UNESCO-IHE
Online Course on Environmental Flows

Environmental Flows for the Ayeyarwady (Irrawaddy) River Basin, Myanmar

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Citation:
## Table of Contents

1. Chapter 1: Introduction to the Ayeyarwady River Basin  
   1.1. Overview - Country Context  
   1.2. Introduction to the Ayeyarwady River Basin  
   1.2.1. Hydrological Characteristics of the Ayeyarwady River Basin  
   1.2.2. Climate  
1.3. The Ayeyarwady River Basin’s Natural Resources  
   1.3.1. Biodiversity and Conservation  
   1.3.2. Habitats  
   1.3.3. Watersheds and Freshwater Resources  
   1.3.4. Oil and Gas  
   1.3.5. Minerals  
1.4. Socio-economic Conditions of the Ayeyarwady River Basin  
1.5. Problems and Issues in the Ayeyarwady River Basin  
   1.5.1. Irrigation and drainage development  
   1.5.2. Hydropower Developments  
   1.5.3. Land-use change and Deforestation  
   1.5.4. Oil and Gas Extraction  
   1.5.5. Mining  
   1.5.6. Climate Change  
   1.5.7. Unsustainable Fishing Practices  
   1.5.8. Biodiversity Loss  
   1.5.9. Conclusions  

2. Chapter 2: Governance of Natural Resource Management in the Ayeyarwady River Basin  
   2.1. Overview of Governance  
   2.2.1. Stakeholders and Policy Fragmentation  

3. Chapter 3: Environmental Flows Objective of the Ayeyarwady River Basin  
   3.1. Vision  
   3.2. High Level Objectives  
   3.3. Sub-objectives  

4. Chapter 4: Environmental Flow Assessment of the Ayeyarwady River Basin  
   4.1. EFA Introduction  
   4.1.2. Flow Regime & Rainfall Pattern of the Ayeyarwady River  
   4.2. EFA Methods  
   4.2.1. Assumptions and Analysis for the EFA  
   4.3. Assessment Results  
   4.4. Effects of the recommended EF to the Irrawaddy River Dolphin & Hydropower Development  

5. Chapter 5: Environmental Flows Implementation of the Ayeyarwady River Basin  
   5.1. Overview of Environmental Flows Implementation  
   5.2. Issues to consider in the Implementation process  

6. Chapter 6: Conclusion  

References  
Annex I: Key Stakeholders/Groups in Myanmar
1. Chapter 1: Introduction to the Ayeyarwady River Basin

1.1. Overview - Country Context

Myanmar is the largest, least developed and most ethnically diverse country in South East Asia (Sovacool 2012). The country is home to an estimated population of 58 million with more than 100 ethnic groups. The population is spread across seven divisions and states and largely resides in rural areas (approx. 60%). Myanmar is characterised as one of the poorest countries in the world, with a Human Development Index (HDI) of 0.483, significantly below the regional average of 0.6713 (UNDP 2011). Myanmar’s rural population faces increasing livelihood pressures with high levels of malnutrition, household food insecurity, low household incomes, unemployment; environmental degradation; and increasing pressures from climatic risks (UNDP 2011). In 2008, Myanmar was ranked the worst-hit country in the world to climate related hazards due to the severe destruction caused by Cyclone Nargis which devastated the Ayeyarwady Delta in early May and killed an estimated 150,000 people (German Watch 2010). More recently in 2010, Cyclone Giri caused further socio-economic and ecological damage to the country via the destruction of 15,000 houses and over 7,000 hectares of agricultural land as well as the displacement of over 70,000 people ((BEWG 2011). These events are increasing the vulnerability of rural communities and are resulting in huge destruction of Myanmar’s valuable ecosystems such as mangrove forests. Despite this series of events, the potential for much higher economic growth levels in the country remains. With the recent introduction of political and economic reforms; the strategic location in Asia (Figure 1); and a rich natural resource base; there is a huge potential for economic growth and environmental stewardship (Sovacool 2012).

Myanmar is a biodiversity hotspot and has some of the rarest and most interesting flora and fauna found within all of Asia (Sovacool 2012). The country sits at the intersection of three biogeographic regions and is characterised by a diverse range of ecosystems: Himalayan Mountains, large deltas and estuaries, alpine meadows, rainforests, dry forests, coral reefs and island archipelagos. Due to the interplay of geography, topography, climatic conditions and seasonal rainfall, Myanmar provides an incredible rich cache of biodiversity and ecosystem services (Beffasti 2011; Sovacool 2012). Much of Myanmar’s natural habitats and ecosystems still exist due to the country’s slow rate of economic development. A recent report highlights that approximately 40% of the remaining forests in all of South-East Asia are presence within Myanmar, which 50% of its land covered by forests (FAO 2009; FAO 2010; Beffasti 2011; Sovacool 2012).

Myanmar’s great diversity of habitats and ecosystems support a rich biodiversity, including many international threatened species such as the Ayeyarwady River Dolphin; charismatic mega-fauna such as tigers, elephants; four critical regions for the conservation of birdlife (Endemic Bird Areas- EBAs); and four areas for the conservation of the greatest number of plant species (Centres for Plant Diversity) in the world (Sovacool 2012). Due to favourable climatic conditions and large river basins that cover 90% of the country’s area, Myanmar is perceived as a low water stress country. In terms of available water resources, Myanmar stands at 14th position globally and 5th position in the Asian region. There are altogether eight major river basins and it is estimated that the surface and groundwater potential of Myanmar is 876 and 400 million acre feet per annum respectively (Zaw Win, 2004). The country includes all or part of five major rivers: the Ayeyarwady (Irrawaddy), Thanlwin (Salween), Chindwin, Sittaung and Mekong. One of the most incredibly rich bio-diverse regions in Myanmar is the Ayeyarwady River basin. (Source: Irrigation Department 2005).
Environmental Flows for the Ayeyarwady River Basin, A. Simmance

Environmental, socio-economic, and governance issues prevailing and emerging in Myanmar therefore have a significant impact on the state of water resources within the Basin.

As the pages to come show, the Ayeyarwady River basin provides a host of ecosystem services to the vast rural and urban communities along its waterways. Despite water management and conservation areas being placed more prominent in national campaigns and legislation to alleviate rural poverty, pressures from hydropower development, land-use changes, unsustainable resource practices, mining and climate change are altering the hydrological characteristics of the river and inter-linked ecological integrity. These accumulative impacts have knock on effects on the health of vital ecosystem services of which local livelihoods crucially depend upon. This first chapter of this paper will provide a detailed Situation analysis, an assessment of the current governance and social aspects of the river basin, and finally, provide recommendations for environmental flow objectives.

Figure 1: A) Strategic Position of Myanmar on the Indochinese Peninsula (BLI 2005); and B) Administrative Map of Myanmar.
1.2. Introduction to the Ayeyarwady River Basin

The Ayeyarwady River is one of the five great rivers in the Mekong region and flows through the heartlands of Myanmar. The river’s basin is 413,674 square kilometres, covering a remarkable 61% of Myanmar’s total area and is Myanmar’s most important commercial waterway. The United Nations Environment Programme’s World Conservation Monitoring Centre lists the Ayeyarwady as one of the world’s top thirty high priority river basins due to both its support of high biodiversity and high vulnerability to future pressures. Total population in the basin is 36.1 million.

1.2.1. Hydrological Characteristics of the Ayeyarwady River Basin

The 2170 km long Ayeyarwady River runs through the country from south eastern Himalayas to the Andaman Sea in the Bay of Bengal and has a drainage basin area of 412,650 km² (Figure 2). Headwaters of the river are Nmai H’ka and Mali H’ka rivers that join about 50 km north of Myitkyinā, the northern limit of seasonal navigation. Limit for year round navigation is Bhamo, situated 240 km south from headwaters confluence point. The headwaters of both rivers originate in the south-eastern Himalayas. The N’Maï rises in the Languela Glacier north of Putao. The confluence is 28 miles (45 km) north of the Kachin State capital of Myitkyina. Three major tributaries, the Chindwin, Shweli, and Myintge, meet the river as it flows south through Myanmar’s central heartland, and the country’s second largest city of Mandalay.

Between Myitkyinā and Mandalay the river flows through three defiles. In the vicinity of Mandalay, the river is home to the critically engendered Ayeyarwady River Dolphin (Orcaella brevirostris). After Mandalay the river joins with the Chindwin River and meanders through a densely populated dry zone.

Downstream, the river empties into the Andaman Sea through a nine-armed delta. The delta of the river begins about 93 km north from Hinthada and is boarded by Pegu and Arakan mountains.

The Ayeyarwady Delta lies in the Ayeyarwady Region, the lowest expanse of land in Myanmar that fans out from the limit of tidal influence at Myan Aung to the Bay of Bengal and Andaman Sea, 290 km to the south at the mouth of the Ayeyarwady River. The delta consists of a large and fertile plain that is 290 km long and 240 km wide. The delta region is densely populated with a population of over three million people, and plays a dominant role in the cultivation of rice (60% of Myanmar’s total rice production) in rich alluvial soil which has termed the region the Rice Bowl of Myanmar (Beffasti 2011). Also most of the agricultural processing industry is practised in the delta area.

The basin is rich in biodiversity. Over 50% of basin area is forest and about 6% is wetlands. Mangrove ecosystems located in the delta area are fragile and in continuous decline (Blasco and Aizpuru, 2002).

Cultural diversity is great in the river basin. Kachin people populate the upper parts of the basin. In the middle and in the lower parts, the Burman are in majority. In the delta area there are considerable minorities, such as Karens, Arakans and Shans. In addition, minorities of Indian and Chinese people are living in the river basin area.

The River is the fifth most heavily silted river in the world. The river carries large amounts of sediment that deposits in the delta area and causes extending of the delta area towards the sea.
Sedimentation due to seasonal flooding in the delta area is important for rice growing, making the area one of the world’s major rice producers.

1.2.2. Climate

Myanmar has a tropical monsoon climate. The rainy season typically occurs from May to September, resulting in a wet and humid climate across much of the country. The dry season occurs from October to April, resulting in drier conditions across much of the country. This general pattern disguises extreme variation in climate within the country, with mean annual rainfall ranging from under 500 mm in the centre of the country up to a high of 6,000 mm in Tanintharyi Division and northern Rakhine State (BirdLife International 2011).
Climate zones in the basin vary from warm sub-tropical climate in the upper basin to humid tropical climate in the lower basin, both dominated by the South Asian summer Monsoon. Strong variation in precipitation, in addition to seasonal melting snow from the Himalayan slopes, cause that discharge in the river varies throughout the year between 2,300 m3/s and 32,600 m3/s, the average being 13,000 m3/s. Annual average discharge is 410 km3/year.

The Ayeyarwady floodplain, sheltered from south-west and north-east monsoons by mountain ranges, has an extremely dry and seasonal climate, which has given rise to specialised vegetation types, including thorn scrub and deciduous dipterocarp forest. Myanmar’s monsoon pattern is however being affected by climate change. Estimates suggest that global warming has shortened and shifted the monsoon pattern for the past 30 years (Sovacool 2012). Changes to the weather patterns, including increased storminess and decreased rain, has resulted in a decrease in annual rainfall (Sovacool 2012).

1.3. The Ayeyarwady River Basin’s Natural Resources

Many ethnic and indigenous peoples in Burma are dependent on natural resources for their livelihoods and traditionally have maintained natural resource management systems that ensure the sustainability of these natural resources. Previously known as the “last frontier of biodiversity in Asia,” Burma has a seemingly unparalleled abundance of animal and plant life. The Ayeyarwady River basin is one of the world’s eight hottest hotspots of biodiversity.

1.3.1. Biodiversity and Conservation

The Ayeyarwady River is home to 79 known fish species and as of 2002 there were four known endemic bird species in the basin. The river also provides vital important wintering and staging habitat for migratory waterfowl. Near Mandalay, the river provides crucial habitat to the critically endangered Ayeyarwady Dolphin (Orcaella brevirostris) which is one of only four species of river dolphins in the world (Figure 4b). The Ayeyarwady Dolphin typically reach 2-2.75 meters in length, are dark blue to dark grey and have a unique socio-economic cooperative relationship with local fishermen.

About 250 mammal species, more than 1,000 birds, 370 reptiles and 7,000 plants are recorded in Myanmar, including 39 species of mammals, 45 of birds, 21 of reptiles and 38 of plants which are globally threatened (NCEA, 2009a) Beffasti 2011. A report by BirdLife International in 2005 identified 76 Key Biodiversity Areas (KBAs) have been, out of which 54 are recognized as Important Birds Areas (IBAs). Conservation corridors identified included Central Ayeyarwady River and the Ayeyarwady Delta (Figure 3 and Table 1).
Table 1. Summary of conservation corridors in Myanmar

<table>
<thead>
<tr>
<th>Conservation Corridor</th>
<th>Area (km²)</th>
<th>No. of KBAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ayeyarwady Delta</td>
<td>5,300</td>
<td>1</td>
</tr>
<tr>
<td>Bago Yoma Range</td>
<td>17,800</td>
<td>2</td>
</tr>
<tr>
<td>Central Ayeyarwady River</td>
<td>18,000</td>
<td>13</td>
</tr>
<tr>
<td>Central Myanmar Dry Forests</td>
<td>15,000</td>
<td>2</td>
</tr>
<tr>
<td>Central Myanmar Mixed Deciduous Forests</td>
<td>7,600</td>
<td>2</td>
</tr>
<tr>
<td>Central Thanlwin River</td>
<td>11,000</td>
<td>0</td>
</tr>
<tr>
<td>Chin Hills Complex</td>
<td>23,900</td>
<td>5</td>
</tr>
<tr>
<td>Kayah-Kayin Range</td>
<td>13,000</td>
<td>1</td>
</tr>
<tr>
<td>Lower Chindwin River</td>
<td>8,400</td>
<td>1</td>
</tr>
<tr>
<td>Naga Hills</td>
<td>5,500</td>
<td>1</td>
</tr>
<tr>
<td>Nan Yu Range</td>
<td>20,500</td>
<td>0</td>
</tr>
<tr>
<td>Northern Mountains Forest Complex</td>
<td>25,800</td>
<td>3</td>
</tr>
<tr>
<td>Rakhine Yoma Range</td>
<td>53,000</td>
<td>5</td>
</tr>
<tr>
<td>Sundaic Subregion (Tanintharyi)</td>
<td>44,200</td>
<td>12</td>
</tr>
<tr>
<td>Upper Chindwin Lowlands</td>
<td>24,400</td>
<td>4</td>
</tr>
</tbody>
</table>
Figure 3: List of Key Biodiversity Areas (KBAs) in Myanmar (BLI 2005).
The Central Ayeyarwady River is an important wintering and staging area for migratory waterfowl from Tibet and other areas north of the Himalayas (Figure 4A). In addition to the four nationally endemic bird species, Myanmar supports at least 19 other restricted range bird species (species with a global breeding range of less than 50,000 km²), most of which have distributions that include parts of other countries. These restricted-range species define four Endemic Bird Areas (EBAs) and three Secondary Areas (SAs) which includes the Ayeyarwady Plains (Figure 3) (BLI 2005 and IUCN-WCPA 2007; Beffasti 2011). The Ayeyarwady Plains EBA is located in the Central Dry Zone of Myanmar. Three restricted range species occur in the EBA, all of which are national endemics: Hooded Treepie; White-throated Babbler; and Burmese Bushlark.

Figure 4: A) Ruddy Shelduck (Tadorna ferruginea) and Bar-headed Goose (Anser indicus) find refuge on the sand-bars of the Ayeyarwady River (Source: Photo: J. C. Eames); B) to the critically endangered Ayeyarwady River Dolphin (Orcaella brevirostris).

1.3.2. Habitats

Myanmar is comprised of a diverse range of important habitats ranging from forests, wetlands and the marine habitat. Eight different forest types exist: mixed deciduous forest, hill and temperate evergreen forest, tropical evergreen forest, dry forest, deciduous dipterocarp forest, tidal forest or mangrove forest, beach and dune forest, swamp forest (Figure 5) (Tint, 1995; NCEA 2009; Beffasti 2011).

Mangrove forests are extensive across the tidal habitats of Myanmar which represent approximately 9% of total mangrove forests area in all South-East Asia. These significantly important habitats are found along alluvial flats of river deltas and on muddy coastal areas (Beffasti 2011). The majority of these mangrove forests are found in the Ayeyarwady Region (46% of total mangrove cover in Myanmar) (Giesen et al. 2006; Beffasti 2011). This type of forest provides a set of important and valuable ecosystem services: storm protection through shoreline stabilisation; reduces coastal erosion; regulates carbon and nutrients; and provides crucial habitat for migratory water birds, juvenile fish populations and aquaculture production (Beffasti 2011). Mangroves offer a variety of socio-economic and ecological values which provide critical support to many coastal populations.
1.3.3. Watersheds and Freshwater Resources

Myanmar is endowed with abundant water resources, but here are problems, related to their uneven spatial and temporal distribution. The monthly distribution of river flows closely follows the pattern of rainfall, which means that about 80% flows during the monsoon season (May-October) and 20% in the dry season (November-April).

The north-south direction of Myanmar’s mountain ranges is reflected in the flow of its major rivers which comprises six river basins: the Ayeyarwady (Irrawaddy) river basin, the Sittaung river basin, the Thanlwin (Salween in Thailand, Nu in China) river basin, the Mekong (Lankang in China) river basin, the Rakhine (Arakan) coastal basin; and the Tanintharyi (Tenasserim) coastal basin.

Over 90% of the Ayeyarwady River basin lies within Myanmar and the river drains over 55% of the country’s surface area. The basin can be divided into three sub-basins: Upper Ayeyarwady, Middle- Lower Ayeyarwady and the Delta Ayeyarwady. According to a 2005 assessment by the Irrigation and Water Utilization Departments the drainage area for Upper Ayeyarwady River Basin is 74,600 (square miles) and 36,900 (square miles) for the Lower Ayeyarwady River Basin.

Given the geo-graphic location of Myanmar, many countries are beginning to look to Myanmar to help meet their energy demands through mass hydropower developments as well as irrigated agriculture. Many of these hydropower developments are planned for the upper Ayeyarwady River Basin. The Irrigation Department, which was established to coordinate the development and management of water resources for irrigation, has constructed about 200 irrigation projects, which receive water from constructed dams, weirs and sluices.
1.3.4. **Oil and Gas**

Myanmar’s territory is home to great deposits of oil and gas which has resulted in intensive exploration projects, development and associated human right conflicts over the past 30 years. Today there are 49 onshore blocks and 26 offshore being explored and/or developed in Myanmar. Gas reserves are also estimated at 20.1 trillion cubic feet, or 0.3% of the world’s total gas reserves. Oil and gas development is resulting in environmental and socio-economic degradation with for example pipe lines causing displacement of people.

1.3.5. **Minerals**

Myanmar has rich mineral resource deposits including tungsten, tin, zinc, silver, copper, lead, coal, gold, and industrial minerals.2Antimony, limestone, and marble deposits also dot the landscape. Gemstones including diamonds, rubies, jade, and sapphires can also be found with one report estimating the value of rubies as contributing towards 90% of global trade (BWEG 2011). Extensive mining, such as mining for gold, along much of the major rivers in Myanmar is causing environmental degradation.

1.4. **Socio-economic Conditions of the Ayeyarwady River Basin**

There are still substantial socio-economic pressures within Myanmar. Although some progress has been made towards meeting the United Nations (UN) Millennium Development Goals (MDGs), an acceleration of improvement in numerous indicators is still required (i.e. Goal no 1 Poverty Eradication). Disparities in living conditions between rural and urban remains high, with poverty and food security in a number of states considerably higher than the national average (26%), including Shan North 37% which lies in the vicinity of the Ayeyarwady River Basin.

The average human population density is 73 people per km2, although there is great variation across the country, with the floodplains of the Ayeyarwady and other major rivers supporting the highest population density. The most populous cities in the country are Yangon, the capital, and Mandalay (BLI 2011). Mandalay straddles the Ayeyarwady River with the vicinity providing crucial home to the critically engendered Ayeyarwady River Dolphin (*Orcaella brevirostris*).

Myanmar’s economy is predominantly based on agriculture (crops, livestock, fisheries and forestry), which currently contributes 43% of GDP and provides over 50% employment. A critical problem within the rural poor is landlessness which contributes up to 75% in the southern-most part of Ayeyarwady Delta. This lower part of the delta is a fragile and intricate ecosystem of mangrove swamps and tidal estuaries. The delta supports a population of over three million people and provides nearly 60% of Burma’s total rice production.

The interconnected ecosystems within the Ayeyarwady river basin provide valuable ecosystem services (provisional, cultural, supportive and regulatory) which support the livelihoods of many people within the region via productive agriculture, fisheries, aquaculture and tourism (Table 2). In addition, the fisheries cooperation between fishers and the Ayeyarwady dolphin represent a unique cultural tradition which protects both a critically endangered wildlife population and a sustainable, local livelihood.
Table 2. Suggested Ecosystem Services and Ecosystem Goods provided by the River Basin

<table>
<thead>
<tr>
<th></th>
<th>Ecosystem Services</th>
<th>Ecosystem Goods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Part</td>
<td>Water for human consumption, recreational practices.</td>
<td>Agriculture products, water for livestock, hydropower, transportation routes.</td>
</tr>
<tr>
<td>Middle Part</td>
<td>Water for human consumption, Tourism (Bird and Natural Reserve), recreational practices.</td>
<td>Agriculture products, transportation routes, water for livestock.</td>
</tr>
<tr>
<td>Lower Part</td>
<td>Water for human consumption, recreational values, floods regulation.</td>
<td>Agriculture products, transportation routes, water for livestock.</td>
</tr>
<tr>
<td>Delta</td>
<td>Water for human consumption, floods regulation, recreational practices, input of nutrients to the Andaman Sea in the Bay of Bengal.</td>
<td>Agriculture products, transportation routes and fish (delta and the Andaman Sea in the Bay of Bengal).</td>
</tr>
</tbody>
</table>

1.5. Problems and Issues in the Ayeyarwady River Basin

Maintaining the ecosystem integrity of enormous watersheds is critical to both the unique flora and fauna within them and to the human populations that rely on them. Myanmar faces a unique and daunting set of biodiversity conservation challenges. Habitats and wildlife face the growing threat of destruction and extinction, with thirty-four rare species within the country now endangered and growing amounts of air and water pollution jeopardizing national parks and old-growth rainforests (Sovacool 2012).

Myanmar is well endowed with natural resources on which economic development and people’s livelihoods are largely dependent. Despite the low levels of industrialization and the relatively low population density, the country’s environment is under threat from both human activities and climate change (ADB, 2012).

Major threats to the ecological and hydrological integrity of the Ayeyarwady River Basin include: hydropower developments; logging and deforestation; mineral prospecting; unsustainable fishing practices and overfishing; land use change; habitat destruction; and climate change. These pressures are resulting in declining populations of key biodiversity, loss of habitat and a decline in the health of ecosystem services. This is particularly evident along the Central Ayeyarwady River and the Ayeyarwady Delta.

1.5.1. Irrigation and drainage development

There are two types of irrigation management in Myanmar: public and private schemes. Government schemes account for 53% of weir schemes and 81% of the dams and tanks (all
Environmental Flows for the Ayeyarwady River Basin, A. Simmance

dams of and above 6.1 m). Wells and pump irrigation, although possibly originally implemented by the services of the former Ministry of Agriculture, are mainly private.

The total area equipped for irrigation in 2004 was an estimated 2,110,000 ha (MOAI, 2010). In 2000, out of the total irrigated area of 1841000 ha, 31% was supplied by canals (57% managed by the government and 43% by farmers), 11% was supplied by tanks (93% managed by the government and 7% by farmers), 4% by tube wells, 46% by pumps and 8% by other types of irrigation water supply (Fujita and Okamoto, 2006). Water resources for pump lift irrigation are mainly based on the flow of three major rivers, the Ayeyarwady, Chindwin, and Sittaung. All irrigation in Myanmar is surface irrigation. Sprinkler and localized irrigation have been developed only on pilot farms, and altogether do not exceed 50 ha.

1.5.2. Hydropower Developments

Within the Ayeyarwady River basin region despite well documented evidence of the ecological and socio-economic impacts of dam developments, the government of Myanmar has embarked on a strategy to shift reliance on gas to hydropower via making it the sole source of electricity by 2030 which will result in seven large hydropower developments along the waterway. According to studies by the United Nations and other sources, the hydropower potential of Myanmar is estimated to be as much as 40,000 MW.

The government signed an agreement with China Power Investment Corporation in 2007 for the construction of seven large dams along the Ayeyarwady, Mali, and N’Mai rivers in Kachin state. The largest one, the Myitsone dam, will be located at the confluence of the Mali and N’Mai rivers, which then become the Ayeyarwady River and will be 152 m high with an installed capacity of 6000 MW. The reservoir will flood an area larger than Singapore in one of the world’s most disputed biodiversity ‘hotspots’. An estimated 10,000 people will have to be displaced (BRN, 2010).

A map detailing planned hydropower development projects, such as the large Ayeyarwady Myitsone Dam, can be seen in Figure 6.

The constructions of these dams pose a great threat to the ecological integrity and flow regime of the river basin. Dams block migration route of fish preventing them reaching upstream spawning grounds resulting in substantial losses to downstream fishery production. The disturbance to fish migration patterns also result in a loss of prey to critical species such as the critically endangered Ayeyarwady Dolphin.

Dams also result in adverse impacts to the flow regime of a river with grave implications to the health of floodplains and delta ecosystems and the ecosystem services they provide to local livelihoods. Unnatural changes in the flow regime of a river will result in: riverbank destruction due to increased erosion; altered flood cycles and disruption to the replenishment of wetlands, floodplains and delta ecosystems. This results in a decline of fisheries and aquatic plants dependent on these nutrients rich ecosystems. In addition, water quality will be reduced resulting in a decline of fish species and knock on impacts to the abundance and diversity of bird populations within the basin. Socio-economic conditions will be affected. The changed hydrological regime will reduce the productivity of agriculture, fisheries and the health of forest ecosystems such as mangroves along the Ayeyarwady delta which provides nearly 60% of Myanmar’s rice.
Upon completion of the Myitsone dam, the primary determinant for the water levels and flooding patterns of the Ayeyarwady would be neighbouring China’s demands for electricity at any given moment. If the Myitsone dam’s generating capacity is needed, then the gates would be opened, the turbines run, and the generated electricity sent to China. It would be unlikely that the situation of downstream inhabitants whose livelihoods depend upon the timely seasonal variations of the river would be taken into consideration.
1.5.3. Land-use change and Deforestation

Land degradation is an increasing problem in Myanmar, with soil erosion in upland agricultural areas and dry zones being of particular concern. Rapid changes in land use and deforestation throughout the country have resulted in astronomically high rates of greenhouse gas emissions. Myanmar ranks fourth in the world for its emissions from land use change and deforestation.

While Myanmar’s forest cover is comparatively higher than other Greater Mekong Sub region (GMS) countries, there has been a steady decline in forest cover and quality. At present, nearly half of the country remains covered with natural forests, with total forest in 2006 corresponding to approximately 49% of country land area. Natural forest loss has averaged 392,540 hectares annually since 1989, representing a major acceleration in forest cover loss compared with the prevailing situation (ADB, 2012). Myanmar still remains one of the ten countries in the world with the largest annual net loss of forest area and among the
Environmental Flows for the Ayeyarwady River Basin, A. Simmance

five countries (Indonesia, Australia, Myanmar, Madagascar and Mozambique) with the largest net loss of mangrove area during the period 2000–2010 (FAO 2010).

Unsustainable extraction represents a key pressure on forests. Fuel wood extraction, constituting around 92% of total wood removal in 2000, is significant compared to roundwood removals, with more than 80% of total primary energy in Myanmar still being supplied by fuel wood.

In the Ayeyarwady Region, mangrove forest has been seriously degraded in recent years due to agricultural conversion and the high demand for firewood and charcoal from Yangon, with consequent decline of fish catches and increased vulnerability to natural disasters. Since shrimp farming is still encouraged without any proper planning, mangrove forests are expected to continue to decrease (Angell 2004). Agricultural expansion, shifting cultivation, conversion of forest to plantations are the main causes of habitat degradation and loss. Rubber plantations have almost doubled from 1990 to 2010 (FAO 2010) and together with large scale palm oil plantations are among the most impacting threats on biodiversity. Previously the main cause of mangrove deforestation (particularly in the delta area) was rice cultivation. According to the Mangrove Action Project, 85% of mangroves in the Ayeyarwady Delta have been lost to rice farming. Shrimp farming is now considered the leading cause of mangrove deforestation along the coastline. Land-use changes in the form of prawn farms and unsustainable practices such as deforestation and private prawn aquaculture have destroyed much of the delta ecosystem resulting in a ‘bleak’ eco-region.

Moreover, as a result of land-use changes and development along the Ayeyarwady waterway, critical habitat for the Ayeyarwady Dolphin has declined by nearly 60% in the last century resulting in a drastic decline in the population of the dolphin with only 59 to 72 individuals remaining in a region approximately 1,000 kilometres from the sea.

1.5.4. Oil and Gas Extraction

Myanmar is rich in oil and gas resources, which are located both on- and off-shore. Oil and Gas extraction are increasing across the country with increasing demands and investment from neighbouring countries. As a result of this increasing extraction, environmental degradation such as water quality due to leakages, habitat loss and displacement due to pipeline construction are increasing (BEWG 2011).

1.5.5. Mining

The Mining industry has become one of the country’s key development sectors in recent years, attracting considerable foreign investment and generating important export earnings (ADB, 2012). Myanmar has a rich source of mineral and gemstones deposits which includes: tin, silver, copper, gold, lead, diamonds, and sapphires. Artisanal mining of these deposits is increasing and the mining operations have shifted from small scale to large scale industrial operations in the past 20 years. The annual growth rate of mining production during the period 2001-2006 was 15.5%, which is higher than gross domestic product growth (ADB, 2012). The impacts of these methods are causing environmental degradation through habitat loss and degradation, declines in water quality and land-use change which is predominately evident in northern states and especially along the Ayeyarwady River. Land, including forests, is indiscriminately cleared for hydraulic and pit mining operations. Pit mining guts
Environmental Flows for the Ayeyarwady River Basin, A.Simmance

the remaining soil, leaving it pock-marked…while hydraulic mining blasts away soil[, causing erosion on river banks. Wastes from the mining process, including mercury contaminated rocks and soil, are discarded throughout the landscape. These contaminants enter many tributaries of Myanmar’s rivers, causing water pollution and a decline in water quality. Impacts on food security and water pollution are already evident in many river downstream from mining operations along the Ayeyarwady River (BEWG 2011).

1.5.6. Climate Change

The issue of climate change has only recently been assessed as a high priority in Myanmar. The Government’s perspective changed fundamentally after the severe cyclonic storm Nargis, which caused large loss of life, destruction, and livelihoods impacts. Myanmar’s vulnerability to climate change is now widely recognized, with the country coming second in world rankings (German Watch) and ranked highly vulnerable to water resource availability ISF-UTS (2011) (see Table 3). The Berlin-based climate watchdog also ranked Myanmar as the worst-hit country in the world in 2008 due to the impact of Cyclone Nargis, which devastated the Ayeyarwady delta in early May that year, killing an estimated 150,000 people.. Furthermore, a report by the Intergovernmental Panel on Climate Change (IPCC) highlights that low lying coastal areas, small islands and deltas like those of the Ayeyarwady River in Burma are at serious risk of sea level rise, especially during cyclones and floods.

Myanmar is already experiencing the effects of climate change, with a clear trend of rising temperatures, shortening of monsoon duration, and increased frequency of intense rainfall and severe cyclones along Myanmar’s coastline (ADB, 2012).

Along the Ayeyarwady River the impacts of climate change on the availability of freshwater is highly variable. ISF-UTS (2011). There is also evidence that the Himalayan glaciers that feed Burma’s main rivers are slowly melting. This means that over time Burma’s rivers, including the Ayeyarwady River, will soon lose significant amounts of water flow and volume.

The middle dry zone, increased drought, reduced annual rainfall and higher dry season temperatures are expected. ISF-UTS (2011). In the deltas areas, potential climate change impacts include more frequent storms (cyclones) and floods, sea level rise, salt water intrusion and changes in rainfall pattern and intensity (Zaw and Then 2010).

Combined with the flow-changing effects of dozens of dams in Myanmar and China, water will become increasingly scarce, resulting in more damage to both biodiversity and local livelihoods within the Ayeyarwady River Basin.
Environmental Flows for the Ayeyarwady River Basin, A. Simmance

Table 3: Status of water resources and climate vulnerability in Mynamar (adapted from ISF-UTS 2011).

<table>
<thead>
<tr>
<th>Renewable water (ML/population)</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Climate Vulnerability factor 2010 (on scale of acute, severe, high, moderate, low). (Climage Vulnerability Monitor 2010).</td>
<td>Acute</td>
</tr>
<tr>
<td>Overall Climate Vulnerability factor 2030 (on scale of acute, severe, high, moderate, low). (Climage Vulnerability Monitor 2010).</td>
<td>Acute</td>
</tr>
<tr>
<td>Environmental Vulnerability Status (on scale of extremely vulnerable, highly vulnerable, vulnerable, at risk, resilient). (Environmental Vulnerability Index 2004)</td>
<td>Vulnerable</td>
</tr>
</tbody>
</table>

1.5.7. Unsustainable Fishing Practices

Illegal electric fishing, by-catch by fisheries gill nets, mercury poisoning, and habitat loss from gold mining operations in the river have further jeopardized the Ayeyarwady River’s dolphin population. Poverty also contributes to overfishing practices, some of which involve the use of mercury and cyanide, activities extremely damaging both to natural habitats and downstream communities.

1.5.8. Biodiversity Loss

Myanmar’s biodiversity is under increasing threat, especially in the Indo-Myanmar hot spot where a combination of economic development and human population growth is placing pressure on natural habitats and species populations.

Major contributors to biodiversity loss are: (I) conversion of closed forests for other land uses, (ii) shifting cultivation, (iii) weak regulation and control of commercial exploitation and trade in endangered flora and fauna, and (iv) lack of sufficient environmental impact assessment and integration of biodiversity concerns in development activities affecting land use change. Forest degradation is of particular importance in terms of terrestrial biodiversity, potentially affecting approximately 36% of threatened mammals and birds. Additionally, loss of wetlands and grasslands is threatening bird species. For example, mangrove forests drastically declined from 253,018 hectares in 1924 to 71,716 hectares in 2008, with only 28% of original mangroves remaining (ADB, 2012).

1.5.9. Conclusions

Unfortunately, these accumulative pressures are likely to be increasing since Cyclone Nargis (2008) devastated rural economies thereby increasing poverty levels and leading to a “severe lack of resources” in some communities. Moreover, one report has disturbingly concluded that unsustainable activities such as logging and deforestation has occurred in over 80% of Myanmar’s Protected Area’s with grave environmental consequences (Sovacool 2012). The accumulative pressures of land-use change, development and unsustainable practices pose a great threat to the flow regime, ecological integrity and socio-economic value of the Ayeyarwady river basin. For these reasons, an environmental flow process is required to manage these conflicts and protect the River’s natural ecosystem and flow regime.
2. Chapter 2: Governance of Natural Resource Management in the Ayeyarwady River Basin

2.1. Overview of Governance

By far the most far-reaching enshrinement of government efforts to conserve the environment is Myanmar’s vast network of protected areas and parks. To date, a total of thirty-three national parks and wildlife sanctuaries have been created between 1918 and 2007; six additional protected areas have been proposed since 1999 (Sovacool 2012). Existing parks include areas of important cultural areas and habitats (Figure 7). In recognition of the ecological and socio-economic importance of this cultural tradition, the government of Myanmar established a protected area to safeguard the cooperative fishery. Spanning 70 kilometres of the Ayeyarwady River, this protected area supports one third of the river’s population of Ayeyarwady dolphins. The new protected area will boost awareness of the Ayeyarwady dolphin and its unique role in the river’s livelihoods.
However, many reports highlight that the existing network of protected areas covers too little land (2-3% of total land area). Moreover, the protected areas face competing pressures related to economic development, exports and agricultural expansion.

Despite significant recognition for the need to conserve valuable ecosystems through environmental legislation (Table 4), including legislation which relates to river management, many critics highlight that Myanmar’s laws are too broad and lack specific implementation plans and enforcement (Sovacool 2012).

**2.2.1. Stakeholders and Policy Fragmentation**

Environmental conservation has a multitude of concerned stakeholders that can complicate planning and implementation (Sovacool 2012). Myanmar has a suite of private, public and local stakeholders with differing expectations and visions in relation to the management of a specific resource (Table 5). These differing opinions and goals often result in policy fragmentation, conflicts of interest and difficulties in managing the socio-economic and ecological trade-offs of major political decisions such hydropower developments.
Table 4: Major Laws Relating to Environmental Conservation and Protection in Myanmar (Sovacool, 2012).

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factory Act</td>
<td>1951</td>
<td>To make effective arrangements for the disposal of waste in every factory, promote health and cleanliness, and provide precaution against danger.</td>
</tr>
<tr>
<td>Public Health Law</td>
<td>1972</td>
<td>To promote and safeguard public health and take necessary measures to ensure environmental health.</td>
</tr>
<tr>
<td>Territorial Sea and Maritime Zone Law</td>
<td>1977</td>
<td>To implement the United Nations Law of the Sea treaty defining maritime and contiguous zones and preserving and protecting the marine environment.</td>
</tr>
<tr>
<td>Fishing Rights of Foreign Vessels Law</td>
<td>1989</td>
<td>To conserve fisheries and enable the participation of foreign investors in fishery operations.</td>
</tr>
<tr>
<td>Marine Fisheries Law</td>
<td>1990</td>
<td>To conserve and enable systematic operation of fisheries.</td>
</tr>
<tr>
<td>Pesticide Law</td>
<td>1990</td>
<td>To direct the Myanmar Agriculture Service to analyse and test pesticides, and to undertake bio-efficacy trials on crops.</td>
</tr>
<tr>
<td>Private Industrial Enterprise Law</td>
<td>1990</td>
<td>To avoid environmental pollution in the face of rural development and industrialization, and to promote the use of energy in the most economical matter.</td>
</tr>
<tr>
<td>Forestry Law</td>
<td>1992</td>
<td>To prevent dangers of destruction to forests and biodiversity and to conserve and establish forest plantations.</td>
</tr>
<tr>
<td>Plant Pest Quarantine Law</td>
<td>1993</td>
<td>To prevent pests from entering Myanmar by any means and to suppress their spread.</td>
</tr>
<tr>
<td>Development of Border Areas and Natoinal Races Law</td>
<td>1993</td>
<td>To cherish and preserve the cultural and customs of national races and to preserve the tranquility of border areas.</td>
</tr>
<tr>
<td>National Environmental Policy</td>
<td>1994</td>
<td>To establish sound environmental policies in the utilization of water, land, forests, minerals resources and other natural resources to preserve the natural environment and prevent its degradation.</td>
</tr>
<tr>
<td>Protection of Wildlife and Wild Plants and Conservation of Natural Areas Law</td>
<td>1994</td>
<td>To protect wildlife, wild plants and conserve natural areas, to contribute to the works of natural scientific research and to establish a network of zoological and botanical gardens.</td>
</tr>
<tr>
<td>Myanmar Mines Law</td>
<td>1996</td>
<td>To implement mineral resources and protect environmental conservation works that may have detrimental effects from mining operations.</td>
</tr>
<tr>
<td>Protection and Preservation of Cultural Heritage Regions Laws</td>
<td>1998</td>
<td>To protect cultural heritage from natural disasters and man-made destruction.</td>
</tr>
<tr>
<td>Fertilizer Law</td>
<td>2002</td>
<td>To boost development of agriculture, control fertilizers, and facilitate soil conservation.</td>
</tr>
<tr>
<td>Conservation of Water Resources and Rivers Law</td>
<td>2006</td>
<td>To conserve and protect water resources and rivers for beneficial utilization by the public, and to prevent serious environmental contamination.</td>
</tr>
</tbody>
</table>
Table 5: Key stakeholders within Myanmar

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>Primary/Secondary</th>
<th>Key</th>
<th>Water Usage</th>
<th>Impact of the River</th>
<th>Hydrological Impact</th>
<th>Influence/Authority</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood Control/Irrigation Agencies</td>
<td>Primary</td>
<td>Key</td>
<td>Keep and release the flows to minimize the flood risk</td>
<td>water quantity</td>
<td>high</td>
<td>High</td>
<td>Play a critical role in flood defence and environmental risk protection, particularly in the Delta region.</td>
</tr>
<tr>
<td>Hydropower Companies</td>
<td>Primary</td>
<td>Key</td>
<td>Dam developments incl. disturbances to the river during construction/destructio n and permanent changes to flow.</td>
<td>water quantity, quality, pollution, sedimentation and habitat destruction</td>
<td>high</td>
<td>High</td>
<td>Play a critical role in developing economic growth for country, power supply and building international relations (China).</td>
</tr>
<tr>
<td>Mining Industries</td>
<td>Primary</td>
<td>Key</td>
<td>Water extraction.</td>
<td>Water quantity, quality, pollution, sedimentation and habitat destruction</td>
<td>medium</td>
<td>High</td>
<td>Sector contributes to GDP of country.</td>
</tr>
<tr>
<td>Nature Ecosystems</td>
<td>Primary</td>
<td>Key</td>
<td>Natural recycle of nutrients, water retention in soil, etc.</td>
<td>Maintain health of ecosystems.</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Research Institutes</td>
<td>Secondary</td>
<td>Key</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>medium</td>
<td>Influence policy through scientific advice.</td>
</tr>
<tr>
<td>Water Management Authorities/ Government Bodies (Annex I)</td>
<td>Secondary</td>
<td>Key</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>High</td>
<td>Authorized water resource management body and government body.</td>
</tr>
</tbody>
</table>
Environmental Flows for the Ayeyarwady River Basin, A.Simmance

<table>
<thead>
<tr>
<th>Urban Residents</th>
<th>Primary</th>
<th>Key</th>
<th>Water extraction and pollution.</th>
<th>water quantity, quality, pollution, temperature</th>
<th>medium</th>
<th>High</th>
<th>Increasing demands in water scarce region. Cultural and significant provisional services.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Village Elders/ Chiefs/ Groups</td>
<td>Primary</td>
<td>Key</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Aquaculture Farmers</td>
<td>Primary</td>
<td>Water extraction.</td>
<td>Water quality, pollution, and habitat destruction.</td>
<td>low</td>
<td>low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farmers</td>
<td>Primary</td>
<td>Irrigation and run off of water from the land into the river.</td>
<td>water quantity, quality and pollution</td>
<td>medium</td>
<td>medium</td>
<td>Maintain food security in country and contribute significantly to GDP, particular 'Rice Bowl' in Delta.</td>
<td></td>
</tr>
<tr>
<td>Fisherman</td>
<td>Secondary</td>
<td>Fishing practices (extraction of fish)</td>
<td>Ecological impacts, habitat destruction.</td>
<td>low</td>
<td>low</td>
<td>Food security and nutritional source, generates income for local communities and cultural significance (cooperative with Irrawaddy River Dolphin).</td>
<td></td>
</tr>
<tr>
<td>Industries</td>
<td>Primary</td>
<td>Water extraction and pollution.</td>
<td>water quantity, quality, pollution, temperature</td>
<td>low</td>
<td>medium</td>
<td>Contributes to economic development but increasing consumption of carbon emissions and pollution.</td>
<td></td>
</tr>
<tr>
<td>Navigation</td>
<td>Primary</td>
<td>Channelization, geomorphological changes and changes to water depth.</td>
<td>Water quantity, sedimentation.</td>
<td>low</td>
<td>High</td>
<td>Plays a key role in economic and social growth. Cultural, historical significance, particularly in Mandalay.</td>
<td></td>
</tr>
<tr>
<td>NGOs (Annex I)</td>
<td>Secondary</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>low</td>
<td></td>
<td>Focus on environmental conservation and poverty alleviation. Little influence at present due to political history. International presence growing.</td>
</tr>
<tr>
<td>Oil &amp; Gas Extraction-(pipe laying)</td>
<td>Primary</td>
<td>-------</td>
<td>Water quality, pollution.</td>
<td>low</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. **Chapter 3: Environmental Flows Objective of the Ayeyarwady River Basin**

3.1. **Vision**

To maintain the integrity and health of the rich fauna, flora and ecosystem services within the basin, while addressing economic growth, international relations, transport needs, environmental risk and the wellbeing of the basin’s culturally diverse population.

3.2. **High Level Objectives**

To maintain and improve conservation of the rich and fragile freshwater ecosystems, endangered species and natural resources whilst meeting irrigated agricultural needs, mitigating climate and environmental risks, managing increasing energy generation, promoting sustainable land use practices and addressing socio-economic needs of the people.

3.3. **Sub-objectives**

Hydrological, ecological, anthropogenic pressures and socio-economic factors vary along the length of the Ayeyarwady River. As a result, the sub-level objectives are set as three parts respectively, such as the upper, the middle and lower and the river delta.

**The upper** means the part from the headwaters of the river - Nmai H’ka and Mali H’ka rivers that join about 50 km north of Myitkyinā. The confluence is 28 miles (45 km) north of the Kachin State capital of Myitkyina. The priorities in this region are to protect important fisheries, protect tropical moist deciduous forests and protect the wellbeing of the people. The key objective of the upper part is to prevent the decline of the important fish resources, to improve the sustainable use and conservation of deciduous forests, to reduce the ecological impact caused by hydropower infrastructures upstream, whilst maintaining the ecosystem services which critically support the livelihoods of people within the basin.

The **middle and lower** means the part of the river from where three major tributaries, the Chindwin, Shweli, and Myintge, meet the river as it flows south through Myanmar’s central heartland to the country’s second largest city of Mandalay. The priorities in this region are to protect the habitat of the critically endangered Ayeyarwady River Dolphin (Orcaella brevirostris), to conserve critical habitat for endemic bird species, to maintain safe water quality levels, to conserve the tropical dry forest ecosystem, whilst managing flood risks and meeting increasing intensive land use needs of the growing densely populated area. The key objective of the middle and lower part is to improve the conservation of the critically endangered Ayeyarwady River Dolphin via increasing protected areas and reducing the impact of hydropower development upstream, to conserve the critical habitats of endemic bird species and to sustainably manage land-use changes in the region whilst supporting economic growth.

The **delta downstream** means part of the river that begins about 93 km north from Hinthada and is boarded by Pegu and Arakan mountains. The priorities in this region is to protect the high proportion of wetlands and mangrove forests whilst mitigating environmental risks and maintaining the cultivation of rice and production of agriculture yield. The key objective of the delta downstream part is to 1) protect the rich diverse mangrove forest
Environmental Flows for the Ayeyarwady River Basin, A. Simmance

through improved sustainable land-use practices, reduction in deforestation and an increase in protected areas; 2) sustainably manage increasing needs of irrigated agriculture and land-use practices within the regions; 3) mitigate environmental risks (cyclones, sea level rise); 3) support sustainable livelihoods of the poor and marginalised communities within the delta; and finally 4) reduce the impacts of hydropower developments upstream in the headwaters which will cause negative impacts to the ecological and economy conditions of the delta.

4. Chapter 4: Environmental Flow Assessment of the Ayeyarwady River Basin

This paper provides an environmental flow assessment of the middle and lower part of the Ayeyarwady River Basin, characterised by where three major tributaries, the Chindwin, Shweli, and Myintge, meet the river as it flows south through Myanmar’s central heartland to the country’s second largest city of Mandalay (figure 1a). Only one section of the Ayeyarwady River has been identified for this chapter due to a lack of comprehensive data and literature available in the chosen river basin.

Data used for the EFA of the middle and lower part of the Ayeyarwady River Basin is extrapolated from the paper by Furuichi 2009 who provides the best reliable estimates of the annual discharge and suspended sediment load for the Ayeyarwady River. The paper by Furuichi 2009 builds on data gathered by the Department of Meteorology and Hydrology of Myanmar gauge station data (1966-1996); and Robinson et al (2007).

4.1. EFA Introduction

The key EF objectives of the middle and lower part of the Ayeyarwady River Basin are to: a) improve the conservation of the critically endangered Ayeyarwady River Dolphin via reducing the impacts of hydropower development upstream; and b) at the same, support social and economic growth within the area, particularly within the city of Mandalay. These objectives are faced with many ecological, social, economic and political challenges as discussed in chapter 2. In addition, pressures within this section of the river are exacerbated by proximity to Myanmar’s second largest city- Mandalay- as well as proximity downstream of the Katchin state where increasing hydropower projects are being developed.

These restorative and protective objectives require development of scientifically credible estimates of environmental flow needs for the river and the affects to target species. More than 200 methodologies have been developed globally for such assessments, termed Environmental Flows Assessment (EFA). EFAs can be classified into 4 categories:

1. Hydrology-based/Look-up table approaches, such as the Montana method or Tennant method
2. Hydraulic rating methodologies, which are based on single hydraulic cross-sections and limited field preparation;
3. Habitat simulation methodologies, such as Instream Flow Incremental Methodology (IFIM); and
4. Holistic methodologies, such as the Building Block Methodology (BBM) and Downstream Response to Imposed Flow Transformations (DRIFT).

This chapter describes a methodology and an adaptive, inter-disciplinary process for developing an EFA in this section of the Ayeyarwady River.
4.1.2. Flow Regime & Rainfall Pattern of the Ayeyarwady River

The rainfall pattern of the Ayeyarwady River Basin (Figure 1) shows a very seasonal precipitation. The seasonal and spatial rainfall patterns of the basin are dominated by the southwest monsoon. The dry season is clearly defined starting in October and ending in April, resulting in drier conditions across much of the country. The rainy season typically occurs from May to October, resulting in a wet and humid climate across much of the country representing up to 90% of the annual rainfall. Mean annual rainfall in the basin ranges from under 600 mm in the Central Dry Zone of the river up to a high of over 4,000 mm in the northern Rakhine State (Furuichi 2009; Birdlife International 2011) (Figure 8). The middle and lower part of the Ayeyarwady River Basin has an estimated mean annual rainfall of 1000-1500 mm (Figure 8).

As discussed in chapter 1, Myanmar’s precipitation pattern is affected by climate change. Estimates suggest that global warming has shortened and shifted the monsoon pattern for the past 30 years resulting in a decrease in annual rainfall (Sovacool 2012) and highly variable patterns across the basin (ISF-UTS 2011). Future model-based projections of the likely pattern of precipitation within this river basin are very poorly understood and thus the potential impact of climate change on precipitation should be acknowledged within the assumptions of an EFA.

There is high annual variation of discharge in the Ayeyarwady River Basin as a result of strong variation in precipitation as well as seasonal melting of snow in the headwaters of the river, south-eastern Himalayas. Rates vary between 2,300 m3/s and 32,600 m3/s, the average being 13,000 m3/s (Furuichi 2009). The best estimate of the annual average discharge is 410 km3/year, based on data collected from gauges sites in the middle and lower sections of the river (Figure 9) measured between 1966 and 1996 (Furuichi 2009). Monthly discharge is also variable. July to October (most of the wet seasons) represents more than 70% of the annual discharge. Peak discharge generally occurs in August (58%), but is also recorded in July (26%) and September (16%). Lowest monthly flow mostly occurs between February to April (Furuichi 2009).
Figure 8: the rainfall pattern in Myanmar based on the mean annual rainfall between 1988 and 1997. *Letters* indicate names of the cities listed in the figure. Data from the Department of Meteorology and Hydrology of Myanmar (Furuichi 2009).
Figure 9. The catchment of the Ayeyarwady River. Gauge measurement locations indicated (Furuichi 2009).
4.2. EFA Methods

An EFA of the Ayeyarwady River requires a holistic methodology which aims to integrate the expertise of cross-disciplinary teams (hydrologists, ecologists and social scientists) to assess the consequences of a modified flow regime on the ecological integrity of the river. Given the main challenges of meeting the proposed EF objectives are economic and political (hydropower developments), the following recommended methodology for the EFA adopts a top-down, flexible, resource intense but high in confidence approach which incorporates ecological, social and economic indices within the full process. The recommended EFA methodology is as follows:

- An initial assessment of the river using look-up tables (Tennant) and a hydrological analysis (IHA) to provide best estimates of hydrological and bathymetric data to build a better understanding of the flow regime and key species (fish species-prey of the Irrawaddy Dolphin). Hydrological data collated by the gauge stations in the paper by Furuichi 2009 will provide additional data to the analysis.
- To better understand the impact of different flows on the preferred habitat of the Irrawaddy River Dolphin and on the hydraulics, river channel cross-sections and velocity measurements will be measured several times. Hydraulic rating methods will be used to provide a flexible approach to data inefficiencies and to include ecological habitat information.
- A hydrological yield analysis will be used to calculate the likelihood of being able to maintain the recommended EF objectives throughout the wet and dry seasons.
- Several environmental flow scenarios will be created using the DRIFT methodology to better understand the effects of changing flows and to develop a framework to assess social and economic costs and benefits (trade-offs) of hydropower developments. The method will also aim to identify an assurance level to the recommended EF.

4.2.1. Assumptions and Analysis for the EFA

The analysis of the EFA required must consider historical changes to the natural flow of the river and identify the best possible estimate of the natural river flow. The flow regime in the Ayeyarwady River has experienced a reduction in the annual discharge and monthly discharge in the peak month (August) over the last 100 years. This reduction in discharge has been caused by water extraction for human uses and land use change. In addition, precipitation is becoming more variable due to shortened monsoon duration and increase frequency of rainfall caused by climate change (ISF-UTS 2011; ADB, 2012). As a result, a precautionary approach must be taken when assessing the confidence of flow scenario models for future decision making, particularly when assessing the impact of future planned hydropower development projects.

Data by the Irrigation Department should also be sought to try to build a better understanding of planned irrigation activities within the lower and middle Ayeyarwady River, particularly in the dry season. Patterns of irrigation use and future demand will help improve the confidence of the scenario models.
4.3. Assessment Results

Environmental flow for the lower and middle section of the Ayeyarwady River is proposed as the annual average discharge rate 410 km3/year (average 13,000 m3/s) from data recorded 1966-1996. During the dry season, the minimum low-level flow that should pass through this section of the river should present 15% of the annual average discharge rate (Furuichi 2009). Peak flow during the wet season that should pass through this section of the river should represent 58% of the annual average discharge rate (Furuichi 2009).

4.4. Effects of the recommended EF to the Irrawaddy River Dolphin & Hydropower Development

The critically endangered Irrawaddy Dolphin (Orcaella brevirostris) (Figure 4b) population in the Ayeyarwady River are concentrated in geomorphically complex reaches upstream and downstream of channel confluences, islands, and defiles. The middle and lower section of the river, near the vicinity of Mandalay, provides much of these crucial habitats for the remaining 50 individuals in the Ayeyarwady River. Although the Irrawaddy dolphins have been reported along almost the entire navigable length of the Ayeyarwady River (Beaseley 2007), recent sightings have suggested that their potential range has declined by 60% (488 km in river length) as a result of habitat destruction (approx. 60%) (Beaseley 2007; Smith and Reeves 2012). The dolphins are known to prefer areas of slow moving water. During the dry season, the dolphins are known to reside in deep pools >8-10 m, which provide critical shelter from swift river currents and support high prey fish populations (Beaseley 2007; Smith and Reeves 2012).

The proposed EF objectives assume different scenario flows throughout the year and comparing these flows with the habitat requirements of the Irrawaddy Dolphin against the need to meet hydropower development needs, it is clear that protection of the critical habitat for the dolphin may not be fulfilled all year long.

Although a protected area has been established in the upper reaches near Mandalay to preserve the local cooperative fishing practices between local villagers and dolphins (via reduction in illegal electric fishing and by-catch), measures to protect flow dynamics which support the critical habitat and health of key prey species have not been included. As detailed in chapter 1 of this study, the government signed an agreement with China Power Investment Corporation in 2007 for the construction of seven large dams (Figure 6b) along the Ayeyarwady in the northern Kachin state (Figure 6a). The largest one, the $3.6 billion Myitsone dam, will be located at the headwaters of the Ayeyarwady River with an installed capacity of 6000 MW. The planned hydropower developments pose a significant threat to the protection of crucial habitat downstream in the middle and lower sections of the river as well as to the abundance of prey species of the Irrawaddy Dolphin. The dams will result in a redistribution of river flows; flow will typically increase during the dry season (April to October) and monsoon peaks will typically decrease. This will result in changes to the natural flow dynamics (daily flow, water velocity) and sedimentation patterns of the Ayeyarwady River which will alter primary habitats for the Irrawaddy Dolphin (slow moving areas, deep
Eddy pools and affect the availability of prey fish species such as carp (Smith and Reeves 2012). Disturbance during the planned construction of the dams may also affect foraging behaviour of the dolphins. Carp is the primary species consumed by the Irrawaddy Dolphin which is found in still or slowly flowing waters. Increases in flow velocities will have a negative impact on the abundance of the species in key regions downstream such as the defiles in the middle and lower sections of the river.

Scenario based models will be provide a significant input to the analysis process in testing different trade-offs and identifying the best approach to meet the proposed EF objectives. Daily and monthly demand for electricity by the proposed hydropower developments is likely to vary considerably by China resulting in an increase of peak discharge at various points of the year. The study therefore proposes that discharge during the mating season of the Irrawaddy Dolphin (April to June) be kept to near minimum natural flow for this given period to increase the survival rate of the remaining sub-population.

5. Chapter 5: Environmental Flows Implementation of the Ayeyarwady River Basin

5.1. Overview of Environmental Flows Implementation

This chapter describes an implementation process to deliver an adaptive, inter-disciplinary process for developing the proposed EF recommendations within the Ayeyarwady River. The proposed process can be tailored according to available time and resources for determining environmental flow needs. The five-step process, adapted from Richter et al 2006 and Jay O’Keeffe (UNESCO-IHE Ecosystem Flow Online Course 2013), includes:

Stage 1: Scoping meeting.
Stage 2: Preparation for the assessment workshop (incl. a literature review on existing hydrological and ecological knowledge).
Stage 3: EFA workshop to identify EF recommendations, objectives and data gaps.
Stage 4: Negotiation: further analysis including scenario analysis.
Stage 5: Implementation and compliance monitoring.

The following diagram, adapted from Jay O’Keeffe (UNESCO-IHE Ecosystem Flow Online Course 2013), highlights which of the ‘key’ stakeholders listed in Table 5 will be involved in the different stages of the implementation process:
Stage 1: Scoping meeting.
This first stage is an initial assessment of the Ayeyarwady River Basin which is to include the identification of issue of concern, stakeholders who are to be included within the assessment as well an initial plan for the assessment. The key stakeholders involved in this initial scoping meeting as the relevant experts, research institutions and management authorities.

Stage 2: Preparation for the assessment workshop
This preparation stage involves all the different specialists, such as ecologists, sociologists, economists and hydrologists who will cooperatively on tasks incl. the development of a comprehensive literature review and synthesis of available hydrological and ecological data.

Stage 3: EFA workshop
During the workshop, multidisciplinary teams of experts will work with government officials and relevant water management authorities to identify EF recommendations, EF objectives for the Ayeyarwady River Basin, process and analyse the information gathered and identify key data gaps.

Stage 4: Negotiation:
Once the environmental flows have been assessed, this stage addresses the analysis and decision-making process for implementation. It is at this stage that the environmental flows and the user requirements are integrated into the analysis. Key water end users will become involved in the process incl.: flood and irrigation agencies, hydropower companies, mining industries, urban residents and village leaders; and will work with the experts and local governmental authorities to incorporate their requirements and characteristics into the scenario based methodologies.
This stage includes the delivery of three tasks as described by Jay O’Keeffe (UNESCO-IHE Ecosystem Flow Online Course 2013):

**Task 1: Hydrological yield analysis:** A hydrological yield analysis calculates the likelihood of being able to maintain the environmental flows and supply the user needs, in wet and dry years. If all these requirements can be met with a high assurance, a water allocation plan can be agreed. If not, proceed to Scenario analysis.

**Task 2: Scenario analysis:** Different scenarios are developed, allocating a series of assurance levels to different users (and to the recommended environmental flows).

**Task 3: Decision:** The decision to implement environmental flows may rest with different authorities, depending on the scale of the river (international, national, regional etc.) and the governance protocols of the basin. In areas where there is competition for scarce water resources, the best chance for a decision in favour of implementation of environmental flows will depend on a high-confidence assessment, and on the support of the majority of stakeholders.

**Stage 5: Implementation and compliance monitoring.**

Implementation and compliance monitoring is the final step in the process and will be continued post implementation of the assessment. Implementation is to be achieved through a transparent and adaptive approach. A flexible approach is to be taken in light of research developments, new data, political developments, environmental risk (incl. climate change) and socio-economic demands. Monitoring of the river is to use available infrastructure such as gauge stations to continue to monitor hydrological and ecological characteristics, particularly pre and post new hydropower developments. This stage is to involve all stakeholders and aim to facilitate long-term capacity building and communication between those key stakeholders involved in order to successfully implement and monitor the EF objectives.

**5.2. Issues to consider in the Implementation process**

A key issue to consider in the implementation of any recommended EF objectives is the policy uptake and application to decision making. As detailed in chapter 2, the current laws and policies in Myanmar relation to water resource management are weak. Myanmar has embarked on its own national objectives for improving the status of water bodies within the country. Known as the Conservation of Water Resources and Rivers Law, the aims of the Law (adopted in 2006) are as follows: (a) to conserve and protect the water resources and rivers system for beneficial utilization by the public; (b) to smooth and safety waterways navigation along rivers and creeks; (c) to contribute to the development of State economy through improving water resources and river system; and (d) to protect environmental impact.

Although the Law represents the first call for protection of all water resources ‘above and underground… including water resources that flow into rivers’ within Myanmar, it does not set key quantitative targets, ecosystem flow recommendations or thresholds to achieve a good
ecological or chemical status as developed in the European Water Framework Directive. In addition, there is no accompanying implementation programme to enable these aims to be met and maintained. Furthermore, the Irrawaddy dolphin is described under the “Completely Protected Animals” category in the list of protected animals issued by the Forest Department, Ministry of Forestry, and Union of Myanmar’s notification No 583/94, Dated 26 October 1994. However, under both laws there is no statement for the need to preserve and monitor hydrological conditions and the associated requirements to support the ecological integrity of the river. The final stage of the implementation process should specifically recommend policy guidelines for effective uptake of ecosystem flow recommendations within legislation, particularly in light of planned hydropower developments and the robust evidence supporting the detrimental impacts of such dams to ecological integrity and ecosystem services.

6. Chapter 6: Conclusion

The 2170 km long Ayeyarwady River (Figure 2) is one of the world’s eight hottest hotspots of biodiversity with over 50% of the basin covered in forest and about 6% covered in wetlands. The basin is also home to rich deposits of minerals such as gold and copper with artisanal mining industries along much of the middle part of the river. Many ethnic and indigenous peoples in Burma are dependent on the natural resources along the length of the river (table 2) which crucially sustain livelihoods and provide key provisional services such as water and food. Although some progress has been made towards meeting the United Nations (UN) Millennium Development Goals (MDGs), an acceleration of improvement in numerous indicators is still required (i.e. Goal no 1 Poverty Eradication). Disparities in living conditions between rural and urban remains high and many communities within the Ayeyarwady River Basin live below the national average (26%).

Maintaining the ecosystem integrity and associated goods and services of enormous watersheds is critical to both the health of the river as well as to the human populations that rely on them. The Ayeyarwady River faces a unique and daunting set of environmental risks and pressures. Major threats include hydropower developments which are concentrated in the head waters of the river. The negative impacts of planned hydropower developments pose significant changes to the natural flow of the river resulting in grave consequences for critical species such as the critically endangered Irrawaddy Dolphin.

The recommended ecosystem flow objectives in this report focus on addressing the conservation of this important species whilst at the same allowing hydropower growth to be met in light of political and economic drivers. These restorative and protective objectives require development of scientifically credible estimates of environmental flow needs for the river and the affects to target species. Using methodologies such as the DRIFT methodology; look-up tables (Tennant); hydrological analysis (IHA) and Hydraulic rating methods for such assessments, termed Environmental Flows Assessment (EFA), play a critical role in developing robust decision led scientific analysis. The successful implementation of an EFA requires an adaptive, inter-disciplinary and transparent approach with target stakeholders.
Within this study location there is a severe lack of data and literature available in order to comprehensively analyse the ecosystem flows of the Ayeyarwady River Basin. Future research should look to build new research in this field and crucially provide analysis relating to the increased developments of hydropower projects and their impacts on the ecological integrity of the river. The region is also under increase stress from climate change. Future research should seek to incorporate climate change predictions of precipitation into scenario models and these factors should be recognised in policy developments.

References


Environmental Flows for the Ayeyarwady River Basin, *A. Simmance*


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Environmental Flows for the Ayeyarwady River Basin, A. Simmance


Environmental Flows for the Ayeyarwady River Basin, A.Simmance


Annex I: Key stakeholders/ Groups in Myanmar

**International Governmental Bodies:**
- FAO – Food and Agriculture Organization of the United Nations
- ILO – International Labour Organization
- IOM – International Organization for Migration
- UN RC/HC – Office of the UN Resident / Humanitarian Coordinator
- UNAIDS – United Nations Joint Programme on HIV/AIDS
- UNDP – United Nations Development Programme
- UNDSS – United Nations Department of Safety and Security
- UNESCO – United Nations Educational, Scientific & Cultural Organization
- UNFPA – United Nations Population Fund
- UN-HABITAT – United Nations Urban Settlements Programme
- UNHCR – United Nations High Commissioner for Refugees
- UNIC – United Nations Information Centre
- UNICEF – The United Nations Children's Fund
- UNOCHA – United Nations Office for Coordination of Human Affairs
- UNDCP – United Nations Office on Drugs and Crime
- UNOPS – United Nations Office for Project Services
- WFP – World Food Programme
- WHO – World Health Organization

**Union of Myanmar Governmental Bodies:**
- Ministry of Agriculture and Irrigation
  - Department of Agricultural Planning,
  - Myanmar Agriculture Service,
  - Myanmar Farms Enterprise,
  - Irrigation Department,
  - Agricultural Mechanization Department, S
  - settlement and Land Records Department,
  - Myanmar Sugarcane Enterprise,
  - Manna Cotton and Sericulture Enterprise,
  - Myanmar Jute Industries,
  - Myanmar Perennial Crops Enterprise,
  - Water Resources Utilization Department,
  - Myanmar Agricultural Development Bank and Institution of Agriculture.
- The Ministry of Energy
- The Ministry of Livestock and Fisheries
- The Ministry of Mines
- The Ministry of National Planning and Economic Development
- The Ministry of Transport

**NGOs:**
- Arakan Oil Watch (AOW)
- Biodiversity And Nature Conservation Association (BANCA)
- Border area Development Association (BDA)
- Bridging Rural Integrated Development and Grassroots Empowerment (BRIDGE)
- Burma Rivers Network
Environmental Flows for the Ayeyarwady River Basin, A.Simmance

- Dag Hammarskjold Foundation -- Burma Seminars
- Dear Myanmar
- Earth Rights International (ERI)
- Eco-Swiss
- Ecosystem Conservation and Community Development Initiative (ECCDI)
- Fauna and Flora International
- Forest Resource Environment Development And Conservation Association (FREDA)
- Friends of Wildlife
- International Rivers
- Kachin Development Networking Group (KDNG)
- Mercy Corps
- Metta Mon Co-operative Limited (MTM)
- Mon-region Social Development Network (MSDN)
- Myanmar Environment Rehabilitation-conservation Network (MERN)
- Network Activities Group (NAG)
- Network for Environmental and Economic Development (NEED)
- Rakhine Coastal Region Conservation Association (RCA)
- Shan Sapawa Environmental Organization (Sapawa)
- Social Vision Services (SVS)
- Swanyee Development Foundation (SDF)
- The Burma Environmental Working Group
- The Burma Net News
- The International Centre for Integrated Mountain Development (ICIMOD)
- The Karen Environmental and Social Action Network (KESAN)
- The Lahu National Development Organization (LNDO)
- The Pa-Oh Youth Organization (PYO)
- The Shwe Gas Movement (SGM)
- Wildlife Conservation Society