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RIVER SAND MINING - INTERNATIONAL REVIEW

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Version	A

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report is a rapid review of international practice in riverbed sand mining. The purpose of the report is to identify and introduce ideas and guidelines that may assist Nepal in better management of the sector.

Riverbed sand mining (which includes sand, gravels and boulders) is widespread internationally. Many countries rely on rivers for part or most of their supply of aggregates for construction. It is therefore an essential industry.

Riverbed sand mining depends on a supply of materials (sediment) from upstream. If more material is removed than is supplied, the riverbed will be lowered locally; this lowering may propagate both upstream and downstream, in turn affecting infrastructure such as bridges and irrigation system intakes. If less material is removed than is supplied, riverbeds may rise, increasing the chances of the river changing course. Sustainable riverbed sand mining therefore requires accurate assessment of available materials and closely-managed extraction operations. This is a challenge for many countries.

Riverbed sand mining may have ecological and social impacts as well as physical impacts: water quality and habitat may be affected, usually negatively; on the positive side, the industry can provide formal and informal employment opportunities – although working conditions may be dangerous and wages low.

No reports on climate change adaptation and riverbed sand mining have been identified by this review. Climate change will probably increase the sediment supply in Nepal (due to more rain and floods) creating both a **threat** (rising riverbed levels) and an **opportunity** (more sand and gravel). Under these circumstances **riverbed mining can be regarded as an important climate change adaptation measure**, by keeping river channels clear for safe passage of floodwaters.

Some countries have developed specific guidelines for riverbed sand mining. These vary in their technical content. The most useful and relevant for Nepal include guidelines from Malaysia, the USA, and the UK's Department for International Development.

Key lessons for Nepal from international experience are that:

- River sand mining **can be sustainable** and can be successfully managed.
- **Significant technical knowledge and resources** are required to identify safe extraction sites and volumes.
- Most importantly, **an effective governance environment is essential** (policy, laws, regulations and administrative machinery) - and this should recognise the importance of the industry as both an economic driver and a key management tool for flood protection.
- If river mining cannot be managed effectively, it is generally **environmentally safer to develop non-river sites** (in floodplains and river terraces).

The basic requirements of an effective control system include:

1) An **effective legislative framework** that allows the exercise of control over river mining and other forms of quarrying activity.
2) An administrative structure that gives **clear responsibility and authority** to the respective agencies involved in such regulation.
3) **Well informed policies** for the development and control of river mining and other forms of land-use as part of an integrated approach to land-use and the environment.

4) A system of permitting or licensing that requires a **consistent level of information** to be provided prior to individual decisions on applications to open a mine or quarry, measured against the policies and proposals set out in the forward planning context.
5) A **shared commitment to the effective operation of the system by government and other stakeholders**, including a commitment to effective monitoring and enforcement that is adequately resourced and informed of illegal mining or activity inconsistent with the licence or permit.

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ADB	Asian Development Bank
CA	Constituent Assembly
CC	Climate change
DDC	District Development Committee
DFID	Department for International Development (UK)
DFO	District Forest Office
DHM	Department of Hydrology and Meteorology
DID	Department of Irrigation and Drainage (Malaysia)
DoLIDAR	Department of Local Infrastructure Development and Agricultural Roads
DSCO	District Soil Conservation Office
DTO	District Technical Officer
DWIDP	Department of Water-Induced Disaster Prevention
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EPA	Environmental Protection Act
EPR	Environment Protection Rules
GLOF	Glacial lake outburst flood
GoN	Government of Nepal
GSI	Geological Survey of India
HEC-RAS	Hydrologic Engineering Centers River Analysis System
ICEM	International Centre for Environmental Management
IEE	Initial Environmental Examination
LAPA	Local Adaptation Plan of Action
LDO	Local Development Officer
LDOF	Landslide dam outburst flood
LDRMP	Local Disaster Risk Management Planning
LSGA	Local Self-Governance Act, 1999
LSGR	Local Self-Governance Regulations, 2000
MoFALD	Ministry of Federal Affairs and Local Development
MoLD	Ministry of Local Development (now MoFALD)
MoSTE	Ministry of Science, Technology and Environment
NAPA	National Adaptation Programme of Action
NMFS	National Fisheries Marine Service (USA)
PEP	People's Embankment Programme
SGS	Sand, gravel and stone
SPCR	Strategic Programme for Climate Resilience
STD	Sexually-transmitted disease
TA	Technical assistance
TOR	Terms of Reference
UK	United Kingdom
UNDP	United National Development Programme
UNEP	United Nations Environment Programme
USGS	United States Geological Survey
VDC	Village Development Committee

GLOSSARY

aggradation	raising of riverbed level due to deposition of sediment
anadromous	fish that migrate between fresh and salt water
bankfull	the flow (discharge) of a river when it completely fills its channel but has not yet extended into the floodplain (Note: bankfull discharge (Q1.5), which typically has a recurrence interval of approximately 1.5 years, is an important benchmark because it is a dominant channel shaping flow (Leopold, 1994))
bar	elevated part of a riverbed created by deposition of sediment during high flows
bar skimming	removal of shallow layer of sediment (sand or gravel) from the surface of a bar
basin (drainage basin)	see a) catchment, b) watershed
bedload	the sediment (sand, gravel, boulders) transported downstream by sliding or rolling along the bed of a river
braided river	river with multiple shallow channels that split and rejoin, typically with variable discharge and coarse sediment
catchment	area of land within which all water moves to one river system (US: watershed)
degradation (downcutting)	the lowering of a river channel by riverbed erosion
divide	US: line of elevation from which water runs in two directions (UK: watershed)
evulsion (avulsion)	sudden change in course of a river, typically by breaking the banks of a meander
flash flood	sudden high discharge in a river or stream typically caused by localised intense rainfall
fluvial geomorphology	the science of the form and function of rivers and their interaction with the landscape around them, with particular reference to how channel form changes over time
incision	a) degradation; b) the movement upstream (headcut) or downstream of erosion from a localised low point such as a site of riverbed sand extraction
knickpoint	point at which there is a sudden change in slope in a river channel, typically caused by erosion moving upstream (see incision)
mass movement	large-scale erosion from a small area, i.e. a landslide (as opposed to generalised surface erosion, gullying, riverbank erosion etc.)

profile	the longitudinal elevation of the bed of a river channel (slope)
reach	a length of river (varies according to context)
retrogression	phrase used by some technical staff in Nepal to describe riverbed incision and degradation
riffle	a short, relatively shallow and coarse-bedded length of river or stream over which the flow is at a lower velocity and higher turbulence than in the reach immediately above or below; typically there is a pool-riffle sequence streams
saltation	movement of sediment particles by 'bouncing' along the bed of a river
scour	localised riverbed and bank erosion associated with high flows; may result in hazards to infrastructure
sediment delivery ratio	ratio (%) of all sediment mobilised in a catchment by erosive forces (raindrop erosion, surface runoff, gullying, landslides etc.) to sediment actually transported by a river out of the catchment (sediment yield)
sediment yield	total amount of sediment transported out of a catchment
specific sediment yield	sediment yield per unit area, typically expressed in $t/km^2/yr$; often used to estimate to annual surface lowering (mm/yr)
stage	description of river discharge as indicated estimated by the height (stage) of the water surface in a river channel
suspended sediment	sediment transported by a river in the main body of water, not bouncing on the bottom (saltation) or rolling or sliding (bedload)
thalweg	line along the lowest part of a valley, typically along the bottom of the main river channel; also used to describe the centre of the main navigable channel
watershed	UK: line of elevation from which water runs in two directions (US: divide); US: area of land within which all water moves to one river system (UK: catchment)

1 INTRODUCTION

1.1 Background to the Study

The Asian Development Bank (ADB) has contracted the consortium of ICEM - International Centre for Environmental Management, METCON Consultants and APTEC Consultancy to provide technical assistance (TA) to the Ministry for Environment, Science and Technology (MoSTE) in implementing the project *Mainstreaming climate change risk management in development*. The TA supports MoSTE to implement Component 3 of Nepal's Strategic Programme for Climate Resilience (SPCR) and will last for five years (2012 - 2017).

The expected **impact** of the TA is that Nepal has increased resilience to climate variability and climate change. The expected **outcome** of the TA is that the Government of Nepal's (GoN) infrastructure development programmes, policies and projects incorporate safeguards to address the effects of climate change.

To achieve this outcome the TA has three **Outputs**, each composed of a number of **Activities**. **Output 1:** *Climate change risks are integrated into Nepal's implementation of development projects*, aims to integrate climate change risk management into physical implementation of development projects, with a focus on infrastructure and urban and rural service provision (especially water supplies and sanitation, roads and irrigation). In addition, the Terms of Reference (TOR) for the project include consideration of **riverbed sand mining**.

To achieve the outcome of Output 1, the TA is preparing climate change (CC) adaptation recommendations and training materials for the various line agencies based on case studies from eight pre-selected districts in various physiographic regions in Nepal. The riverbed sand mining aspect of the TA has fewer resources, and has focused on four of the districts (Dolakha, Kathmandu, Chitwan and Banke).

Reports and materials to be prepared by the TA in relation to riverbed sand mining are:

- An **institutional analysis** of the Ministry of Federal Affairs and Local Development (MoFALD) in relation to its responsibilities for management and administration of the sector.
- **Case studies** ("baselines") of the four districts.
- An **international review** of riverbed sand mining.
- **Recommendations on climate change adaptation** in the sector, based on the case studies and other investigations.
- **Recommendations on monitoring**.
- **Training materials**, to assist government at various levels in implementing the recommendations.

1.2 Purpose and Layout of this Report

This report is a brief review of international practices in riverbed sand mining. The material provides lessons and guidance for policy makers and technical staff working on reform of the sector in Nepal.

The report contains four further sections:

- An introduction to riverbed sand mining (Chapter 2)
- Notes on climate change and riverbed sand mining (Chapter 3)
- Riverbed sand mining guidelines (Chapter 4)
- Lessons for Nepal (Chapter 5)

Annexes include:

- References
- Extracts from international and national guidelines

2 OVERVIEW OF RIVERBED MINING

2.1 General

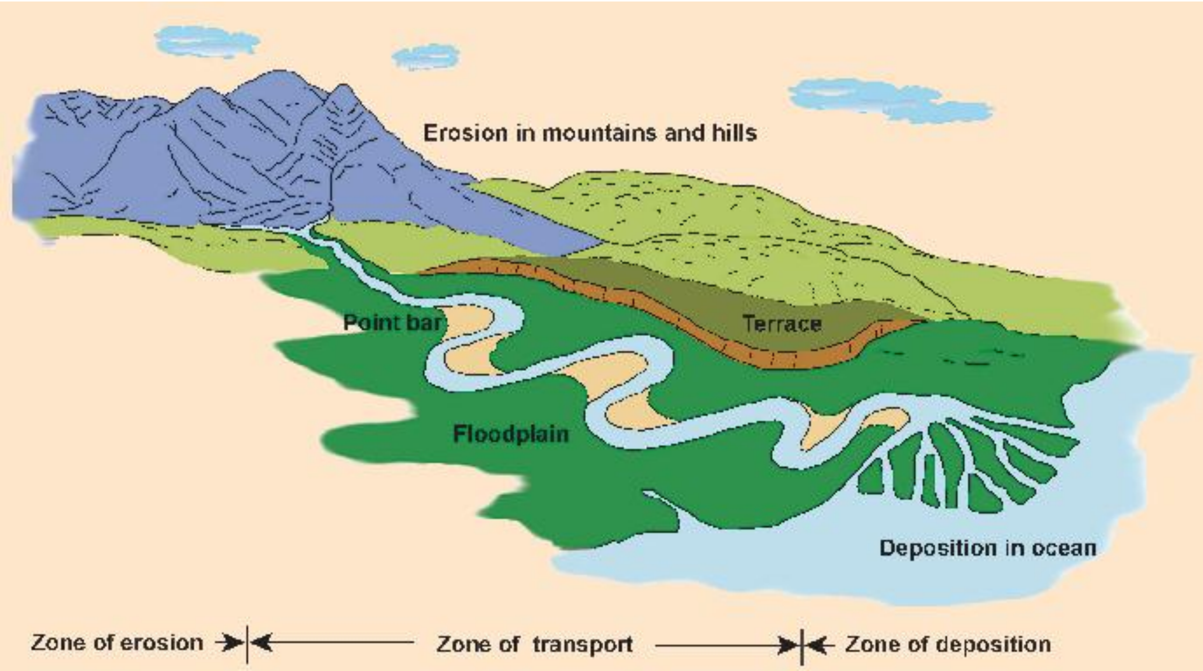
Construction requires the use of natural aggregates. These may be sand and gravel, found in a variety of locations across the landscape such as alluvial fans, glacial deposits, river terraces, floodplains and river channels, or crushed rock. Since natural aggregates are a high-volume, heavy and low cost commodity, they are sourced from as close to the point of consumption as possible. Consequently riverbed or in-stream mining for sand and gravel is a global phenomenon, occurring in virtually every country where there are rivers transporting sand and gravel.

Riverbed mining may be sustainable, or it may have severe negative impacts on aquatic wildlife, fisheries and stream channels.

2.2 River Erosion and Sedimentation

The amount of sand and gravel in a river is determined by the geological, hydrological, topographic and climatic characteristics of the watershed, together with watershed condition - a key factor reflecting human interference with natural conditions and processes. Gravity moves soil and stone material downslope to stream and river channels, where it is transported downstream by water. For sand, gravel and larger particles this process may be episodic, not continuous, since it is dependent on flow velocity. As they move downstream rock particles are abraded and rounded, and the resulting graded material is alternately deposited, eroded and transported until it eventually reaches the sea (or final internal drainage basin) (Figure 2.1).

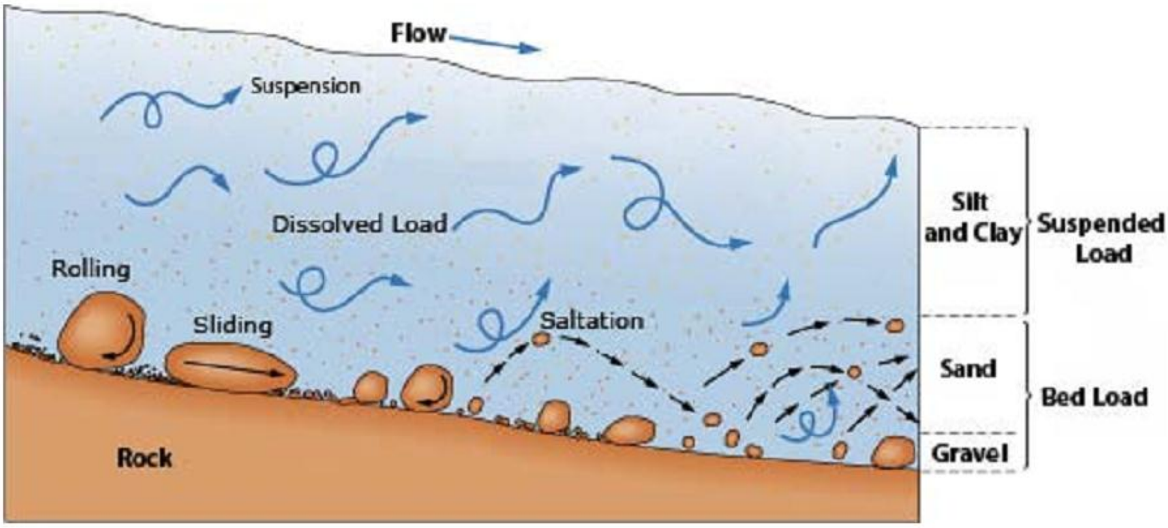
Figure 2.1: Origin, transport and deposition of stream sediments



Source: Langer (2003), modified from Kondolf (1997)

Modes of sediment transport along rivers are illustrated in Figure 2.2.

Figure 2.2: Modes of sediment transport in rivers



Source: DID (2009)

2.3 Stream Dynamics

As stated by Langer (2003), rivers are complex, dynamic geomorphic systems whose major function is to transport water and sediment. Over time, each river develops a particular combination of channel width, channel depth, channel slope, channel roughness, bed particle size, and water velocity that allows it to function in the most efficient manner - the river's "hydraulic geometry". Once established, the pattern will be maintained as long as variations in discharge and sediment load are within the limits of the existing hydraulic geometry. This may be termed dynamic stability - the river channel and form change over engineering timescales but the relationships are constant.

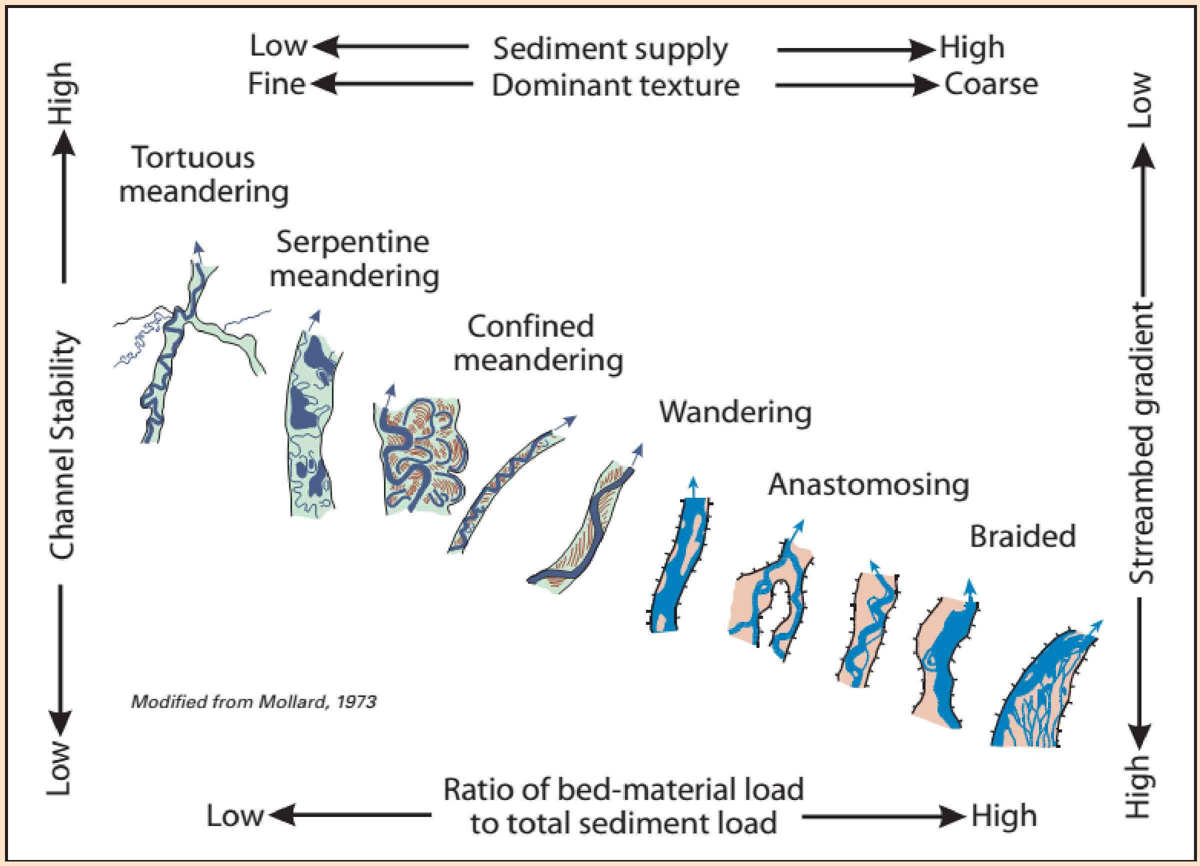
Langer (2003) notes that most river channels form and reform during a distinct range of relatively large flows referred to as the **dominant discharge**. After a dominant discharge event, the river will establish a new equilibrium by adjusting its hydraulic geometry. Because the hydraulic variables are inter-dependent and continuously adjusting, at best the river might achieve a state of quasi-equilibrium. The time that it takes for a river to return to its quasi-equilibrium form after a dominant discharge event is called the **recovery time**. In humid climates the recovery time is in the order of 1 to 20 years, while in semi-arid to arid regions the recovery time tends to be much longer. For a river to return to its state of quasi-equilibrium, the recurrence interval of a dominant discharge event must be greater than the recovery time.

As stated by Kondolf (1997), **bedload** ranges from a few percent of total sediment load in lowland rivers to perhaps 15% in mountain rivers to over 60% in some arid catchments. The rate of sediment transport typically increases as a power function of flow; that is, a doubling of flow typically produces more than a doubling in sediment transport, and most sediment transport occurs during floods.

Although a relatively small part of the total sediment load, the arrangement of bedload sediment constitutes the architecture (physical form) of sand and gravel-bed channels.

The relationship of stream geomorphology to sediment size and supply is illustrated in Figure 2.3.

Figure 2.3: Relationship of river and stream geomorphology to sediment size and supply



Source: Langer (2003)

2.4 Excavation (Extraction)

Sand and gravel in river channels may be above or below the water table. Dry deposits – sand bars and bed deposits in ephemeral streams - may be excavated using normal earthmoving machinery and equipment such as bulldozers and excavators, or manually. Wet-pit mining involves the use of a dragline or hydraulic excavator to remove gravel from below the water table or in a perennial stream channel. Deposits in flowing or standing water may be exploited by land-based excavators or draglines, or by dredging from barges, or again, manually. Bar skimming or scalping removes the surface from gravel bars without excavating below the low water flow level. Wet deposits may be dried out by dewatering, and stream channels may be diverted to facilitate riverbed mining. One categorisation of excavation methods is (Kondolf *et al*. 2001):

- Bar scalping or skimming
- Dry-pit channel mining
- Wet-pit channel mining
- Bar excavation
- In-stream gravel traps
- Channel-wide in-stream mining

2.5 Processing

Sand and gravel excavated from riverbeds may be used as is or processed to produce specific grades of material. Oversize stone (cobbles and boulders) may be crushed.

Sand and gravel processing is normally a simple mechanical process involving dry and wet sieving, and washing. Chemicals are not used, but the process is often associated with dust and noise.

2.6 Environmental Impacts

River mining may cause environmental and social impacts during all its major process - extraction, processing and transport (MacFarlane & Mitchell, 2003). This review focuses on the physical impacts of extraction.

As reviewed by Langer (2003), environmental impacts to river systems where in-stream mining has been improperly managed have been described by Collins and Dunne (1990), Kanehl and Lyons (1992), Mossa and Autin (1998), Kondolf (1997, 1998), Florsheim *et al.* (1998), Norman *et al.*(1998), as well as other authors. Key impacts may include (Table 2-1):

Table 2-1: Key physical and biological impacts of in-stream mining

- **Channel modifications** such as widening or deepening, creation of deep pools, loss of riffles, alteration of bedload, alteration of channel flow, and degraded aesthetics.
- **Upstream and downstream erosion** and related impacts.
- **Modifications of aquatic habitat** including spawning beds, nursery habitat, shellfish habitat, and riparian habitat.
- **Degradation of water quality** including increased turbidity, reduced light penetration, increased temperature, and re-suspension of organic or toxic materials.
- **Bridge scour** and other **impacts on infrastructure**.

Source: Langer (2003)

Another list of the physical and biological impacts of gravel extraction is shown in Table 2-2.

Table 2-2: Physical and biological impacts of river gravel extraction

- Bed degradation and consequent effects on channel and bank stability.
- Increased sediment loads, decreased water clarity and sedimentation.
- Changes in channel morphology and disturbance of ecologically important roughness elements in the river bed.
- Ecological effects on bird nesting, fish migration, angling, etc.
- Modification of the riparian zone including bank erosion.
- Direct habitat destruction from heavy equipment operation.
- Discharges from equipment and refuelling.
- Lowering of groundwater levels.
- Impacts on structures and access.
- Biosecurity and pest risks.
- Impacts on coastal processes.

Source: Kelly *et al*. (2005); Rinaldi *et al.* (2005)

Many rivers and streams can accommodate the removal of some portion of their bedload without creating adverse environmental impacts - provided that the mining activities are kept within the hydraulic limits set by the natural system. If in-stream aggregate mining changes the river system to where it can no longer transport water and sediment in an efficient manner, the river will attempt to create a new, more efficient system, and the resulting changes in the hydraulic variables may produce environmental impacts.

The nature and severity of potential environmental impacts from in-stream mining are highly dependent on the geologic setting and characteristics of the stream, the type of extraction techniques employed, the location of extraction, and the amount of material extracted.

Physical impacts of river mining: the principal cause of physical impacts from in-stream mining is the modification of channel characteristics, especially the removal of more material than the system can naturally replenish. Impacts can be a result of extracting too much material at one site, or the combined result of many small but intensive operations (Rowan & Kitetu, 1998). The removal of gravel from a stream creates a change in the cross-section of the channel, and may also affect the longitudinal profile: removing too much sand and gravel may cause an increased gradient at the site of excavation, resulting in upstream incision. It may also cause a decrease in bedload, which can result in downstream incision. Excavation may also result in a change in stream course, causing bank erosion and the undercutting of riverside structures.

In 1990 Collins and Dunne (1990) summarised the physical effects of river sand and gravel mining as listed in Table 2-3:

Table 2-3: Physical effects of sand and gravel mining in rivers

- Extraction of bed material in excess of replenishment by transport from upstream causes the bed to lower (degrade) upstream and downstream of the site of removal.
- Bed degradation can undermine bridge supports, pipe lines or other structures.
- Degradation may change the morphology of the river bed, which constitutes one aspect of the aquatic habitat.
- Degradation can deplete the entire depth of gravelly bed material, exposing other substrates that may underlie the gravel, which could in turn affect the quality of aquatic habitat.
- If a floodplain aquifer drains to the stream, groundwater levels can be lowered as a result of bed degradation.
- Lowering of the water table can destroy riparian vegetation.
- Flooding is reduced as bed elevations and flood heights decrease, reducing hazard for human occupancy of floodplains and the possibility of damage to engineering works.
- The supply of overbank sediments to floodplains is reduced as flood heights decrease.
- Rapid bed degradation may induce bank collapse and erosion by increasing the heights of banks.
- In rivers in which sediments are accumulating on the bed (aggrading) in undisturbed condition, gravel extraction can slow or stop aggradation, thereby maintaining the channel's capacity to convey flood waters.
- The reduction in size or height of bars can cause adjacent banks to erode more rapidly or to stabilise, depending on the amount of sand and gravel removed, the distribution of removal, and on the geometry of the particular bend.
- Removal of gravel from bars may cause downstream bars to erode if they subsequently receive less bed material than is carried downstream from them by fluvial transport.

Source: Collins and Dunne (1990)

An example of severe riverbed lowering due to the extraction of an estimated 9.6 million m^3 of gravel over 32 years is described by Manariotis and Yannopoulos (2014) in the Lower Alfeios Basin in Greece.

Impacts on riverine habitat: physical changes to the river channel may affect aquatic habitat extent and quality. Meador and Layher (1998) summarised the impacts of improper in-stream aggregate mining on aquatic habitat:

- Erosion caused by in-stream mining can cause bank failure, which can cause loss of riparian habitat and loss of shade along stream banks.
- Channel shortening can increase flow velocities, which can reduce the occurrence of coarse woody debris in the channel.
- In-stream mining can result in channel bed armouring, destabilisation of spawning gravels and nursery habitat, increases in suspended sediment load, lowering of alluvial water tables, and stagnant low flows.

All these impacts can result in major changes to aquatic and riparian habitat.

Impacts on fish: altering habitat parameters can have deleterious impacts on instream biota, food webs, and impacts of riverbed mining on fish and fisheries, but the impacts are highly context-specific: in some rivers suspended sediment stirred up by mining may settle in downstream gravel spawning beds and affect fish reproductive success; in others fish may be adapted to high-sediment environments and turbid waters. For example, gravel mining on floodplains in Alaska produced severe channel alterations, which were thought to have resulted in elimination or reduction in fish populations (Woodward-Clyde Consultants, 1980). On the other hand, no major differences in fish species composition, diversity, relative abundance, or biomass were reported in a comparison of dredged and non-dredged control areas in the Tennessee and Cumberland Rivers in Tennessee, which are naturally high in suspended sediment some times of year (Nelson, 1993).

As stated by Packer *et al.* (2005), in general terms, Rivier and Seguier (1985) suggest that the detrimental effects to biota resulting from bed material mining are caused by two main processes: (1) alteration of the flow patterns resulting from modification of the river bed, and (2) an excess of suspended sediment. Packer *et al.* (2005) summarised the potential effects of gravel extraction activities on stream morphology, riparian habitat, and anadromous fishes and their habitats under ten headings, as listed in Table 2-4.

Table 2-4: Potential effects of gravel extraction from rivers on fish

1. Instream gravel mining can disrupt the pre-existing balance between sediment supply and transporting capacity, and can result in channel incision and bed degradation.
2. Instream gravel extraction can increase suspended sediment, sediment transport, water turbidity, and gravel siltation.
3. Bed degradation can change the morphology of the channel and decreases channel Stability.
4. Gravel bar skimming can significantly impact aquatic habitat.
5. Operation of heavy equipment in the channel bed can directly destroy spawning habitat, rearing habitat, the juveniles themselves, and macroinvertebrates; can produce increased turbidity and suspended sediment downstream; and has the potential to cause toxic chemical spills.
6. Stockpiles of overburden and gravel left or abandoned in the channel or floodplain can alter channel hydraulics during high flows.
7. Removal or disturbance of instream roughness elements during gravel extraction activities can negatively affect both quality and quantity of anadromous fish habitat.
8. Dry pit and wet pit mining in floodplains may reduce groundwater elevations, reduce stream flows, increase water temperature, and create potential for fish entrapment.

9. Destruction of the riparian zone during gravel extraction operations can have multiple deleterious effects on anadromous fish habitat.
10. Gravel mining can cause a change in disturbance regimes and patterns with a concomitant change in habitat and species.

Source: Packer *et al.* (2005)

Social impacts: river sand mining is a major industry worldwide, and as such a major source of income and employment (Figure 2.4), and revenues to government. In some locations river sediments can be used for land reclamation, creating new agricultural land (Figure 2.5).

However, conditions in the industry are highly variable and, especially in developing countries, sub-standard. MacFarlane and Mitchell (2003) categorised river mining social impacts into those related to health (e.g. accidents, STDs), cultural aspects (e.g. loss of social cohesion), economics (e.g. revenue, compensation), and livelihoods (e.g. displacement, employment). To these could - and should - be added the 'resource curse' impact of generalised corruption and criminality which arises where governance is weak and potential profits high.

Figure 2.4: India: manual wet river sand mining from boat

Source: http://www.thehindu.com/multimedia/dynamic/01450/DE08PERISCOPENISHA_1450843g.jpg

Figure 2.5: Pumping sediments from River Nile for land reclamation for agriculture, Egypt 2006

Source: J. Ramsay

3 RIVERBED MINING AND CLIMATE CHANGE

No reviews or guidelines specifically on riverbed mining and climate change were located by online literature searches for this study. However, there is a very large literature on climate change and its probable effects on the hydrology of rivers in many countries. The findings of these studies are entirely predictable: in many regions rainfall events are likely to become more frequent, more erratic, and more intense; this will affect watershed condition, floods, erosion, the mobilisation of sediment, sediment delivery to streams and rivers, and sediment transport and deposition.

The increased activity of geomorphic (landform-changing) systems will present an increasing management challenge. However, it is also an opportunity - river channels must be maintained to provide safe passage of flood flows, and riverbed mining is part of the solution.

Note that uncontrolled sand mining in other environments such as beaches can greatly increase the vulnerability of coastlines and associated infrastructure to the impacts of climate change – sea level rise, storms, waves and tidal surges (Figure 3.1).

Figure 3.1: Uncontrolled sand mining on beach in Sierra Leone

Source: http://cdn.coastalcare.org/wp-content/uploads/2013/02/beach-sand-mining-sierra-leone11.jpg

4 TYPICAL MANAGEMENT APPROACHES

4.1 Principles

Three principles are widely applied in riverbed sand mining, based on the physical aspects of sediment supply and channel stability:

- The fundamental parameter in riverbed mining management is **the amount of material that can be extracted on an annual basis without unacceptable negative consequences**. This is usually taken to be some proportion of the amount of material that the system can replenish - i.e. the bedload. Both measuring and estimating bedload are very difficult.
- Defining a minimum elevation for the deepest part of the channel and restricting mining to the volume above this elevation may allow gravel extraction without adverse impacts.
- It is best to exploit aggrading streams rather than those which are already eroding.

4.2 Operating Practices to Limit Environmental Impacts

As listed by Langer (2003), there are some **general operating practices** that can be followed to limit environmental impacts from in-stream mining (Table 4-1).

Table 4-1: General operating practices to limit environmental impacts from in-stream mining

(i)	Extracting sand and gravel from areas of riffles should be avoided because removing gravel from riffles commonly results in increased erosion and threats to important fish habitat.
(ii)	Relocating or straightening stream channels should be avoided because such actions shorten the stream, which results in increased flow velocity and associated erosion.
(iii)	Settling ponds for sand and gravel wash water should properly sized, should be protected so that they are not inundated during flooding, and should be located far away from the river channel so that the warm, silty wash water cannot enter the stream.
(iv)	Berms, dikes, and stockpiles can modify flood levels and flow patterns. Berms and dikes should be designed with this in mind, and aggregate stockpiles should be located out of the floodplain or as far away from the channel as possible.
(v)	An undisturbed buffer should be maintained at the top of the riverbank for the length of the excavation, and the access areas should be replanted once excavation is completed.
(vi)	Mining should be avoided during spawning seasons or other critical habitat times, if sand and gravel extraction causes increased turbidity.
(vii)	Clearing of riparian woodlands should be avoided if sufficient material can be obtained in less densely vegetated areas.
(viii)	Waterlogged trees, deadheads, and large boulders can be placed along streamsides to provide diversity of habitat.
(ix)	Aggregate extraction can add to habitat diversity by varying configuration, slopes, and elevations of graded areas during final reclamation.

Source: Langer (2003)

4.3 Guidelines

Many countries have prepared guidelines for mining non-metallic minerals (e.g. in Western Australia (Water & Rivers Commission, 1999) and Australia's Queensland Government, 2013), and some have also prepared codes of practice specific to the aggregates industry. However, these focus on extraction from river terrace deposits and floodplains rather than from river channels.

An internet search indicates that only a few countries have prepared guidelines in English specifically for riverbed sand mining; two examples are given below (Malaysia and India), followed by notes on two guides from the USA and a British report intended for general application in developing countries, based on Caribbean and Latin American case studies.

The Malaysian guide is the only one which includes step-by-step procedures for determining safe extraction locations and volumes.

4.3.1 Malaysia

In 2009 Malaysia's Department of Irrigation and Drainage (DID) produced the *River Sand Mining Management Guideline*, a detailed manual focusing on sediment transport mechanisms, the estimation of sediment loads, channel modelling with HEC-RAS, and physical monitoring (www.engr.colostate.edu/~pierre/ce_old/classes/.../Sand%20mining.pdf). The guideline's in-stream mining recommendations are based on 12 concepts (Table 4-2). Further details are given at Annex B.

Table 4-2: Malaysia: 12 concepts underlying national river sand mining guidelines

1.	Permit a mining volume based on measured annual replenishment.
2.	Establish an absolute elevation below which no extraction may occur.
3.	Limit in-stream mining methods to bar skimming.
4.	Extract sand and gravel from the downstream portion of bars.
5.	Concentrate in-stream extraction activities to minimise the area of disturbance.
6.	Review the cumulative effects of sand and gravel extraction.
7.	Maintain river channel flood discharge capacity.
8.	Establish a long-term monitoring program.
9.	Minimise activities that release fine sediment to the river.
10.	Retain riparian buffer at edge of water and against river bank.
11.	Limit in-stream operation to the period between May and September and during dry season only.
12.	An annual status and trends report should be produced by DID.

Source: DID (2009)

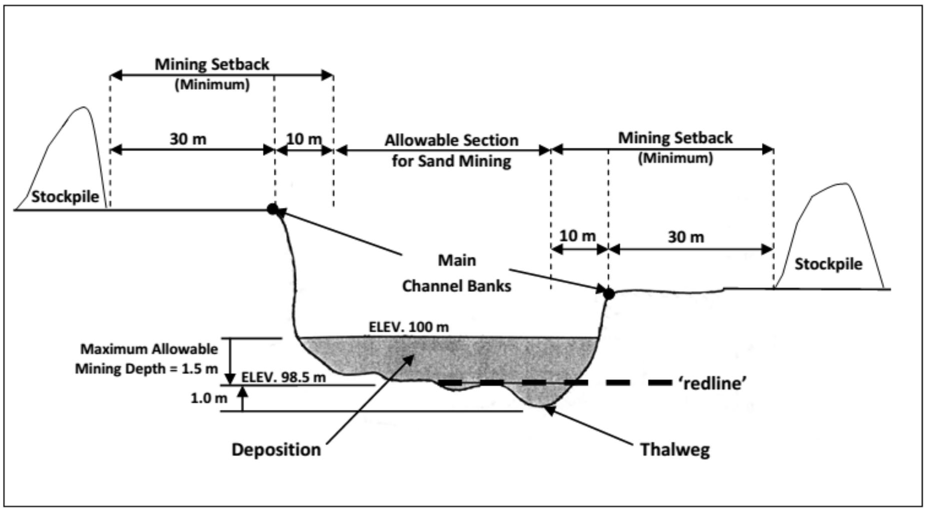
The Malaysian report includes a number of graphics illustrating key recommendations, such as the minimum setback of stockpiles from riverbanks (30 m) and the 'redline' concept (maximum allowable mining depth) (Figure 4.1).

Importantly, the guidelines include a step-by-step process for determining safe extraction locations, volumes and timing of sand and gravel extraction operations using either (i) sediment transport equations and sediment ratings curves, or (ii) river modelling (using the common software HEC-RAS).

The general process for using the sediment transport method is illustrated in Figure 4.2, and each step is described in Table 4-3. The sediment transport equations used are those of (i) Yang, and (ii) Engelund Hansen since, of the many sediment transport equations available, these two have been found to best fit observed data on sediment transport in Malaysian rivers (see Chapter 2 of the DID report for an explanation).

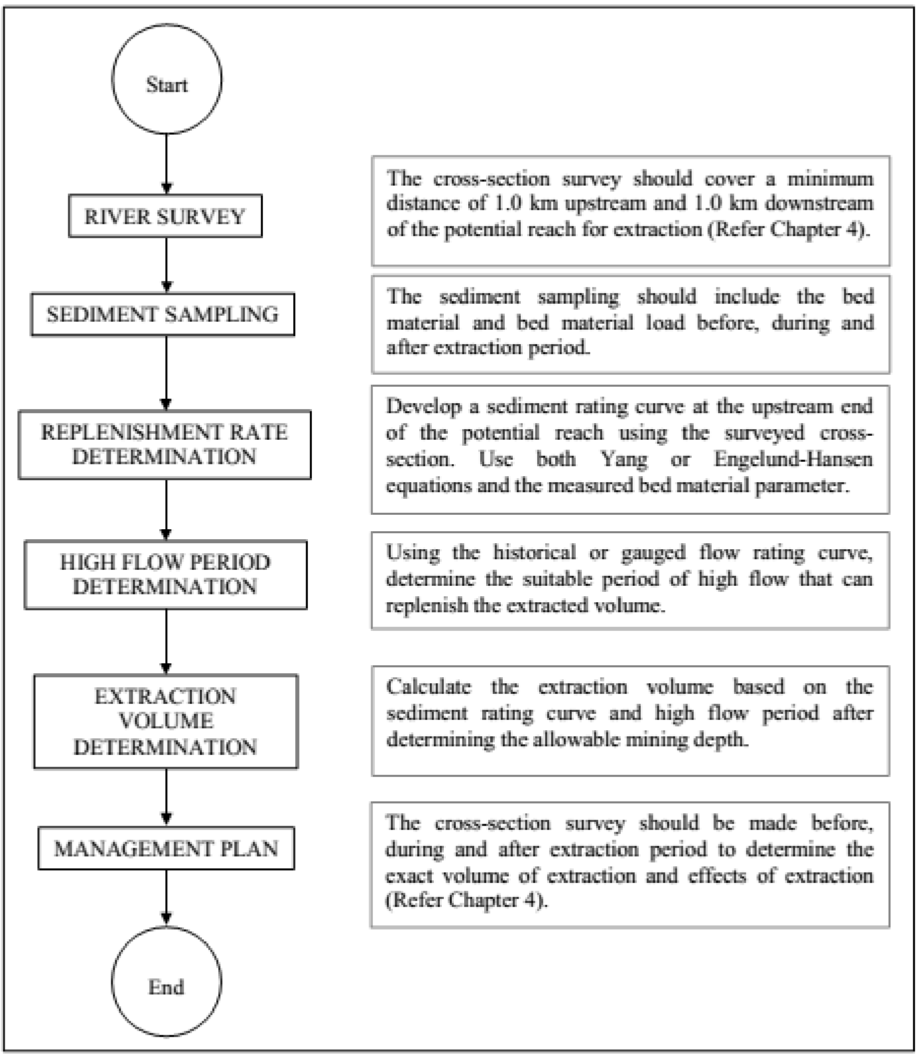
A flow chart for extraction volume determination using HEC-RAS modelling is given in Figure 4.3.

Figure 4.1: Malaysia: setback, "redline" and maximum allowable mining depth for in-stream mining



Source: DID (2009)

Figure 4.2: Malaysia: flow chart for volume extraction determination using sediment rating curve



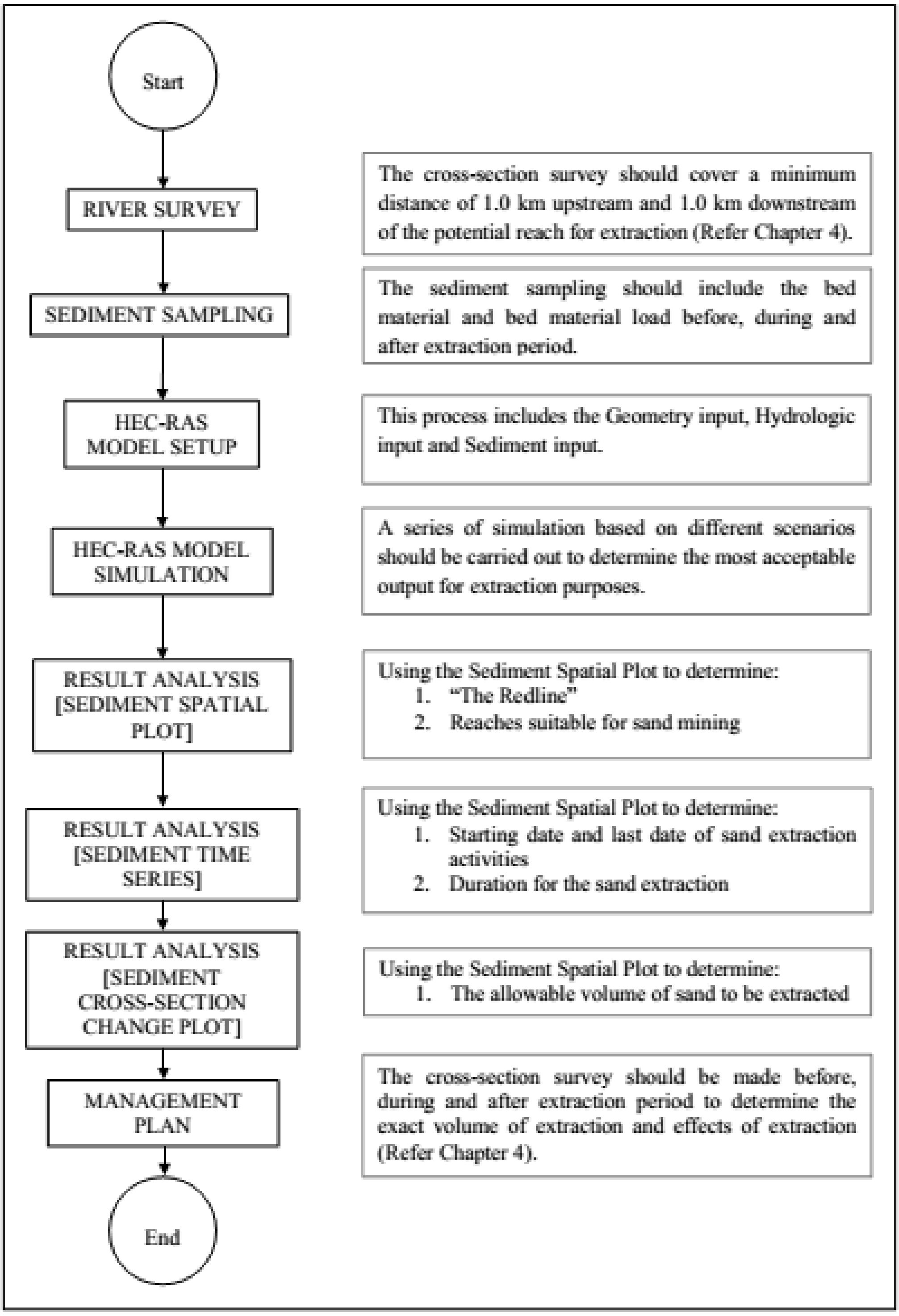
Source: DID (2009)

Table 4-3: Malaysia: step by step procedure for determining safe location, duration and volume of river sand mining using sediment rating curves

a)	Parts of the river reaches that experience deposition or aggradation shall be identified first. Operators may be allowed to extract the sand and gravel deposit in these locations to lessen aggradation problem.
b)	The distance between sites for sand and gravel mining shall depend on the replenishment rate of the river. Sediment rating curve for the potential sites shall be developed and checked against the extracted volumes of sand and gravel.
c)	Sand and gravel may be extracted across the entire active channel during the dry season (May to September).
d)	Layers of sand and gravel which could be removed from the river bed shall depend on the width of the river and replenishment rate of the river.
e)	Sand and gravel shall not be allowed to be extracted where erosion may occur, such as at the concave bank.
f)	Sand and gravel shall not be extracted within 1,000 m from any crucial hydraulic structure such as pumping stations, water intakes, bridges, buildings and such structures. o The cross-section survey should cover a minimum distance of 1.0 km upstream and 1.0 km downstream of the potential reach for extraction. o The sediment sampling should include the bed material and bed material load before, during and after extraction period. o Develop a sediment rating curve at the upstream end of the potential reach using the surveyed cross-section. Use both Yang or Engelund-Hansen equations and the measured bed material parameter. o Using the historical or gauged flow rating curve, determine the suitable period of high flow that can replenish the extracted volume. o Calculate the extraction volume based on the sediment rating curve and high flow period after determining the allowable mining depth. o The cross-section survey should be made before, during and after extraction period to determine the exact volume of extraction and effects of extraction.
g)	Sand and gravel mining could be extracted from the downstream of the sand bar at river bends. Retaining the upstream one to two thirds of the bar and riparian vegetation is accepted as a method to promote channel stability.
h)	Flood discharge capacity of the river could be maintained in areas where there are significant flood hazard to existing structures or infrastructure. Sand and gravel mining may be allowed to maintain the natural flow capacity based on surveyed cross-section history.
i)	Alternatively, off-channel or floodplain extraction is recommended to allow rivers to replenish the quantity taken out during in-stream mining.

Source: DID (2009)

Figure 4.3: Malaysia: flow chart for volume extraction determination using HEC-RAS modelling



Source: DID (2009)

4.3.2 India

In response to concern about riverbed sand mining, the Geological Survey of India (GSI) has recently circulated *A Model Document on Impacts and Methodology of Systematic and Scientific Mining of the River Bed Material*. It recommends that the following 16 "geoscientific considerations" are taken into account for riverbed sand/gravel mining (Table 4-4).

Table 4-4: India "geoscientific considerations" for riverbed mining

1) Abandoned stream channels on terrace and inactive floodplains may be preferred rather than active channels and their deltas and floodplains. Replenishment of ground water has to be ensured if excessive pumping out of water is required during mining.
2) Stream should not be diverted to form inactive channel.
3) Mining below subterranean water level should be avoided as a safeguard against environmental contamination and over exploitation of resources.
4) Large rivers and streams whose periodic sediment replenishment capacity are larger, may be preferred than smaller rivers.
5) Segments of braided river system should be used preferably falling within the lateral migration area of the river regime that enhances the feasibility of sediment replenishment.
6) Mining at the concave side of the river channel should be avoided to prevent bank erosion. Similarly meandering segment of a river should be selected for mining in such a way as to avoid natural eroding banks and to promote mining on naturally building (aggrading) meander components.
7) Scraping of sediment bars above the water flow level in the lean period may be preferred for sustainable mining.
8) It is to be noted that the environmental issues related to mining of minerals including riverbed sand mining should clearly state the size of mine leasehold area, mine lease period, mine plan and mine closure plan, along with mine reclamation and rehabilitation strategies, depth of mining and period of mining operations, particularly in case of river bed mining.
9) The Piedmont Zone (Bhabar area) particularly in the Himalayan foothills, where riverbed material is mined. This sandy-gravelly tract constitutes excellent conduits and holds the greater potential for ground water recharge. Mining in such areas should be preferred in locations selected away from the channel bank stretches. Areas where channel banks are not well defined, particularly in the braided river system, midstream areas should be selected for mining of riverbed materials for minimizing adverse effects on flow regime and in-stream habitat.
10) Mining of gravelly sand from the riverbed should be restricted to a maximum depth of 3 m from the surface. For surface mining operations beyond this depth of 3 m (10 feet), it is imperative to adopt quarrying in a systematic bench- like disposition, which is generally not feasible in riverbed mining. Hence, for safety and sustainability restriction of mining of riverbed material to maximum depth of 3 m is recommended.
11) Mining of riverbed material should also take cognizance of the location of the active channel bank. It should be located sufficiently away, preferably more than 3 m away (inwards), from such river banks to minimize effects on river bank erosion and avoid consequent channel migration.
12) Continued riverbed material mining in a given segment of the river will induce seasonal scouring and intensify the erosion activity within the channel. This will have an adverse effect not only within the mining area but also both in upstream and downstream of the river course. Hazardous effects of such scouring and enhanced erosion due to riverbed mining should be evaluated periodically and avoided for sustainable mining activities.
13) Mineral processing in case of riverbed mining of the sandy gravelly material may consist of simple washing to remove clay and silty area. It may involve crushing, grinding and separation of valueless rock fragments from the desirable material. The volume of such waste material may range from 10 to 90%. Therefore, such huge quantities of mine wastes should be dumped into artificially created/ mined - out pits. Where such tailings / waste materials are very fine grained, they may act as a source of dust when dry. Therefore, such disposal of wastes should be properly stabilized and vegetated to prevent their erosion by winds.
14) Identification of river stretches and their demarcation for mining must be completed prior to mining for sustainable development.

15) The mined out pits should be backfilled where warranted and area should be suitably landscaped to prevent environmental degradation.
16) Mining generally has a huge impact on the irrigation and drinking water resources. These attributes should be clearly evaluated for short-term as well as long-term remediation.

Source: GSI (undated)

4.3.3 USA - USGS

In 2003 the US Geological Survey (USGS) published *A General Overview of the Technology of In-Stream Mining of Sand and Gravel Resources, Associated Potential Environmental Impacts, and Methods to Control Potential Impacts* (Langer, 2003). The purpose of the paper is to describe, by way of examples, the broad range of potential impacts of river mining for aggregates and to describe some techniques to prevent or limit those impacts. As stated by Langer (2003), the report begins with an overview of the sand and gravel industry in general, and then describes in-stream mining of sand and gravel including extraction, processing, and reclamation. It follows with a generalised description of stream dynamics, and concludes with a discussion of the potential environmental impacts from in-stream mining and some of the techniques that can be employed to limit those impacts.

The report makes the important point that some sections of a stream are more conducive to aggregate extraction than others:

- Most stream erosion takes place during high-flow events. Constant variations in the flow of the river make the channel floor and riverbanks a dynamic interface where some materials are being eroded while others are being deposited. The net balance of this activity, on a short-term basis, is referred to as scour or fill. On a long-term basis, continued scour results in erosion (degradation), while continued fill results in deposition (aggradation). Removal of gravel from some aggrading sections of a river may be preferable to removing it from eroding sections.
- A general indicator of the stability of a stream relates to the amount of vegetation present. Gravel bars that are vegetated, or where the gravel is tightly packed, generally indicate streams where the gravel supply is in balance. Streams with excessive gravel generally have gravel bars with little or no vegetation, and are surfaced with loosely packed gravel.

The report considers near-stream mining as well as in-stream mining, i.e. excavations in the floodplain or from river terraces: there are some general relationships between environmental impacts, where the extraction site is located, whether or not the excavation penetrates the water table, how deep the excavation is, and the size and shape of the river or stream. These relationships can be used as a general guide for the design of in-stream and near-stream aggregate extraction. All other things being equal:

- In general, sand and gravel extraction will have less impacts to the river or stream hydrologic processes the higher up in the landscape the extraction site is located. Extracting sand and gravel from floodplains generally is preferable to removing sand and gravel from stream channels. Extracting sand and gravel from terraces is generally preferable to extracting sand and gravel from floodplains.
- Extracting gravel from a water-filled excavation located away from an active stream channel should cause little or no change to the natural hydrologic processes of the stream unless the stream captures the pit during periods of flooding. The exception is that changes in evapotranspiration, recharge, and runoff may create minor changes to the ground-water system, which may in turn affect stream flow.

- Extracting gravel from an excavation that does not penetrate the water table and is located away from an active stream channel should cause little or no change to the natural hydrologic processes unless the stream captures the pit during periods of flooding. The exception is that changes in evapotranspiration, recharge, and runoff may create minor changes to the ground-water system, which may in turn affect stream flow.
- Extracting gravel from an excavation that penetrates the water table, is mined dry by draining the ground water, and is located away from an active stream channel may change the natural hydrologic processes of the stream due to lowering of the ground-water system, which may in turn affect stream flow.
- Limiting extraction of material in floodplains to an elevation above the water table generally disturbs more surface area than allowing extraction of material below the water table.
- In-stream extraction of gravel from below the water level of a stream generally causes more changes to the natural hydrologic processes than limiting extraction to a reference point above the water level.
- In-stream extraction of gravel below the deepest part of the channel (the thalweg) generally causes more changes to the natural hydrologic processes than limiting extraction to a reference point above the thalweg.
- Excavating sand and gravel from a small straight channel with a narrow floodplain generally will have a greater impact on the natural hydrologic processes than excavations on a braided channel with a wide floodplain.
- Extracting sand and gravel from a large river or stream will generally create less impacts than extracting the same amount of material from a smaller river or stream.

The USGS report also includes general operating practices to minimise river mining impacts (Table 4-1).

4.3.4 USA - National Marine Fisheries Service

In 2005 the US National Marine Fisheries Service (NMFS) updated its guidance on gravel extraction from fish-bearing rivers (Packer *et al.*, 2005). The objectives of the NMFS Gravel Guidance are to (1) assist NMFS staff in determining whether proposed gravel extraction operations will be conducted in a manner consistent with Federal law, while (2) avoiding, minimizing, and mitigating any adverse impacts to anadromous fishes and their habitats.

The NMFS recommends that gravel extraction operations not interfere with anadromous fish migration, spawning, or rearing, or negatively impact viable existing or historic anadromous fish habitat. Further, it is recommended that individual gravel extraction operations be judged in the context of their spatial, temporal, and cumulative impacts, and that potential impacts to habitat be viewed from a watershed management perspective.

The guidance makes the important point that, in general terms, gravel extraction operations located in or immediately adjacent to streams have greater impacts to anadromous fish resources and habitats than operations located farther from the stream. Therefore, NMFS recommends that all reasonable efforts be made to identify gravel sources in upland areas and terraces before deciding to site project operations in or near streams. This is consistent with the standard impact assessment principle of impact *avoidance* rather than impact *mitigation.*

If in-stream mining is unavoidable, the NFMS report makes the recommendations listed in Table 4-5.

Table 4-5: US National Marine Fisheries Service recommendations for instream gravel extraction

1. NMFS recommends that larger rivers and streams be used preferentially to small rivers and streams.
2. NMFS recommends that braided river systems be used preferentially to other river systems.
3. NMFS recommends that instream gravel removal quantities be strictly limited so that gravel recruitment and accumulation rates are sufficient to avoid prolonged impacts on channel morphology and anadromous fish habitat.
4. NMFS recommends that gravel bar skimming be allowed only under restricted conditions.
5. NMFS recommends that, prior to gravel removal, a thorough review of sediments and point and non-point sources of contaminants be conducted.
6. NMFS recommends that removal or disturbance of instream roughness elements during gravel extraction activities be avoided, and that those that are disturbed be replaced or restored.
7. NMFS recommends that gravel extraction operations be managed to avoid or minimize damage to stream/river banks and riparian habitats.
8. NMFS recommends that the cumulative impacts of gravel extraction operations to anadromous fishes and their habitats be addressed by the Federal, state, and local resource management and permitting agencies and be considered in the permitting process.
9. NMFS recommends that an integrated environmental assessment, management, and monitoring program be a part of any gravel extraction operation, and encouraged at Federal, state, and local levels.
10. NMFS recommends that mitigation be an integral part of the management of gravel extraction projects.
11. NMFS recommends that gravel extraction projects proposed as stream restoration activities be regarded with caution.

4.3.5 Generic River Mining Planning Guidelines - DFID

From 2000-2004 the UK's Department for International Development (DFID) sponsored a research project *Effective Development of River Mining*. Based on field studies in Jamaica and Costa Rica, the research team developed generic planning guidelines "applicable to developing countries worldwide" (see Scott *et al.*, 2003). The project produced six reports on various aspects of the industry (river gravel resources, ecological effects, etc.) and a final set of guidelines entitled *River Mining: Planning Guidelines* (Fidgett, 2003).

The Guidelines make many points, provide numerous recommendations on policy, planning and regulation, and reinforce these with a **Code of Practice** which deals with each of 26 potential issues raised by riverbed sand mining. Selected recommendations are given below, and extracts from the Code of Practice covering incision, bank erosion, quarry plans and licensing/permitting are given in Annex C.

- **Policy:** the policy framework should clearly set out at the national level the approach to be adopted by government and by the departments or agencies responsible for its administration. **These policies should be prepared in consultation with all stakeholders**, including all government departments, operators, community groups and the public. They should be published and made widely available. They should be reviewed on a regular basis.
- **Public consultation:** it is … recommended that a system of public consultation be built into the legislation and practice that provides for a two tier consultation process (including other departments and the general public) with opportunity to comment on (a) the general policies that guide mining and quarrying activity, and (b) the determination of individual licence applications.

- **Control/regulatory system:** the first and primary recommendation … must be that there is a review of existing legislation, roles and responsibilities between the departments and the means by which these responsibilities are discharged, to ensure that for any new system of control there are:
  - Clear and understandable aims and objectives.
  - Clear lines of responsibility between departments and within departments/agencies.
  - Clear policies and proposals, both nationally and for individual areas.
  - Better coordination of activities between departments/agencies.
  - More standardization and consistency in information requirements and licence standards.
  - More effective and unified enforcement for both legal and illegal operations.
  - A greater degree of accountability.
- **Responsibilities:** monitoring and enforcement are undermined by regulatory inconsistencies and a lack of clarity regarding responsibilities and strategic priorities among and between government departments.
- Where a division of responsibility for the administration of control over mining/quarrying occurs it is important to have regard to the need for:
  - Clear and consistent national legislation, definitions, administration and policy on mining and quarrying.
  - Policies to guide land-use, or zoning, and to apply development control criteria at an appropriate level (whether carried out nationally/regionally/locally).The need for effective public consultation on policies at national and local level and on individual mine and quarry proposals.
  - Provision for effective monitoring and enforcement of legislation, regulations and individual permissions.
- The principal focus of administration to provide for and regulate mining and quarrying activity is most appropriately vested with the departments having the relevant expertise to define policy, consider applications and monitor on-the-ground activities.
- This means that a combination of environmental expertise and knowledge of geology and mining/quarrying practices is required. These may be within a combined department or may be split between departments providing there is clarity of purpose, shared commitment and effective liaison between each function.
- **Taxation and permitting:** the administration of a mining tax should … should be independent of the licensing process.
- **Licences:** …. should relate to the land on which the mining or quarrying takes place. They should not relate purely to the individual or company operating the site.
- **Land-use planning:** there needs to be an effective means of plan making or land-use zoning to guide the future development of river mining and other forms of development and to provide a context for the consideration of decisions on licence applications and exploration proposals.
- **Physical processes:** there needs to be greater understanding in the decision-making process of the relationship between river mining and the deposition of sediments through natural

processes in each of the river environments, in order to ensure that the river is not damaged by over-exploitation.

- **Mine plans:** … plans should show the location of the quarry plant and the total area of the proposed extraction operations, together with the sequence of work or phases to be adopted.
- The plans should be supported by marking out key features on the ground to guide the machine operators as to the area, depth and means of access, together with other relevant requirements.
- **Standard conditions:** There should be a series of … detailed standard conditions agreed at the national level. These should provide the basis and starting point for the consideration of appropriate conditions specific to the relevant operation under consideration.
- The provision of clear, comprehensive and detailed conditions on every permission, read in conjunction with the relevant Quarry Plan, will allow effective enforcement action and provide the certainty and security required to enable longer term permissions that allow companies to invest.

5 LESSONS FOR NEPAL

5.1 Introduction

Riverbed sand mining (which includes coarser aggregates - gravels - and also boulders, which are crushed) produces construction materials which are essential for Nepal's economy and development processes. At the same time their extraction has been associated with serious negative environmental and social impacts, particularly riverbed lowering (which can destroy critical infrastructure such as bridges and render irrigation schemes ineffective) and corruption (a major social problem in Nepal which affects all sectors, but is particularly noticeable in the construction sector).

In theory riverbed sand mining in Nepal should be an entirely sustainable industry because the Himalaya are continuing to rise and the rivers are continuing to erode, with the resulting supply of sediment being carried downstream to the edge of the Gangetic Plain where it is deposited (the Terai). Climate change is predicted to increase the intensity and frequency of rainfall over much of Nepal, and therefore will increase the scale of flood events which is when most sediment is transported. This is a significant threat - but it is also an opportunity, since there is unlikely to be any reduction in demand for construction aggregates, and there will be an increasing need to clear and maintain river channels.

Under these circumstances riverbed sand mining can be viewed as an important climate change adaptation measure. However, high demand for aggregates, including from neighbouring states in India which are experiencing a construction boom, inconsistent policies and laws, fractured responsibilities, lack of practical regulations and enforcement capacity and the pressure of profits have combined to create a situation in which climate change is essentially irrelevant to improved management of the sector.

5.2 Key Points on Regulatory Systems

The DFID river mining planning guidelines (Fidgett, 2003) make three key points:

- Mine and crusher operators need sufficient **regulatory certainty** to be able to invest and put in place proper operational and environmental infrastructure.
- This implies **granting permits for longer periods** (10 years or longer; with provision for review at defined intervals such as 5 years).
- At the same time, **effective monitoring and enforcement** by the regulator are essential.

The guidelines go on to state that to achieve practices that are sustainable and deliver effective governance, the basic requirements of a control system must be in place. These include:

1) An **effective legislative framework** that allows the exercise of control over river mining and other forms of quarrying activity.
2) An administrative structure that gives **clear responsibility and authority** to the respective agencies involved in such regulation.
3) **Well informed policies** for the development and control of river mining and other forms of land-use as part of an integrated approach to land-use and the environment.
4) A system of permitting or licensing that requires a **consistent level of information** to be provided prior to individual decisions on applications to open a mine or quarry, measured against the policies and proposals set out in the forward planning context.

5) A **shared commitment to the effective operation of the system by government and other stakeholders**, including a commitment to effective monitoring and enforcement that is adequately resourced and informed of illegal mining or activity inconsistent with the licence or permit.

The Malaysian river sand mining guidelines (DID, 2009) highlight the significant technical requirements for determining safe riverbed mining sites and volumes, based on sediment supply and river morphology.

5.3 Conclusions

The lessons from experience elsewhere in the world are that:

- River sand mining can be sustainable and can be successfully managed.
- Significant technical knowledge and resources are required to identify safe extraction sites, volumes and methods.
- Most importantly, an effective governance environment is essential (policy, laws, regulations and administrative machinery) - and this should recognise the importance of the industry as both an economic driver and a key management tool for flood protection.
- If river mining cannot be managed effectively, it is generally environmentally safer to develop non-river sites (in floodplains and river terraces).

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7 ANNEX B: MALAYSIA: RIVER SAND MINING GUIDELINES

The following notes are extracts from the Malaysian Department of Irrigation and Drainage's 2009 *River Sand Mining Management Guideline.* The extracts cover in-stream mining, extraction sites, setbacks and levels, reclamation plans and monitoring.

For full details and additional guidelines, including sediment transport equations and sample calculations, the original document should be consulted (available from http://redac.eng.usm.my/html/projects/Sand%20Mining/SandMining.html).

7.1 In-Stream Mining Recommendations

a) Permit Mining Volume Based on Measured Annual Replenishment

In the first year following adoption of the management plan, a volume equal to the estimated annual replenishment could be extracted from the reach of channel. Replenishment (up to the elevation of the selected channel configuration) would need to occur before subsequent extraction could take place.

The concept of annual replenishment accounts for the episodic nature of sediment transport. For example, during wet periods with high stream flows, and a high contribution of sediment from hillslopes and tributaries, monitoring data would show that sand and gravel bars are replenished quickly. During drought periods with low streamflow, and little sediment supply or transport, monitoring data would likely show that bars were replenished at a slower rate. The use of monitoring data is essential in measuring when actual replenishment occurs. The use of the concept of annual replenishment protects long-term channel stability as well as aquatic and riparian habitat by extracting a volume sustainable by watershed processes.

It is important to develop a system to allocate the total estimated annual replenishment between all of the operators.

b) Establish an Absolute Elevation below which No Extraction May Occur (Minimum Envelope Level or Redline)

The absolute elevation below which no mining could occur or "redline" would be surveyed on a site-specific basis in order to avoid impacts to structures such as bridges and to avoid vegetation impacts associated with downcutting due to excessive removal of sediment.

An extraction site can be determined after setting the deposition level at 1 m above natural channel thalweg elevation, as determined by the survey approved by DID.

c) Limit In-stream Extraction Methods to Bar Skimming

If mining is limited to the downstream end of the bar with a riparian buffer on both the channel and hillslope (or floodplain) side, bar skimming would minimise impacts.

Other methods such as excavation of trenches or pools in the low flow channel lower the local base level, and maximise upstream (headcutting and incision) and downstream (widening and braiding) impacts. In addition, direct disturbance of the substrate in the low flow channel should be avoided.

Trenching on bars may be beneficial in the future if the river becomes severely aggraded, flat, shallow and braided. Trenching of bars may initially impact a smaller area of riparian habitat than skimming - as a result of excavating deeper rather than shallow skimming of a large area. However, over the long-term, the upstream and downstream effects of a trench on the bar or in the channel may offset any short-term benefit derived from this method.

d) Extract Sand and Gravel from the Downstream Portion of the Bar

Retaining the upstream one to two thirds of the bar and riparian vegetation while excavating from the downstream third of the bar is accepted as a method to promote channel stability and protect the narrow width of the low flow channel necessary for fish. Sand and gravel would be redeposited in the excavated downstream one to two thirds of the bar (or downstream of the widest point of the bar) where an eddy would form during sediment transporting flows. In contrast, if excavation occurs on the entire bar after removing existing riparian vegetation, there is a greater potential for widening and braiding of the low flow channel.

e) Concentrate Activities to Minimise Disturbance

In-stream extraction activities should be concentrated or localised to a few bars rather than spread out over many bars. This localisation of extraction will minimise the area of disturbance of upstream and downstream effects. Skimming decreases habitat and species diversity - these effects should not be expanded over a large portion of the study area.

f) Review Cumulative Effects of Sand and Gravel Extraction

The cumulative impact of all mining proposals should be reviewed on an annual basis to determine if cumulative riverine effects or effects to the estuary are likely and to ensure that permits are distributed in a manner that minimises long-term impacts and inequities in permits between adjacent mining operations.

g) Maintain Flood Capacity

Flood capacity in the river should be maintained in areas where there are significant flood hazards to existing structures or infrastructure.

h) Establish a Long-term Monitoring Program

Monitoring of changes in bed elevation and channel morphology, and aquatic and riparian habitat upstream and downstream of the extraction would identify any impacts of sand and gravel extraction to biologic resources. Long-term data collected over a period of decades as sand and gravel extraction occurs will provide data to use in determining trends.

i) Minimise Activities that Release Fine Sediment to the River

No washing, crushing, screening, stockpiling, or plant operations should occur at or below the streams "average high water elevation," or the dominant discharge. These and similar activities have the potential to release fine sediments into the stream, providing habitat conditions harmful to local fish.

j) Retain Vegetation Buffer at Edge of Water and against River Bank

Riparian vegetation performs several functions essential to the proper maintenance of geomorphic and biological processes in rivers. It shields river banks and bars from erosion.

Additionally, riparian vegetation, including roots and downed trees, serves as cover for fish, provides food source, works as a filter against sediment inputs, and aids in nutrient cycling. More broadly, the riparian zone is necessary to the integrity of the ecosystem providing habitat for invertebrates, birds and other wildlife.

k) Limit In-stream Operations to the Period between May and September

In-stream mining should only be allowed during the dry season.

l) An Annual Status and Trends Report

This report should review permitted extraction quantities in light of results of the monitoring program, or as improved estimates of replenishment become available. The report should document changes in bed elevation, channel morphology, and aquatic and riparian habitat. The report should also include a record of extraction volumes permitted, and excavation location. Finally, recommendations for reclamation, if needed should be documented.

7.2 Appropriate Extraction Sites

Note: although quoted in the DID Guidelines, these recommendations are actually from a US source: PWA (1996).

- Appropriate extraction sites are locations chosen based on knowledge of the local rate of aggradation or scour, a site-specific determination of channel stability and bank erosion and evaluation of riparian resources.
- Site-specific evaluation is needed to evaluate each proposed operation to minimize disturbance and maximise stability of channel.
- In-stream extraction sites should be located where the channel loses gradient or increases in width, and deposition occurs unrelated to regular bar-pool spacing in channel. Particular sites may include sites upstream of a bedrock constriction or backwater, or at deltas created near confluences.

7.3 Setbacks and Mining Envelope Levels for In-Stream Mining

- The excavation must be setback for a minimum distance of 10 m from the main channel bank toward the flow channel.
- Stockpiles must be located at least 30 m to the left or right of the main channel bank.
- The minimum depth of the excavation or redline must be at 1 m above natural channel thalweg elevation, as determined by the survey approved by DID.
- The maximum allowable mining depth is 1.5 m.

7.4 Reclamation Plans

In-stream reclamation plans should include:

a) A baseline survey consisting of existing condition cross-section data. Cross-sections must be surveyed between two monumented endpoints set back from the top of bank, and elevations should be referenced to the Department of Survey and Mapping's benchmark;

b) The proposed mining cross-section data should be plotted over the baseline data to illustrate the vertical extent of the proposed excavation.

c) The cross-section of the replenished bar should be the same as the baseline data. This illustrates that the bar elevation after the bar is replenished will be the same as the bar before extraction.

d) A planimetric map showing the aerial extent of the excavation and extent of the riparian buffers.

e) A planting plan developed by a plant ecologist familiar with the flora of the river for any areas such as roads that need to be restored.

f) A monitoring plan.

The appropriate reclamation plans can turn in-stream and floodplain sand and gravel mining operations into something perceived by the public as desirable.

7.5 Monitoring

Note: these extracts from the DID Guidelines concern *physical* monitoring of in-stream mining operations. The Guidelines make additional recommendations concerning protection of *riparian habitat* which are not repeated here.

Monitoring will provide data to evaluate the upstream and downstream effects of sand and gravel extraction activities, and long-term changes. A brief report summarizing the annual results of the physical and biological monitoring should document the evolution of the sites over time, and the cumulative effects of sand and gravel extraction. The summary should also recommend any maintenance or modification of extraction rates needed to minimize impacts of extraction (PWA, 1996).

7.5.1 Sand Replenishment, Geomorphology and Hydrology

Physical monitoring requirements of sand and gravel extraction activities should include surveyed channel cross-sections, longitudinal profiles, bed material measurements, geomorphic maps, and discharge and sediment transport measurements. The physical data will illustrate bar replenishment and any changes in channel morphology, bank erosion, or particle size.

In addition to local monitoring for replenishment at specific mining sites, monitoring of the entire reach through the estuary will provide information on the cumulative response of the system to sand and gravel extraction. For example, it is important for downstream bars and the estuary to receive sufficient sand and gravel to maintain estuarine structure and function.

Because the elevation of the bed of the channel is variable from year to year, a reach-based approach to monitoring will provide a larger context for site-specific changes.

If long-term monitoring data show that there is a reach-scale trend of bed lowering (on bars or in the thalweg), the extraction could be limited.

Cross-sections: surveyed channel cross-sections should be located at permanently monumented sites upstream, downstream and within the extraction area. Cross-sections intended to show reach scale changes should be consistently located over geomorphic features such as at the head of riffles, across the deepest part of pools, or across particular types of channel bars.

Cross-section spacing should be close enough to define the morphology of the river channel.

Cross-section data should be surveyed in March or April to evaluate changes that may occur during the flooding season. Cross-section data should be collected over the reach to the estuary, and locally upstream, downstream, and within each mining site.

Reach Scale Cross-sections

a) One long-term monitoring set to include the existing cross-sections to illustrate long term changes over the scale of the reach to the estuary.

b) Cross-sections surveyed by other government agencies should be incorporated into this program.

c) Additional cross-sections could be added to the set to aid in answering specific questions that arise.

d) Cross-section spacing should range from about 100 m to 250 m depending on the local channel morphology.

e) At least 10 survey points to be measured for each cross-section.

f) It is advantageous to locate new cross-sections at the head (upstream end) of riffles, where changes in bed elevation are most likely representative of larger scale trends.

g) This long-term monitoring data should be collected and analysed even if no mining occurs in order to understand the trends of the river.

Mining Site Cross-sections

a) One set of cross-sections at each extraction site to illustrate local changes related to specific in-stream extraction activities.

b) At least 10 survey points to be measured for each cross-section at 20 to 30 m interval.

c) Cross-sections should illustrate the upstream, mid-, and downstream portion of the channel bar being excavated, and at least one cross-section upstream and one cross-section downstream of the bar.

d) Thus, at least five cross-sections should be located at every extraction site to illustrate local changes. Cross-sections should be oriented perpendicular to the channel, extend from the top of bank to the opposite top of bank, and show the morphology of the channel (including the portion below the water surface).

e) Survey notes should describe geomorphic features including top and base of bank, edges of bars, thalweg (the deepest part of the channel) and sediment characteristics.

f) All cross-section elevations should be tied into a benchmark referenced to Department Survey and Mapping Malaysia (JUPEM)'s bench mark.

g) By standardizing the horizontal and vertical reference datum, data can be used in a watershed data base, or GIS which could be used to address issues related to river stability, flood control, bedload transport, and the cumulative effects of sand and gravel extraction.

h) A standard format for recording cross-section data should be provided to operators by DID to ensure that cross-section data is repeatable, and usable as part of the long-term record.

i) Scour chains (Nawa & Frissell, 1993) may be used in addition to cross-sections to document changes in bed elevation.

j) Scour chains should be placed on a bar, and the location should be mapped and described in field notes, to aid in data recovery.

7.5.2 Longitudinal Profile

A longitudinal profile should extend through a reach extending from upstream of the project area to downstream of the project area. Profile points should be surveyed in the thalweg and be detailed enough to illustrate the channel morphology (riffle-pool sequences). Profile elevations should reference to JUPEM's bench mark.

7.5.3 Geomorphic Maps

Geomorphic maps may be constructed using a tape and compass for the project reaches to illustrate channel morphology. Maps should illustrate bed and bank characteristics of the channel and particle size.

7.5.4 Photodocumentation

Photographs of the project sites should be taken prior to excavation to document the baseline conditions, and again during each monitoring session. Aerial photos should be taken twice a year (spring and autumn) at a scale of 1:6,000 or larger. Local field photographic station locations should be mapped on the geomorphic map and staked in the field in order to establish permanent photo stations.

7.5.5 Hydrology and Sediment Transport

Discharge and bed material measurements including suspended and bedload transport measurements taken by DID should continue in order to provide a statistically significant data base. Long-term data taken over a range of flows will add to our knowledge of river processes and aid in objectively evaluating the long-term trends in the river.

7.6 Compliance

The DID Guidelines include three sample inspection and compliance forms. The Compliance Inspection form is given below (Figure 7.1).

Figure 7.1: Malaysia: compliance inspection form

CIR-1

Department of Irrigation and Drainage Malaysia

COMPLIANCE INSPECTION REPORT

Permittee: ____________________ Permit Number: ____________

Location: ____________________ Date/Time: ____________

Accompanied By Name: ____________ Inspector: ____________

Title: ____________ State DID: ____________

Affiliation: ____________ ____________

Phone No.: ____________ ____________

Synopsis:

1. Activity:

2. Mining Setbacks:

3. Depth and Extent of Excavation/Operation:

4. Adverse Affects to Banks:

5. Structures in Channel/Floodway:

6. Maintenance of Drainage and Silting Pond:

7. Pit Slopes (Floodplain):

8. Other:

Inspector's Signature: ____________________ Date of Report: ____________

JPS Negeri: ____________________

8 ANNEX C: RIVER MINING - CODE OF PRACTICE

The following checklists are taken from the Code of Practice for riverbed mining included in the DFID River Mining Planning Guidelines (Fidgett, 2003). They cover 4 of the 26 issues in the Code, specifically:

- Incision
- Bank erosion
- Quarry plans
- Permitting/licensing

Note that each issue checklist starts with an **Objective** and then follows this with a set of **Performance Indicators**.

8.1 Incision

Issue Number:	11
Objective:	**Incision** – minimise the impact of river mining on the river channel and prevent progressive erosion up stream.
Performance Indicator:	57. Is working in accordance with licensed/permitted area and relevant conditions? 58. Does the permit or license limit the depth, area and rate of removal of sand and gravel resources from the river bed and is working in accordance with these controls? 59. Has a sediment balance or budget been undertaken and is the rate of extraction less than the rate of natural deposition from upstream sediment erosion (not erosion from man made channel migration or incision) in order to maintain a long term materials balance? 60. Is regular monitoring of the river channel undertaken and if any erosion or incision is apparent, are steps taken to remedy the situation? 61. Is regular monitoring of sediment levels upstream and downstream undertaken and measures undertaken to reduce or eliminate unnecessary sediment release into the river? 62. If the problem is persistent, has any review of the license/permission conditions or quarry plan been undertaken to remedy situation and prevent recurrence? 63. Should working be restricted to the higher terrace of the river channel above the normal water table (sometimes known as bar skimming – Roell, 1999), with buffer separation between the low flow channel and further separation with the active river bank? 64. Has consideration been given to floodplain mining as alternative to river mining, with buffer between the mine and river to protect the channel and minimise the risk of the capture of the mine by the river during flood events?
Activity or Location:	Extraction or Closure
Impact Group:	Physical
Issue Description:	*The progressive deepening (incision) of the river channel both upstream and downstream of the mine operation caused by poorly controlled river mining, leading to potentially widespread erosion of banks, river bed and associated structures and habitats, including unpredicted loss of land, pipelines, roads and bridges. It also leads to greater sedimentation down stream and resultant disruption to the river environment, fishery or tourist potential and degradation of habitat.* *The effects of incision have been well documented (Roell, 1999, Kondolf 1997). Excavation in the bed of the river tends to increase the energy in the river by increasing the rate of fall. This speeds the resultant rate and extent of bed erosion and the migration of bed degradation, particularly upstream, together with increased sediment and potential erosion downstream. Removal of material from the channel (including that above the water table) increases potential flow capacity (possibly seasonal if above normal water table) and reduces potential flow speed and resulting sediment load, which then increases the scouring effect further downstream as speeds increase, leading to higher than normal erosion.*

	Where in channel river mining is to continue a possible rate of extraction of 50% of the replenishment rate has been suggested, based on a sediment budget approach (Kondolf 1997 and North Carolina Chapter of the American Fisheries Society, 2002).
Intervention Level:	Technical, Policy
Minimum Acceptable Standard:	Avoidance of undue erosion.
Best Practice Guidance:	Consider alternatives to in stream river mining. Where in stream mining occurs, undertake sediment budget to maintain materials balance in river system, avoid deepening channel and maintain buffers along river bank. Keep all accesses and egress to minimum and keep plant away from river channel. Maintain natural continuity of sediment transport through the river system by implementation of best practice river mining. Monitor sediment levels, any incision and bank erosion in vicinity of working and undertake remedial work to stabilise, avoid further working in that area.

8.2 Bank Erosion

Issue Number:	12
Objective:	**Bank erosion** – to prevent the erosion of the river bank and channel, change in river course or the progressive migration of the nick point up stream.
Performance Indicator:	60. Is working in accordance with licensed/permitted area and relevant conditions? 61. Is regular monitoring of the river channel undertaken and if any erosion or incision apparent are steps taken to remedy the situation? 62. If the problem is persistent, has any review of the license/permission conditions or quarry plan been undertaken to remedy situation and prevent recurrence?
Activity or Location:	Extraction, Processing, Transport
Impact Group:	Physical
Issue Description:	*Where there is damage to the river bank, though actual mining of the bank or by unrestricted access and egress from the river channel by heavy vehicles, the erosion of the river bank and its accelerated migration up and down stream can occur. The character of the river changes and the river may in some cases move its course, leading to erosion of land, roads and bridges. There are also downstream impacts arising from increased turbidity and sedimentation affecting rivers and estuaries.*
Intervention Level:	Technical
Minimum Acceptable Standard:	Minimal impact on the river bank and channel with no significant erosion.
Best Practice Guidance:	Maintain natural continuity of sediment transport through the river system by implementation of best practice river mining. Minimise access and egress points from river. Maintain a buffer zone either side of river banks to maintain their integrity. Do not undermine channel by extracting from or below banks. Protect vulnerable banks and remedy erosion where apparent. Review operations if this persists.

8.3 Quarry Plans

Issue Number:	25
OBJECTIVE:	**Quarry Plans –** to ensure that all river mining and quarry sites in floodplains have quarry plans and that these provide an effective guide for day to day operations, the overall planning of mine and quarry development and as a basis for effective control.
Performance Indicator:	150. Is there a Quarry Plan that shows in plan form and in written text how the mine or quarry is proposed to be developed and operate? 151. Does this show the overall layout of the site and all key elements of infrastructure (e.g. extraction areas, location of plant sites, buffer zones and areas to be retained where no working is to take place) and nearby sensitive features? 152. Is the Quarry Plan kept under review and are any amendments notified to government and regulating agencies and to local community? 153. Are employees aware of the Quarry Plan and familiar with its contents so far as it affects their areas of responsibility? 154. Outside of their direct areas of responsibility, are employees familiar with the overall approach that is intended and who to contact should problems or issues arise? 155. Is the Quarry Plan discussed on a regular basis and monitored against operations with the regulating agencies?
Relevant Activity or Location	Extraction, Processing, Traffic and Closure
Impact Group:	Physical, Health, Quality of life, Livelihoods, Economic
Issue Description:	*Many of the issues arising from mining or quarrying activity can be predicted and measures planned to ensure that the risk of problems arising is minimised. This is best undertaken through the preparation of a Quarry Plan which can then form the basis of successful license/permit applications, conditions and ongoing employee training and operation.*
Intervention Level:	Planning & land use and Technical.
Minimum acceptable standard	Provision of key information on quarry design, layout and operation.
Best Practice Guidance:	It is usual in Jamaica for Quarry Plans to set out the geology and basic information on the operations proposed, but in order to address fully the overall impact of quarrying/mining further information is required. The preparation of a Quarry Plan should start from the pre development state and address all relevant site constraints and opportunities, including all of the key environmental impacts and how they are proposed to be addressed during operation. The Quarry Plan should detail how the site is to be developed initially, the mining process and ongoing phasing of operations. The Quarry Plan should contain a site location plan, an overall site layout plan (showing all relevant infrastructure and features and the maximum extent/limit of working), a restoration plan (showing how and when each phase is to be restored to a beneficial afteruse) and cross sections showing the depth of working and nature of any bank treatment where working is within the river channel. The Quarry Plan should also detail the health and safety and environmental monitoring and controls to be adopted.

8.4 Licence / Permit

Issue Number:	26
OBJECTIVE:	**License/Permit** – To ensure that effective and up to date licenses and permits exist for all sites and that operations comply with the requirements of those licenses/permits.
Performance Indicator:	156. Does the site have a valid copy of all of the necessary licenses/permits? 157. Are copies of the licenses/permits kept on site for inspection? 158. Are employees familiar with the contents so far as relevant to their work? 159. Is there a clear line of responsibility for site employees to ensure that they are aware of the need for compliance and any remedial steps that may need to be taken where any conditions are breached? 160. Are the conditions up to date and relevant to the operation of the mine/quarry or do they need to be reviewed? 161. Are the conditions consistent with the Quarry Plan?
Relevant Activity or Location	Extraction, Processing, Traffic and closure
Impact Group:	Physical, Health, Quality of life, livelihoods, economic
Issue Description:	*The general failure of operations to have effective regard to permit conditions or understand the potential impacts on the environment. Compliance with conditions of any license or permit is essential to the minimisation of adverse impacts on the environment and communities.*
Intervention Level:	Planning & land use and Technical.
Minimum acceptable standard	Full compliance.
Best Practice Guidance:	Regular and frequent audits by an appropriate site manager is the best way of ensuring compliance with conditions. A good working knowledge by site employees helps day to day compliance.