expensive per MW than Guddu and Sukkur	Sufficient space available to develop site Lower costs for development than Sukkur and Guddu Barrage Grid connection to be confirmed but likely to be viable at Sukkur/Rohri Power potential varies little over the year with exception of Jan to Mar when flows are low Short programme duration to commissioning Staff with experience of operation and maintenance of large hydraulic structures is available in the vicinity of the structure at Sukkur Barrage. It is anticipated that the staff would be able to assist with the operation and maintenance of the hydropower plant. Some training would be required. Potential to increase head

			difference and power output through changes in operation of this regulator and the Rohri head regulator Relatively low risk
Rohri Canal RD118	2.5 MW	Sediment concentrations unknown. Additional data required Structure condition to be confirmed Potential for grid connection to be confirmed Power potential more variable than Rohri Canal RD 15 Operational staff at this site are likely to be less experiences than at Sukkur or Guddu More expensive than Guddu and Sukkur. Likely to be more expensive than Rohri RD15 if it is confirmed that the distance to the grid connection point is further.	Sufficient space available to develop site Lower costs for development than Sukkur and Guddu Barrage No new access road required. Short programme duration to commissioning Relatively low risk
Guddu Barrage	42.4 MW	May exacerbate sedimentation issues at the barrage and the off-take canals. Further investigations required. Likely to require more detailed investigations and therefore likely to take longer to implement High risk For head differences <1.8m no power generation is feasible. Therefore the period of high flows during the summer months cannot be utilised for power	Access to site is available. No new access roads required. Potential for grid connection likely to be available Proposals may be incorporated as part of the proposed Guddu Barrage refurbishment thereby reducing implementation costs Higher certainty of available flows as data is available over a longer period of time. Staff with experience of

		generation. Longer programme duration	operation and maintenance of large hydraulic structures is available in at Guddu Barrage. It is anticipated that the staff would be able to assist with the operation and maintenance of the hydropower plant. Some training would be required. Slightly lower cost per MW than canal sites.
Sukkur Barrage	30MW	May exacerbate sedimentation issues at the barrage and the off-take canals. Further investigations required. Likely to require more detailed investigations and therefore likely to take longer to implement High risk Long programme until comissioning	Access to site is available. No new access roads required. Potential for grid connection likely to be available Proposals may be incorporated as part of the proposed Sukkur Barrage refurbishment thereby reducing implementation costs Staff with experience of operation and maintenance of large hydraulic structures is available in at Guddu Barrage. It is anticipated that the staff would be able to assist with the operation and maintenance of the hydropower plant. Some training would be required. Slightly lower cost per MW than canal sites. Higher certainty of available flows as data is available over a longer period of time.

Table 5. Comparison of sites

It is recommended that Rohri RD15 should be taken forward for development as the preferred site due to the available power and the limited constraints of the site. Subject to discussions with the Irrigation Department it may be possible to optimise the head difference at this site by changing the operating procedures at this site and the Rohri head regulator.

5.2. Next Steps

Following on from this initial site selection process the following activities will be undertaken:

- Confirmation of grid connection location
- Socio-Economic viability assessment
- Technical viability assessment including development of schematic designs and selection of equipment
- Initial environmental examination
- Financial viability assessment
- Preparation of tender documents for development under a EPC contract

6. References

1. Energy Efficiency And Renewable Energy, Small Hydropower Systems – Department of Energy (July 2001)
2. http://en.wikipedia.org/wiki/List_of_countries_by_energy_consumption_per_capita (Source of data is the World Resources Institute)
3. Vision 2030, Chapter 9 – Energy for Growth
4. Integrated Energy Plan 2009-2022 – Energy Expert Group, Ministry of Finance, Economic Advisory Council (March 2009)
5. Hydropower Resources of Pakistan – Private Power and Infrastructure Board (February 2011)
6. Hydropower Potential in Pakistan – Pakistan Water and Power Development Authority (November 2011)
7. http://www.ooskanews.com/daily-water-briefing/pakistan-approves-24-billion-usd-irrigation-energy-infrastructure_23998
8. Guddu Barrage Rehabilitation: Feasibility Study, Annex N: Hydropower – Mott MacDonald (December 2011)
9. a) The Sukkur Barrage Site Investigation Preliminary Report – CTGPC (June 2011)
   b) Sukkur Hydropower Project: Technical Assessment – China International Water and Electric Corporation; China Water Resources Beifang Investigation, Design, and Research Co. Ltd (August 2011)
10. Rohri Canal: Technical Offer – Andritz Hydro (2011)

Appendices

Appendix A. Available Data

A.1. Overall Strategic Context

1. *Energy State of the Industry Report 2006 to 2011*
2. *Vision 2030 – Chapter 9 Energy for Growth*
3. *Annual Plan 2011-12 – Chapter 10 Energy*
4. *Pakistan Integrated Energy Model – Model Design Report and Policy Analysis Report (2011)*
5. *Annual Plan 2011/12 – Chapter 11 Water resources*
6. *Global Climate Projections, Intergovernmental Panel on Climate Change (IPCC)*
7. *Regional Climate Projections, IPCC*
8. *Glaciers Behaviour under Climate Change and its Impacts on Agriculture in Pakistan, Seminar Proceedings, June 2008, Food and Agriculture Section, Planning Commission Islamabad*
9. *Climate Change in Central and West Asia, ADB*

Information on any hydropower projects previously undertaken or planned on any of the other barrages outside of Sindh province

10. *Guddu Barrage Rehabilitation Project, Hydropower Feasibility Study, Mott MacDonald, 2012*

Information on silt/suspended sediment materials in the Indus River

11. *Suspended sediment concentrations and grading at Sukkur Barrage undertaken during the 2005 feasibility study.*
12. *Suspended sediment concentrations at Sukkur 2009 to 2011*
13. *Guddu Barrage Rehabilitation Project, Geomorphology Report, Mott MacDonald, 2012*

Overall strategic context/studies for Sindh

14. *Command system map*
15. *Details of trans-provincial water agreements* – Statement of the Province of Sindh on the Points Laid Down by the Indus Water Committee, Jan 1971

Sindh Barrages

16. *General arrangement drawings for the barrages and head regulators*
    Sukkur Barrage general arrangement, cross sections through

    Sukkur Barrage cross section through

    Guddu Barrage – cross section available

    Kotri Barrage – cross section available

17. *Schematics of head regulators, sub regulators and each barrage*

    Schematics available for head regulators and barrages. Design bed levels, supply water levels, design discharges and design bed widths are available for sub regulators from the canal long sections. Canal long sections are available for the following canals:

    Dadu Canal

Rohri Canal

Rice Canal

Rainee Canal

Ghotki Canal

Beghari Canal

Kalri Bhagar Upper, Lower and Link Canals

Pinyari Upper and Lower Canal

Akram Wah Canal

Phulleli Canal

18. *Topographic survey information at the barrage site*

    Available for Sukkur Barrage. Not available for Guddu or Kotri

19. *Information on ground conditions.*

    Some information available for Sukkur. None available for Guddu or Kotri.

20. *Any previous studies on hydropower potential at the barrage sites.*

    The following reports have been made available:

    The Sukkur Barrage Site Investigation Preliminary Report

    Sukkur Hydropower Project Technical Assessment

    Rohri Canal Technical offer Andritz Hydro

21. *Maximum, minimum and average discharge for each of the barrages, head regulators and sub regulators.Discharge records.*

    Available for the following:

    Sukkur Barrage

    Guddu Barrage

    Kotri Barrage

    NW Canal

    Rice Canal

    Dadu Canal

    Nara Canal

    Khaipur Feeder East

    Khaipur Feeder West

    Rohri Canal

Ghotki Canal

Beghari Canal

Desert Canal

22. *Maximum, minimum and average head at each of the barrages, head regulators and sub regulators. Water level records.*
    Available for the following:

    Sukkur Barrage

    Guddu Barrage

    Kotri Barrage

    Ghotki Canal

    Beghari Canal

    Desert Canal

    For the following sites a limited period of water level records of one year is available.

    NW Canal

    Rice Canal

    Dadu Canal

    Nara Canal

    Khaipur Feeder East

    Khaipur Feeder West

    Rohri Canal

23. *Suspended sediment materials information at each barrage site and for the head regulators if available.*

    Some limited information available at Sukkur. Guddu and Kotri not available.

24. *Record of temperature at each barrage site*

    Internet source identified providing data for Sukkur and Kotri. Unavailable for the other sites.

25. *Grid connection information for each barrage site.* Not available
26. *Information on transport capacity to each site/vicinity to ports*. Not available

Mike Woolgar
WS Atkins International
Woodcote Grove
Ashley Road
Epsom
KT185BW
UK

Email: mike.woolgar@atkinsglobal.com
Telephone +44 1372 756 280