STATE of KNOWLEDGE

River Health in the Ayeyarwady

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The Ayeyarwady River Basin (ARB) is the largest and most economically significant river basin in Myanmar, comprising 66% of the national population, and 61% of the total land area. As Myanmar opens up to political reform and economic development accelerates, it is important to understand the impact of development on the Ayeyarwady, and on the livelihoods and biodiversity it supports.

Ayeyarwady River Basin basics

The ARB covers an area of 413,710 km^2 of which 91% lies within Myanmar, around 5% (21,400 km^2) in China, and 4% (17,400 km^2) in India.

The Ayeyarwady, which is 2,170 km long, flows through Myanmar from the Himalayas in the north to the Delta in the Andaman Sea. The source of the Ayeyarwady is the confluence of the Nmai and Mali rivers, at Myitsone in Kachin State. The Chindwin River joins the Ayeyarwady near Myingyan in the Dry Zone, where the river forms an extensive alluvial floodplain. About 300 km from the coast, the Ayeyarwady fans out from its braided channel to form a major nine-armed delta discharging into the Andaman Sea, bounded by the Pathein (Bassein) River on the west and the Yangon River on the east. The Delta covers an area of around 31,000 km^2 with a coastal front of 260 km.

Based on hydrology, geomorphology and ecology, the ARB is divided into five main zones: the Upper Ayeyarwady (north of Myitkyina); the Middle Ayeyarwady (north of the confluence with the Chindwin); the Chindwin; the Lower Ayeyarwady (between Myingyan and Kyangin) and the Delta (Figure 1).

With a total annual flow of around 400 km^3,the Ayeyarwady ranks as the 22nd largest river in the world in terms of discharge. It is a monsoonal flood-pulse river, with strong seasonal flow, peaking during the wet season between July – September and reducing by an order of magnitude during the dry season, meaning that people experience both severe flooding and droughts. The main river is navigable for 1,280 km from the sea, opening a vast highway deep into the Dry Zone and interior of the basin.

What are the demographics of the basin and the significance for livelihoods?

The total population in the ARB was estimated at 39.5 million people in 2015, with about 1.9 million in Yunnan, 2.8 million in India and 35 million in Myanmar– making up about 66% of that country's total population. The population is concentrated in the agricultural heartlands of the basin, the Dry Zone and the Delta region. Myanmar still has a predominantly agricultural economy, with around two-thirds of the population employed in agriculture, and 37% of GDP generated in the agricultural sector.

Industrial growth in Myanmar is amongst the highest in the world; much of this development is within the ARB, in population centers such as Mandalay and Yangon. The ARB includes six of Myanmar's largest cities: Yangon (5 million), Mandalay (1.2 million), NayPyiDaw (0.9 million), Pathein (237,000), Monywa (182,000).

The lowland central and southern areas of the ARB are of mainly Bamar ethnicity but the upland areas around the periphery of the basin are ethnically diverse. This includes: in the north, Kachin (Jingpho), Shan and Tibetan ethnic groups; in the west, Chin (including multiple language groups, some straddling the border with India); in the east, Shan (Tai or Dai) and Pa-O. In the Delta, there are populations of Mon and Karen in the east, and Rakhine in the west.

Poverty levels are higher in the upland ethnic territories than in the lowlands. The highest incidence and severity of poverty are found in Chin State (73%) and Northern Shan State (37%).

1 - International Center for Environmental Management
2 - International Water Management Institute
3 - Ecosystem Conservation and Community Development Initiative
4 - Myanmar Institute for Integrated Development

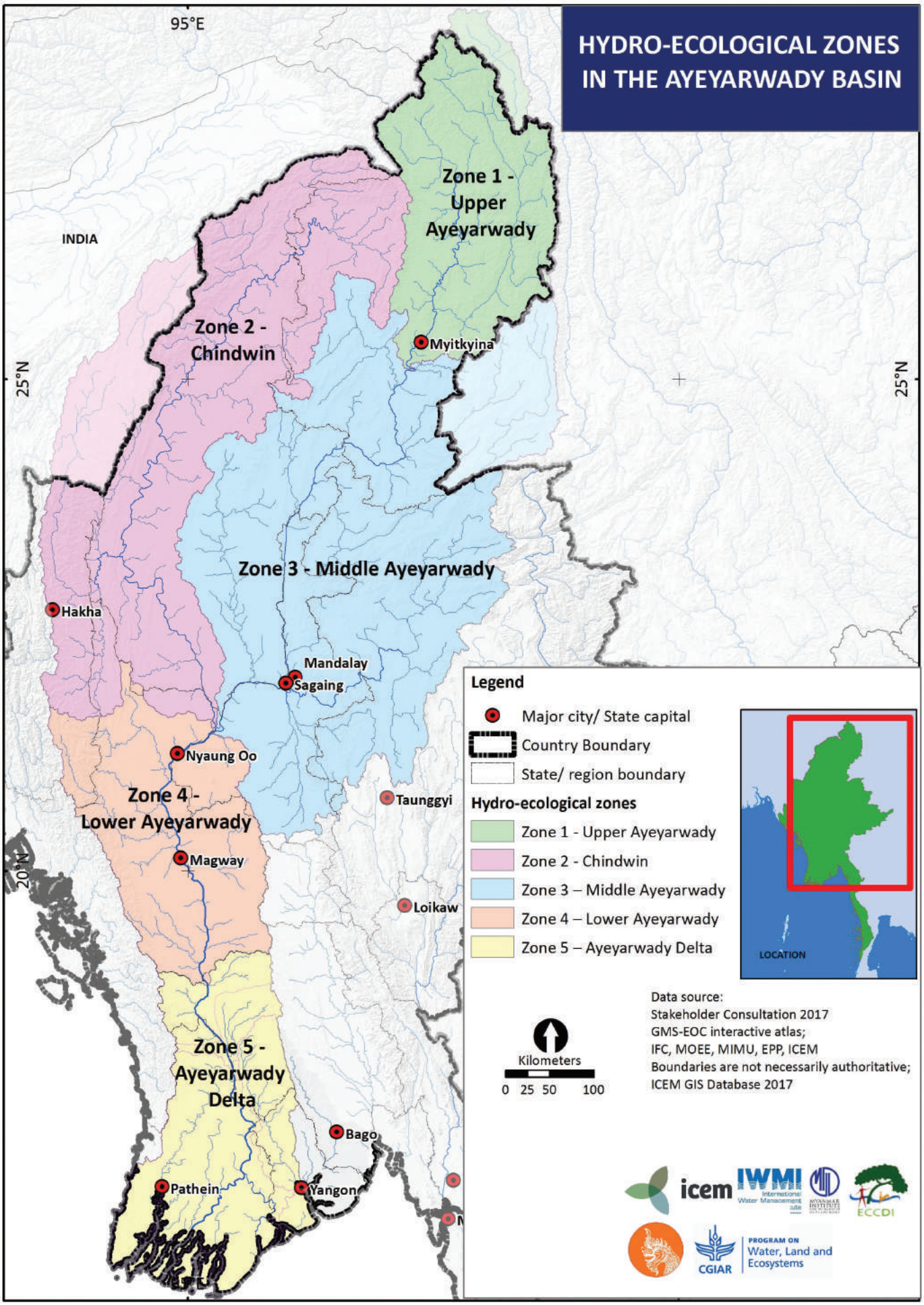

Figure 1: Hydro-ecological zones in the ARB

Although poverty incidence in the Dry Zone is close to the national average (26%), under- five mortality rates are very high in the regions of Magway (108 per 1,000) and Ayeyarwady (109 per 1,000), reflecting high levels of rural poverty and nutritional shortfalls in these areas (IHCLA, 2011).

Conclusion: *The size and length of the Ayeyarwady River, with its vast floodplain in the Dry Zone and extensive deltaic system at the outlet, place it at the center of Myanmar's cultural and economic life. Myanmar is still a dominantly agricultural economy, and all communities living along the river depend on it to contribute to their livelihoods through agriculture. Many communities in and around the ARB rely on the basin's natural resources and ecosystems.*

What is known about the hydrology of the basin?

Available data suggest a total annual flow of around 400 km^3 annually. Based on flow records for 16 stations, Hasman (2014) estimated total annual flow in the Ayeyarwady as varying between 313 and 501 km^3 between 1998 and 2009 (average 412 km^3). The lowest flow occurs from February to March, with more than 80% of flow of the Ayeyarwady occurring during the wet season from May to October.

The discharge volumes and flow patterns in the Ayeyarwady system are still not well quantified. Hydrological data collected by the Department of Meteorology and Hydrology (DMH) at 20 stations in the Ayeyarwady system are mainly for flood-warning purposes, but there has been limited analysis and compilation at basin scale to inform water resources management and planning. The availability of data to the research community has been limited, and there are inconsistencies in the reported data. Total out-flow to the sea through the delta is difficult to monitor accurately, due to the large number of distributary channels.

Hydrological models developed for the ARB represent the hydrological patterns at a broad scale, but do not capture the details well (Hasman, 2014). Hydraulic models developed by the Stockholm Environment Institute (SEI) are available only for very small areas in the Delta and in the lower part of Chindwin River around the confluence with the Ayeyarwady. By incorporating the full archive of hydrological data, much more robust models could be developed.

Conclusion: *The overall water balance for the whole basin and spatiotemporal flow patterns are still not well quantified, except for some zones. Compilation, analysis and modelling of hydrological data is urgently needed to provide a baseline against which future changes to the river can be simulated and monitored. In the short term, global datasets (topography, land use, climate) are now of sufficient quality to support basin-scale modelling.*

What is the status of water quality in the river?

The Ayeyarwady system is currently ranked as carrying the fifth largest suspended sediment load globally, with estimates ranging from 261 to 364 million tons / year (Bird et al. 2008). Little is known of the source and deposition sites, sediment dynamics or the nature or quantity of nutrients that are attached to sediment particles.

Experience from neighbouring river basins suggests that the sediments of the Ayeyarwady are likely to be rich in attached nutrients. These sediments play a critical role in the ARB, fertilizing the vast floodplains of the Dry Zone and Delta and creating a diverse complex of riparian habitats throughout the river network. The extent of sediment trapping from existing hydropower and irrigations dams is not known; these impacts are, however, expected to be significant based on experience with other large basins in the region (Gupta et al. 2012).

There is limited information available on pollution trends within the Ayeyarwady at the basin scale. Agricultural intensification is leading to increased levels of agricultural chemicals in runoff. Land disturbances from mining and pollution from alluvial gold mining are critical issues in the upper reaches of both the Ayeyarwady and Chindwin rivers. The preliminary results of a two-year water quality monitoring program conducted by SEI, Myanmar Environment Institute (MEI) and the Department of Water Resources and Improvement of River Systems (DWIR) in the Chindwin River indicate elevated levels of heavy metals and nutrients (Piman et al. 2017).

Release of untreated sewage and industrial waste from growing urban areas is impacting downstream water quality. The heavily populated industrial and agricultural areas of Myanmar's coastal regions are particularly at risk. A report by the Myanmar Centre for Responsible Business (2014) identifies that the main sources of land-based coastal pollution include: sewage; excess nutrients from agriculture and aquaculture; chemical fertilizer residue; Persistent Organic Pollutants from used pesticide residue; used household materials like plastic bags; and medical waste and excreted pharmaceuticals.

Conclusion: *Information on water quality is limited for the Ayeyarwady system. The impacts of development are, however, starting to be seen. There is growing evidence of nascent pollution problems from a range of sources, which may be directly affecting local communities and biodiversity. Agriculture runoff and urban waste may be increasing sediment loads and pollutants in the basin, but baseline data are needed for more investigation.*

How important are fisheries in the Ayeyarwady?

Myanmar fisheries are vital to national food security, income generation and export earnings. The Southeast Asia Fisheries Development Center (SEAFDEC, 2012) placed Myanmar as the top Southeast Asian producer for inland fisheries, with a production volume almost twice that of the next biggest

producer, Indonesia. Myanmar government statistics indicate that inland fisheries produced 1.3 million tons of fish in 2013. Over the last decade, fisheries exports have grown steadily, at an average annual growth rate of 4.5%, and were valued at USD 653 million in 2012 (WorldFish, 2014).

The actual catch may be significantly higher than official statistics suggest. All licensed fishers in Myanmar are required to report their catches, but in reality this only occurs with larger fisheries. A significant proportion of the population relies on fishing for household consumption, and this catch often goes unreported (SEAFDEC, 2012). Increases in illegal fishing methods (electro-fishing, poison, explosives) are also poorly captured in official statistics. As a result, statistics on inland catches are considered underestimated and detailed trends in species harvested are not known.

The Ayeyarwady Delta is among the most productive areas for fisheries in Myanmar, with the most fishing sites. The Ayeyarwady Delta has the potential to be as productive as other major deltas, such as the Mekong, but long-term sustainability will require improvements in regulation, monitoring and management.

Conclusion: *The fisheries sector is an important and quickly evolving sector, especially in the Ayeyarwady Basin. The lack of data on fisheries consumption and production creates problems for resource monitoring and management, and hinders the development of a sustainable fisheries sector.*

What is known of the ecosystems and biological diversity of the basin?

The ARB encompasses 14 major ecoregions, with a variety of montane, alpine, temperate and subtropical forest ecosystems. High mountains in the northern part of the basin support mammal species characteristic of the Eastern Himalayas, including the red panda, which occurs nowhere else in the region. The Chin Hills have a wide range of endemic high-rainfall and cool-adapted species (Tordoff et al. 2012).The forests also provide valuable ecosystem services for local communities; it is estimated that the current annual value of forest ecosystem services is MMK 7 trillion, or US$ 7.3 billion (Emerton and Aung, 2013).

Forest ecosystems are under pressure from rapid deforestation; it is estimated that Myanmar lost more than 546,000 hectares (over 1.3 million acres) of forest on average each year from 2010-15 (UNFAO, 2015). Over half of the loss occurred in the Upper Ayeyarwady and Chindwin in the Kachin and Shan States, and the Sagaing Region. Forest loss has mainly been due to illegal and legal timber extraction; however forest clearing for the expansion of commercial agriculture is now becoming the leading cause of deforestation in Myanmar (Woods, 2015).

The Ayeyarwady floodplain of the Dry Zone, sheltered from southwest and northeast monsoons by a horseshoe of mountain ranges, has an extremely dry and seasonal climate, which has given rise to specialized vegetation types, including deciduous dipterocarp forests and thorn scrub (Tordoff et al. 2012). Freshwater ecosystems range from fast-flowing rocky mountain streams to wide, slow-flowing lowland rivers braided by large, partly vegetated sand and rock bars. Freshwater swamp forests occur in the Ayeyarwady Delta and in the floodplains of the Chindwin. These ecosystems are important for a number of globally threatened species, notably for large water birds.

The river is home to the critically endangered Irrawaddy Dolphin, found mainly in the coastal regions of the Delta. There is a small population of dolphins in a 200 km stretch north of Mandalay, where a conservation zone was established by the Department of Fisheries, with support from the World Conservation Society (WCS). This population, famous for cooperative fishing with local communities, is under threat from electro-fishing, increased sediment loads from land use changes and pollution from alluvial gold mining.

The Ayeyarwady Delta divides into three zones: a largely marine-influenced, tidal coastal front (including extensive mangroves); a brackish water estuarine zone; and a freshwater floodplain. These zones shift with seasons and tides: spring tides are highest in the summer season, leading to strong seasonal intrusion of saline waters. Other important coastal habitats include intertidal mud flats and sand flats, which are the key habitats for many migratory shorebirds. The Delta is one of Myanmar's key biodiversity areas, hosting some of the most floristically diverse mangroves in the world and more than 30 species of endangered fauna. Several of Myanmar's key biodiversity areas (KBAs) are concentrated in the Upper Ayeyarwady, a biodiversity hotspot for terrestrial and aquatic fauna.

Altogether, 81 KBAs are defined in the ARB (three of which are in China) covering a combined area of 81,380 km^2. Only 23, or about 30% of the KBAs are, however, formally protected areas (PAs). Within the ARB, PAs cover around 37,754 km^2. There is insufficient information to ensure that all major ecosystems are represented; coastal and freshwater ecosystems are likely to be underrepresented as many KBAs are categorized as data deficient. An analysis of the full range of species and ecosystems is needed to ensure comprehensive coverage of Myanmar's rich biodiversity. This may require targeted field surveys to fill gaps in knowledge on the distribution of priority species, as well as on poorly known taxonomic groups, such as amphibians, fish and invertebrates (Tordoff et al. 2012).

Conclusion: *The ARB hosts a wide array of ecosystems and globally significant biodiversity, including a number of endangered species. To date, no systematic review of the distribution of Myanmar's biodiversity and ecosystems has been conducted. The freshwater ecosystems of the Ayeyarwady are of high subsistence importance for some of the region's most economically marginalized people. High levels of human use are impacting biodiversity and further monitoring and management is needed to address critical issues of deforestation*

and land use changes. Many KBAs in the Upper Ayeyarwady and Chindwin are data deficient and urgently need further biodiversity surveys and conservation.

How do population and economic growth in the basin affect river health?

The total population of Myanmar is 51.4 million; the total population in the ARB is around 39.5 million, with around 35 million in Myanmar. Data from the 2014 Census indicated a slower than expected rate of population growth since the previous census in 1983. According to the 2014 Census, around two million people had emigrated to other countries due to conflict and in search of economic opportunities. Census results indicate that the growth rates within the ARB are generally lower than the national average, except in Yangon (where in-migration is high).

Although the rate of population growth slowed,economic activity continues to grow. Between 2000-2010 average real economic growth ran at approximately 12% and between 2010-2015 about 8% (World Bank, 2017). That growth has been accompanied by rapid structural changes in the economy. As is typical of the growth pattern in developing Asia, growth has been driven largely by the industrial and services sectors over the last 10-15 years.

Conclusion: *Although rates of population growth are slowing overall, significant economic growth and structural change is placing increasing demands on the river as Myanmar moves to develop a market economy, particularly in urban areas.*

How is irrigation infrastructure affecting the river?

Over the last 35 years, the government has expanded the provision of irrigation considerably. The WLE dataset on dams detected 118 irrigation reservoirs of 0.5 km^2 and above in the basin; 115 of these are in Myanmar (WLE, 2017)[5]. The area equipped for irrigation within the ARB is estimated at between 0.86 and 0.92 million hectares (Mha) (Hasman, 2013). The Central Dry Zone has at least 0.515 Mha of formal irrigation in government schemes, and accounts for about 80% of dam-related irrigation infrastructure (ADB 2013). The main irrigated crops are paddy rice, horticultural crops, sugarcane, cotton, maize and oilseeds. In many areas, irrigation is used primarily to extend the wet-season growing period or protect wet-season crops, rather than for full dry-season irrigation. A second irrigated crop is grown on only 27% of equipped areas (MOAI, 2014).

Modes of agricultural water management differ across the basin. In the upland areas, irrigation is mostly limited to small gravity-fed systems, ponds and tube wells. The Dry Zone has a mix of reservoir- and gravity-fed canal systems; large pump irrigation projects (PIPs), diesel or electric pumps; irrigation from small ponds and tanks; spate irrigation; and groundwater from tube wells. A study by IWMI (2015) estimated that the volume of water used in irrigation in the Dry Zone (around 7,540 million m^3 per year) is less than 3% of the total flow, and that irrigation efficiency is very low, with less than 5% of water abstracted transpired by crops. Availability of surface water (from rivers and storage) is less limiting than access, due to costs of pumping and sparse infrastructure in areas remote from the major rivers.

In the Delta, the monsoon crop is dominantly rain-fed, but in the lower Delta, cultivation of monsoon paddy is only possible if crops are protected from intrusion of saline water by construction of embankments, sluice gates and drainage systems. There are around 1,300 km of major embankments in the delta built to protect 600,000 ha of paddy land.

MOAI (2014) reports a steady growth in irrigated areas since the late 1980s, when the government began a program of expansion and modernization of irrigation infrastructure. The Myanmar Government has set a national target to make irrigation available for 25% of agricultural land, with an emphasis on the provision of irrigation for summer paddy. Many schemes do not operate at full capacity, however, due to a range of issues including inappropriate operation of reservoirs, incomplete irrigation and drainage infrastructure, inappropriate siting, and poor maintenance. Groundwater accounts for less than 10% of irrigation, but there is anecdotal evidence that pumping from shallow groundwater is expanding rapidly.

Conclusion: *Irrigation currently uses only a small fraction of total Ayeyarwady flow. The continued expansion of irrigated areas, and rehabilitation and intensification within existing areas, are of high priority for the Government. In the ARB, there is significant scope for expansion of irrigation, but this must be accompanied by improvements in irrigation efficiency and crop water productivity. Comparative analysis of the productivity and efficiency of different irrigation approaches is needed to target irrigation investment more effectively.*

How will planned hydropower development affect the river?

Myanmar has one of the lowest electrification rates in Asia, where less than a third of the population has access to the electricity grid (World Bank, 2014); insufficient power is a major constraint for economic development. The government's power generation strategy relies heavily on hydropower, which provides around 75% of supply. In 2014, much of the total installed power capacity of 4,581 MW was developed on tributaries of the Ayeyarwady, including the Lower Yeywa Dam (Myitnge River – 790 MW), Shweli Dam (600 MW – Shweli River), and Dapein I and II (Dapein River, 408 MW) (Khine, 2014).

The International Finance Corporation (IFC) is currently implementing the Strategic Environmental Assessment (SEA) of the hydropower sector in Myanmar. The hydropower database developed to assess the sustainability of all existing and planned projects estimates that, in the

5 - WLE (2017) lists only reservoirs with an area greater than 0.5 km^2

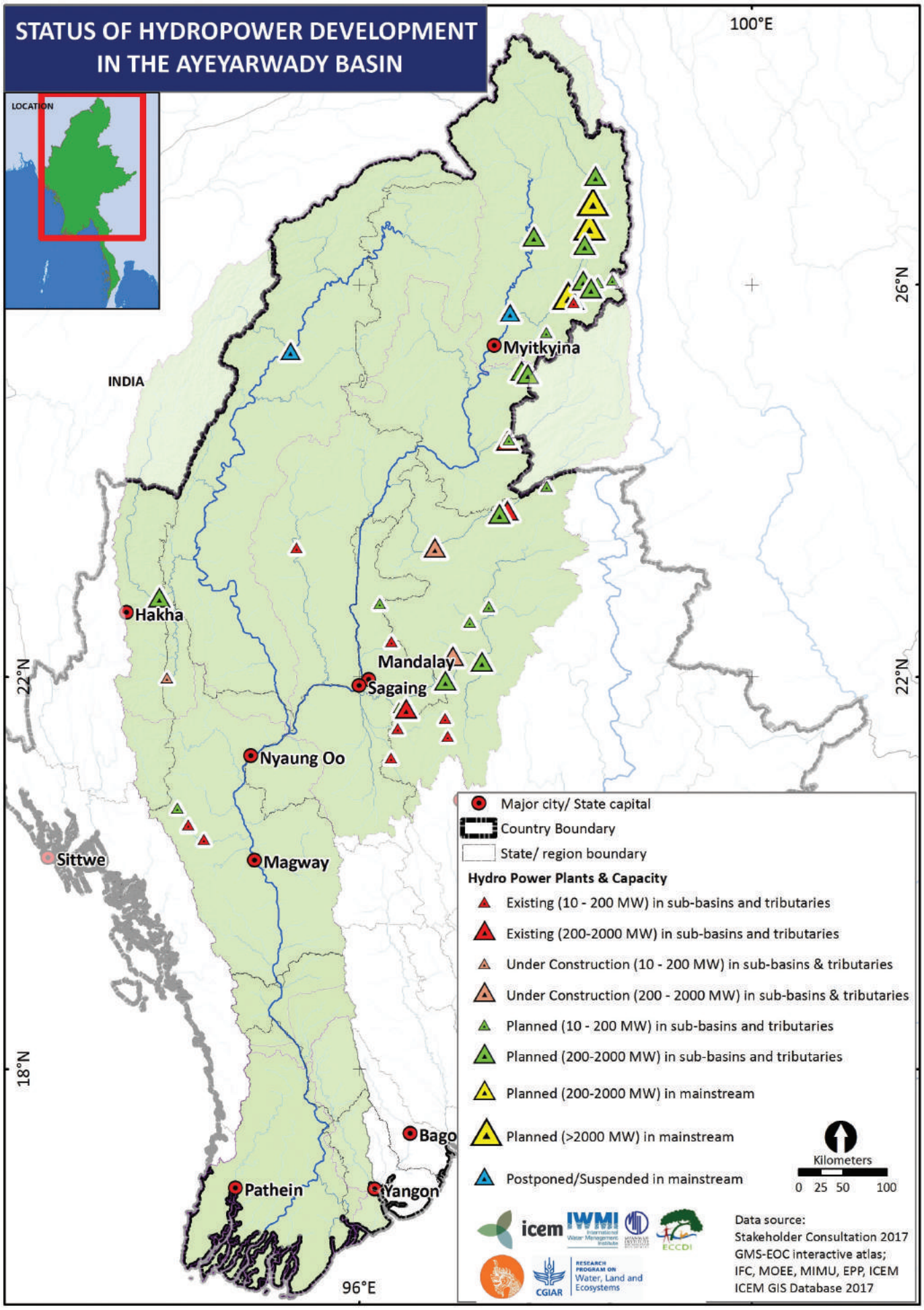

Figure 2: Status of hydropower development in the ARB

Ayeyarwady Basin in Myanmar, there are currently 12 existing projects with a capacity of 2,049MW, with two under construction (1,300MW), and 28 planned projects; if all proceed, this would increase capacity to 26,219 MW (ICEM, 2017) (Figure 2). Six of these projects are large dams on the Nmai and Mali rivers with a combined generating capacity of 13,360 MW (Khine, 2014).

Construction of the Myitsone project, a 6,000 MW joint venture between the China Power Investment Corporation, the Myanmar Government and the Asia World Company, was suspended in 2011 following public protests and has not yet recommenced. There is widespread concern both within Myanmar and externally that unless adequate mitigation measures are developed, these dams will damage the ecosystems of both the Mali and Nmai and the ARB. A Presidential Order was issued on August 12, 2016 to form a commission to review the Myitsone project and other projects planned in the Upper Ayeyarwady.

The Myitsone project also threatened to destroy an area near the confluence of the Mali and Nmai rivers that is recognized as the cultural homeland of the Kachin people (Kiik, 2016).In June 2011, the 17-year ceasefire between the Kachin Independence Organisation (KIO) and the Myanmar army broke. Construction of the dam at Myitsone did not in itself cause the resumption of armed conflict in Kachin State, but it did exacerbate underlying tensions (ICEM, 2017).

A comprehensive lists of proposed dams are currently being prepared as part of the SEA, which is important as there is no definitive information in the public domain on the detailed specifications for individual projects, or on which projects are given highest priority by the government. The planning and tendering processes are opaque, and only some environmental impact studies have been released for public scrutiny. Joint venture agreements between Myanmar and international companies have been signed for several other dams.

Experience from neighbouring basins indicate that a much better understanding of hydropower development is urgently needed for the Ayeyarwady, because it will be one of the sectors with the greatest capacity to impact on the biophysical systems of the Ayeyarwady at a whole-of-basin scale. Large hydropower facilities can become barriers in the river system, blocking the movement and cycling of sediments, nutrients and biological species (e.g. fish migrations), which could have profound impacts on livelihoods of those living within the basin. The regulation of the river's characteristic flood-pulse hydrograph will also affect seasonal water availability, as well as the balance between terrestrial and aquatic states in the basin's diverse complex of wetland habitats.

Conclusion: *Hydropower is an important component of Myanmar's future power generation strategy, and is also a potential source of export earnings. A rational approach is needed to optimizing hydropower development to provide maximum power generation while minimizing impacts. Realistic assessment of the likely impacts of dam development on downstream communities and ecosystems will require that information on proposed dams is made available early in a project planning for public study and debate. It is particularly important that sufficient information is provided to allow coordinated planning, rather than ad hoc development of individual schemes.*

How do urban growth and industrial development affect the Ayeyarwady?

Around 30% of Myanmar's population lives in urban areas (DOP, 2015). Six of Myanmar's ten largest urban centers are in the ARB, including Yangon and Mandalay. Although Myanmar's overall population growth is relatively low, economic growth is resulting in rapid urban growth. Yangon's population has grown from 4.57 to 5.21 million since 2006, and the population of smaller regional centers of Meiktila and Monywa have grown by 200 and 170%, respectively, in less than ten years.

Many urban areas along the Ayeyarwady draw a major part of their water supply directly from the river, or from reservoirs on the tributaries; water quality in the river system is thus a serious concern at both the national and local level. Few urban areas in Myanmar have adequate water and sewerage infrastructure. Large parts of Yangon and Mandalay consist of resettlement areas without proper drainage or sewerage networks. Historically, investment in urban infrastructure (water supply, sanitation, drainage, wastewater, and solid waste management) has been neglected. Most households in formal residential areas have some form of septic tank, but these are not routinely serviced, nor is there a systematic collection and treatment of domestic wastewater. Informal settlements depend primarily on improvised latrines, and storm-water drains carry untreated sewage in open channels. It is common practice for cities along the river, such as Mandalay, Pathein, and Yangon, to dispose solid wastes, untreated storm-water, industrial wastewater and raw sewage directly into the river (Bowles, 2013). Solid waste debris is obvious along riverbanks close to urban areas.

The Government of Myanmar has a focus on developing the manufacturing and industrial sector as part of its strategy of export-led economic development. It has built industrial zones and special economic zones to promote the growth and concentration of the manufacturing sector. Of the 18 existing regional industrial zones developed since 1990, 15 are within the ARB. Ten new industrial zones are proposed, including three within the ARB. The majority of existing industrial zones have no wastewater treatment plants, and are vulnerable to pollution issues. It is estimated that only around 10% of manufacturers treat wastewater before releasing it to the environment. In addition to a range of industrial chemicals such as lead (battery production), cyanide and arsenic (electronics), chromium and dyes (leather), organochlorine compounds (paper mills), organic waste, agricultural industries and food producers can deplete oxygen

levels and cause eutrophication of waterways (Win, 2013). Solid waste disposal from industry is also a problem.

Conclusion: *Urban growth is placing serious stress on urban infrastructure, particularly water, drainage and waste disposal. Localized pollution (both solid waste and polluted water) represents a troubling and significant threat downstream of urban areas in the rivers of the Ayeyarwady system. There is no comprehensive listing of manufacturing and industrial enterprises nationally, and no systematic program to monitor water quality in or downstream of urban or industrial areas. There are at least four government agencies with some responsibility for collection of data on water quality, but none specifically in the context of urban and industrial pollution. A coordinated approach to monitoring and enforcing pollution standards is urgently needed.*

How important is the basin for inland water transport?

The Ayeyarwady River system constitutes a major transport route for both goods and passengers, with year-round access to Bhamo (1,080 km) on the Ayeyarwady and Homalin, and (640 km) on the Chindwin. The Delta has around 3,200 km of navigable waterways. There are 10 main ports in the Ayeyarwady system, with major landing facilities at Mandalay, Chauk, Prome and Hinthada. Chauk functions as a petroleum port. In 2014, the throughput of river cargo on inland water transport was 5.28 million tons of freight, and around 15.7 million passengers. River cruises are an increasingly popular tourist option, with established routes between Yangon, Nyaung-U (Bagan) and Mandalay, as well as in the Delta. Boat transport still provides important access to services for communities that live in areas of the Basin that are not accessible by road.

The DWIR collects information on water quality and river depth to monitor environmental impacts of inland water transport. Pollution risks include fuel spills and inappropriate disposal of waste. Petroleum transport from Chauk represents a particular threat.

During the low water season, from November to May, some sections of the river have insufficient water depth for inland waterway vessels to operate safely. The Ministry of Transport and Communications (MoTC) is proposing a major program of works to improve navigability in the Ayeyarwady and Chindwin rivers, but it is not clear whether these are sustainable, given the highly mobile nature of the riverbed. Dredging and the construction of river training structures may also impact local fisheries.

Conclusion: *Inland water transport remains a popular and competitive transport option in the ARB, despite improvements in the road network. Ambitious plans for river training works to maintain sufficient depth in the dry season may not be sustainable, given the high sediment loads and mobile nature of the riverbed. Understanding sediment dynamics of the river is a critical priority before major investments are made in river training structures.*

How does mining affect the basin?

The ARB has very substantial mineral resources. Major deposits of silver, lead and zinc are currently mined at Bawdwin, Shan North and Panwa, Kachin, and further deposits have been identified at Yadanatheingi and Phaleng in Shan North and Paungdaw, Mandalay. Copper deposits are common throughout central Myanmar; there is already an active mine, with very large reserves identified around Monwya at Letpadaung, KyesinTaung and SabeTaung. Amnesty International (2015) has alleged a range of social and environmental problems associated with the Letpadaung mine, including pollution of streams and groundwater by acid and heavy metal discharges from the mining operations.

Coal is widespread throughout Myanmar, including in the Chindwin and Minbu-Salin basins, and the Lashio Basin in Shan State. National reserves are estimated at 480 MT, with much of this within the Ayeyarwady Basin. The Kalewa coalmine in Sagaing, with an annual production capacity of 13,000 tons, is the largest operating coalmine. Community groups at several mines have complained of pollution of streams due tomining activities (see, for example, Ban Chaung Coal Mining Report, 2015).

There are large gold mines at Kyaukpahto and numerous small deposits throughout Sagaing, around Mandalay and throughout Kachin. In northern Kachin, deposits are found along the rivers and streams of the Ayeyarwady and Chindwin systems (PKDS, 2004). Gold mining is causing increasing environmental degradation of the rivers, due to aggressive mining methods including suction dredges, hydraulic mining of riverbanks, and the use of mercury and cyanide in extraction processes. Serious damage has been reported even within protected areas, including the remote Hugawng Valley tiger reserve (KDNG, 2007).

Kachin hosts Myanmar's largest jade deposits, mainly in the vicinity of the Uyu River, a tributary of the Chindwin. Debris from the jade mines impedes river flow, exacerbating flooding. Local residents have recently expressed concerns about environmental damage from the resumption of mining in 2014 (Mon, 2015).

Oil and gas resources have been exploited in Central Myanmar since the 1850s. The Yenangyaung field was opened in 1887 and the Chauk field in 1902; both are still in production. Small-scale production occurs in the area around Magway, with reports of up to 40,000 small wells in a field abandoned by the state oil company, and concerns about the potential environmental impact of unregulated production (Lin, 2013). The region is considered highly prospective for expansion of production (Eliet, 2013). Of the 18 onshore blocks released for exploration in 2013, about 15 are wholly or partially within the Ayeyarwady Basin. Large-scale oil production could also potentially impact very significantly on water resources in the basin, in terms of both extractions for production use and water quality of return flows.

Conclusion: *A large increase in mining activity is expected over the next 10 years, as Myanmar opens the mining sector up to foreign investment. To date, the mining sector has a poor record, with allegations of unregulated environmental and social impacts. Information on the impacts of mining on water quality is limited, but there are significant concerns expressed by affected communities and concerned governmental agencies. A coordinated approach to monitoring of water quality around mine sites is an urgent priority.*

How will climate change affect the river?

Myanmar is believed to be one of the most vulnerable countries to climate change on a global basis, and, excluding small island states, the most vulnerable in the Asia Pacific (Centre for Global Development, 2014). Climate projections for Myanmar (based on the PRECIS model) suggest that by 2050, the annual mean temperature will increase by 10°C, and the mean annual rainfall will increase by around 10%. Overall, Myanmar has already experienced an increase in extreme weather events such as erratic rainfall, flooding, droughts, and a rise in sea level (GCCA, 2012). Climate projections for Myanmar suggest that temperatures will continue to rise, with longer summers, heavier rainfall during the rainy season and higher annual total precipitation, though projections vary across the country (Han Swe, 2014). The adverse effects of climate change on agriculture in the Ayeyarwady will come from higher temperatures, changing rainfall patterns and subsequent flow regimes, and sea-level rise.

Floods have been a major hazard in Myanmar, accounting for 11% of all disasters, and in recent years flooding events have compromised many rice fields and paddies around the Ayeyarwady. In May 2008, Cyclone Nargis caused extensive damage to mangroves, agricultural land, houses and infrastructure, and freshwater sources. Around 3.2 million people were affected, with 138,373 people dead and property damage to the value of USD 4.1 billion, including the loss of approximately 4 Mha of rice, or 47% of Myanmar's total production. In 2011, heavy rains and flooding in the Ayeyarwady and Rakhine resulted in losses of 1.7 million tons of rice. In June 2010, intense rains reduced rice harvests, resulting in total loss to the value of USD 1.64 million in Rakhine State (CCAFS, 2015)

Climate change may also be a threat to Myanmar's growing fisheries sector. Temperature increases and more intense and variable climate events suggest that wild fish stocks may be affected by degraded water quality, changes in fish migration, intensified competition in fishing areas, and more migration by fisher folk (WorldFish, 2014).

Conclusion: *Climate change could impact river flows due to changes in rainfall and intensified weather patterns, with attendant effects on riverine ecosystems. The projected increase in extreme weather events could threaten food security, as well as loss of biodiversity and ecosystems. At present, little is understood of the wider implications of climate change on the Ayeyarwady system. Projections for atmospheric changes have not been systematically applied to the basin's hydrological regime and these hydrological changes have not been comprehensively assessed for knock–on impacts on biophysical and socioeconomic characteristics of the river system.*

Who is involved in managing the ARB?

The National Water Resources Committee (NWRC) was formed by Presidential Decree in 2013 to improve coordination of water resources policy and management, and has a strong mandate to promote Integrated Water Resources Management in the country. The NWRC was briefly disbanded early in 2016, pending revision of committee structures by the new Government, and then reinstated in June 2016. The NWRC represents the lead body to drive and coordinate management and use of the Ayeyarwady River. As a new committee emerging in a time of significant political reform in Myanmar, the NWRC's institutional modalities to implement reform in water resources are still being developed. In 2013, an Expert Advisory Group was established, comprising senior, high-level experts, including former government officials and university professors. In 2016, a Hydro-Informatics Centre (HIC) was established as the primary technical organ to advise the NWRC.

Responsibility for planning and management of water-resources is now spread across multiple government ministries at the union and state/region level. A summary of the key ministries, departments and their function is provided below in Table 1.

The Ministry of Health and Sport, and the Ministry of Construction are involved in water quality, and health and provision of domestic water, respectively. City Development Committees (CDCs) and township authorities also have responsibility for the provision of water for domestic, agricultural and industrial uses. Limited coordination exists between the various sector agencies in water resources management, and moves to decentralise responsibilities to state/region and township may further complicate basin planning unless capacity is improved.

The Ayeyarwady Integrated River Basin Management Program (AIRBMP), which began in 2015, will prepare a Basin Master Plan and is supporting institutional, legal and regulatory reform for more integrated basin management. The program is executed by the NWRC and managed through MoTC, with loan- financing from the World Bank. The Project aims to develop the institutions and tools needed to implement integrated river basin management in the Ayeyarwady Basin.

The State of the Basin Assessment (SOBA) report is now being prepared as a foundation for a basin planning process and includes the following six packages:

1. Surface water modelling
2. Groundwater and data management
3. Sediments and geomorphology

Ministry	Department/s	Function
MoTC	• DMH • DWIR	Development of inland water transport and collection and analysis of hydrological data.
MoAli	• Irrigation and Water Resource Utilization Department • Department of Fisheries	Provision of irrigation water to farmlands and the operation of irrigation reservoirs. Managing fisheries sector.
Ministry of Natural Resources & Environmental Conservation (MoNREC)	• Environmental Conservation Department (ECD) • Forest Department	Lead EIA process for water-related developments, and watershed management.
MOEE	• Department of Hydropower Planning (DHPP)	Hydropower project planning and implementation.

Table 1: Key functions for water resource management in Myanmar.

4. Biodiversity and fisheries
5. Sectoral development, macroeconomics and basin pollution assessment
6. 3D mapping and local consultations

The SOBA process will be completed in October 2017 and is expected to fill critical information gaps.

The Ayeyarwady River Basin Research Organization (ARBRO) was established in 2012 to support integrated research and management in the basin, with a belief that the River Basin Organisation (RBO) would serve as a mechanism for engaging many stakeholders in managing water and other related resources at a smaller scale. SEI and MEI have been supporting the Sagaing regional government to establish an RBO for the Chindwin Basin.

Conclusion: *The National Water Resources Committee (NWRC) has been established as the lead water management body with the mandate to integrate and coordinate management of water resources, including the Ayeyarwady. A new structure, the NWRC is starting to develop the right kinds of institutions to implement its mandate, such that coordinated planning, management and monitoring that can facilitate sustainable development of the river and the basin resources. Further emphasis is needed on developing mechanisms and improving capacity to enhance coordination across sectors and between the union, state/region and local government levels.*

Where are the main information gaps?

The Ayeyarwady is the best known and most studied of Myanmar's rivers, but information on the river and its ecosystems to support planning and management is still sparse. Hydrological data are collected by DMH for 20 stations, but there has been limited analysis and compilation at basin scale. Concerted effort in compilation, analysis and modelling of hydrology is urgently needed to provide a baseline against which future changes to the river can be simulated and monitored. Despite growing community concerns about pollution of rivers from deforestation, agriculture, mining and industrial development, and collection of water quality data by at least three different Ministries and several other non-governmental organizations, there is limited information available to characterize trends in water quality. Coordination is needed across ministries to provide a systematic approach to monitoring trends in water quality.

Sediment loads in the river system impact navigation, irrigation and hydropower infrastructure, riverine ecosystems, and floodplain and delta agriculture. A better understanding of sediment dynamics is a critical priority before major investments are made in dams and river training works, both to reduce costs and to protect ecosystems and fisheries. Construction of hydropower dams and continued deforestation significantly impact sediment volumes.

There remain substantial knowledge gaps about the abundance and distribution of biodiversity assets in the ARB. Key gaps include a comprehensive survey of ecosystems and habitats, a systematic assessment of the value of ecosystem services and natural capital, and sufficient assessment of the vulnerability of riverine ecosystems to climate and other changes.

Better understanding is needed of interactions between surface water and groundwater systems in the large alluvial floodplain and delta to support design of conjunctive use of surface water and groundwater for irrigation, to improve sustainability, and to reduce costs. The impacts of climate change on water availability in the dry season and flooding in the wet season need further consideration in river basin management.

Large hydropower development is potentially the most significant driver of change in the ARB. Reliable information on proposed projects and their potential impacts is an essential precursor to a constructive, open debate about Myanmar's energy policy.

Conclusion

Myanmar's economy is expanding rapidly, with some estimates predicting that the economy will quadruple over the next 15 years. This rapid growth is based largely on growth in natural resource sectors of agriculture, mining, and energy – for which the ARB has a wealth of resources. Exploitation of these resources will impact on the integrity and health of the river systems.

The starting point for effective management is understanding. Every river basin is a complex interaction of sociocultural and economic systems with the underlying ecosystems of the catchment. As the largest and most significant river basin in Myanmar, the Ayeyarwady is of central importance, both nationally and internationally. Nowhere are these issues of resource exploitation and river management more pressing, or accurate and updated information more necessary.

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The SOK series evaluate the state of knowledge on subjects related to the management and development of rivers in the GreaterMekong Region. Publications in the series are issued by the CGIAR Research Program on Water, Land and Ecosystems –Greater Mekong. The papers draw on both regional and international experience. Papers seek to gauge what is known abouta specific subject and where there are gaps in our knowledge and understanding. All SOK papers are reviewed by experts in the field.

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The CGIAR Research Program on Water, Land and Ecosystems in the Greater Mekong (WLE Greater Mekong) is a research-for-development initiative that seeks to improve the governance and management of water resources by generating and sharing the knowledge and practices needed to do so. The programme works in the Irrawaddy, Mekong, Red and Salween river basins. WLE Greater Mekong works through a wide range of partners and builds on the work of the CGIAR Challenge Program on Water and Food (2002-2014). The program is based in Vientiane, Lao PDR. For more information, see **wle-mekong.cgiar.org**

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