BASELINE ASSESSMENT REPORT GEOMORPHIC AND SEDIMENT TRANSPORT

Strategic Environmental Assessment of the Hydropower Sector in Myanmar

IN PARTNERSHIP WITH:

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ABBREVIATIONS

ADB	Asian Development Bank
AIRBM	Ayeyarwady Integrated River Basin Management
AWP	Australian Water Partnership
DWIR	Directorate of Water Resources and Improvement of River Systems
GMS	Greater Mekong Sub-region
GoM	Government of Myanmar
HPP	Hydropower Project
ICEM	International Centre for Environmental Management
IFC	International Finance Corporation
MHRI	Myanmar Healthy Rivers Initiative
MOTC	Ministry of Transport and Communications
NGO	Non-government Organization
PMU	Project Management Unit
SEA	Strategic Environmental Assessment
SOBA	State of the Basin Assessment
SWAT	Soil and Water Assessment

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EXECUTIVE SUMMARY

This report is the Geomorphic and Sediment Transport Baseline Assessment Report (Chapter 3) for the Strategic Environmental Assessment (SEA) of the Hydropower Sector in Myanmar. Subsequent reports will provide an environmental vulnerability and hydropower sustainability assessment of the Business as Usual (BAU) hydropower development scenario, and recommendations and mitigation options related to sustainable hydropower development in Myanmar.

This Baseline report defines the extent of the study, provides an overview of the geology and geomorphic characteristics of rivers in Myanmar, discusses how geomorphic processes can be altered by hydropower development, provides an overview of the status of fluvial (river related) geomorphic processes and a trend analysis identifying potential future changes in the absence of hydropower development.

The review draws on the available literature and includes an analysis of limited flow and sediment transport data. Major findings of the review include:

- Myanmar has a highly complex geologic and tectonic setting that combined with the hydrology of the region controls the 'natural' geomorphic processes. The distribution of older 'hard' mountain ranges in the north and east of the country, and younger 'softer' active mountain belts in the west result in sediment loads with differing characteristics being derived from the different areas of the country. Hard, resistant sands are derived from the weathering of the 'harder' strata, while fine-grained silts and clays are predominantly derived from the 'soft' strata;
- Large alluvial basins are located between the mountain ranges that temporarily store sediment. These areas can provide large 'pulses' of sediment in response to short-duration high intensity rainfall events;
- Sediment storage also occurs within the Ayeyarwady - Sittaung delta complex and along the western and eastern coastal areas where the rivers of the Rakhine and Tanintharyi, respectively, deliver sediment from the mountainous coastal areas. The stability of these areas is dependent on the continued supply of sediment from the mountains to the coastline;
- The flood pulse hydrology of the rivers in Myanmar governs the movement of water and sediment through the river systems. The hydrology of some sub-basins has been altered through the development of hydropower and irrigation, and seasonal water and sediment flows at the sub-basin level have likely occurred associated with these developments and other land use changes. More detailed monitoring and analysis is required to identify potential impacts at the basin scale;

The key themes related to hydropower development are the alteration of water and sediment flows associated with river regulation. The potential interaction between these changes and land use changes (mining), other water uses (irrigation), floodplain developments and aggregate extraction from rivers also need to be considered and understood for the implementation of 'sustainable' hydropower.

Substantial data gaps have been identified during this review. These include:

- A need for systematic geomorphic descriptions of the rivers at a scale that can be used to assess potential changes to rivers in response to hydropower or other water resource developments;
- More detailed suspended and bedload sediment transport information is needed from sub-basins and mainstem rivers to provide the required information to underpin sustainable hydropower development. This information is also required for effective management of sand and gravel mining, as well as understanding the dynamics of the river;
- Detailed flow information from sub-catchments and mainstream rivers is required at a higher resolution than provided by the present network of flow gauges. This information may be able to be provided through the development of catchment hydrologic models;
- Information about the characteristics of sediment moving through the system, including grain-size and mineralogy. Grain-size will allow a better understanding of what flows are required to transport sediment and mineralogy will provide information about the source of the material;

- More information is required about how individual hydropower projects will alter flow regimes at the sub-basin level, how sediments will be managed and what mitigation strategies are to be included in the project design. A sound understanding of the project is required to understand how it will affect the upstream and downstream environments;
- More information is required about other planned water resource developments that have the potential to alter flow and sediment regimes. A sub-basin and basin management approach to water resource development is required to minimize impacts and maximize outcomes;
- An increased understanding of how climate change may affect the river systems is needed for long-term sustainable planning of hydropower and other water resource developments.

The review has found that even in the absence of additional hydropower development there are substantial pressures on the river systems of Myanmar, related to existing hydropower projects (both in Myanmar and upstream of the border), land use changes such as mining, deforestation, sand and gravel mining, irrigation extractions, and floodplain and river modifications. Catchment management at the sub-basin scale is required to control and manage these activities, and the implementation of stringent Government policies to minimize impacts from these activities is warranted. Sustainable hydropower can only be developed within a catchment that is being sustainable managed with respect to other land use and water resource activities.

1 SCOPE OF THE GEOMORPHOLOGY AND SEDIMENT TRANSPORT COMPONENT OF THE SEA

1.1 Scope of study

The scope of this study is to understand the present processes and status of the river systems in Myanmar with respect to geomorphology (river form and functioning) and sediment transport (movement of sediment and nutrients through the river system); to project how these processes and systems are likely to change into the future under different development scenarios; and to understand how these changes may affect the ecosystem and livelihoods of those dependent on the river systems. The scenarios to be considered include:

- Development under the hydropower 'Business as Usual' scenario; and
- Hydropower development which aims to minimize impacts and maximize sustainability.

These two scenarios will be informed by considering development in the absence of hydropower, with issues such as irrigation, land use changes and sand mining considered.

This report summarizes Baseline geomorphic and sediment transport information and provides a trend analysis based of the present status of the system. It also identifies knowledge gaps that limit the ability to determine existing and future trends. Subsequent reports will evaluate the vulnerability to geomorphic change of the rivers in Myanmar on a catchment basis, and evaluate the potential impacts associated with the 'Business as Usual' hydropower development scenario. Recommendations with respect to information gaps, hydropower development pathways and mitigation measures will also be included in these later reports.

1.2 Geographic/spatial extent of study

The geomorphology and sediment transport component of the SEA will consider the major river basins within Myanmar (Ayeyarwady, Chindwin, Thanlwin, Sittaung, Myit Mo Hka and Bago, Mekong, and the Tanintharyi and Rakhine). There is more information available for the Ayeyarwady, Chindwin and Thanlwin as compared to the other catchments, so these are considered in more detail, with the findings extrapolated to other basins with similar characteristics.

1.3 Substantive coverage of the theme

The range and depth of investigations associated with this theme is limited by the availability of relevant information. The intent is for the baseline assessment to cover the following topics as much as practicable:

- The large scale, long-term natural factors controlling the geomorphic characteristics of the river basins, including large scale tectonic and geological factors, physiographic attributes, and the magnitude and seasonality of water and sediment discharge;
- The characteristics of the sediments being transported and stored within the catchments (grain-size distribution, mineralogy, nutrient content);
- How present development activities (including hydropower) have altered the natural sediment transport and geomorphic processes; and
- How existing hydropower projects are likely to impact the geomorphic and sediment transport characteristics of the rivers based on relevant regional and global experience (other hydropower plants to be considered in the impact assessment phase).

The last two bullet points will be expanded in the subsequent impact assessment phase of the SEA.

1.4 Linkages with other themes

Geomorphology and sediment transport, in combination with hydrology, define the physical attributes of river systems. The physical features determine the distribution and quality of aquatic habitats and underpin the ecological functioning and biodiversity of the rivers. A principle aim of understanding geomorphic and hydrologic changes is to understand how they will translate into changes to the ecosystem, and what effect they will have on livelihoods dependent on aquatic and riparian resources.

Geomorphic processes also control riverbank characteristics and stability, the distribution of flood plains and patterns of inundation, all of which can affect agriculture, fisheries and navigation.

Changes to sediment storage and/or hydrologic patterns can also affect the distribution and availability of groundwater resources.

1.5 Studies and activities relevant to theme

The following activities are relevant to the understanding of geomorphology and sediment transport in Myanmar:

Historic data and ongoing monitoring of discharge and sediment transport*:* The Ayeyarwady and Thanlwin, along with the smaller catchments discharging to the Andaman Sea, are significant contributors of sediment, carbon and nutrients to the world's oceans (Bird, *et al.,* 2008). Monitoring of the Ayeyarwady River has been occurring for years - to decades at several locations - and these monitoring results if accurate are invaluable for understanding the overall flux of sediment to the sea from the catchment, and also the seasonality, timing and relationships between the flow regime and sediment transport. An understanding of these aspects of the sediment cycle are essential for the identification of potential changes and impacts associated with water resource developments such as hydropower, and for identifying appropriate mitigation measures. Information from the Ayeyarwady can be applied to other river systems in the country, increasing its usefulness in the context of the SEA.

The Ayeyarwady Integrated River Basin Management (AIRBM) Project State of the Basin Assessment (SOBA)*:* The Ministry of Transport and Communications (MOTC), Directorate of Water Resources and Improvement of River Systems (DWIR) through the Project Management Unit (PMU) is implementing a project to document the 'baseline' conditions in the Ayeyarwady River. One of the packages included in the project is geomorphology and sediment transport, and the project has a lot in common, and to offer the SEA. It is expected that following initiation, the SOBA will provide a more in-depth analysis of available hydrologic, sediment and geomorphic information, and provide an assessment of the existing geomorphic processes and trends operating in the catchment based on GIS and field based assessment.

Activity 1 of the Australian Water Partnership (AWP): To support the SOBA, the AWP are carrying out a hydrological data audit of the Ayeyarwady Basin, including digitizing existing data. The preliminary data should be available later in 2017. The flow data of the Ayeyarwady, and size and inflow/outflow characteristics of existing reservoirs are relevant to the SEA;

Additional activities and investigations will be identified throughout the duration of the SEA through the stakeholder consultations.

Section summary: This section provides an overview of the SEA process, the aspects of geomorphology and sediment transport that will be investigated and how this baseline report 'fits' within the broader project.

2 GEOLOGY AND TECTONICS OF MYANMAR

Myanmar lies at the heart of the collision zone between the Indian plate and Eurasia, making it a highly active tectonic region (Figure 2.1) with diverse and complex geology (Figure 2.2, Figure 2.3). The tectonics and geology both exert a strong control on the characteristics of the rivers and catchments. Long before the theory of plate tectonics was developed, the structural control and geologic influence on the river systems was recognized by Stamp (1940) who identified three distinct reaches in the Ayeyarwady: the 'antecedent' reach encompassing the headwaters to approximately Bhamo, and characterized by Cretaceous or older rocks; a middle 'tectosequent' reach from Bhamo to Monyo (~25 km north of Hinthada), where uplift and faulting of Tertiary strata control the river morphology; and a deltaic section downstream of Monyo dominated by the reworking of predominantly Quaternary sediments. These broad divisions are still valid in the context of plate tectonics, and reflect the relationship of the different areas to the Sagaing fault zone.

The north south trending Sagaing fault zone is a major structure, extending ~1,500 km and bisecting the country. The right lateral strike slip fault has resulted in the development of both compression and pull part basins that affect the drainage patterns of the rivers and control the location of lakes (Aug, 2012). Estimates of displacement along the fault line range from 330 to 450 km.[1]

West of the fault, thrust faulting associated with subduction in the Andaman trench has resulted in north-south trending ridges and strike valleys that delineate the Chindwin River Basin and its major tributaries. The thrusting has uplifted and exposed relatively young and 'soft' rocks (Figure 2.2) which are susceptible to erosion and account for the large sediment loads discharged by the Chindwin. Strike slip movement on several of the major thrust faults, successive cycles of uplift and volcanic activity have affected the planform (shape) of the rivers.

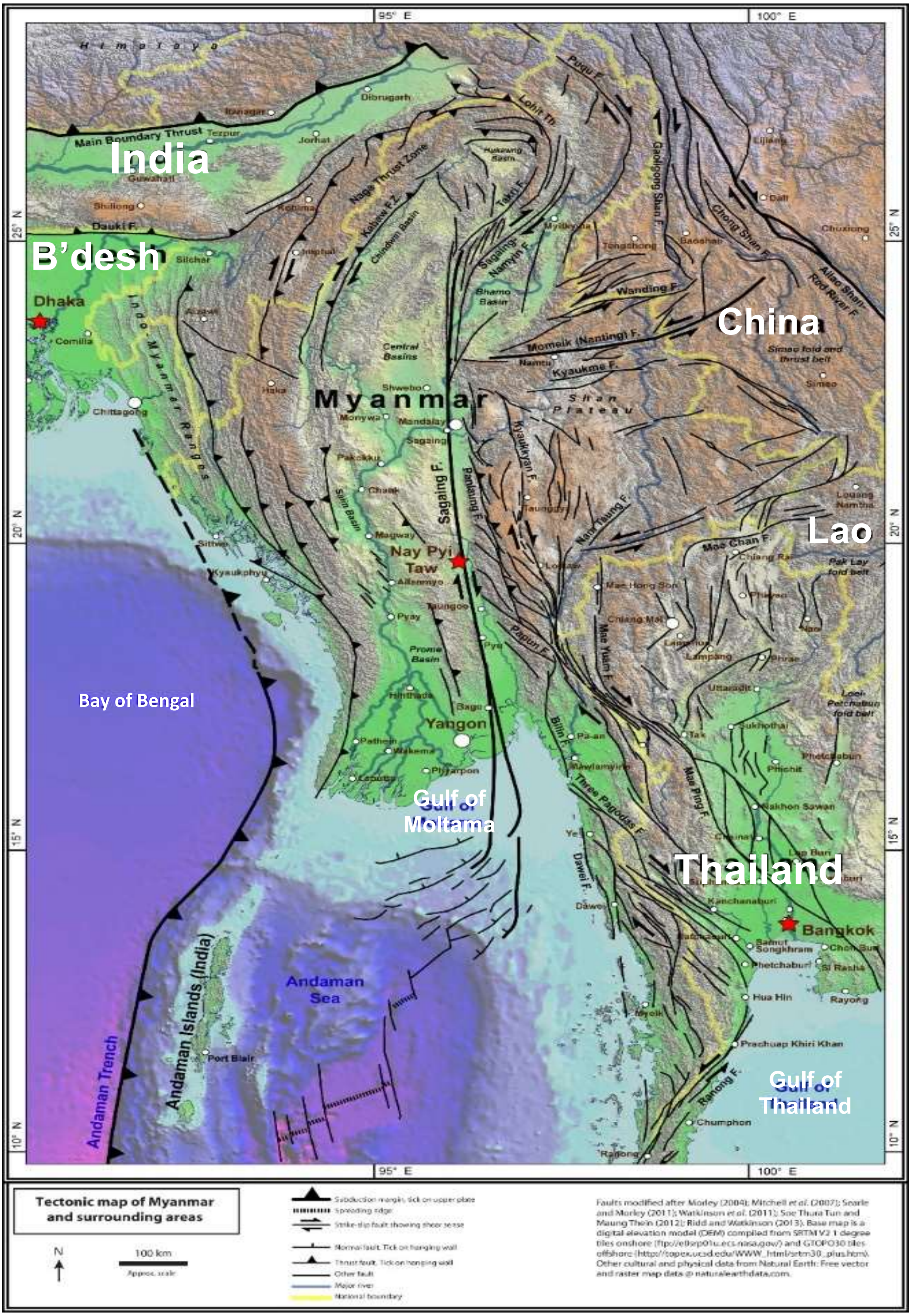
East of the Sagaing fault line, the geology consists of generally more resilient rocks underpinning the Kumun range in the north, and the Shan plateau in the central and southern area (Figure 2.3). Rivers in these areas, including the headwaters of the Ayeyarwady in the north and the mid-Thalnwin in the east reflect this geology, with higher slopes, bedrock controlled channels and rapids common. Strike slip faults, trending both north-south and east-west, control the drainage patterns of the river systems in these areas.

The course of the middle Ayeyarwady follows the Sagaing fault zone downstream of Bhamo where the main channel occupies the fault zone between Inywa to Mandalay. The north south course of the river is altered as it flows around volcanic deposits and exits the fault lineament upstream of Mandalay. Farther downstream, the river flows through the less resistant, sediment filled large Central Basin before being joined by the sediment rich Chindwin and cutting through the hills between Chaulk and Pauk and flowing south to the delta.

The Sagaing fault lineament south of Mandalay is occupied by the northward flowing Zawgyi tributary of the Ayeyarwady, and the southward flowing Sittaung River. It is likely that previously, these catchments were joined and separated due to uplift creating Mt Popa and the Pegu hills.

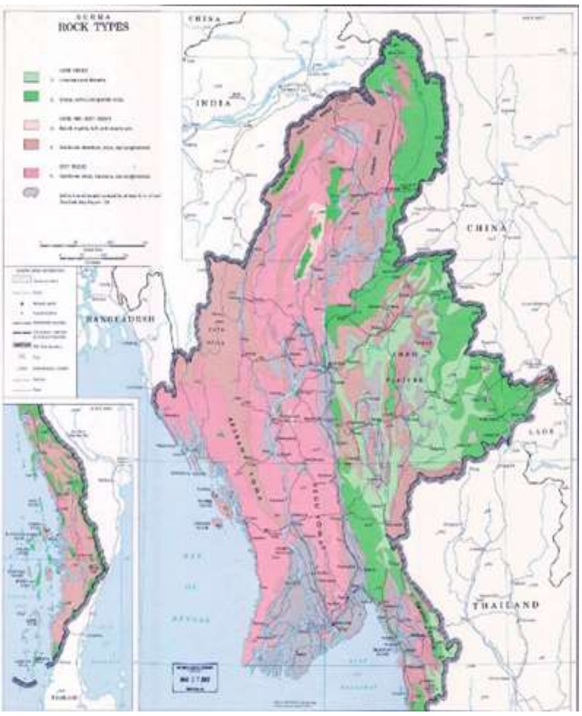
[1] References contained on http://www.sagaingfault.info, accessed Jan 2017

Figure 2.1: Tectonic features of Myanmar showing relationship between faults and river systems



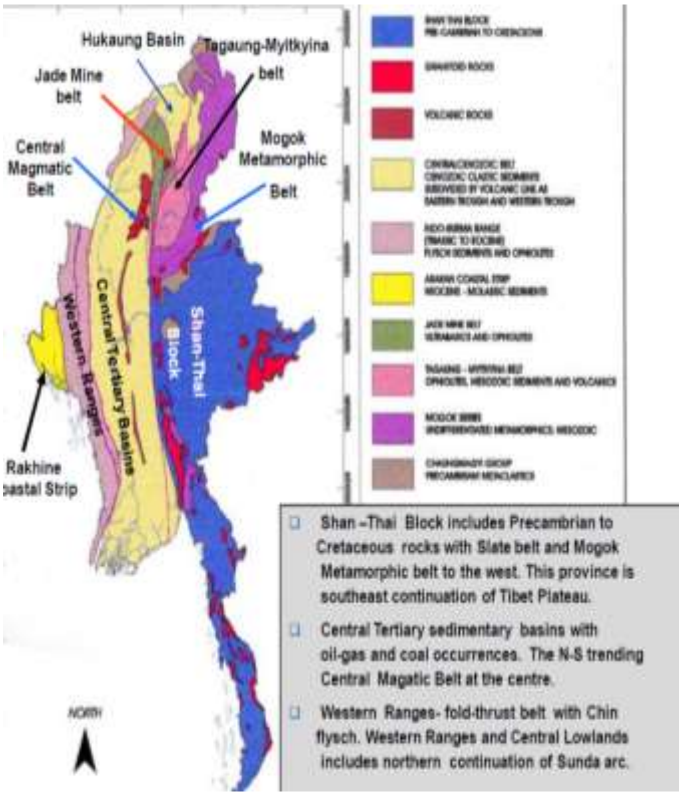
Source: Map accessed on http://www.sagaingfault.info/. Website caption states: Faults modified after Morley (2004); Mitchell et al., (2007); Searle and Morley (2011); Watkinson et al. (2011); Soe Thura Tun and Maung Thein (2012); Ridd and Watkinson (2013)

Figure 2.2: Simplified geologic map of Myanmar showing the distribution of ‘hard’ and ‘soft’ rocks in Myanmar, with the Sagaing fault as the main contact between the soft and hard units



Source: USGS, 2007

Figure 2.3: Geo-tectonic map of Myanmar showing ranges, belts and blocks



Source: Ye Mint Swe, 2013

Section summary: This section has provided an overview of the large scale geologic and tectonic processes that control geomorphic processes at a large scale and over long timeframes. The complex and unique geology of Myanmar are important to understand and consider when investigating or planning large scale water resource developments.

3 GEOMORPHIC CHARACTERISTICS OF THE RIVER BASINS

The SEA has identified eight major river basins for consideration: the Ayeyarwady, Chindwin, MekongMekong, Myit Mo Hka and Bago, Rakhine, Sittaung, Tanintharyi, and Thanlwin. There is a lack of detailed, geomorphic information for each of these catchments, but there are a range of GIS layers that are available and can be used to understand the geomorphic characteristics and important geomorphic processes operating in each of the catchments.

The tectonic and geologic characteristics of Myanmar, combined with rainfall and fluvial processes have developed distinct geomorphic regions in the country. A GIS analysis based on geology (Figure 2.2), slope (Figure 3.1), and elevation show distinct geomorphic regions with the characteristics of the regions described in Table 3.1. Four of the groupings relate to areas with high to intermediate slope and either 'soft' or 'hard' underlying geology. These four groups represent the potential sediment sources in the river basins. The other two groupings have very low slopes (<3°), and differ by elevation. The low slope areas situated at elevations greater than 30 m reflect alluvial basins that can be considered temporary storage areas for sediments, and are prone to 'reworking' by rivers and are susceptible to hydrologic changes. The low slope areas situated at elevations below 30 m have similar attributes, but also include deltaic areas where tidal flows affect sediment movement along with riverine inputs.

The relative proportion of these geomorphic regions within Myanmar and within each of the major river basins is summarized in Table 4.2 and presented graphically in Figure 3.3. It is recognized that many factors, especially deforestation, land use and water resource infrastructure can alter geomorphic processes at a range of scales and over a range of time-frames. River alterations associated with hydropower development will be evaluated in the next stage of the SEA process, and land use changes will also be considered by the biodiversity theme and integrated with the geomorphology findings in this next sub-basin evaluation stage. This review of geomorphology is based on a high level, basin scale analysis of the major factors which control large scale processes in rivers.

Figure 3.1: Slope classes in Myanmar

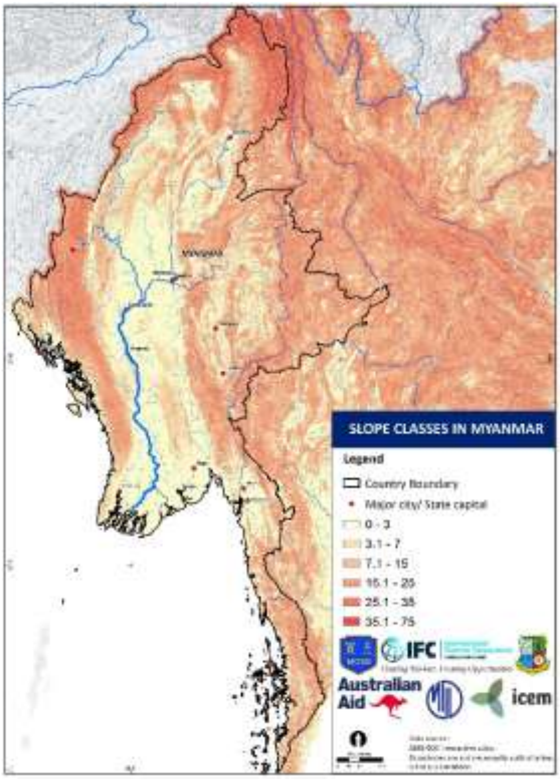


Figure 3.2: Geomorphic 'regions' in Myanmar

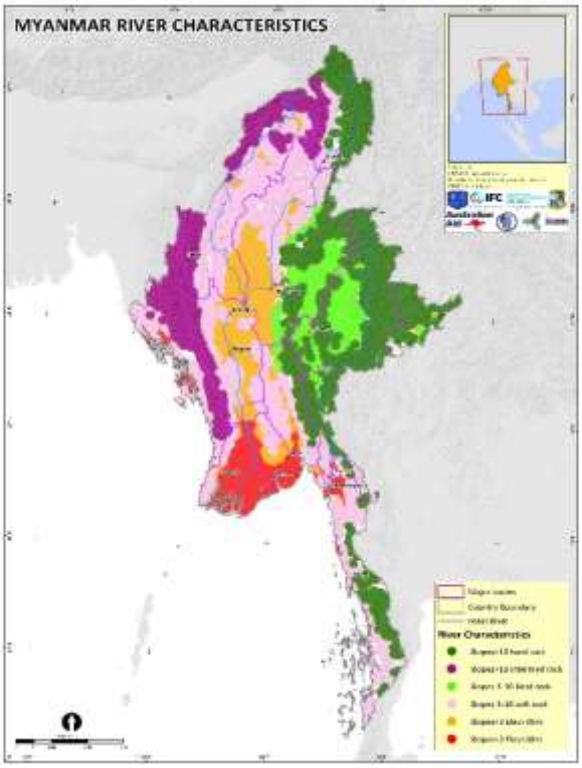


Table 3.1: Geomorphic characteristics of major catchments in Myanmar based on geology, slope and elevation

Geomorphic Regions	Characteristics and distribution
High slope (>10°), resistant 'hard' rock (dark green in Figure 3.2)	Generally higher elevation, older crystalline bedrock areas in the headwaters of the Ayeyarwady, the Shweli, Dapien and Mytinge tributaries, the Thanlwin and Mekong catchments, the eastern boundary of the Sittuang catchment, and central region of the Taninthayi rivers. These highlands represent the southern extension of the Tibetan plateau. Weathering of this rock produces minerals that are resistant to weathering, and can persist as sand for long distances
High slope (>10°), intermediate rocks (purple in Figure 3.2)	Located predominantly in the Western ranges of the Chindwin and eastern ranges of the Rhakine catchments at high elevation. The tectonically active ranges have the potential to contribute high sediment loads to steep tributaries
Intermediate slopes (3° - 10°), hard rock (Light green in Figure 3.2)	This unit reflects the intermontane basins that have developed on the Shan Plateau. Predominantly located in the Thanlwin but also present in the eastern Shweli, Dapien and Mytinge tributaries and the Mekong catchment. These areas are likely to contribute lower sediment loads 'naturally' but because they are typically developed for agriculture and other uses may input locally high sediment loads
Intermediate slopes (3° - 10°), soft rock (pink in Figure 3.2)	This unit reflects the large central basin of the Ayeyarwady, and is also present in the Rakhine, Sittuang, Myit Ma Hka and Bago and Taninthayi catchments. It contains low foothills connecting the higher, steeper slopes with the lower and flatter alluvial basins or coast. Likely to be a moderate source of sediments, although may locally be important, such as in the Ayeyarwady where it flows through the shear zone associated with the Sagaing fault north of Mandalay, or following intense rainfall events
Low slope (<3°), low elevation basins (>30 m) (orange in Figure 3.2)	This unit is generally limited to the 'Dry Zone' of the Ayeyarwady and Chindwin Central Basin and in the Myit Ma Hka and Bago catchments. It is an area of sediment storage and reworking.
Floodplain and delta (3°, <30 m) (Red in Figure 3.2)	Low lying alluvial floodplains and deltas representing the large delta of the Ayeyarwady and Bago and Myit Ma Hka catchments, and smaller deltas of the Sittuang and Thanlwin rivers. The coastal areas of the Rakhine and Tanintharyi are also characterized by sediment accumulation, delivered from the short step coastal river basins.

Table 3.2: Distribution of geomorphic regions by basin

Percentage of each geomorphic region in each river catchment	Ayeyarwad y	Chindwin	Thanlwin	Taninthanyi	Rakhine	Sittaung	Mekong	Myit M Hka & Bago
Slopes>10° Hard rock	29		68	31		23	88	
Slopes>10° Intermed rock	5	36			59			
Slopes 3°-10° Hard rock	8		25			2	6	
Slopes 3°-10° Soft rock	22	44	4	53	27	38	6	15
Slopes<3° Elev>30m	26	20	1	2	1	23	<1	22
Slopes<3° Elev<30m	10		2	15	13	13		64

Figure 3.3: Distribution of geomorphic regions by basin. First chart shows relative size of catchments

These characteristics govern the characteristics of the rivers and are reflected in the planforms (shape) of the river channels. In the east, the Thanlwin downstream of the Chinese boarder is confined to the bedrock controlled Shan or Eastern Plateau until it emerges in the coastal lowlands in the Mon State. This strong bedrock control results in a relatively straight mainstem channel with numerous small tributaries draining the undulating plateau. Similarly, the morphology of the headwaters of the Ayeyarwady is controlled by the bedrock control associated with cutting through the northern Kumun Mountains.

In contrast, the Ayeyarwady downstream of Mandalay, the mainstream of the Chindwin, the Sittaung and Myit Ma Hka rivers are low slope systems that are reworking the sediment filled basins of the Central Basin and lowlands, whereas the western Kaladan River in Rakhine is cutting through silts and shales exposed in fault controlled valleys, in a tectonically active region, and delivering sediment to low-lying coastal areas. The characteristics of the mainstem and tributaries can vary markedly as shown in the Chindwin, which is fed by steep tributaries from the tectonically active northern and western mountains (Figure 3.4). Similar characteristics are found in the Sittaung which receives flow from steep tributaries draining the Shan plateau, but the mainstem is confined to a low slope alluvial valley.

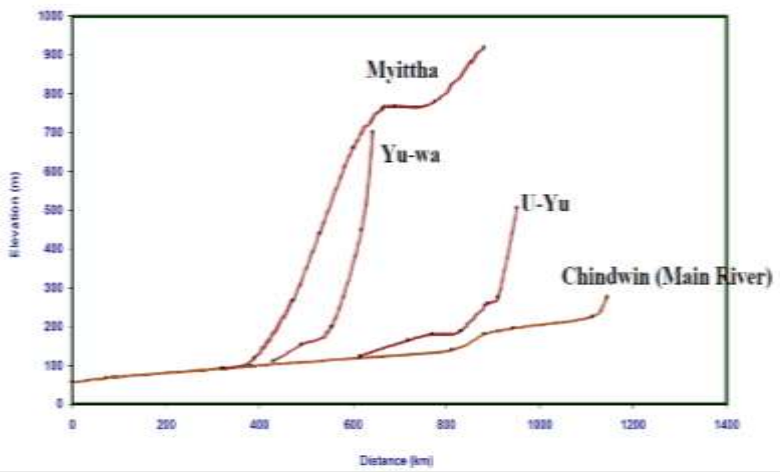
Due to the lack of basin specific geomorphic information for most of the river basins, these geomorphic regions will be used as the basis for assessing the hydropower development scenarios.

3.1 Strahler Order

Relevant to the geomorphic functioning of rivers at a large scale is the Strahler Order, which is based on the number and complexity of tributaries upstream of any river reach. The Strahler Order of rivers in Myanmar reflect the geological and physiographic characteristics of the basin with low orders coinciding with the areas of steeper and higher elevated bedrock and the higher orders (5 and 6) restricted to the broad central basin (Figure 3.5). The orders also provide an indication of geomorphic functioning of the sub-catchments, with low order tributaries prone to rapid changes in flow and episodic sediment inputs associated with localized land slips. Higher order rivers, which integrate large catchment areas, tend to have more modulated responses to flow and sediment changes.

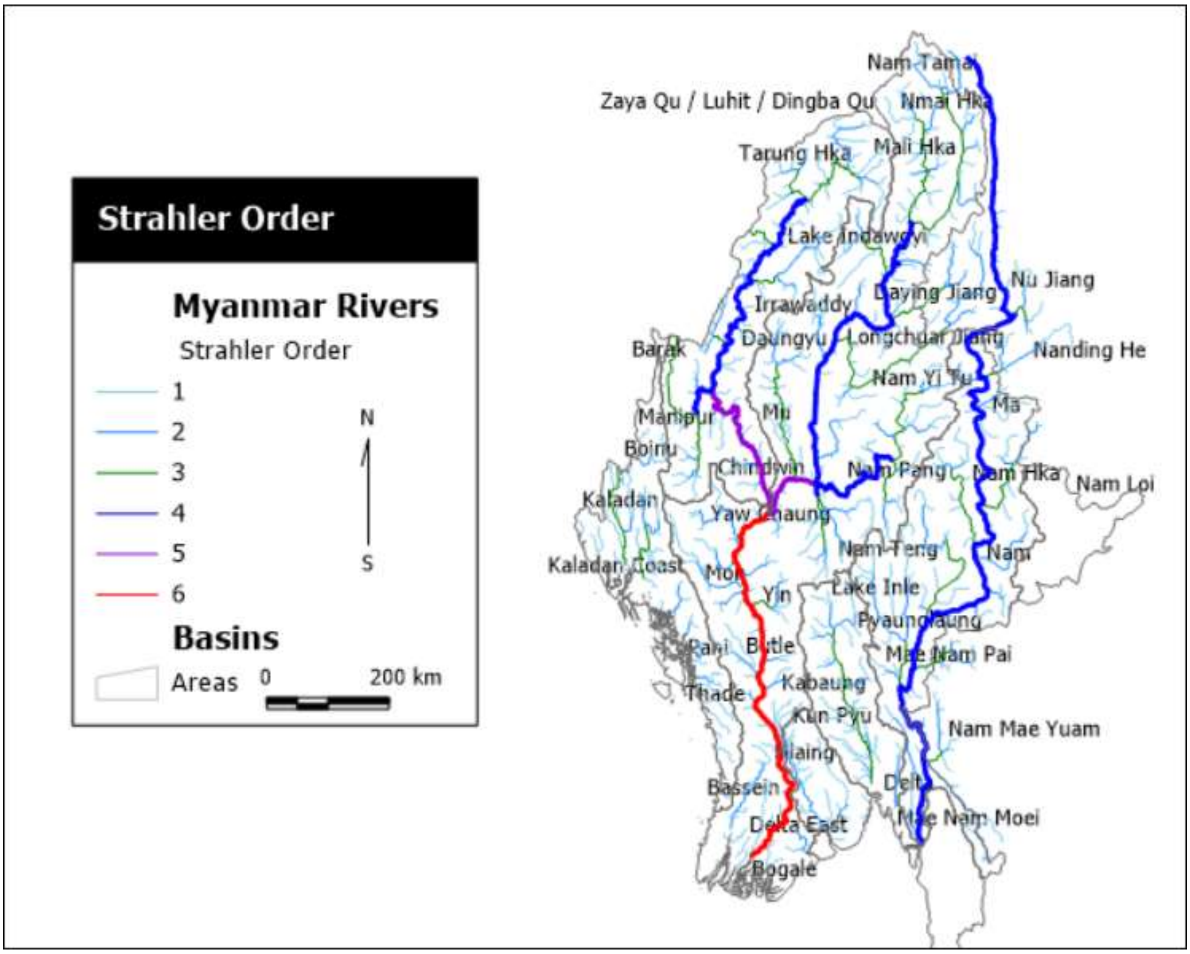
The Strahler Order map (Figure 3.5) includes the Thanlwin catchment upstream of Myanmar, and shows that the length of the Thanlwin mainstem is classified as order 4 at this scale. This indicates that the tributaries entering the mainstem are class 3 or lower, and suggests that the Thanlwin is likely to be a 'flashy' system and subject to frequent 'pulses' of water and sediment from these low order catchments following rainfall events.

Figure 3.4: Longitudinal profiles of the Chindwin mainstream and major tributaries, showing steep tributaries entering a low-slope main channel



Source: Chikamori, et al., 2012

Figure 3.5: Preliminary Strahler Order classification of rivers based on the Greater Mekong Sub-region datasets



Source: River GIS information obtained from Environment Operations Centre, ADB. Actual Strahler numbers are likely higher due to the low resolution of the data set. Strahler Orders 4 and greater are shown in thicker lines

Section summary: This section described catchment characteristics based on available information. Myanmar ranges from steep, elevated areas to low-slope, low lying areas and these physical characteristics are important for understanding the large scale geomorphic processes affecting rivers. Unfortunately there is a lack of detailed sub-basin scale information and more investigations and characterization of the land-scape would assist in the understanding of geomorphic processes and they will respond under different development scenarios.

4 GEOMORPHIC CHARACTERISTICS OF THE RIVER CHANNELS

The geomorphic characteristics of the rivers in Myanmar have not been documented in a detailed systematic manner. A regional geomorphic description of the Greater Mekong Sub-region (GMS) has recently been completed that includes Myanmar with the exception of the area west of the Ayeyarwady River Basin (Lehner and Oullet Dallaire, 2014). This classification is based on the physical attributes of the rivers, and integrates the previously discussed characteristics of the rivers in Myanmar with respect to channel characteristics and gradient. The analysis also identified the distribution of floodplains, and shows they are generally limited to the low slope Central Basin and delta areas associated with the Ayeyarwady, Sittaung and other southern coastal rivers. This classification is consistent with the previously suggested grouping of rivers, with the characteristics of the Thanlwin being similar to the headwaters of the Ayeyarwady, and the Sittaung and coastal rivers of Myit Ma KHka and Bago having similar attributes as the lower Ayeyarwady.

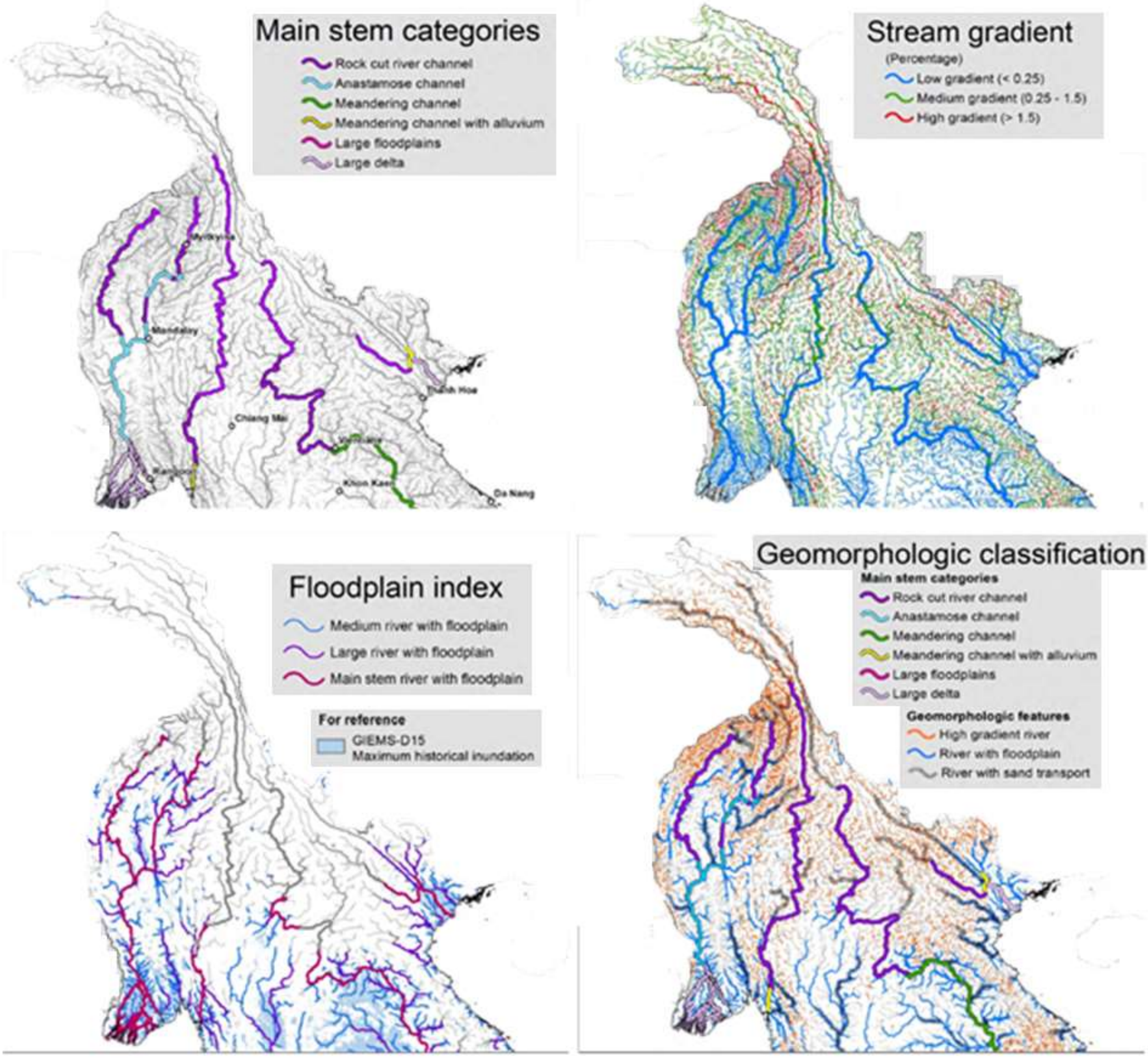
A more detailed analysis of the Ayeyarwady and Thanlwin channel characteristics has been completed by ICEM based on Google Earth images (Figure 4.2, Figure 4.3). The ICEM analysis determined channel features at 5 km intervals along the mainstem of each river. The results are consistent with the regional classification of Lehner and Oullet Dallaire (2014) but provide more detail.

In the Ayeyarwady, the steep, elevated headwaters are characterized by a narrow bedrock constrained channel containing numerous rapids, with low Strahler Order tributaries entering at close intervals. Bedrock outcrops within the channel are restricted to the upper ~500 km of the river channel, however bedrock controls the river valley width at narrow sections along the length of the river. These bedrock controlled valleys in the middle and lower river are filled with sands, accounting for the channel being mapped as 'sandy' for most of the length of the river.

A widening of the channel is associated with the entrance of the Chindwin system approximately 100 km downstream of Mandalay. The broad alluvial reaches are characterized by braided channels that are highly active and prone to rapid lateral migration, meander cutoffs and avulsion during high flow events (Brakenridge et al., 2017). Figure 4.4 shows some of these features in the Ayeyarwady, where the river (flowing from top to bottom in the photo) exits the Sagaing shear zone and flows out into a broad alluvial floodplain. Additional features are highlighted in the figure caption.

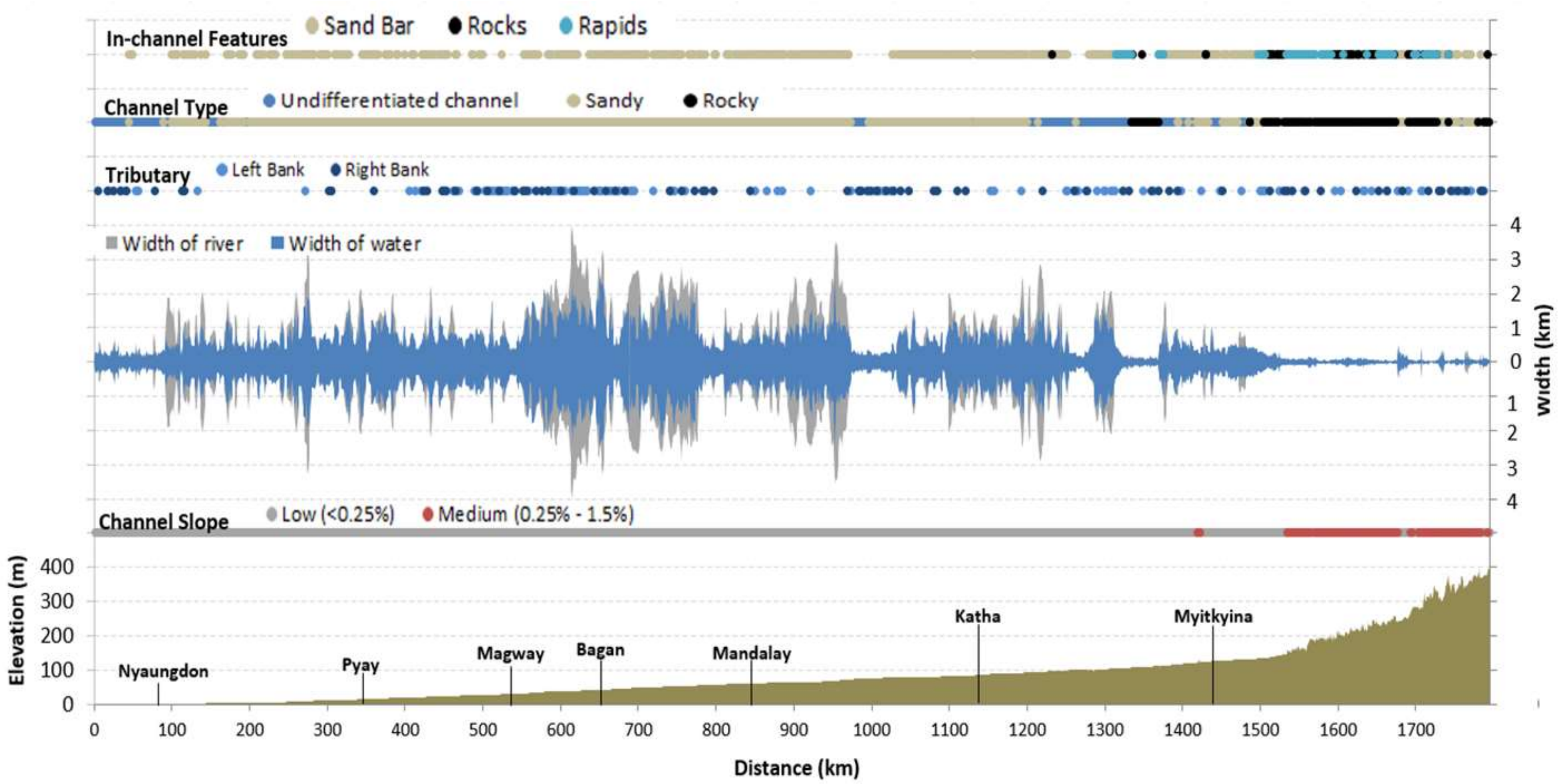
The Thanlwin shows very different features (Figure 4.3), with a narrow channel characterized by rocky outcrops forming rapids interspersed with pools to within ~100 km of the mouth of the river. The channel is flanked by sandy terraces with vegetation on the terraces increasing with distance downstream. These features reflect the strong bedrock control of the river. Near the mouth, where the river exits the resistant underlying strata and flows through softer rocks and floodplain, the channel widens and becomes braided.

Figure 4.1: River reach classification of rivers in Myanmar and the Greater Mekong Region



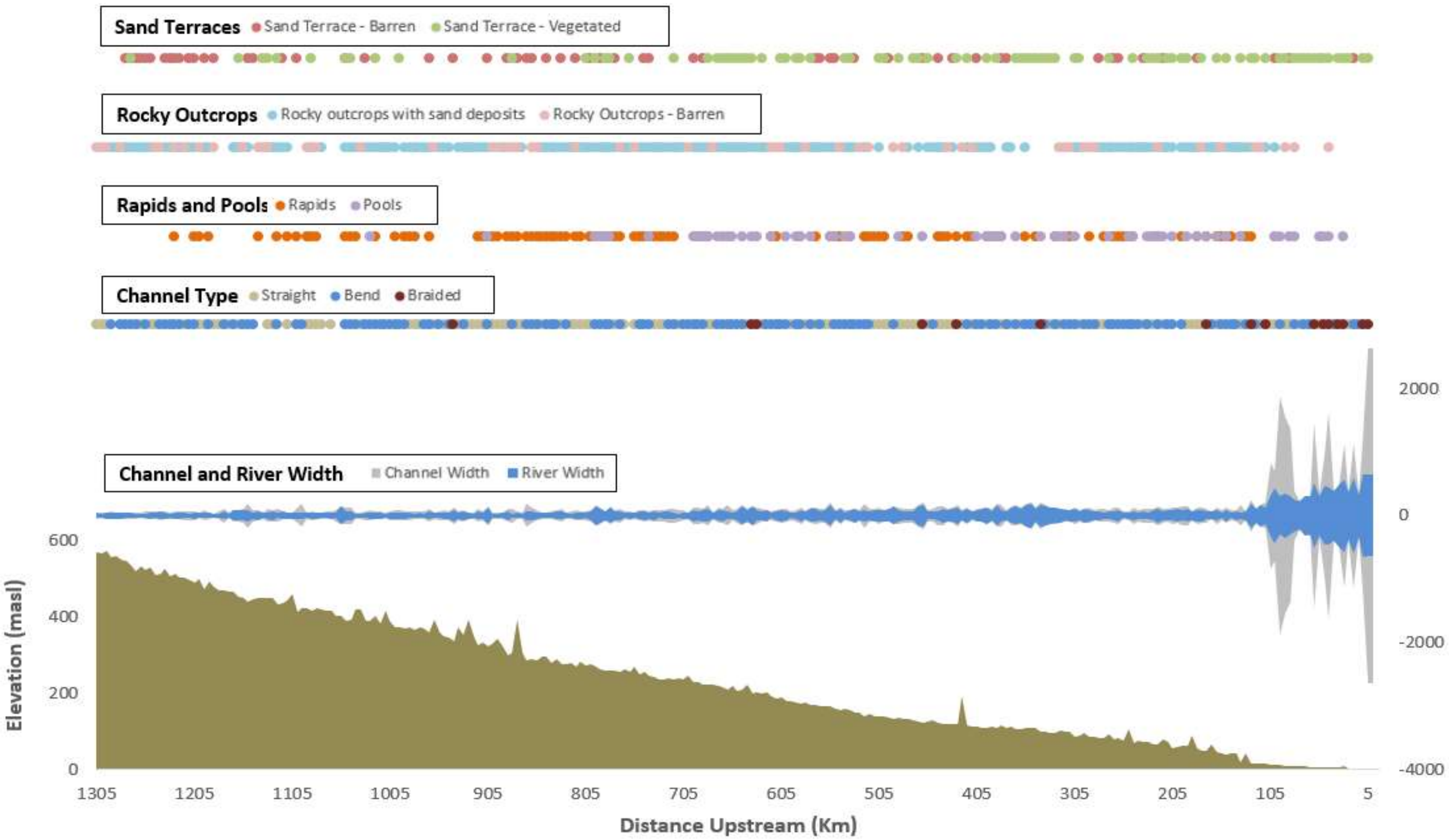
Source: Lehner and Oullet Dallaire, 2014

Figure 4.2: Characteristics of the Ayeyarwady River, based on analysis of Google Earth imagery at a scale of 5 km



Graphic shows from bottom to top: channel elevation, channel slope, the width of the river channel and the width of the river at the time of the analysis, where tributaries enter the mainstem, the channel type and prominent features. Analysis completed by ICEM.

Figure 4.3: Characteristics of the Thanlwin River, based on analysis of Google Earth imagery at a scale of 5 km



Graphic shows from bottom to top: channel elevation, channel slope, the width of the river channel and the width of the river at the time of the analysis, where tributaries enter the mainstem, the channel type and prominent features. Analysis completed by ICEM.

Figure 4.4: Google Earth image showing prominent geomorphic features in the middle Ayeyarwady River.

The river flows from north to south in photo. At the upstream extent of the figure, the river is following along the Sagaing fault. It flows westward around a lava flow before exiting the fault lineament and spilling into the eastern extension of the Central Basin and becoming an anastomosing system. In the eastern part of the photo the Mytinge River has been developed for hydropower as it drains the Shan Plateau. In the western portion of Figure 4.4, the meandering Mu River drains the central basin and lowlands.

4.1 Suspended sediment transport

The rivers in Myanmar are recognized as some of the largest contributors of sediment, carbon and nutrients to the sea, but have not been accurately quantified (Robinson *et al.,* 2007).

Historic sediment transport information from Seiktha, near the head of the Ayeyarwady delta was collected in 1877 - 1878 by Gordon (1885), who estimated an annual sediment load of 340 Mt yr^{-1} for the year, but revised the figure to 261 Mt yr^{-1} based on a revision in the discharge volumes of the river during the monsoon. Using the flow, sediment relationship derived from the monitoring results, sediment loads ranging from 248 Mt yr^{-1} to 352 Mt yr^{-1} have been subsequently calculated for the period 1869 - 1879 (Robinson *et al*, 2007).

Stamp (1940) published monthly sediment load values based on Gordon's annual average load of 261 Mt yr^{-1} showing that ~66% of the sediment load was delivered in July to September, and ~87% in June to October (Figure 4.5). Stamp (1940) also provides a rough sediment budget for the basin, although the basis for the values are not well documented (Table 4.1). The budget suggests that less than 15% of the total sediment load was derived from upstream of Mandalay, with over 85% derived from the Chindwin and remaining dry belt.

Table 4.1: Sediment budget as determined by Stamp (1940) based on Gordon's estimate of 261 Mt yr^{-1} for the river at Seiktha

Location / Source	Annual Sediment Load (Mt yr^{-1})
Mandalay	32 (12%)
Chindwin	109 (42%)
Dry belt excluding Chindwin	120 (46%)

Robison *et al.,* (2007) measured suspended sediments in the Ayeyarwady and Thanlwin rivers in 2005 - 2006, and used the findings to re-analyze Gordon's suspended sediment data set. They found that Gordon's estimate was likely low due to the loss of very fine-grained material during filtration, and suggested a revised 19th century sediment load of 364 ±60 Mt yr^{-1} for the Ayeyarwady. Using these results, the authors scaled the results based on discharge to other rivers in the region, and estimated a combined suspended sediment load from the Ayeyarwady and Thanlwin systems of 370 to 600 million tonnes yr^{-1} to the Andaman Sea.

Table 4.2: Summary of suspended sediment loads as determined by Robinson et al., 2007

River System	Suspended Sediment Load (Mt yr^{-1})
Ayeyarwady	364±60
Thanlwin	180
Sittuaung, Bago, Bilin, Attaran, Gyaning (combined)	50

Source: Robinson et al, 2007

Furuichi *et al.,* (2009) derived a sediment budget of 325±57 Mt yr^{-1} based on measurements at Pyay between 1969 - 1996. The same investigation suggested a decrease in water discharge at the site compared to historic values.

Water level and sediment monitoring have been completed at several sites in the Ayeyarwady by DWIR in Myanmar, allowing the calculation of discharge volumes and suspended sediment loads. This data has been previously used by ICEM for the development and calibration of a Soil and Water Assessment (SWAT) model for the river system under the Myanmar Healthy Rivers Initiative (MHRI). This same data has been subjected to a preliminary analysis for this project and summarized below. Information relating to the methods of data collection and calculation of water volumes and sediment loads is not included with the data set, and it is the intention of the SEA team to discuss these methods and approaches with the responsible agency if possible.

The daily sediment load data for Sagaing, Chauk and Magway have been aggregated to monthly data sets and summarized in Figure 4.6 and Figure 4.7 and time-series of the annual sediment loads are shown in Figure 4.8. The results show a strong seasonality, although there is high variability in sediment loads during the June to October period. Sagaing has the lowest sediment loads, as would be expected as it is located highest in the catchment and upstream of the Chindwin River, with a long-term average of 70 Mt yr^{-1} and an average of 64 Mt yr^{-1} for the period 1990 - 2010. The loads at Chauk exceed those at Magway, which is surprising given that Magway is located further downstream. The average sediment load at Chauk based on the entire monitoring period is 151 Mt yr^{-1} and 154 Mt yr^{-1} for the period 1990 - 2010. At Magway, the 1990 - 2010 average load is 125 Mt yr^{-1}. Not surprisingly, the SWAT model derived by ICEM calibrated with these results provides a catchment sediment yield of ~136 Mt yr^{-1}(ICEM, 2017).

These sediment load estimates are considerably lower than the 261 Mt yr^{-1} determined by Gordon (1885), the 364 Mt yr^{-1} re-calculated by Robinson *et al.,* (2007) or the 325 Mt yr^{-1} reported by Furuichi *et al.,* (2009), as demonstrated in Figure 4.9. Some of the discrepancy is likely attributable to the different locations for each estimate and the inherent variability of sediment transport in river systems. Other potential sources of discrepancy include unrecognized changes to cross-sections leading to changes in the relationship between water level and flow at gauging stations. Channel alteration at these sites will affect the accuracy of flow calculations. Differences in sampling methods may also be a contributor to the difference in results.

Despite the discrepancy in total sediment loads, the recent data sets show consistency with respect to the pattern and seasonality of sediment transport (Figure 4.9) with the majority of sediment delivered between April and October. This pattern reflects the monsoonal rainfall in the catchment, and can be assumed to be applicable to the other river catchments in Myanmar (e.g. that highest sediment loads correspond with peak flow events), which is important for understanding potential changes associated with water resource developments.

Figure 4.5: Distribution of sediment load by month and cumulative at Seiktha as determined by Gordon (1885) and reported by Stamp (1940). Total sediment load was estimated at 261 Mt yr^{-1}.

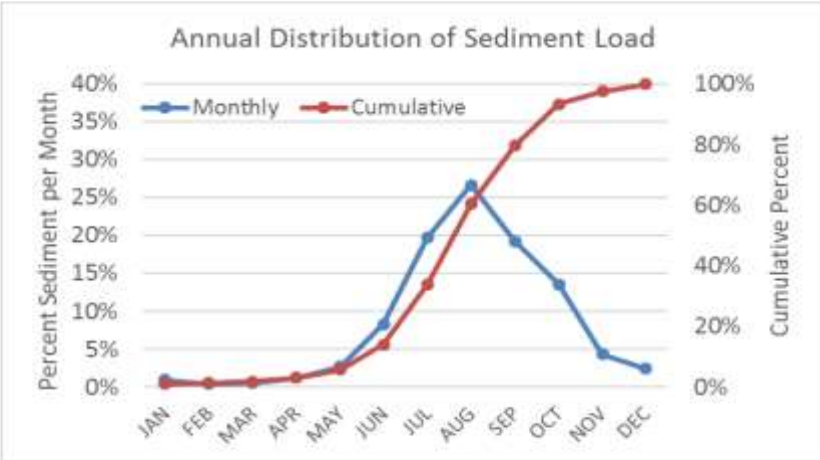
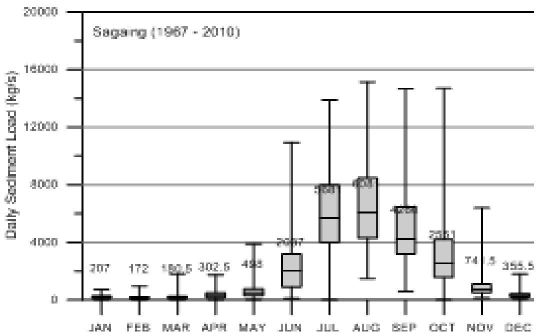


Figure 4.6: Monthly sediment loads based on on daily sediment load data from DWIR for Sagaing



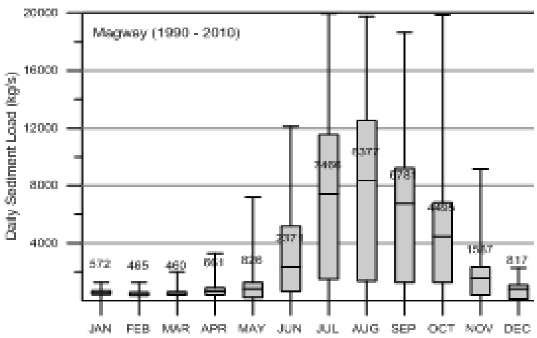
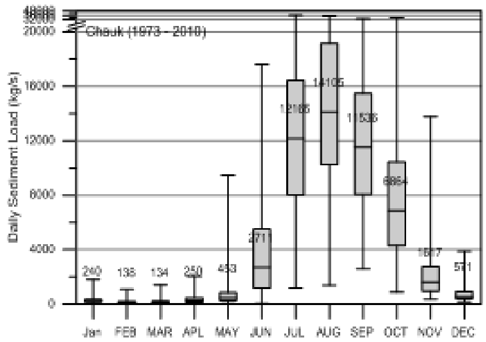


Figure 4.7: Monthly sediment loads based on daily sediment load data from DWIR for Chauk



The 'box' encompasses the 25th to 75th percentile range of results with the median value shown by a line in the box. The 'whiskers' indicate the minimum and maximum values. The median value is labelled for each month.

Figure 4.8: Annual sediment loads based on daily sediment loads determined by DWIR

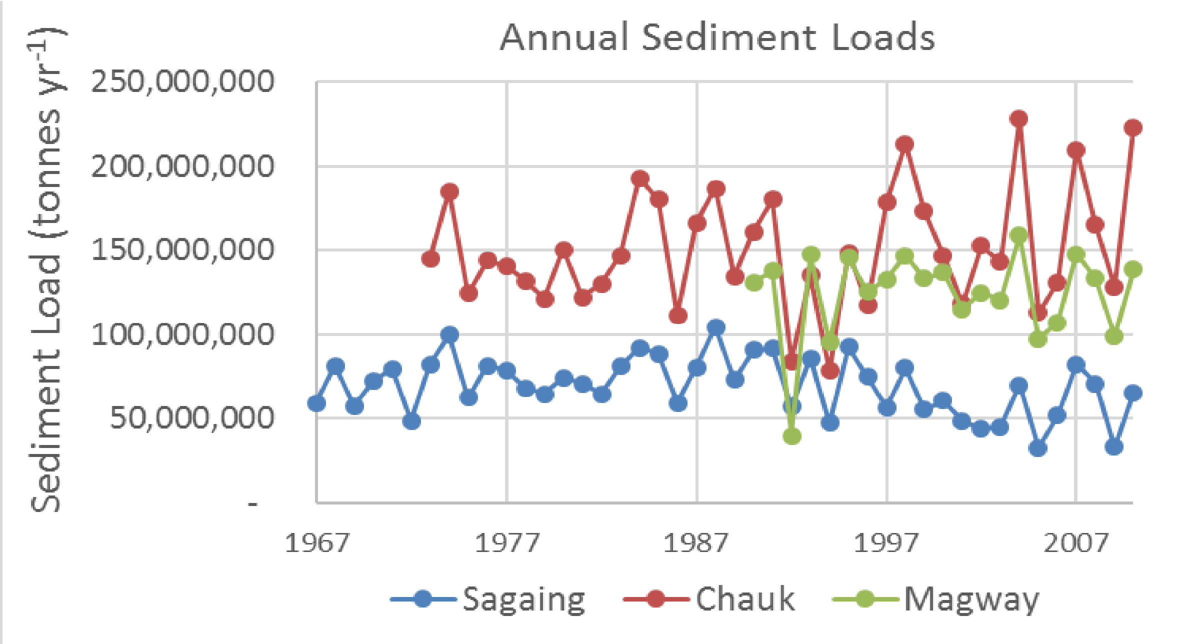
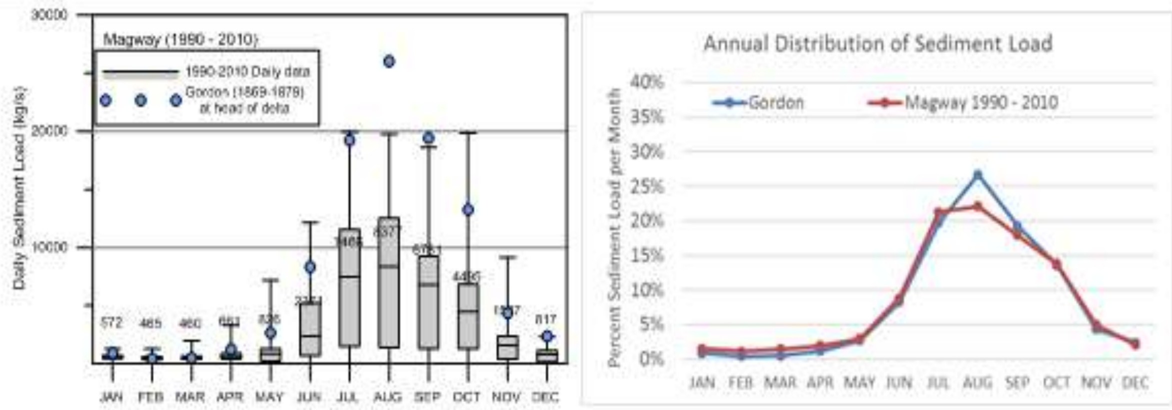


Figure 4.9: Comparison of monthly sediment loads from Gordon (1885) to results at Magway (1990-2010) (left) - Comparison of the percentage of sediment load discharged each month in the same two data sets (right)



Number on 'box' shows median value of data set.

4.2 Bedload and sediment budget

A recent investigation by Garzanti *et al.,* (2016) used the provenance (source) of heavy minerals and the geochemical and geochronological signatures of bedload sand in the Ayeyarwady to estimate the relative contributions of sand from different sub-catchments. This information can be applied to other catchments and sub-catchments in the SEA study area that have similar geologic and tectonic characteristics. Garzanti *et al.,* (2016) estimated sediment fluxes and denudation rates for the sub-catchments based on an estimate of 325 - 364 Mt yr^{-1} of suspended sediment and an additional 10% contribution from bedload. This approach assumes that the suspended load and bedload have similar ratios of minerals, which Garzanti *et al.,* (2016) suggest is a reasonable assumption, although the finer-grained mineralogy of the Chindwin is identified as a potentially complicating factor.

The analysis suggests that approximately half of the sediment load in the Ayeyarwady is derived from the Chindwin catchment, with the headwater rivers of Nmai and Mali collectively contributing an additional ~35%. The remaining sub-catchments are estimated as contributing < 15% of the total annual sediment load.

Table 4.3: Estimated sediment loads, denudation (erosion) rates and sediment yields in sub-catchments in the Ayeyarwady based on mineral provenance and geochemical and geochronological signatures

Catchment	Sediment Input (Mt yr^{-1}) % based on load of 375 (Mt yr^{-1})	Denudation rate (mm yr^{-1})	Sediment yield (tonnes km^{-2})
Nmai	60 - 70 (~17%)	0.5	1,300
Mali	60 - 70 (~17%)	0.5	1,300
Taping	10 (~3%)	0.5	1,000 - 1,500
Sweli	30 (~8%)	0.5	1,000 - 1500
Mytinge	5 (~1%)	0.1	200
Chindwin	200 (53%)	0.7	1,700
Total for catchment	**365 - 385**	**0.3 - 0.4**	**~1,000**

Source: Garazanti et al., 2016

These estimates are in line with the analysis completed by Lehner and Oullet Dallaire (2014) with respect to the transport of sand and gravels (Figure 4.10). High inputs are projected for the headwater and mainstems, with lower inputs from the tributaries near Mandalay, and in the Chindwin. This relationship between the underlying geology and sediment input is demonstrated in Figure 4.11 and Figure 4.12 for the Ayeyarwady and Thanlwin catchments, respectively. The upper Ayeyarwady contributes a low percentage of suspended sediment, but a large percentage of bed material, owing to the resistant bedrock that resists weathering and remains transported as bedload. Material contributed from the Chindwin is more susceptible to weathering and is easily reduced to material that can be transported as suspended load.

In the Thanlwin, the mainstream carries a large suspended load that is derived from the Himalaya upstream of Myanmar where the rocks are susceptible to weathering and produce fine sediments. The Shan plateau is likely to provide proportionately less suspended load but a major proportion of bedload due to its more crystalline nature being more resistant to weathering. Fine-sediment input from the Shan plateau is likely to increase in areas where land disturbance has occurred (discussed in more detail under '*key themes*'.

Figure 4.10: Sediment transport in large rivers based on river reach classification of rivers in Myanmar and the Greater Mekong Region. Source: Lehner and Oullet Dallaire, 2014.

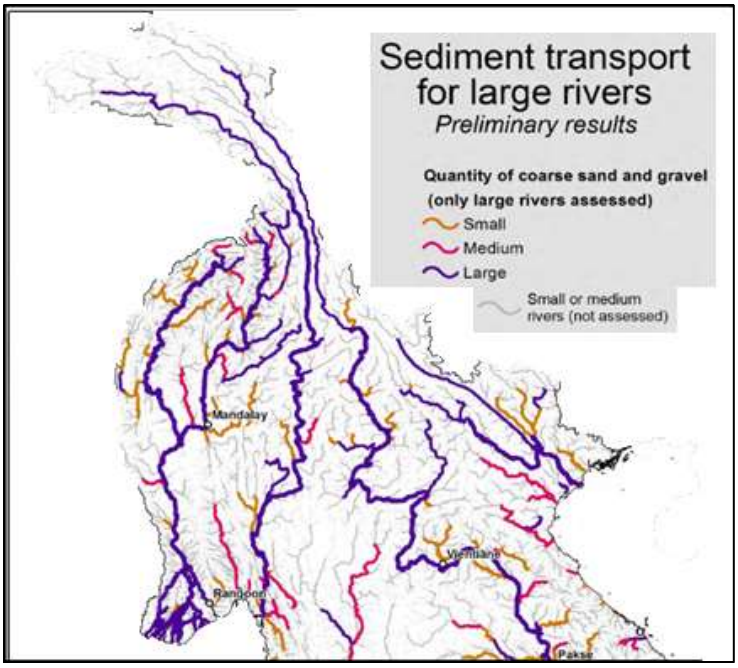
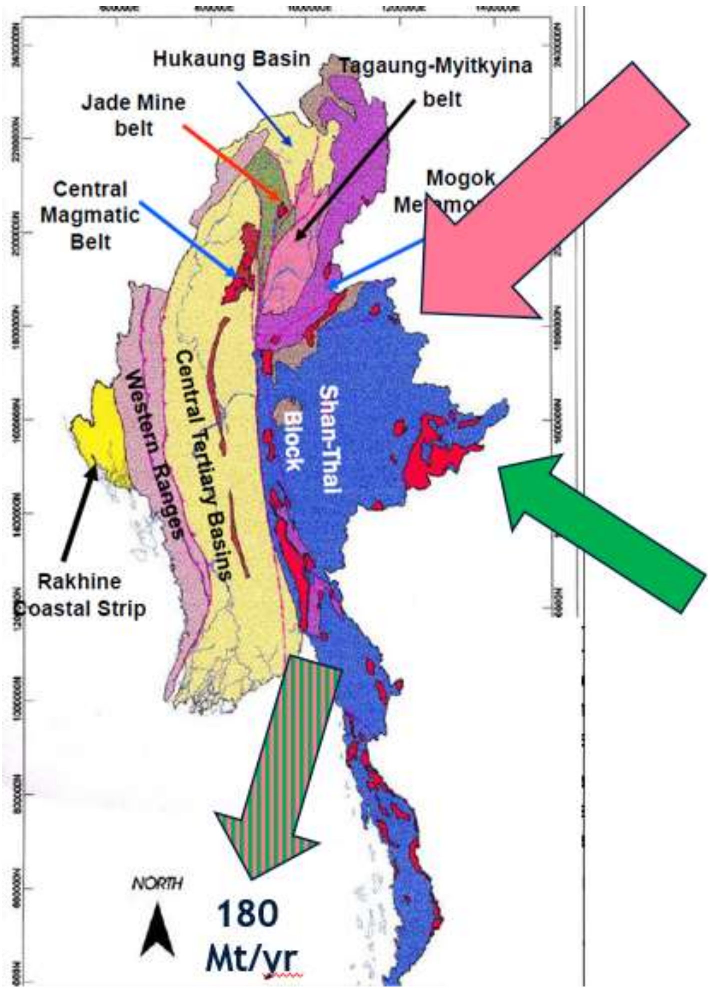


Figure 4.11: Comparison of suspended (left) and bedload (right) sediment input in the Ayeyarwady from upstream of Mandalay (green) and from the Chindwin River and downstream (red)

The colors in Figure 4.11 correspond to the ‘soft’ and ‘hard’ rocks shown in the geologic map in Figure 2.2. ‘Hard’ rocks are more likely to persist as bedload because soft rocks will abraid (erode) and able to be transported in suspension. Sediment inputs based on values presented in this report.

Figure 4.12: Geologic map of Myanmar showing sediment inputs from ‘soft’ (red) and ‘hard’ (green) rocks in the Thanlwin catchment.

The red arrow in Figure 4.12 represents fine-grained sediment input from the Himalaya in China, and the green arrow represents coarse grained sediment input from the Shan plateau. Base map from Swe, 2013, sediment estimate as per Table 4.2.



Section summary: The available information about river channel characteristics and sediment transport have been summarized. Unfortunately, there are many gaps in the understanding of geomorphic processes and in the sediment transport and yields of the catchments. A lack of recent monitoring results prevents the ability to quantify sediment loads transported by the rivers. Historic results suggest that the Ayeyarwady transports very high volumes of sediment, but little has been quantified with respect to the other river systems in the country. These information gaps are explored in more detail in the following section.

5 INFORMATION GAPS

To understand how hydropower or other water resource developments will affect rivers, an accurate understanding of the river systems and the potential projects are required. The following data and information gaps have been identified during the baseline assessment phase. Over the course of the SEA, some of these gaps might be partially addressed through provision of information by the relevant Ministries and groups. Information gaps include:

- A systematic geomorphic description of the water ways at a local scale that can be used to assess potential changes to rivers related to hydropower or other water resource development. This includes the composition and characteristics of river channels, banks and flood plains and the locations and positions of infra structure that can alter geomorphic processes;
- Recent monitoring results related to flow and sediment transport in the water ways. There is some sediment monitoring information available for the Ayeyarwady, but its quality is questionable. The scarcity of information from other river basins is a major gap in the understanding of flow and sediment transport in the country, and extrapolating the (questionable) Ayeyarwady results to other catchments, such as the Thanlwin, is not applicable due to the differences in geology, geomorphology and hydrology between the catchments. Flow and sediment transport information needs to be collected on spatial and temporal scales appropriate to provide reliable information regarding the magnitude and seasonality of sediment delivery, and the relationship between flow and sediment transport. Detailed information is required for areas where navigation has been affected by sedimentation and shifting sand bars;
- Information about sediment characteristics (grain-size) is missing for both suspended and bed load sediment loads. Quantifying the types of sediment being transported at different points in each main river system as suspended and bed load is required to understand how transport may be disrupted by hydropower development;
- Details regarding how potential hydropower projects will alter the flow and sediment regime in the local catchment (note: this information is being collated as part of the hydropower plant (HPP) database outlined in the hydropower chapter). Relevant information includes: flow and sediment characteristics of the unregulated waterway, the size of the catchment to be regulated, the size and geometry of potential impoundments, the proposed operating regime of the project (base load, peaking, minimum and maximum flows, provision of irrigation flows), proposed mitigation measures (including re-regulation weir, low level gates for sediment passage, power station operating rules, environmental flows and joint operations within cascade systems), trapping efficiencies of impoundments, the location and characteristics of downstream unregulated tributaries, and the local uses and values of the river;
- Detailed information about other existing or planned water resource developments or land uses that will alter water and sediment flows is lacking. Hydropower development needs to be considered within the context of catchment development and activities;
- An understanding of how climate change is likely to alter sediment generation and transport with or without hydropower development is required for identifying potential future changes.

6 DESCRIPTION OF THE KEY THEMES

The key geomorphology and sediment transport themes associated with hydropower development can be grouped into two main areas, namely, how hydropower projects can directly affect the flow and sediment movement in rivers, and how hydropower activities and impacts can interact with other land use and water resource developments. These issues have relevance to geomorphology and sediment transport but are also critical for the maintenance and distribution of ecological habitats, and human activities linked to the river, such as fishing and riverbank and floodplain agriculture.

6.1 The alteration of river flows and trapping of sediment in impoundments by hydropower developments

Changing the magnitude, frequency, duration, seasonality or rate of water level change in a river, or altering the quantity, quality or size distribution of sediment moving through the system will result in a geomorphic 'response' in the downstream river channel. In the case of hydropower developments, these 'responses' can include channel deepening and/or widening, bank erosion, coarsening and armoring of river beds, or channel constriction due to vegetation encroachment (if high flows are removed). Floodplains are particularly susceptible to flow regulation as the changes to water level can affect the timing and extent of floodplain inundation, and a reduction in sediment loads can reduce floodplain deposition and potentially lead to floodplain erosion.

At the upstream extent of impoundments, increased sediment deposition can create delta complexes that reduce channel capacities and increase the risk of floods upstream. Within impoundments, fluctuating water levels can promote shoreline erosion, and increased water clarity associated with the settling of sediments can increase the risk of algal blooms. For these reasons, understanding how a hydropower project will alter the flow and sediment regime is critical to predicting potential impacts and mitigation approaches.

How these changes propagate downstream will vary between river systems and hydropower projects. The altered discharge and sediment regime downstream of hydropower stations can result in a disconnect between water flows and sediment loads in the mainstem of the river and entering tributaries, creating changes many kilometers downstream of the hydropower plant. For example, a power station may discharge higher volumes during the dry season and lower volumes during the wet season as compared to 'pre-dam' conditions, while the unregulated tributaries continue to have natural seasonal flow level cycles.

Those changes can lead to erosion or deposition at tributary confluences depending on the relative inflows of sediment and water, and alter the geometry of the downstream channel for very long distances downstream. Activities such as navigation can be greatly affected by these types of downstream interactions between regulated and unregulated waterways. Periodic flushing of sediments from impoundments can also have a deleterious impact through the smothering of habitats and the biota, and impacts from potentially poor water quality;

The interaction between hydropower operations and land use or other developments can affect the flow or sediment transport within a river. Common 'triggers' and their effects include:

- **Land use changes** that alter the delivery of sediment to rivers. A major driver of sediment production is deforestation, the conversion of forests to agricultural uses and the seasonal burning of agricultural lands. These activities tend to increase the exposure of sediment that can be flushed into the river during rain events;
- **Extractive mining** of sand, gravel or alluvial material from river beds and banks that can alter sediment budgets and affect river bank stability and water quality;
- **Extractive water uses**, such as irrigation from surface or ground water that alter the flow regime and hence affect sediment transport and river channel conditions and water quality; and
- **Floodplain developments**, including roads, dikes and infilling that alter the potential water and sediment storage capacity of the floodplain areas. Floodplains serve an important role as storage locations for floodwaters, and the subsequent draining of flood areas provides a

continued and controlled flow to the downstream environment. Reducing the access to or duration of inundation on a floodplain area will alter the hydrology of the system, and can increase channel erosion due to increased energy associated with more water remaining in the channel.

6.2 Key themes by major river basins

The key themes relate to understanding how physical changes to the rivers and landscape due to human development affect the natural flow and sediment patterns of the river systems. Detailed information at the river basin scale is not available for Myanmar, but large-scale GIS and remote sensing data sets can provide a sufficient overview of the present condition of the rivers with respect to flow and sediment regulation. In addition to this large-scale approach, existing examples of interactions between hydropower and other land and water uses have been identified using Google Earth. Additional information will be sought throughout the duration of the project from stakeholders.

6.3 Flow alterations at a basin scale

Climatic changes, along with hydropower developments and irrigation extractions are important mechanisms through which flows are altered at a catchment scale. The distribution of existing and planned hydropower projects, and existing irrigation schemes in Myanmar is presented and discussed in the hydropower chapter of this report. At present, there are 29 hydropower projects in operation and an additional 6 that are under construction. Of these 35 projects, 29 can be considered large, with dam heights in excess of 30 m, and 21 projects are considered 'storage' projects with reservoir residence time of at least several days. Large scale storage projects can have substantial impacts on river flows and sediment transport.

Flow in the Ayeyarwady has been suggested as decreasing between the periods 1871 - 1879 and 1966 – 1996 (Furuichi *et al.,* 2009). Flow for the 1871-1879 period was estimated at 431±42 km^2 yr^{-1} by Robinson *et al.,* (2007) based on the results of Gordon (1885). Furuichi *et al.,* (2009) estimated an annual average flow of 379 ±42 km^2 yr^{-1} based on monitoring results at Pyay from 1966 - 1996. A recent article on the *Eleven* website (http://www.elevenmyanmar.com/local/8003) highlighted changes to flow and river morphology in the Ayeyarwady at Pyay and linked these changes to dams, sand mining in the river, and alluvial mining of river banks.

The drivers of volumetric changes to river volumes are likely to be primarily climatic change combined with irrigation and other extractive uses including groundwater use. In general, hydropower does not remove waters from rivers (with the exception of increasing evaporation during storage, and loss to ground water), but rather alters the seasonality and pattern of delivery, so is unlikely to affect the quantity of water in the rivers to a large degree. Altering the seasonal delivery patterns, however, can promote channel changes including bank erosion and the creation or loss of mid-stream bars.

The locations of existing and proposed hydropower dams are shown in Figure 6.1. Also shown is a histogram grouping existing and under construction impoundments by volume (Figure 6.2). The existing hydro-developments are dispersed throughout the catchments and generally located on low Strahler Order tributaries, although several large ones are on tributary mainstems. Irrigation storages are not included in the histogram, but are generally small having a volume of less than 200 Mm^3.

Most of these impoundments have been developed over the past several decades, as evidenced by comparing the distribution of water in satellite images between 1984 and 2015. Changes in the central Ayeyarwady include the establishment of hydropower projects, combined hydropower and irrigation schemes, and numerous smaller irrigation dams. In southern Myanmar, water resource developments include the combined hydropower and irrigation schemes in the Sittuang River and irrigation impoundments in the lower.

Insufficient water discharge data has been obtained to allow a detailed analysis of seasonal flow changes in the rivers of Myanmar related to these developments. Scientific papers investigating the hydrology or sediment transport in the Ayeyarwady and other catchments have not identified flow regulation as a major factor affecting the hydrology of the basins on a large scale. However, the number and locations of large hydropower projects in the Dapein, Shweli and Mytinge sub-basins,

and the alteration of flows for hydropower and irrigation in the Mu catchment suggests that seasonal flows in the middle reaches of the Ayeyarwady River have been altered at a sub-basin to regional level. Similarly, the large number of irrigation schemes located in the lower Ayeyarwady is likely to have altered flows at least at a local scale. Impacts from these projects will have the largest impacts at the sub-catchment levels, but collectively may be affecting the flow at a larger scale. Additional analysis on a sub-catchment level is required to establish to what degree the present level of flow regulation is affecting water volumes at a catchment scale.

Figure 6.1: Location of existing and proposed hydropower dams

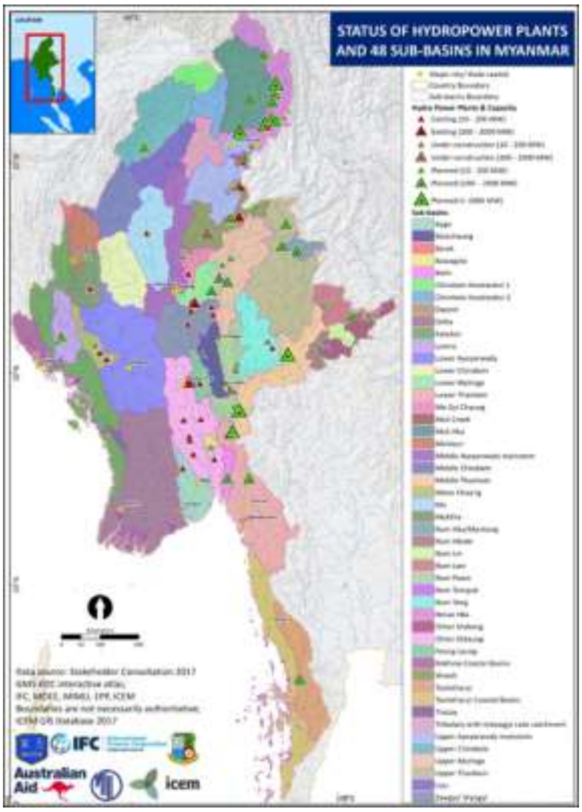
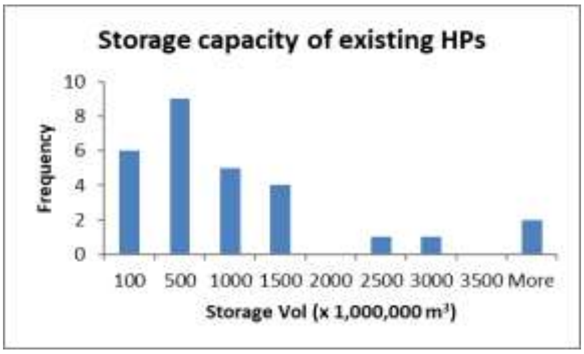


Figure 6.2: (top) Histogram of impoundments grouped by storage volumes

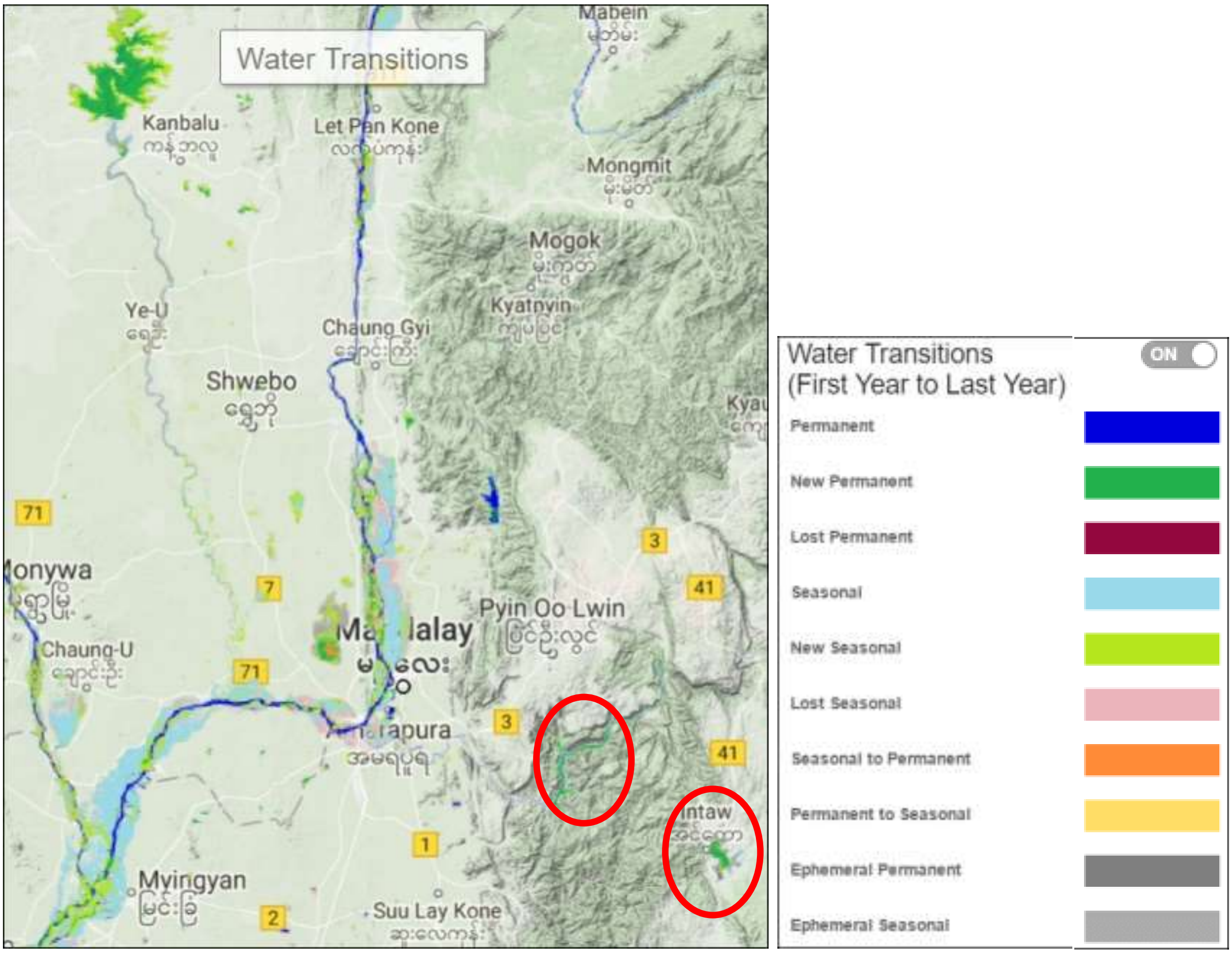


Case Study: Sediment Supply and Mega-dams in Asia

Sediment trapping in dams has a significant impact on the volume of sediment reaching the world's oceans. Gupta *et al.,* (2012) reviewed the role of sediment trapping in dams in East, Southern and Southeast Asia and suggests that in China alone, the sediment load reaching the oceans has been reduced from 1,800 Million tonnes (MT) per year to 370 Mt. This reduction in sediment loads exceeds the estimated increase in sediment loads associated with increased soil erosion arising from the advent of agriculture since the start of the Anthropocene (Syvitski, *et al.,* 2005, *in* Gupta *et al.,* 2012).

Much of this sediment loss is associated with the construction of large (higher than 30 m, reservoir volume >0.5 km^3) and mega (higher than 100 m and reservoir volume> 1 km^3). The distribution of mega-dams in Asia as of 2012 is shown in the map (from Gupta *et al.,* 2012), with the map also showing estimates of sediment loads from different regions. Gupta *et al.,* (2012) suggested there had not been a decrease in the sediment loads discharged from the Southeast Asia region, but this finding was based on the review of data by Robinson *et al.,* (2007) that suggested an increase in sediment loads as compared to previous estimates.

This paper and its findings highlight several important facets of hydropower development in Myanmar. Firstly, that there is an acute ack of recent, accurate sediment transport data for the Ayeyarwady and Thanlwin (and other Myanmar Rivers), as discussed in Section 4.1 of this report raises. This is a serious knowledge gap that needs to be addressed as soon as possible. Secondly, the Business as Usual hydropower development scenario includes many 'large' and 'mega' projects that are known to have extreme impacts on sediment transport at a continental scale. The present relatively low number of mega dams in Myanmar as compared to other regions in Asia provides an opportunity to learn from the regional experience and to develop a hydropower strategy that optimizes sediment passage whilst maximizing hydropower production.



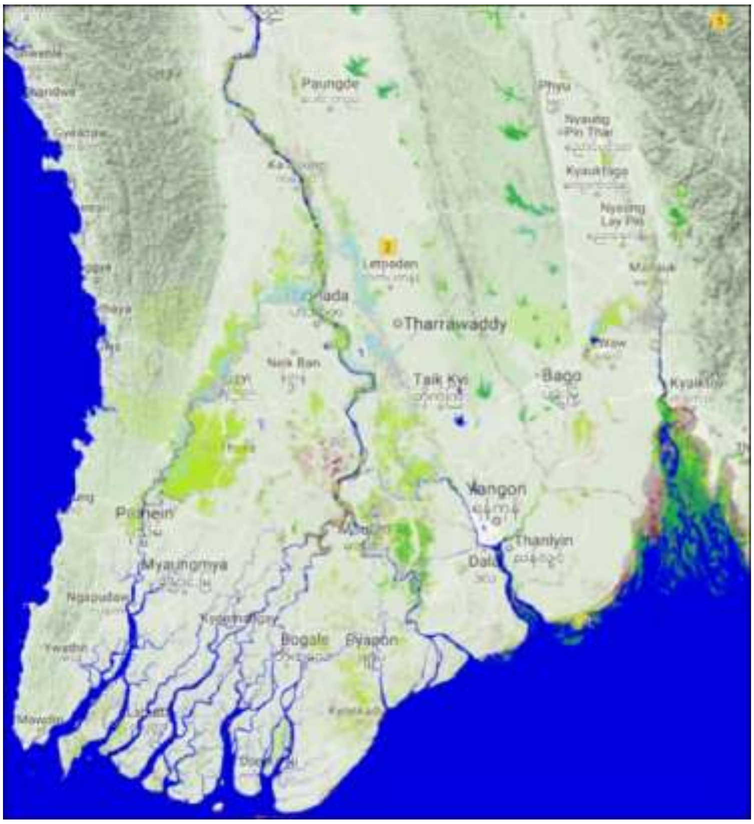


Figure 6.3: Changes to water storages between 1984 and 2015.

Data based on https://global-surface-water.appspot.com/. (Top) Changes include the establishment of the Yewa and Keng Tawng Hydropower projects southwest of Mandalay (red circles), the large hydropower and irrigation dam near Kanbalu in the north, and numerous irrigation impoundments west and north of the Ayeyarwady. Also evident are channel changes within the Ayeyarwady mainstem that have altered the distribution of water within the channel. (left) In southern Myanmar, developments include hydropower and irrigation dams in the western tributaries of the Sittuang River, and irrigation developments in the lower Ayeyarwady.

6.4 Changes to the sediment budget due to hydropower

Changes to the sediment load of the rivers due to the existing hydropower dams have been investigated using GIS tools. The slope classes for Myanmar (Figure 3.1) have been overlaid and combined with the annual rainfall (Figure 6.4, top left) to identify where sediment generation is likely. Areas that are steep and receive high rainfall are considered to have a high potential for generating sediment to the rivers, whereas low slope areas with low rainfall totals are considered to have a low potential for sediment supply.

The results of the analysis are provided for the country (Figure 6.4, right) and enlarged for the Chindwin and Thanlwin catchments (Figure 6.6). This analysis shows that the highlands of the Ayeyarwady catchment and northern highlands and western ranges in the Chindwin catchment have high sediment production potential. Also shown are the previously derived geomorphic provinces with areas receiving greater than 2,500 mm of rainfall or less than 1,000 mm of rainfall highlighted. Note that the analysis did not include the Thanlwin upstream of the Myanmar national border so the relatively 'low' sediment production potential should not be interpreted as potentially low sediment transport by the mainstem, as large quantities of sediment enter the river upstream of the border.

Based on the previous discussion of geology and sediment generation, areas that have a 'high' potential for sediment generation west of the Sagaing fault are likely to produce more suspended sediment as compared to bedload, whereas the reverse is true for the older, crystalline bedrock area east of the fault zone.

Most of the existing hydropower dams are generally located on small, low Strahler Order tributaries, in areas considered to have low or moderate sediment production potential. Exceptions occur in the Shweliand Dapein catchments, where HP developments in China as well as Myanmar are affecting sediment transport. Based on this, sediment transport at the sub-basin scale has undoubtedly been altered but the impact at the larger basin scale is unknown. It also must be recognized that in general, HP projects in Myanmar have high dam heights and to date, there are no projects that include sediment mitigation options such as bypass channels or low-level gates specifically designed for sediment management (based on available hydropower information at time of writing).

Examples of geomorphic changes at a local scale associated with hydropower projects are shown in Figure 6.7 which shows a short section of the 9.5 km of dewatered channel between the Shweli Dam #1 and the Shweli powerhouse. Without flow, the geomorphic functioning of the river will be lost, and the channel will eventually be constricted by the encroachment of vegetation. An example of larger scale geomorphic change in the Shweli is shown in Figure 6.8 where Google Earth images from 1984 and 2016 show straightening of the river channel. Rivers typically straighten when sediment loads are decreased or base levels are lowered. As no large scale changes to flow in the upper Ayeyarwady are known, it is likely that this response is associated with a reduction in sediment loads.

The maps (Figure 6.5) clearly show that many areas targeted for 'planned' dams are in areas identified as high and moderate potential sediment production zones. This is not surprising as the same attributes that contribute to sediment loads (steep slopes and high rainfall) are also conducive for hydropower operations. The maps also indicate that many of the planned hydropower projects are large in size, and would likely have greater impact on flow and sediment transport as compared to the existing projects.

Figure 6.4: Annual precipitation in Myanmar (left) - Potential sediment production in Myanmar, showing existing, under construction and planned hydropower projects (right)

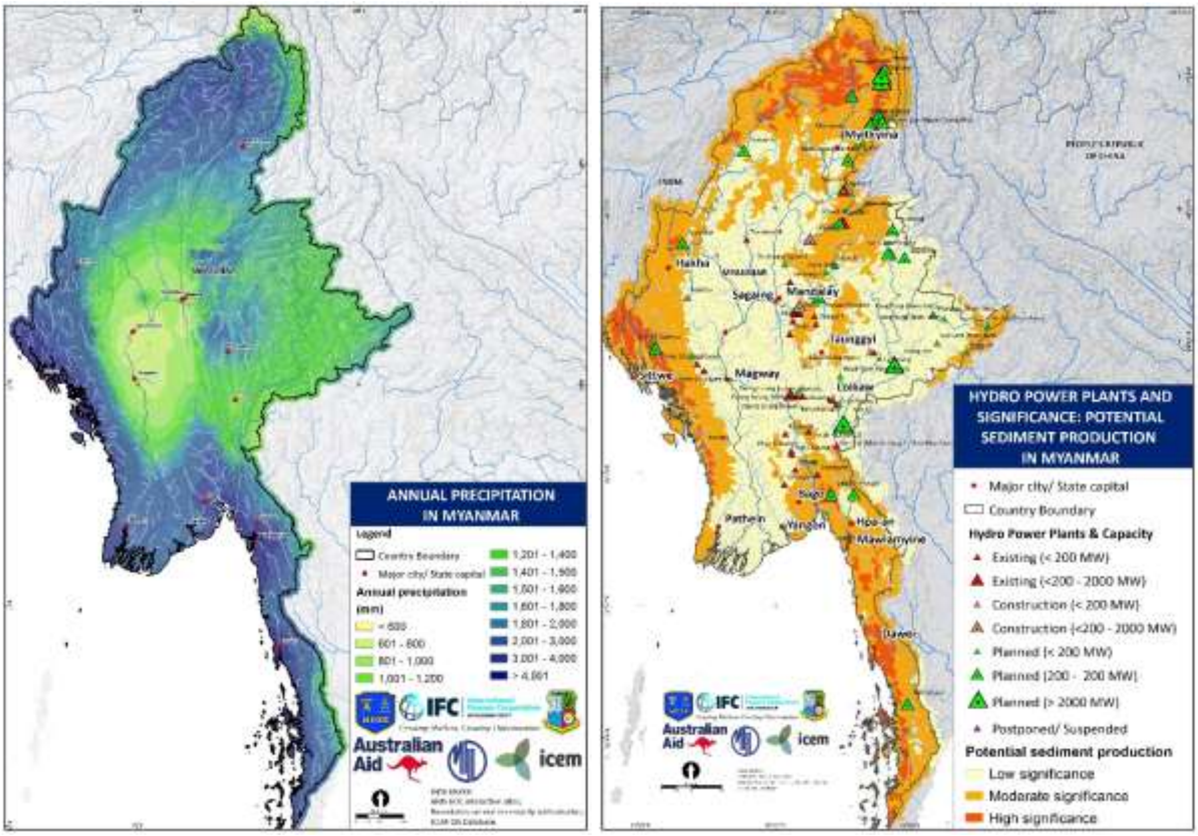


Figure 6.5: Geomorphic provinces showing areas where rainfall exceeds 2,500 mm per year or is less than 1,000 mm per year.

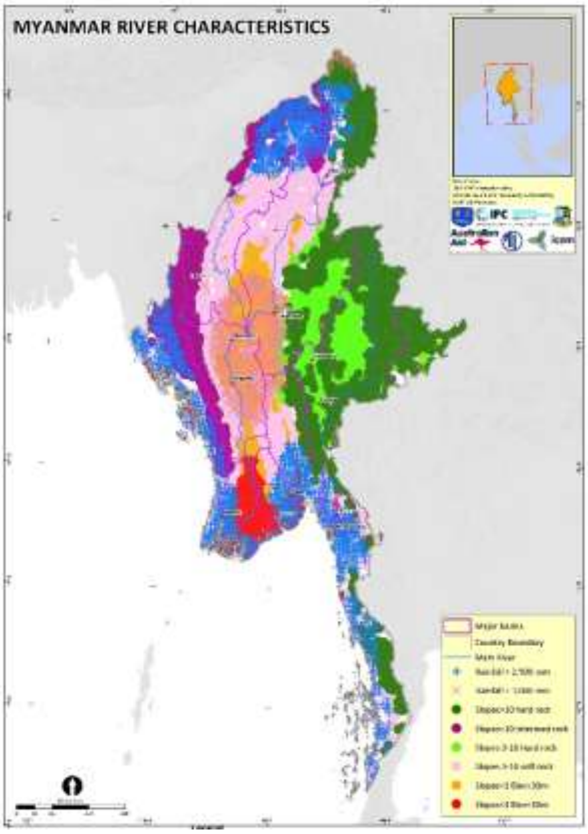


Figure 6.6: Expanded view of the Chindwin catchment - Expanded view of the Thanlwin catchment (bottom right)

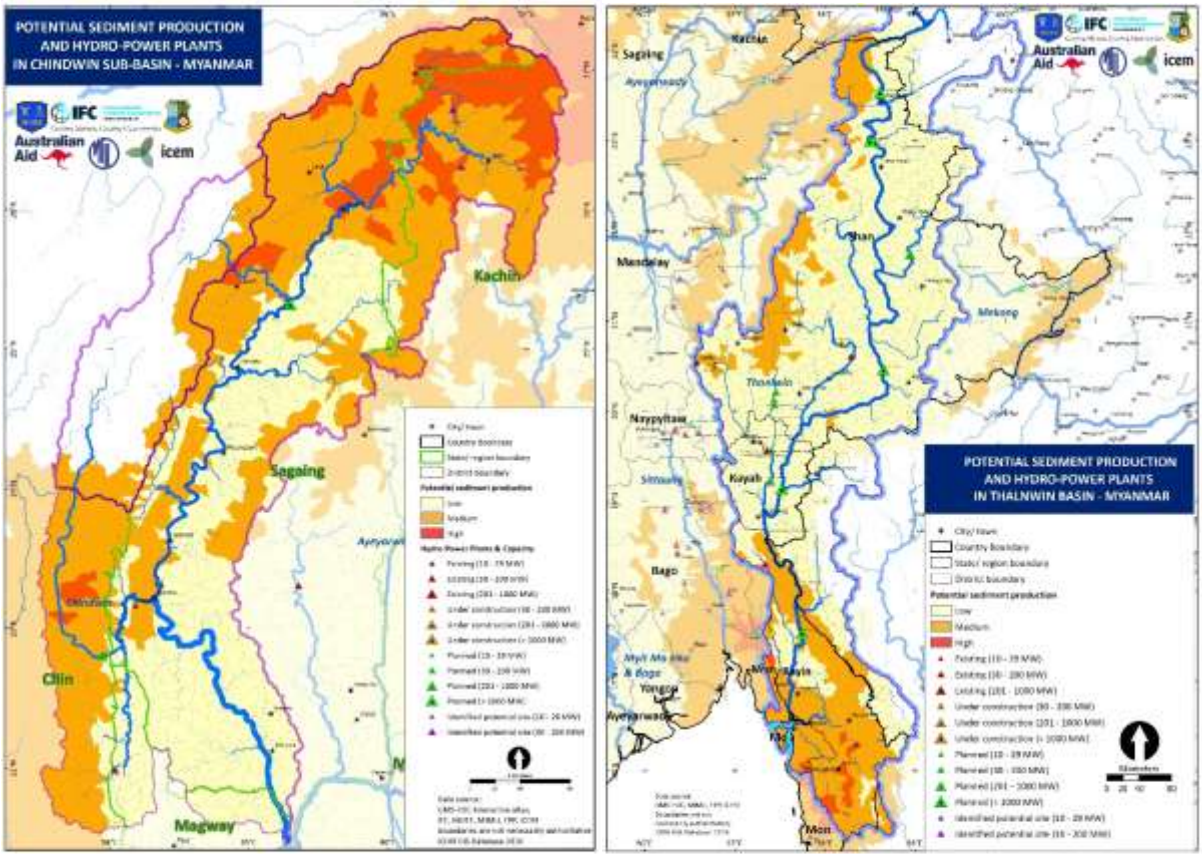
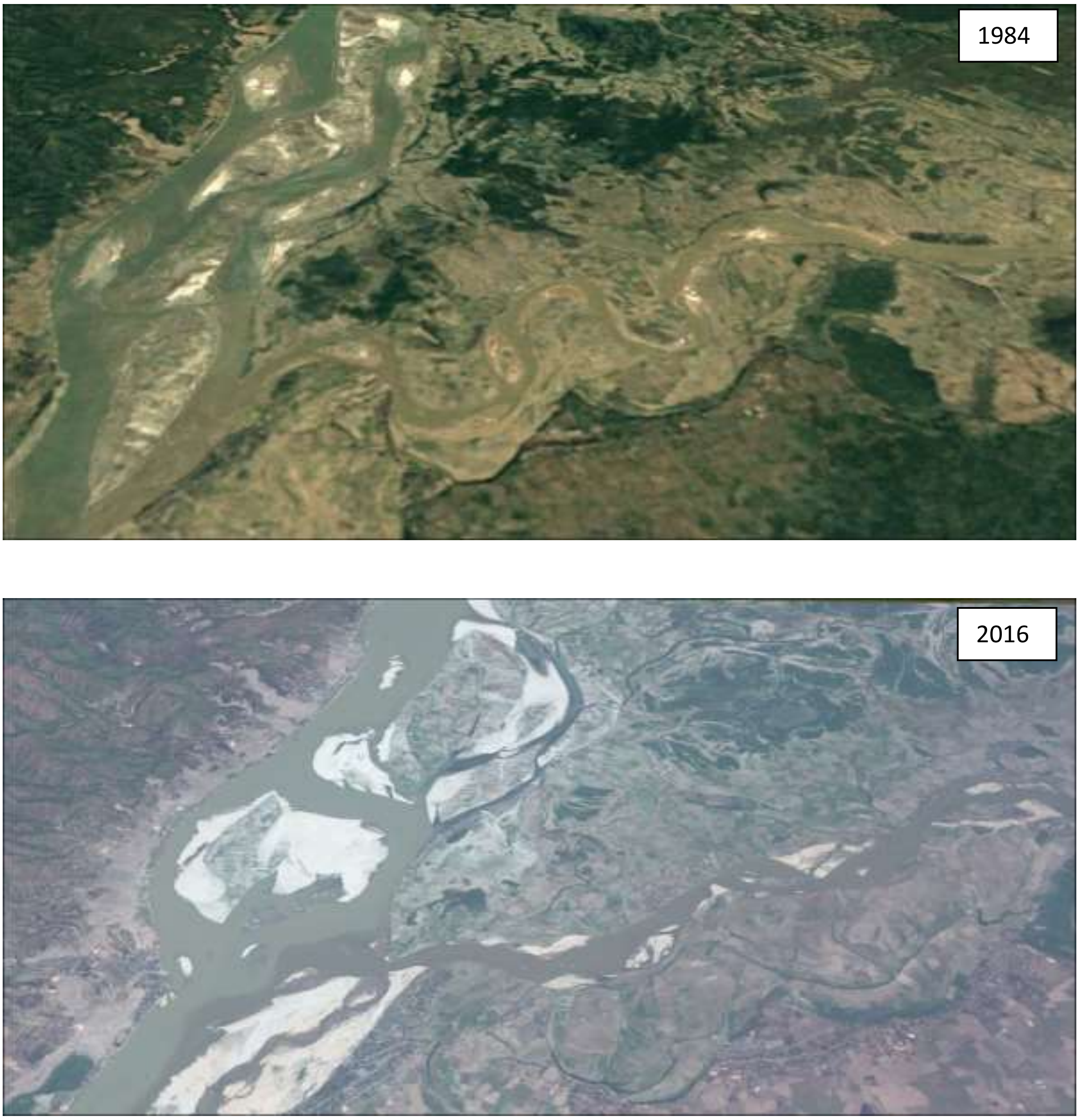


Figure 6.7: Example of dewatered channel between Shweli 1 Dam and the power house

Figure 6.8: Google Earth images of the lower Shweli River in 1986 and 2016 showing channel straightening



6.5 Land use changes

River basin characteristics other than slope and rainfall are also important drivers of sediment production and delivery to rivers. Vegetation cover is one important factor as it can reduce erosion through the physical protection and binding of underlying soils, and dissipating raindrop energy. The removal of forests is frequently associated with secondary activities that can also affect sediment production, such as slash and burn agriculture, or mining. The removal of vegetation on riverbanks and deltas can increase erosion of land forms, as vegetation plays a critical role in providing stability and is especially effective during high flow and storm events in protecting riverbanks and coastlines.

Deforestation and land use changes have been identified as drivers of increasing sediment loads in the upper Mekong River since about the mid-1980s (Walling, 2008; Figure 6.9). Syvitski *et al.,* (2005) modelled world sediment loads pre- and post- human settlement with the findings suggesting that the loads derived from the Thanlwin, Ayeyarwady and nearby rivers have increased by over 200 Mt yr^{-1} due to changes associated with human activities.

Global Forest Watch (accessed 2017) has estimated the annual removal and addition of forest cover in Southeast Asia for the period 2000 - 2014. Three maps of Myanmar are provided in Figure 6.10 showing the results for changes in 2001, 2007 and 2014 relative to 2000. The analysis shows an increasing trend in deforestation, with larger increases occurring between 2007 and 2017 as compared to 2001 and 2007. Decreased vegetation cover has occurred throughout the country, with a greater occurrence near the east, far northwest and southeast of the country, coinciding with the distribution of forests. Deforestation and the forestry sector are discussed further in the biodiversity and economic chapters respectively.

A detailed analysis of land use changes in the in the lower-Ayeyarwady Basin between 1989 and 2003 was completed by Swe (2011). The results show a decrease in forest cover, accompanied by an increase in barren land and a large growth in the extent of agricultural land. Based on the Global Forest Watch results, these trends have continued in the lower-Ayeyarwady post-2003.

The distribution of mangroves in the Ayeyarwady Delta has decreased between 1978 and 2011 (Webb *et al.,* 2014), with the main driver being the expansion of agriculture in this economically important area (Webb *et al.,* 2014).

Collectively, these results suggest an increased availability of sediment for transport by rivers over the past few decades, and a decrease in the stability of the delta front (and probably riverbanks) to extreme flow and weather events.

Figure 6.9: Increases in sediment load in the Lancang (upper Mekong) River as determined by Walling, (2008)

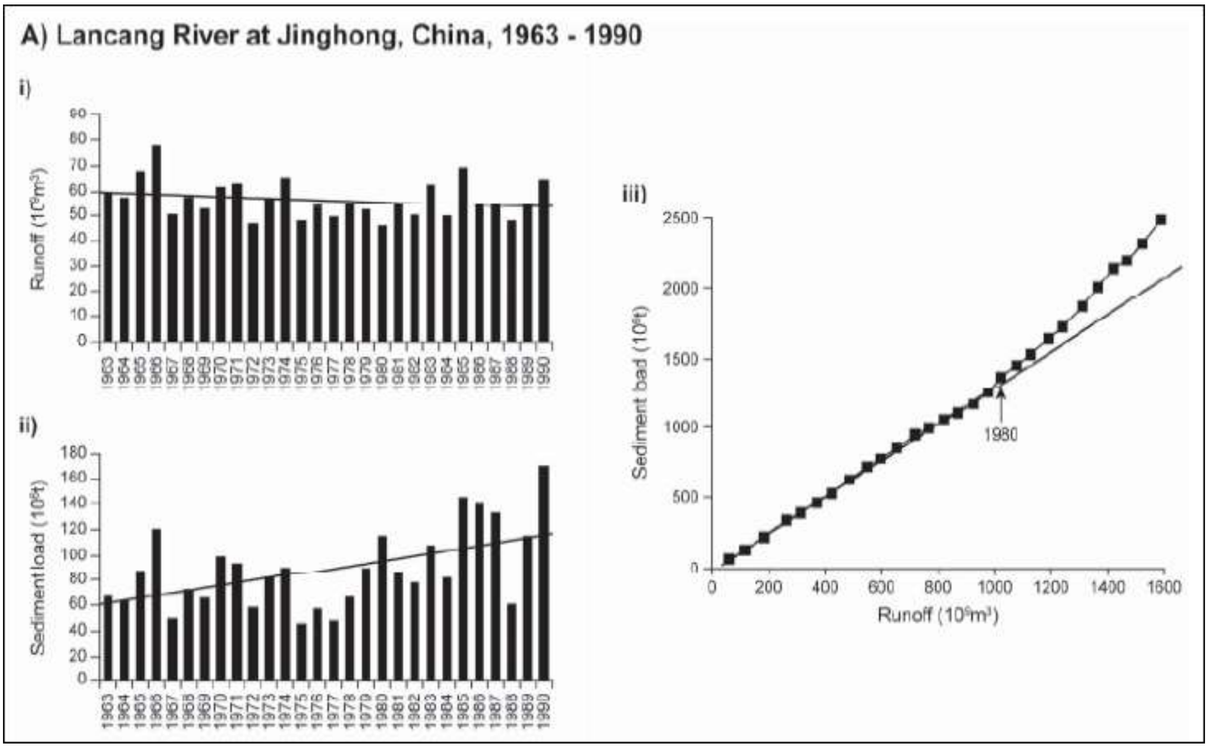
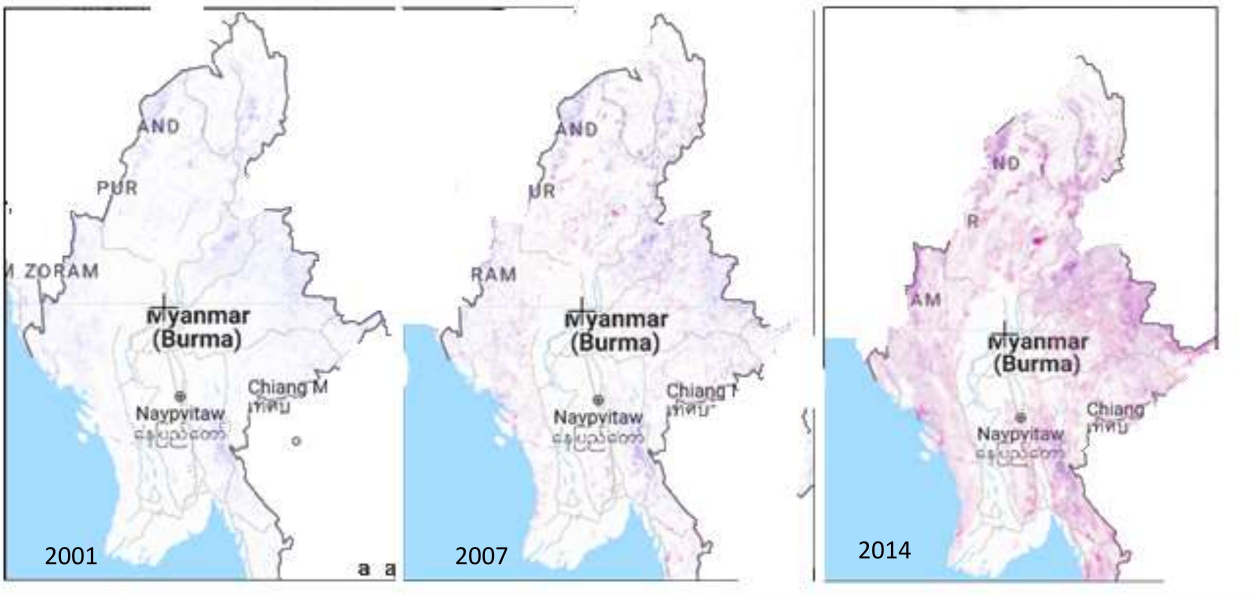
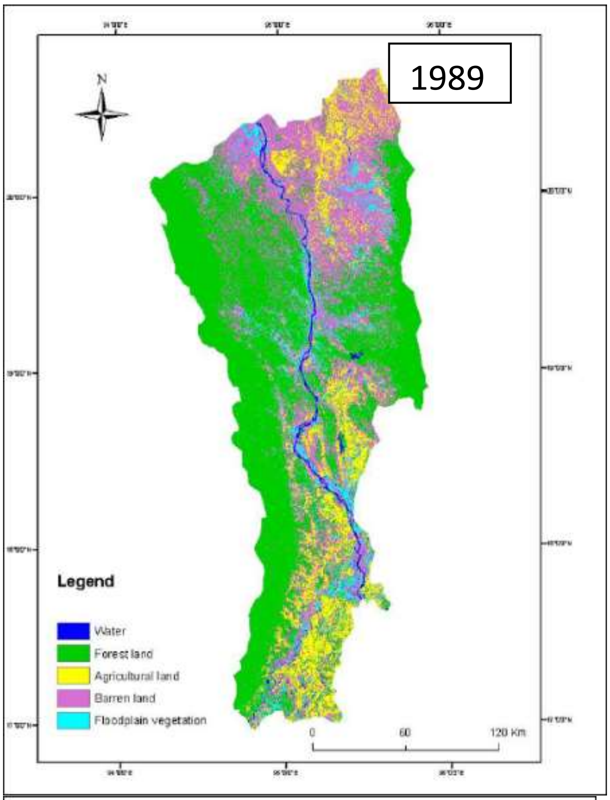


Figure 6.10: Deforestation in Myanmar in 2000, 2007 and 2014

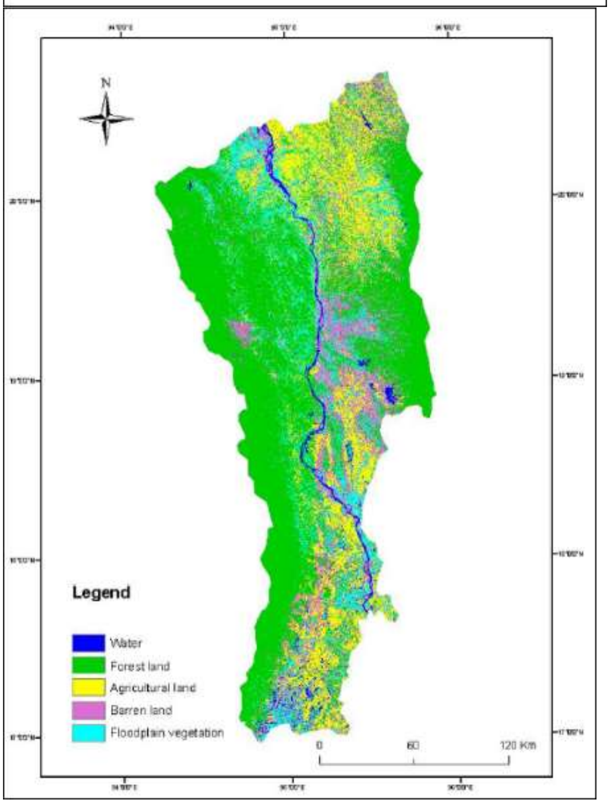


Pink areas indicate loss with > 30 % canopy density, and blue areas indicate forest gain. Tree cover loss is not always deforestation. Global Forest Watch (http://www.globalforestwatch.org/map/6/-37.15/146.05/MMR/grayscale/loss,forestgain?tab=basemaps-tab&begin=2001-01-01&end=2015-01-01&threshold=30&dont_analyze=true; accesses Jan 2017)

Source: Global Forest Watch


1989
N
Legend
Water
Forest land
Agricultural land
Barren land
Floodplain vegetation
0
60
120 Km

1999


N
Legend
Water
Forest land
Agricultural land
Barren land
Floodplain vegetation
0
60
120 Km

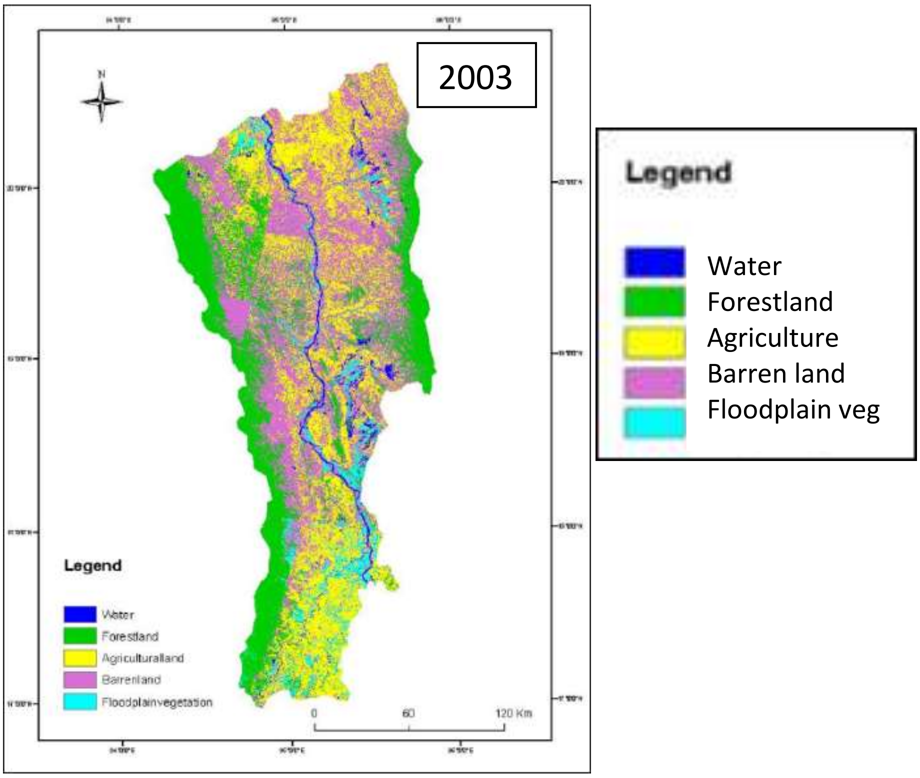
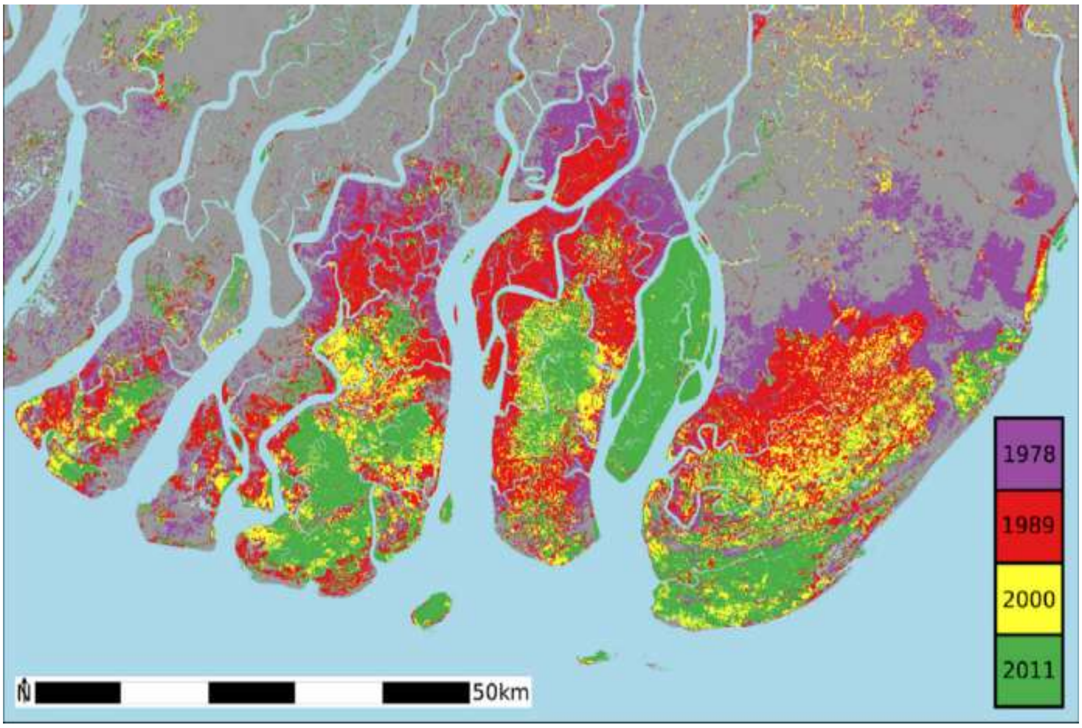


Figure 6.11: Distribution of mangroves in Ayeyarwady delta region



Source: Webb et al., 2014

6.5.1 Interactions between hydropower and other land-based or water resource developments

Flow and sediment changes associated with hydropower development will interact with other land- and river-based developments in the catchment. These interactions need to be recognized to identify catchment specific cumulative impacts and identify appropriate and sustainable development pathways. The management between hydropower and other developments often requires a catchment

approach, and is beyond the control of hydropower managers in isolation. These types of interactions need to be considered on a sub-catchment or catchment scale and will be included in the case studies to be completed as part of the SEA. A few examples of existing interactions between hydropower and other river-based activities are presented here.

6.5.2 Irrigation and hydropower

The provision of water for irrigation from hydropower impoundments is a common element of 'multi-use' schemes. The presence of a large impoundment enables access to a reliable water supply during the dry season, and economic growth around hydropower schemes is often fueled by increased agricultural activities. Figure 6.12 shows the discharge from the Yewya hydropower project being directed down two irrigation canals, as well as the main river channel. The irrigation offtakes in addition to the flow changes associated with regulation for hydropower must be recognized and considered with respect to flow and geomorphic changes in the lower catchment.

6.5.3 Hydropower and alluvial mining in rivers

The mining of sand and gravels from rivers drives construction and development. River channels are commonly excavated to provide these important resources, but the removal of large volumes of material can have detrimental impacts both locally, through bank collapse, and farther downstream due to a reduction in material available for deposition which can result in erosion. The extent to which the rivers in Myanmar have been affected by sand mining is largely unknown, but anecdotal evidence suggests that the pressures on the rivers (and coastlines) are increasing with respect to sand mining. Sand mining in combination with hydropower developments can have a compounding effect if sand mining occurs downstream of dams where sediment passage is reduced.

Alluvial mining for gold or other minerals can increase sediment loads in rivers due to excavation of riverbanks and beds, and discharge of waste material. If located within catchments developed for hydropower, the dispersion of the increased sediment load will be controlled by the operating pattern of power stations. An example from downstream of the Shwegyin hydropower project shows the mixing of the low-sediment water from the outflow of the dam mixing with the sediment rich mining discharges.

There is insufficient sediment and flow data available to quantify these types of impacts at a catchment scale, but they may be considered in case studies during the assessment phase.

Figure 6.12: An example of hydropower and irrigation works affecting river flow

The discharge from the Sedawgyi hydropower project (top right) is diverted into irrigation channels on either side of the river channel as well as released to the Ma Gyi Chaung River. Photo from February when discharge from power station likely exceeds 'natural' flow.

Figure 6.13: Gravel and sand mining in the Ayeyarwady River

Figure 6.14: Alluvial mining on the banks of the Mali Kha River in northern Myanmar

Figure 6.15: Google Earth image from February 2014 showing interaction between increased sediment associated with alluvial mining and discharge from the Shwegyin power project. Mining is evident east and south of the Shwegyin dam.

Section summary: This section has identified the key geomorphic and sediment transport themes relevant to hydropower development, and provided an over view of the current status of these key themes. The main themes include potential impacts to the hydrology and sediment transport characteristics of the system due to changes associated with hydropower implementation and river regulation. There is insufficient information to establish the level of flow and sediment transport changes associated with existing hydropower projects, although it is evident that river systems have been altered at local, sub-basin scales in several catchments. Other activities that need to be considered in the context of flow and sediment regulation include irrigation, land use changes such as mining (alluvial, hard rock and sand extraction), or deforestation.

7 DEFINITION OF SUSTAINABILITY OBJECTIVES AND IMPACT ASSESSMENT PARAMETERS

The key issues associated with hydropower development and geomorphology and sediment transport include:

- The alteration of river flows due to storage in impoundments and controlled releases through hydropower stations. These changes can be minor in the case of 'true' run of river HPPs, or very major in the case of large storage systems that can alter the seasonality of river flows. Changing the magnitude, frequency, duration, seasonality or rate of water level change in a river will result in a geomorphic 'response' in the river channel. These 'responses' can include channel deepening or widening, bank erosion, channel constriction (if high flows are removed). Altering sediment and flow regimes will also have flow on effects to ecosystems through the alteration of habitat condition and distribution, and to human activities linked to river system processes, such as fishing and riverbank and floodplain agriculture. Understanding how a power station is likely to alter the flow regime is critical to the identification of potential geomorphic impacts, and appropriate mitigation measures;
- Reductions in the magnitude of sediment loads downstream of hydropower projects due to the trapping of sediment in impoundments. Sediments are deposited in reservoirs when water velocities decrease, with larger sediments (sand and gravel) deposited rapidly at the head of impoundments, and finer sediments settling out in larger impoundments as well. This sediment capture will reduce the sediment load discharged to the river downstream, and can alter the nutrient quantity and composition in the discharge. Reductions in sediment are linked increases in downstream erosion of river channels, river banks and floodplains;
- Changes to the timing of sediment transport due to changes in the flow regime: The discharge from hydropower stations can result in a disconnection between water flows and sediment loads in the mainstem of the river and entering tributaries. For example, a power station may discharge higher volumes during the dry season and lower volumes during the wet season as compared to 'pre-dam' conditions, while the unregulated tributaries continue to have natural seasonal cycles. These changes can lead to erosion or deposition at the tributary confluences depending on the relative inflows of sediment and water, and alter the geometry of the downstream channel; and
- Interaction between hydropower development and operations and other land and river based activities, including navigation.

Table 7.1: Summary of sustainability objectives and key indicators

Draft sustainability objectives for geomorphology and sediment transport	Indicators
• Maintenance of flows and sediment regimes such that the geomorphic functioning of rivers is maintained, including sediment and nutrient transport and maintenance of the delta • Interaction with other land and water uses and hydropower is understood and managed at a catchment scale to maintain sustainability objectives	• Annual, monthly and daily flow rates • Annual sediment loads • Seasonality of sediment loads • Sediment quality and characteristics (sand, silt, nutrient relationships are maintained) • River cross-sections and long-sections • Land-use changes that can alter sediment or water input • Distribution and magnitude of sand mining • Location and discharges from alluvial (or other) mining • Irrigation volumes and seasonality of extractions

8 TREND ANALYSIS AND DRIVERS OF CHANGE

8.1 Maintenance of flows and sediment transport

The key issue for the geomorphology and sediment theme is the maintenance of flows and sediment transport to maintain geomorphic and ecological functioning of rivers. The past and future trends (without hydropower) are described below.

8.1.1 Past trends and current situation

The maintenance of river flows and sediment transport is necessary to maintain the geomorphic and hence, ecological functioning of river systems. The physical attributes of the river channel and associated floodplain areas are controlled by the flow regime and magnitude and pattern of sediment transport and storage. Altering these fundamental drivers will translate to a change in the physical characteristics and distribution of habitats, and the cycling of organic matter and nutrients. Maintaining the functioning of the river is key to maintaining the ecosystems and biodiversity of the rivers.

Other conclusions on the current situation are:

- The previous sections described the current situation with respect to flow and sediment transport in the major rivers of Myanmar, recognizing the limitations of the available data and information;
- The past and present level of hydropower development in the country has altered flow regimes and sediment transport at the sub-basin scale in rivers such as the Shweli, Dapien, Mytinge, Sittuang and Mu. The impact of these developments on the overall hydrology and sediment transport in Myanmar is unquantified. The additional impacts on flow and sediment from the large number of irrigation dams in the lower catchment is also unquantified. The flow changes associated with the hydropower developments in the tributary catchments of the middle Ayeyarwady (Dapein, Shweli, Mytinge) are likely to include an increase in dry season flows and a decrease in early wet season flows.
- Other factors, such as climatic changes and irrigation and groundwater extractions may have reduced the discharge volume of the Ayeyarwady. Climatic changes would also likely affect other river basins; and
- Deforestation and land use changes have likely increased the sediment delivery to the rivers in Myanmar, with Syvitski et al., (2005) projecting increases in the order of 200 Mt yr^{-1} for the region. How the geomorphology of the river responded to this large increase in sediment loads, or whether it is continuing to respond or has reached a dynamic equilibrium with the increased loads is unknown.

In summary, the flow and sediment transport of the major rivers in Myanmar have likely been altered to some extent due to climatic changes, consumptive uses of water (agriculture) and extensive land use changes associated with settlement and continued deforestation. Based on the available information, the role of hydropower development in contributing to the changes is presently relatively small, due to the low number of existing developments, relatively small size of existing developments, and the location of these developments within generally small tributary basins.

8.1.2 Future trends without hydropower development

In the absence of hydropower development, the future drivers of changes to geomorphology and sediment transport include:

- Population growth and continued development will increase the need for resources, such as wood and sand for construction materials, and water for irrigation;
- Land use changes, including ongoing or increased deforestation, are likely to continue at similar or even accelerated rates compared to the present due to the need for these resources, and for additional land for agriculture, urban developments and infrastructure such as roads;
- Development in the river basins outside of the boundaries of Myanmar;
- Factors which will affect these trends include:

- The availability of capital for investment in new construction, agricultural lands and / or infrastructure;
    - Government policies and laws that control land clearing and land developments;
    - Government policies and laws that regulate activities such as mining and forestry.
- Development and land clearing in more remote mountainous areas that receive high rainfall (e.g. areas denoted as high potential sediment production in Figure 6.4) could greatly alter sediment budgets.

How each of these drivers will affect river systems in the absence of hydropower cannot be accurately predicted, and is dependent on many factors, including government policies, regional and global economic pressures and opportunities, political 'will', and social values and pressures. The following Table summarizes some of the changes to flow and sediment regimes in river systems in response to increased pressure from these drivers. The Table also includes comments about pro-active steps that could be started or implemented now that could reduce potential future impacts on river systems with respect to these pressures.

Table 8.1: Trend analysis for flow and sediment changes associated with future development

Driver	Present Status / Trend	Likely 30 Year Future Trend	Impacts in the Absence of hydropower
Population growth and increasing demand for electricity	Insufficient electricity to meet existing demand	Increased electricity demand is inevitable over the next few decades	Alternatives to HP can impact rivers through the need for increased shipping of alternative fuels, water extraction for cooling. If electricity is not available, increased deforestation for fuel can increase runoff and sediment loads into rivers
Population growth and increasing demand for sand and gravel for construction	Large volumes of material are extracted from rivers as it is a low cost readily accessible building material	Demand for construction material will likely increase, but greater impacts on rivers will occur as extracted material exceeds the volume being replenished (especially if sediment loads decrease due to trapping in irrigation and HP dams)	Sand and gravel extraction is probably already occurring at unsustainable levels near large cities which are rapidly growing. If sand mining is not managed, there will be an increase in bank erosion, channel incision and delta instability. Management requires a sound understanding of the sand and gravel budgets of the rivers, and implementation of quotas to minimize impact on the channel stability. Development of a sustainable sand mining policy now could prevent future impacts. Government policies could also promote the use of alternative sources of sand and gravel and promote alternative building materials.
Water demand	Increasing demand for irrigation water	Likely to increase into the future as populations increase and there is a higher demand for food for domestic consumption and export	Increasing the number of irrigation projects has the potential to alter the flow and sediment regimes of the rivers at a sub-basin and basin scale. Many small projects can affect rivers through 'death by a thousand cuts'. Water flows and sediment discharge should be monitored and managed on a sub-basin (catchment) level to ensure that extractions are taken in a pattern and at a rate that will not substantially alter the environmental flow requirements of the river. Sub-basin water management plans would also allow a better understanding of how mainstream flow will collectively respond to sub-catchment flow and sediment changes.
Land use changes – mining	Increasing mining activity leading to increased sediment discharge to rivers	Likely to increase as it is a profitable export industry	Land disturbance associated with mining locally increases sediment input. The inputs have not been quantified, but are likely substantial at a sub-catchment basis. These inputs are likely to be affecting the rate and distribution of sand bar creation and migration and can affect navigation. Increasing the regulation of the industry and retaining sediment near mining sites is consistent with the present international 'Best Practice' approach. Gravels and sands could be used for construction materials to reduce pressures on the rivers. Finer-grained material should be retained in tailings dams. Developing and enforcing environmental controls at the extraction sites is the best approach for reducing sediment inputs.
Land use-deforestation and land clearing	Increasing	Likely to increase and increase sharply if illegal land clearing is not controlled. Likely to increase	Deforestation typically increases water runoff and sediment input due to the exposure of soils on slopes to rainfall and wind. The loss of fertile topsoil is a secondary impact of land clearing. Managing land clearing and deforestation

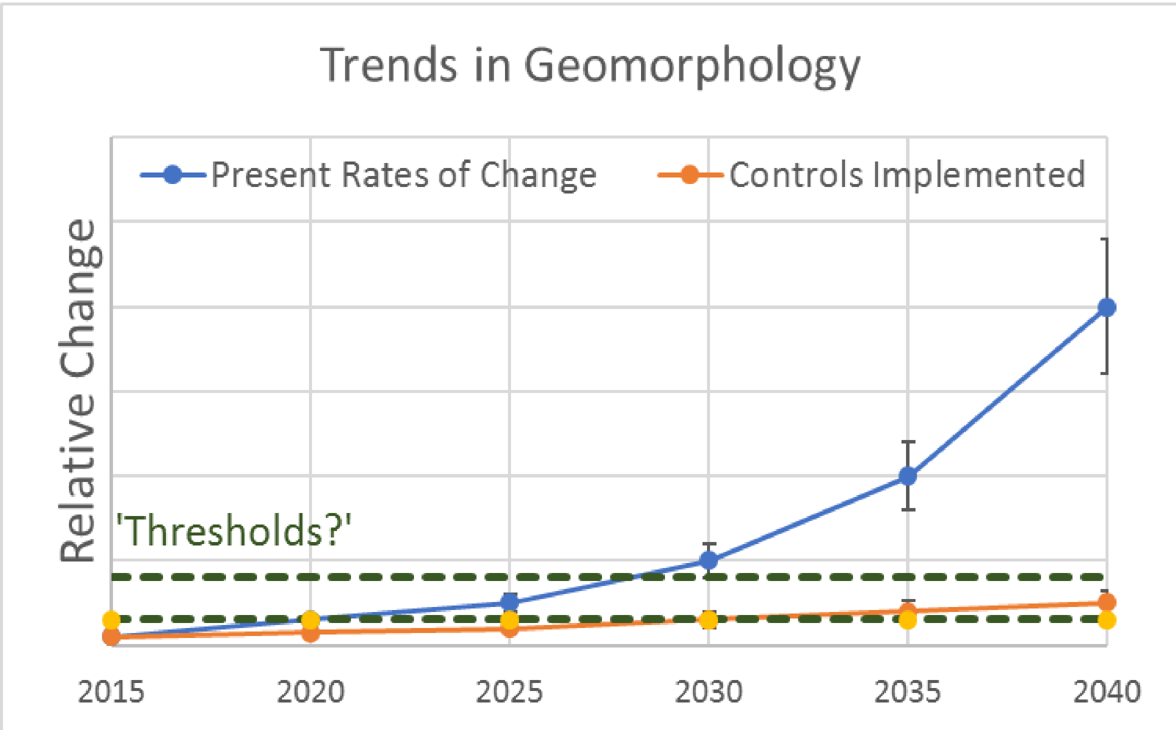
Driver	Present Status / Trend	Likely 30 Year Future Trend	Impacts in the Absence of hydropower
		if wood continues to be used as a fuel source if there is no access to electricity	depends on the enforcement of relevant Government policies. Illegal land clearing is also a transboundary issue that requires cooperation with neighboring countries.
River and floodplain 'improvements' and infrastructure	Increasing engineering controls within river channels in response to channel instability and navigation constraints, increasing infrastructure on floodplains such as roads and railways	River channel alterations such as bank protection will likely increase as sand mining and sediment trapping in impoundments increases. Infrastructure on floodplains will also likely increase as road and rail networks expand	Engineering works within river channels can locally 'improve' conditions but generally move the 'problem' downstream. Understanding the sediment budget of rivers and managing extractions and inputs should be the long-term goal. Developments on floodplains can alter limit the ability of water to enter the flood plain from the river, or to drain from the catchment into the river. These types of development can locally increase flooding, or increase flooding downstream as more water is forced to remain within the river channel. Catchment development plans need to include an understanding of the dynamics and connectivity of floodplain and have provisions for retaining areas for inundation, and flow pathways. Floodplain infilling (especially with river sands) has a negative feedback in that it deepens the channel so that higher flows are transported downstream, and reduces the ability of the floodplain to store water. Both of these can increase the risk of flooding downstream.
Development in river basins upstream of Myanmar	Increasing	Increasing due to increased population	Land use changes in river systems that have their headwaters outside of Myanmar can affect the rivers through the alteration of flows and sediment transport. This is already occurring in the Shweli, Dapein and to a lesser degree the Thanlwin. In the absence of HP in Myanmar, communication with the upstream countries controlling river flow is required for downstream safety and catchment management. Managing transboundary rivers requires cooperation between the upstream and downstream countries. This is especially important if HP is implemented, as the coordination of power generation, release of environmental flows or sediment flushing needs to be coordinated on a catchment rather than project basis.

8.1.3 Uncertainties regarding geomorphic change and hydropower development

Hydropower developments inherently alter geomorphic processes through the regulation of flow and disruption of sediment supply.

- There are large uncertainties in our understanding of geomorphology, hydrology and sediment transport in the rivers of Myanmar. Within this uncertainty, the concept of geomorphic 'thresholds' needs to be considered. At present, it is known that geomorphic processes in the rivers of Myanmar have been altered through land use changes and flow and sediment regulation. It is also recognized that geomorphic processes frequently have 'thresholds' which once crossed make it difficult for a river to 'recover' to its initial state, even if the stressor causing the change is removed. An example of this is sediment starvation in river channels and floodplains. If sediment is removed from a river, but the flow energy of the river remains the same, the channel is likely to deepen due to the erosion of bed material and the lack of subsequent sediment deposition. Because the channel is deeper, more water will remain in the channel, with less water entering onto the floodplains. Once this occurs, floodplain deposition will not return to previous levels, even if the sediment supply to the river is restored, as the steeper and deeper channel will transport more water and sediment, reducing the volume of water entering the floodplains;
- Where the rivers in Myanmar are with respect to these types of threshold values is unknown, but consistent with the Precautionary Principle, management actions should be adopted to minimize geomorphic changes, such that the risk of crossing thresholds is diminished. A graphical representation of development with and without management controls compared to hypothetical threshold values is shown in Figure 8.1. The types of management controls that can reduce future changes include those contained within the National Biodiversity Strategy and Action Plan, 2015 - 2020; and
- The goals and directions of the Government in regulating land clearing and development need to be effectively implemented and enforced to provide benefit. This type of management is best implemented at the catchment or sub-catchment scale.

Figure 8.1: Hypothetical cases for future development



9 ASSESSMENT METHODOLOGY

The study methodology for the geomorphology and sediment transport theme includes the following:

- **Literature review**: A review of available literature related to the geomorphology and sediment transport of the river systems. This includes information related to the geology and tectonics of the river catchments that exert an influence on sediment generation and transport;
- **Data interpretation and review**: Discharge and sediment transport data are available for a limited number of sites in the Ayeyarwady and Chindwin river systems. These data have been analyzed to provide an understanding of the magnitude and seasonal pattern of sediment transport in the rivers, and provide an indication about sediment availability and transport in the different sub-catchments. Where applicable findings from the Ayeyarwady can be applied to other river basins to provide a high-level understanding of sediment transport in the absence of data;
- **Spatial analysis**: The physical characteristics of a river catchment (elevation, slope, land use) exert a strong control on the availability of sediment and the potential for transport. GIS tools have been used to combine and analyze the physical attributes of the catchments to identify likely areas of sediment generation, calculate potential river energy and identify areas of possible sediment deposition. This work will progress throughout the SEA process and be modified and updated as additional information is obtained;
- **Stakeholder consultations**: Stakeholder groups will be canvassed regarding the following areas:
    - How is the river and its resources directly used? For example, what is the distribution of riverbank agriculture and how is it dependent on annual flooding, where in the river are sand and / or gravel being extracted?
    - Identification of areas where riverbank erosion is currently an issue, and what activities are believed to be responsible for the bank erosion?
    - Have there been changes to navigation in the past few years due to changes in the size or distribution of sandbars? If so, what activities are linked to these changes (e.g. land-use changes increasing sediment supply, increased flow leading to the deepening of channels, decreasing flow, dredging, dams, irrigation withdrawals, climate change)
- **Direct observations**: Where ever possible, direct observations of river channels, riverbanks and floodplains will be made, with a focus on trying to observe river catchments downstream of existing hydropower projects.

9.1 Key stakeholders

The key stakeholders for the geomorphic and sediment transport theme include:

- The Myanmar Government departments responsible for water resources:
    - Directorate of Water Resources and Improvement of River Systems
    - National Water Resources Committee
    - Department of Meteorology and Hydrology
    - Ministry of Livestock, Fishery and Rural Development
- Hydropower operators using or interested in adopting adaptive management approaches to minimize the downstream impact of hydro-operations;
- Hydropower developers assessing potential impacts or mitigation measures for existing, under construction or planned dams; and
- Local communities that are dependent on the river system and sediment supply for livelihoods such as river bank-agriculture and sand mining.

9.2 Government of Myanmar (GoM) policy, plans and priorities relevant to geomorphology and sediment transport

These include:

- ***Conservation of Water Resources and Rivers Law***, enacted on 2nd October, 2006 by the State Peace and Development Council of the Union of Myanmar (Law No. 8/2006, The 11th Waxing Day of Thadingyut, 1368 ME). This law has the following aims:
  - To conserve and protect the water resources and river systems for beneficial utilization by the public;
  - To improve and increase safety of waterway navigation along rivers and creeks;
  - To contribute to the development of the State economy through improving water resources and the river system; and
  - To mitigate environmental impact.

The Law outlines the duties and powers of the Ministry of Transport.

- ***The Environmental Conservation Law***, The Pyidaungsu Hluttaw Law No. 9 / 2012, enacted the 8th Waxing Day of Tagu, 1373 M. E. The objectives of the law include:
  - To enable the implementation of the Myanmar National Environmental Policy;
  - To enable the basic principles to be laid down and give guidance for systematic integration of the matters of environmental conservation in the sustainable development process;
  - To enable the emergence of a healthy and clean environment and the conservation of natural and cultural heritage for the benefit of present and future generations;
  - To reclaim ecosystems that are degenerating and may disappear as far as possible;
  - To enable management and implementation towards the decrease and loss of natural resources and their sustainable and beneficial use;
  - To enable the promotion of public awareness and cooperation in educational programs on environmental protection;
  - To enable the promotion of international, regional and bilateral cooperation in the matters of environmental conservation;
  - To enable cooperation with Government departments and organizations, international organizations, non-government organizations and individuals in matters of environmental conservation.

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