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Enhancing fisheries productivity through improved management of reservoirs, dams and other water control structures

IWMI International Water Management Institute

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Contents

Purpose

Dams and the reservoirs they create are increasingly ubiquitous in landscapes throughout the world. They have a major impact on fisheries, presenting both opportunities and constraints. This brief, written for both water sector and fisheries sector practitioners, policy-makers and decision-makers, is intended to: i) increase awareness of the importance of inland fisheries; ii) highlight the impacts of dams and other water control structures on fisheries; and iii) outline approaches for increasing fisheries yields and benefits, both within reservoirs and downstream in rivers and irrigated areas. The focus of the brief is on how reservoirs and associated water management structures can be managed or modified to provide a wider range of benefits. In this context, we advocate a landscape approach with much more prominence given to fisheries since they represent significant untapped potential for sustainably increasing landscape productivity. In future, much greater emphasis should be given to safeguarding and improving fisheries opportunities in the aquatic environments created and impacted by dams and other water control infrastructure.

Key messages

- Inland fisheries—operating in lakes, rivers, floodplains and reservoirs—are a vital resource, globally supporting the food and nutrition security, livelihoods and well-being of millions of people.
- Construction and management of dams, reservoirs and other water control structures has in many instances failed to take into account the food and nutrition security and economic values associated with these fisheries.
- Dams often adversely affect fish production. Downstream, this is a consequence of flow regime modification. Upstream, it is a consequence of the change from relatively shallow, free-flowing habitat to deep, still-water habitat.
- Research has demonstrated that fish yields and related economic opportunities can be increased by proactively managing reservoirs and operation of dams for fisheries, both within the impoundment and downstream.
- Given that there are millions of small reservoirs around the world, there is potential for the application of design and management innovations to increase inland fisheries production, and food and nutrition security even in the face of huge changes in water use and infrastructure.
- Management options to improve fisheries in river basins where dams are built include:
  - considering fisheries in dam operation and attempting to minimize changes to natural patterns of water fluctuation (depth, quantity, quality, flow), both within the reservoirs and downstream of the dams;
  - constructing or modifying water control structures for appropriate fish passage to enhance fish migration and movement across dams (i.e. both upstream and downstream) and within irrigation command areas;
  - protecting existing fish habitat (in particular spawning habitat) on rivers flowing into reservoirs by creating fish sanctuaries or closed fishing seasons;
  - introducing measures (e.g. appropriate stocking) to increase recruitment of fish (i.e. the number of eggs/fry that survive to a size that can be caught and eaten);
  - improving reservoir habitat for fish by, for example, ensuring vegetation growth or creating wetlands on the drawdown zone;
  - regulation to prevent overexploitation of fisheries, improve access to reservoir fisheries for local people and prevent outsiders from plundering the fishery;
  - creating fisheries groups/organizations to empower local people (including women) to manage fishing, stocking, harvesting and marketing more effectively.

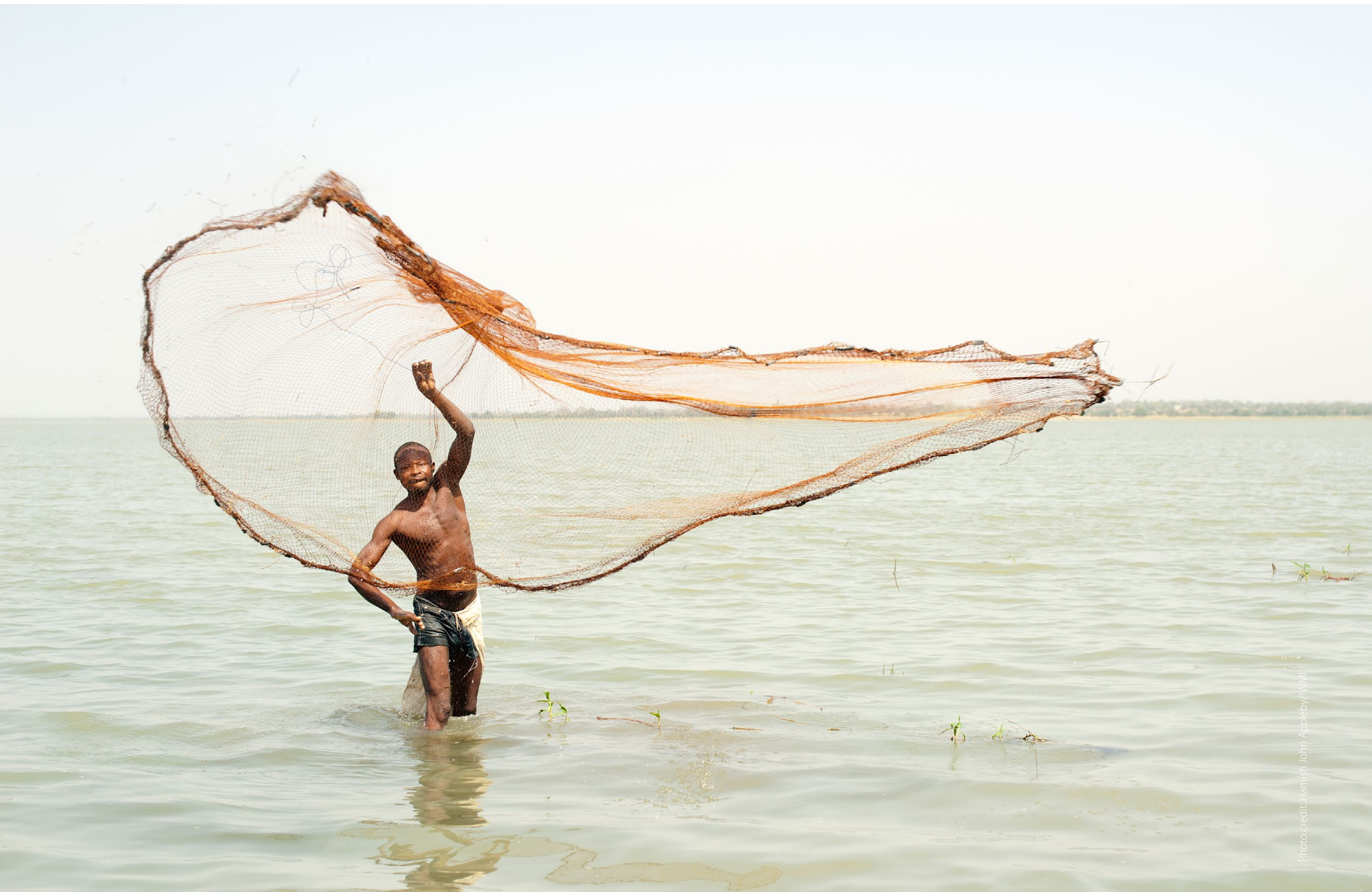
Why inland fisheries are important

The Food and Agriculture Organization of the United Nations (FAO) reported an inland fisheries catch of 11.47 million metric tons in 2015, representing 12.2 percent of total global capture fish production; the remainder being marine fisheries (Funge-Smith 2018). This is certainly an underestimate because of the difficulties of accurately quantifying fish catches (many of which are eaten directly or sold in remote informal markets) from a myriad of disparate sources (Allison and Mills 2018). Studies indicate that freshwater catches are, on average, about 65 percent higher than those national governments report officially (Fluet-Chouinard et al. 2018).

A recent estimate of the fish production from 80,000 of the world's lakes and reservoirs (surface area >10 ha) indicated that catches could be as much as 8.4 million metric tons. This estimate excludes the harvest from highly productive rivers, wetlands and smaller lakes,[1] and is further evidence of the likely underestimate of the total global catch (Deines et al. 2017).

The world's largest inland capture fisheries are concentrated in low-income countries in tropical and subtropical latitudes. Most are predominantly small-scale in nature and, through contributions to food and nutrition security as well as provision of employment, represent a vital resource for some of the world's poorest and most vulnerable people. Fish are the primary source of dietary protein and income in many of the world's least-developed regions (Lynch et al. 2016).

Globally, somewhere between 16.8 and 20.7 million people (50 percent of whom are women) are directly employed in inland fisheries, and the total value of inland fisheries—including recreational fisheries in developed countries—is estimated to be between USD 108–122 billion annually.



Fisher casting a net at Tono Dam, Ghana.

Why water storage is important: the role of reservoirs

In many places, the inability to predict and manage rainfall, and consequent runoff variability, is a key contributor to food insecurity and poverty. Frequent periods with too much water are followed by periods with too little, undermining the productivity of agriculture and contributing to disasters associated with floods and droughts (Sadoff et al. 2015). Rainfall variability is a significant factor affecting economic growth, particularly in predominantly agrarian societies (Brown and Lall 2006).

By safeguarding domestic supplies and supporting crops and/or livestock during dry periods, water storage contributes significantly to agricultural and economic productivity. For millions of smallholder farmers, reliable access to water—often from small reservoirs—is the difference between self-sufficiency in food and hunger. Reservoirs also contribute to electricity generation and provide water to commercial and industrial enterprises. They play a vital role in poverty reduction, sustainable development and climate change adaptation (McCartney and Smakhtin 2010).

It is estimated that, worldwide, there may be 16.7 million humanmade reservoirs with a surface area larger than 0.01 ha (Lehner et al. 2011). Of these, more than 59,000 are behind large dams (i.e. dams more than 15 m tall), with an aggregate storage of about 16,201 km^3 and total inundated area of approximately 400,000 km^2 (ICOLD 2018).[2] Both the total global storage and inundated area are determined primarily by large reservoirs: the 12,600 reservoirs greater than 1.0 km^2 in extent represent 83 percent and 92 percent of total reservoir storage and inundated area respectively (Lehner et al. 2011). Approximately 48 percent of the total volume of rivers around the globe is moderately to severely impacted by artificial flow regulation and/or fragmentation (Grill et al. 2015).

Irrigation is the most common purpose for large dams. About 18 percent of the world's arable land is irrigated, producing about 40 percent of total crop yield (ICOLD 2018). It is estimated that reservoirs created by large dams contribute directly to 12–16 percent of global irrigated food production (WCD 2000). Currently, more than 3500 large dams—many for hydropower—are being planned or built around the world. Although they provide vital opportunities for farmers and smallholders, few data are available on the contribution of the millions of small reservoirs globally.

Key facts and figures (global)

Total number of humanmade reservoirs (estimated)[1]	16.7 million
Total number of large dams (registered by ICOLD)[2]	59,071
Total water stored in reservoirs (km^3) (estimated)[2]	>16,201
Total area inundated by reservoirs (km^2) (estimated)[2]	>400,000
Amount of agriculture that is irrigated[3]	18% (261 million ha) producing 40% of crop yield
Annual irrigation water consumed (km^3)[3]	1500 (from 2673 withdrawn)
Annual amount of electricity produced by hydropower (TWh)[4]	4185 (16.4% of global electricity)
Number of main river basins containing large dams[5]	1293 (59% of global rivers)
Total river length affected by large dams (km)[5]	28.5 million (i.e. 59% of total river length)
Annual river flow (volume) moderately to severely impacted by flow regulation, fragmentation, or both (km^3)[5,6]	19,200 (i.e. 48% of total river flow volume)
Annual inland fisheries catch (metric tons)[7]	>11.5 million
Annual value of inland fisheries (USD)[7]	108–122 billion
Number of people employed in inland fisheries[7]	16.8–20.7 million

Sources: [1]Lehner et al. (2015); [2]ICOLD (2018); [3]FAO (2018); [4]IHA (2018); [5]Grill et al. (2015); [6]Trenberth et al. (2007); [7]Funge-Smith (2018)

The impacts of reservoirs and dams on fisheries

By creating reservoirs and so increasing the abundance of standing water within a landscape, it is often assumed that dams provide huge potential for increasing fish production. In some countries (e.g. India and Sri Lanka), small and medium reservoirs, often built for and within irrigation schemes, make a significant contribution to the total inland fishery yield. However, dependence on stocking (see below) requires appropriate management systems are in place for success. In the case of large dams, proponents often cite increased fisheries as a significant secondary benefit, one that will partly offset the disruption to livelihoods caused by the dam construction. Some large dam reservoirs do produce high fish yields, but the reality is that by disrupting the ecological connectivity of rivers, and by modifying the quantity, quality and timing of downstream flows, most dams have adverse impacts on fish. Too often construction and management of dams and reservoirs fails to take into account the food and nutrition security and economic values associated with fisheries.

The creation of the lacustrine (lake-type) environment in the form of a reservoir is a major change from a free-flowing river environment. The species that can exploit this environment are different from river species and in many rivers do not exist naturally. The lack of flow variation also means that biological cues for spawning and migration are not present so the riverine species often fail to reproduce. The reservoir frequently acts as a sediment sink and nutrients settle out of the water. The fisheries that exist, or are created in reservoirs, are therefore quite different from river and floodplain fisheries. The change in fish and the fishery means that different species (with different value) may be exploited. Often the long-term trend in reservoirs is one of declining productivity as nutrients are gradually lost and the initial fertility created by the decomposing biomass (plants/trees) in the flooded area decreases.

Downstream, the fisheries are impacted by changes to habitat arising from altered river flow, the blocking of fish migration routes and loss of flood pulses that support floodplain fisheries. Discharge of water from deep anoxic regions of large reservoirs reduces oxygen and lowers the temperature of downstream water, often curtailing or eliminating warm-water river fisheries.

In the Mekong River Basin, where 80 percent of the native fish migrate to spawn and breed, studies suggest that if all the large dams currently planned are actually built, total migratory fish biomass may decline by up to 19 percent, directly threatening the world's most productive inland fishery and the food security of some 2 million people (Ziv et al. 2012).

Although the cumulative area of small and medium reservoirs within a river basin may be quite large, the impact of individual small reservoirs/dams on fisheries is generally less negative than that of large reservoirs. This is because they tend to be located on smaller tributaries and are relatively shallow, with the capacity to store much less water. Nonetheless, small dams, built for irrigation and low-head (mini) hydropower generation, act as barriers to fish movement and migration. In basins with large numbers of small dams, the cumulative impact on fisheries can be significant.

In the Mekong River Basin, large dams are not the only barriers to fish migration. There are many thousands of small humanmade structures—often associated with irrigation and/or flood control—that block fish passage just as effectively as large dams. By preventing fish from reaching upstream habitat, these barriers may already have significantly reduced the basin fisheries (Marsden et al. 2014).

There is increasing recognition that the diverse demands for water from rivers requires a more balanced approach to the design and operation of dams and reservoirs. Despite efforts in the twentieth and early twenty-first centuries, the potential for the integration of fish production (capture fisheries and aquaculture) into reservoirs and associated water management systems has yet to be fully realized. Capturing underutilized opportunities could significantly increase local economies, food and nutrition security, household incomes and livelihood diversity.

Irrigation schemes, designed to enhance crop production, may with appropriate design and management, also provide opportunities for new fisheries within the command area. These can be capture fisheries, the integration of fish with crops (e.g. in rice fields) or the incorporation of aquaculture facilities such as ponds and cages.

How much fish production can come from a reservoir?

Humanmade reservoirs can have widely different levels of fish production and are often quite different from natural water bodies. The level of production is affected by three main factors: the fertility of the water; the existence of a stock of fish that can use this fertility; and the presence of people who are able to fish the reservoir.

Reservoirs and nutrient availability

Reservoirs are typically most fertile just after dam closure as inundated vegetation decomposes and releases nutrients. Deep reservoirs act as a nutrient sink and tend to be the least productive; they usually become less productive over time. Wind-driven 'turnovers' (i.e. the process whereby a lake's water turns over from top to bottom) may bring nutrients to the surface, increasing fertility. However, these turnovers can also bring up anoxic water, leading to localized fish kills, which is a risk for both capture fisheries and cage aquaculture operations. Shallow reservoirs can be very fertile, especially if the water flowing into the reservoir comes from agricultural land.

Suitable species and water fluctuation

The amount of water level fluctuation in the reservoir can also affect its productivity and suitability for a variety of fish species. When reservoirs are created, the natural fish species in the river are not usually well adapted to the new lake environment and different species may have to be introduced to exploit the new habitat.

Skilled people to catch fish

New reservoirs often have few communities around the shoreline. Existing communities are often displaced during the flooding of the reservoir. Not all of these communities can settle and become reservoir fishers or fish farmers. They may lack the skills or interest. In reservoirs where trees are not removed before flooding, there are physical problems with snagging of fishing gear (such as gill nets), which can reduce the ability to catch. The previous river fishing communities may also find it hard to access the new reservoir. In time, fishing activities may increase. It is important to organize fisheries for effective management and to ensure that communities benefit from the fishery, especially if they have to invest in fish stocking or other management activities. The development of commercial larger scale fisheries for small, deepwater (pelagic) fish may require investment that is beyond the reach of the existing fishers. The investment cost for cage aquaculture is often too high and the management too complex to be accessible for many households.

The range of reservoir fishery productivity	
Country (reservoir)	**Yield (kg/ha)**
India (large)	9
India (medium)	13
India (small)	30
Indonesia	65
Thailand	74
China (low productivity)	79
South America	144
Mexico	234
Sri Lanka	239

Source: Kolding and Van Zweiten (2006)

The range of reservoir fishery productivity	
Country (reservoir)	**Yield (kg/ha)**
Nigeria (Lake Kainji)	3.5-4.7
Zambia (Lake Kariba)	30-57
Egypt/Sudan (Lake Nasser)	36-49
Ghana (Lake Volta)	42-52

Source: Jackson and Marmulla (2001)

Mitigating the adverse impacts of dams and optimizing the opportunities in reservoirs

There is increasing competition for natural resources, including water. To sustainably achieve the multiple, often competing, objectives of different stakeholders, landscapes must be managed in a more systematic and holistic way than in the past (Sayer et al. 2013). Inland fisheries are a vitally important, though too often neglected, resource. Landscapes and the water flowing through them need to be managed in an integrated way for fisheries as well as crops, livestock and other benefits. In this context, because of both the impacts and the opportunities they create, fisheries come to the fore in the planning and management of dams, reservoirs and other water resource infrastructure.

The potential fisheries productivity of reservoirs is a function of size, depth, the availability of habitats and natural food for fish. Geography, climate, topography and physiographic features of the reservoir itself all influence reservoir productivity. Fluxes of organisms, detritus, nutrients and other materials into the reservoir strongly affect water quality and primary productivity (not least through impacts on turbidity) and hence food webs and fisheries productivity. The ecology of a reservoir tends to evolve rapidly in the first few years after impoundment as the ecosystem ages. A 'mature' reservoir is only achieved when all abiotic and biotic processes stabilize, which can take decades. Because they tend to be shallower, well mixed and oxygenated, smaller reservoirs are generally more productive than large, deep ones.

In broad terms, the actions that can be taken to improve fisheries, whether in a large or small reservoir, fall into three categories: i) biological (i.e. directly influencing the life cycle of fish); ii) physical (i.e. influencing physical and chemical conditions, which in turn affect fish habitat and ecology); and iii) governance (i.e. influencing people's access to fish and the manner in which they exploit the fishery). In all cases, fisheries management must be adapted to local conditions. This requires a participatory approach that makes allowance not only for local livelihood strategies but also gives explicit consideration to the different roles of women and men. Management interventions can be introduced upstream, within and downstream of a reservoir. Actions can also be taken within the command areas of irrigation systems to improve water connectivity and habitat for fisheries.

Upstream

Upstream of reservoirs, maintaining river connectivity and protecting existing fish habitat (in particular spawning habitat) on inflowing tributaries is in many cases the most important management intervention for sustaining natural reservoir fisheries. Managing the upstream watershed to reduce sediment and pollutant inputs and avoid excessive nutrient inputs, all of which can lead to loss of the fish habitat, contamination of aquatic systems and eutrophication, is essential to avoid negative impacts on reservoir fisheries. Payment for ecosystem services is one mechanism that can and has in places (e.g. Vietnam) been used to improve watershed protection in relation to downstream reservoirs.

> The Nam Ngum 1 hydropower reservoir in Lao PDR, completed in 1971, is an example of sustained healthy self-recruiting stocks of native fish, decades after the impoundment, despite the disappearance of long-distance migratory fish. With fishery yields of 133 kg/ha/yr in 2007, the sustained productivity is largely attributed to the presence of spawning areas upstream of the reservoir, and designation of these areas as a fish sanctuary (Mattson et al. 2001).

Within the reservoir

In relation to fisheries, the most significant difference between large and small/medium reservoirs is the possibility of being able to establish a self-sustaining fishery. In the case of small/medium reservoirs, this is generally not possible and the fisheries are almost always dependent on repeated stocking (i.e. using hatchery-raised fingerlings) because natural recruitment is too low to sustain even a very small fishery. Typically, stocking occurs annually (or sometimes even more frequently) with highly productive, fast-growing non-native species, such as tilapias and carps.

In large reservoirs, the chance of being able to create a self-sustaining fishery is far greater. In this case, stocking may still be undertaken soon after reservoir formation, either with native or non-native fish that are better suited to the deepwater habitat created by the reservoir, in the anticipation that the fishery will become self-recruiting over time. Such fisheries may be bolstered by further 'seeding' at irregular intervals. If a self-recruiting fishery cannot be established, regular stocking may need to be introduced, as in the case of small/medium reservoirs.

In 1968, to maximize the use of deepwater habitat, the Zambian Department of Fisheries stocked the large reservoir created behind the Kariba Dam on the Zambezi River with a small fish called kapenta. Within five years, the species had completely colonized the lake and a commercial fishery was established with catches up to 35,000 metric tons per year (valued at USD 25 million in 1990). More recently production has declined as a consequence of overfishing and/or environmental factors (Magadza 2006).

The overall cost-effectiveness, and hence sustainability, of reservoir stocking is often uncertain. It can sometimes create very productive fisheries but in other instances completely fails despite regular stocking effort. Economic viability is the main constraint in developing sustainable stocking programs. Because they are likely to be more sustainable, native fish species are often recommended in reservoirs, in preference to stocking with non-native species.

Fishery yields can be enhanced in large reservoirs containing native fish by managing reservoir water level fluctuations so that they mimic the natural variation as closely as possible. Typically, changes in water level results in periodic exposure and flooding of the shallow littoral zone around the edge of the reservoir. Just as on natural floodplains, many fish species will migrate to the recently flooded areas to feed and breed. To avoid stranding fish in the littoral zone, reservoir drawdown rates should not exceed those that would occur naturally. Large, rapid fluctuations, such as those that occur in reservoirs used for hydropeaking generation (i.e. hydropower stations that are switched on and off to meet hour-by-hour electricity demand) can be especially disruptive for fish.

Research in Africa suggests that, generally, annual water level fluctuation of the reservoir should not exceed 2.5–4.0 m, and drawdown rates should not exceed 0.6 m/month (Bernacsek 1984).

Creation of habitat is another option for enhancing reservoir fisheries. Within small/medium reservoirs that dry up seasonally, the creation of permanent, inundated areas that provide a refuge for fish can reduce the need for annual restocking. Similarly, in large reservoirs, islands may provide additional shallow water (littoral) habitat, and the creation of vegetated areas and wetlands on the drawdown zone can provide breeding habitat and refuges that may enhance reservoir productivity.

The creation of permanent wetlands on the drawdown zones of reservoirs can enhance reservoir fisheries. Such wetlands add to the diversity of habitat and provide fish with refuges, spawning and nursery grounds that are not subject to the marked changes in water level that occur across the rest of the reservoir (Meynell 2014).

Downstream

Releasing water from the highest possible elevation in the reservoir where it tends to be warm and well oxygenated or, alternatively, artificially re-oxygenating reservoir releases can mitigate some of the adverse impacts of altered water quality on downstream fisheries.

Environmental flows are flow releases from dams that are intended to sustain freshwater and estuarine ecosystems and the livelihoods and well-being of those who depend on these ecosystems (Arthington 2012). Implementing an environmental flow process in a river basin enables managers to optimize seasonal flow regimes for human use and to maintain essential processes required to support healthy river ecosystems, including fisheries. To maximize benefits, environmental flow releases ideally need to mimic seasonal changes, albeit at reduced volumes, including periods of high flow often necessary to trigger fish migrations or spawning events, in addition to maintaining river geomorphology and habitat.

Fish passes are human structures that allow fish to travel across or bypass dams, ideally facilitating both upstream and downstream movement. Many technologies exist (e.g. fish ladders, bypass channels, lifts) to facilitate upstream fish migration, but many are only really effective for small (low-head) obstructions, and many only facilitate the passage of relatively few fish species. Fewer options exist to enable the movement of eggs, fry and young fish downstream across a reservoir. However, fish excluders to prevent fish entering water intakes and 'fish-friendly' turbines have been invented and are used in some countries.

In Lao PDR, *in situ* field experiments have shown the effectiveness of low-cost fishways specifically designed to enable local fish to migrate upstream past small (<10 m) barriers. The design developed was successful in enabling 170 species and large numbers of fish to pass an irrigation dam (Boys et al. 2015).

The design, operation and maintenance of sluices, weirs, regulators and culverts in irrigation systems can also have a strong impact on inland fisheries. These structures represent bottlenecks in the irrigation command area through which fish may be forced to pass as they move through the system. Their location, design and operation all play an important part in determining their impact on the fishery. Unsurprisingly, they are often focal points for local fishers. Modifying the design to improve fish passage and operation at critical periods of the year for fish movement can greatly enhance the fish production within the command areas (Gregory and Funge-Smith 2018).

National and regional laws and policies can have a large impact on the extent that fisheries can be integrated within irrigation systems. In Sri Lanka, culture-based (i.e. stocking) fisheries and rice-fish culture are encouraged. In Cambodia, integrated rice-fish practices and community fish refuges that support floodplain fisheries have become national policy. In other countries, irrigated rice field areas may not be converted for fish or rice-fish culture, or the placement of fish cages in irrigation canals may be forbidden (Gregory and Funge-Smith 2018).

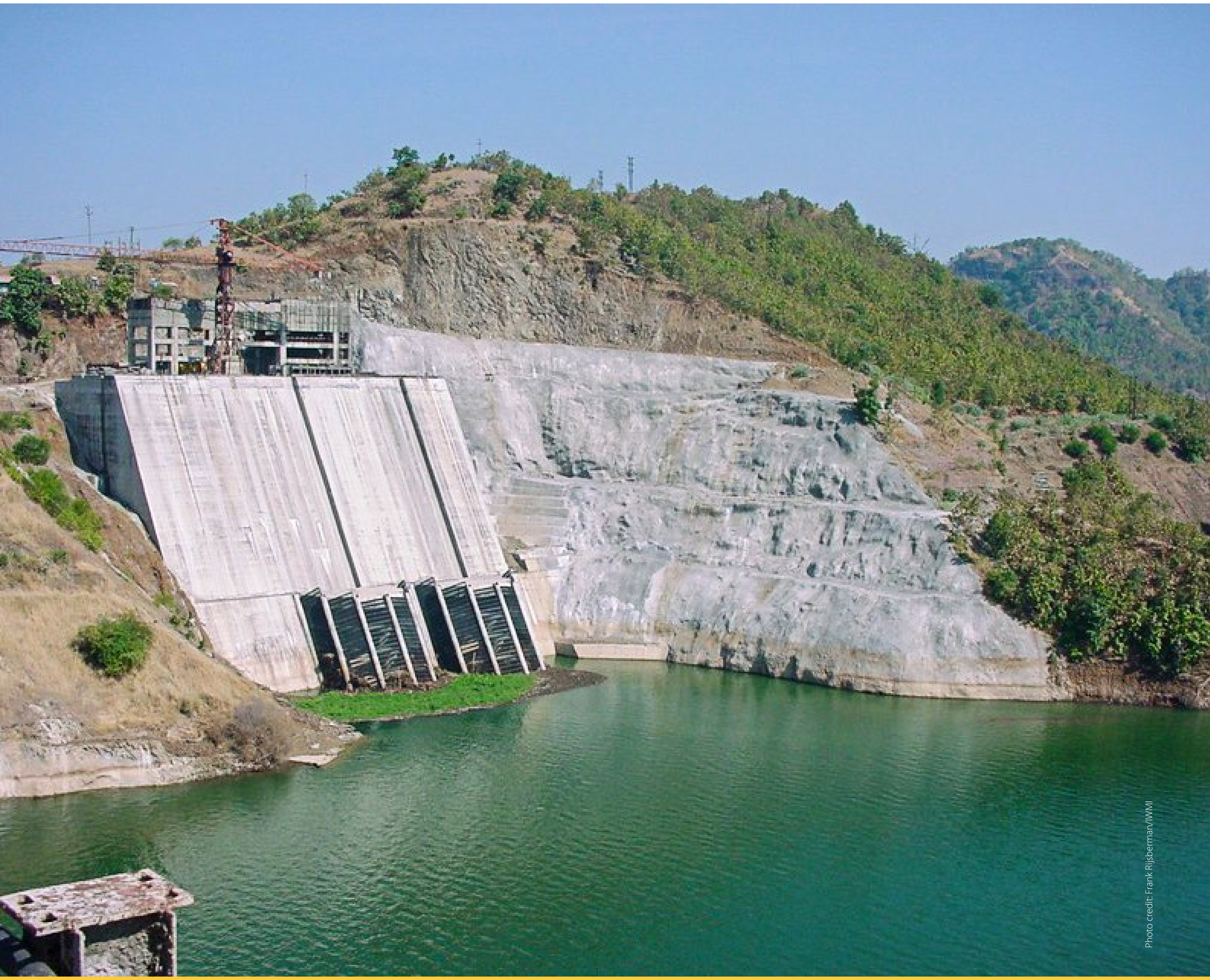


Photo credit: Frank Rijsberman/IWMI

Narmada Dam, India.

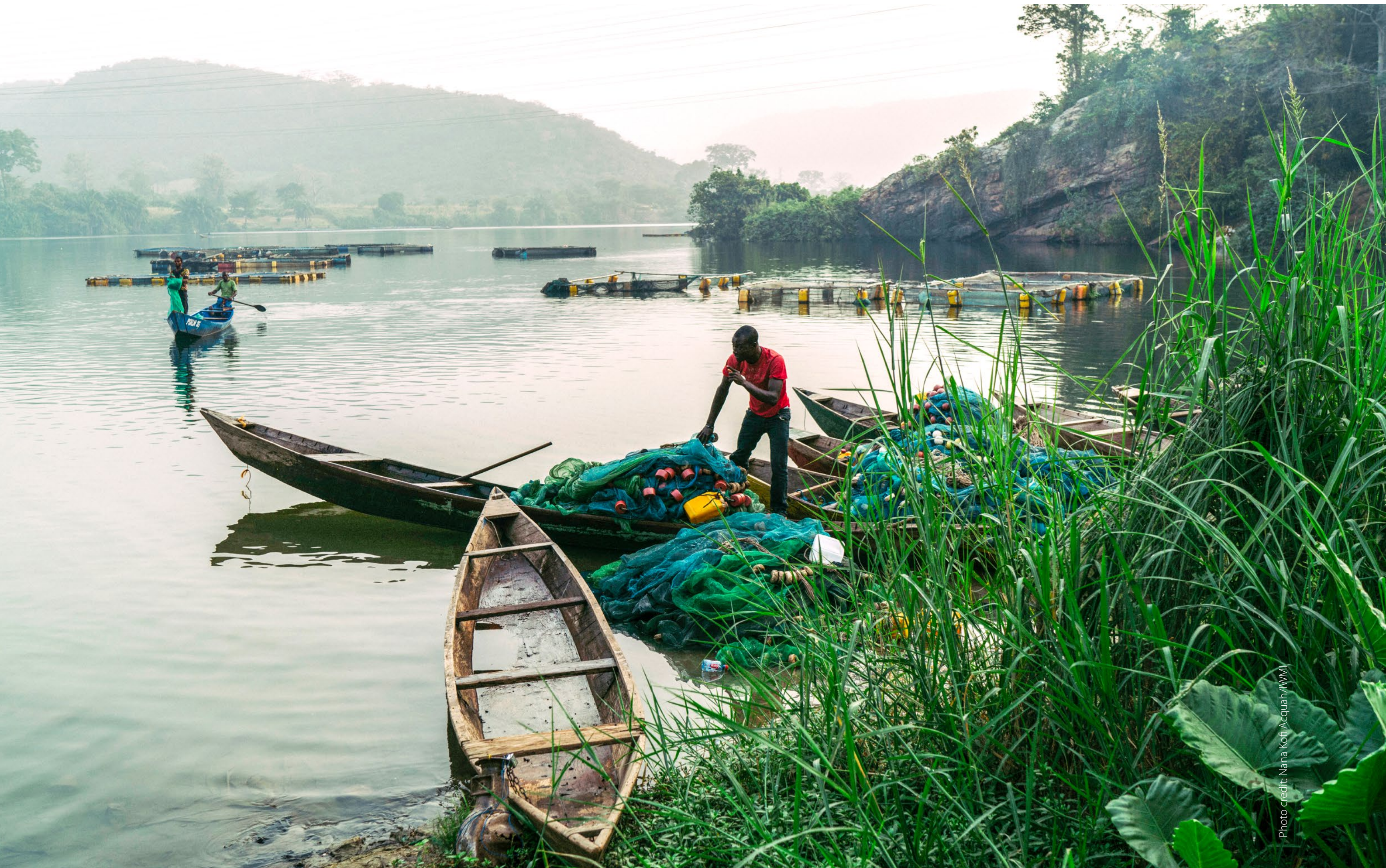
Involving fishers and their communities in the fishery

Governance is a challenge in many fisheries and can be particularly difficult in the immediate aftermath of impoundment of large reservoirs because they represent a new and rapidly evolving resource. Under such circumstances, sustainability of a reservoir fishery often requires adaptive management approaches that both regulate and empower local fishing communities, including women, to:

- prevent overfishing and the use of destructive fishing gear and methods (e.g. nets with too fine a mesh or use of poison/explosives);
- prevent the targeting of vulnerable life stages (breeding/spawning), both within and upstream of the reservoir;
- prevent outsiders moving in and exploiting the fishery to the detriment of local people;
- negotiate issues such as reservoir water level management and mitigation measures;
- create opportunities to maximize, in an inclusive and equitable way, the long-term benefits arising from effective stocking, harvesting and marketing.

Sri Lanka has a large number of seasonal and perennial irrigation reservoirs. The introduction of culture-based fisheries (i.e. stocking) resulted in a six-fold increase in fish production. In order to achieve this, fisher community-based organizations (CBOs) were reorganized and strengthened. Training was provided in basic aspects of culture-based fishery, CBO management, leadership, simple accounting and record keeping. Management measures were developed and the fishers conducted surveillance for compliance (Pushpalatha et al. 2015).

In some cases, restrictions prevent the use of reservoirs for fishing. In these situations, review of policy and streamlining of licensing procedures can facilitate the development of the fishery.



Fishers near the Akosombo Dam, Ghana.

Conclusion

The reservoirs created by dams provide multiple benefits for society. However, depending on size and a range of other factors, dams and other water control infrastructure also generate adverse impacts (on river system function, fisheries and livelihoods). Dam operators and water managers in irrigation systems have an ethical obligation to minimize or mitigate such impacts. An important part of this is recognizing that reservoirs are not simply isolated water storage systems with a sole function to maximize hydropower generation or water delivery. Similarly, irrigation systems are not just a physical water delivery system for crops. Rather, both are complex, dynamic ecosystems that interact with the landscape in which they are situated. What's more, because they are human constructs, there is significant potential for directing their evolution and daily and seasonal dynamics to enable the delivery of a broader range of benefits, foremost of which are fisheries. Adopting an integrated landscape perspective should give due prominence to fisheries within the context of other opportunities and benefits that landscapes provide.

Although there are inevitably trade-offs, the reality is that enhanced fisheries can often be achieved at relatively minor cost to the primary purpose of the reservoir/irrigation scheme and, in some cases, may even result in net economic benefit. Economic analysis of a range of integrated fish-crop systems has shown that fish can be the most profitable component and can improve the overall nutritional diversity and value when compared to monocrop systems. Recognizing the potential for managing the design and operation of reservoirs, dams and water control structures to improve fisheries can enhance benefits accruing in communities living in their vicinity, increase food and nutrition security, improve livelihoods and reduce poverty.

Two of the CGIAR Research Programs—FISH and Water, Land and Ecosystems—are collaborating to investigate how small-scale inland fisheries production can be sustained in multifunctional landscapes, where human interventions—not only dams but also land-use change, increased pollution, climate change and others—both threaten and provide new opportunities for inland fisheries and human development. Research innovations being developed jointly by the two programs aim to improve and restore overall landscape productivity, along with adaptation and mitigation to minimize and reverse adverse ecological impacts and increase resilience, through improved water and land management.

Notes

[1] Analyses of high-resolution satellite images produce a global estimate of 117 million lakes greater than 0.002 km^2 with a combined surface area of about 5 million km^2 (Verpoorter et al. 2014). Small lakes, wetlands and floodplains tend to be highly productive habitats and consequently disproportionately important for fisheries (Downing 2010).

[2] This is equivalent to about 20 percent of the water stored in all natural freshwater lakes on earth (Gleick 2000).

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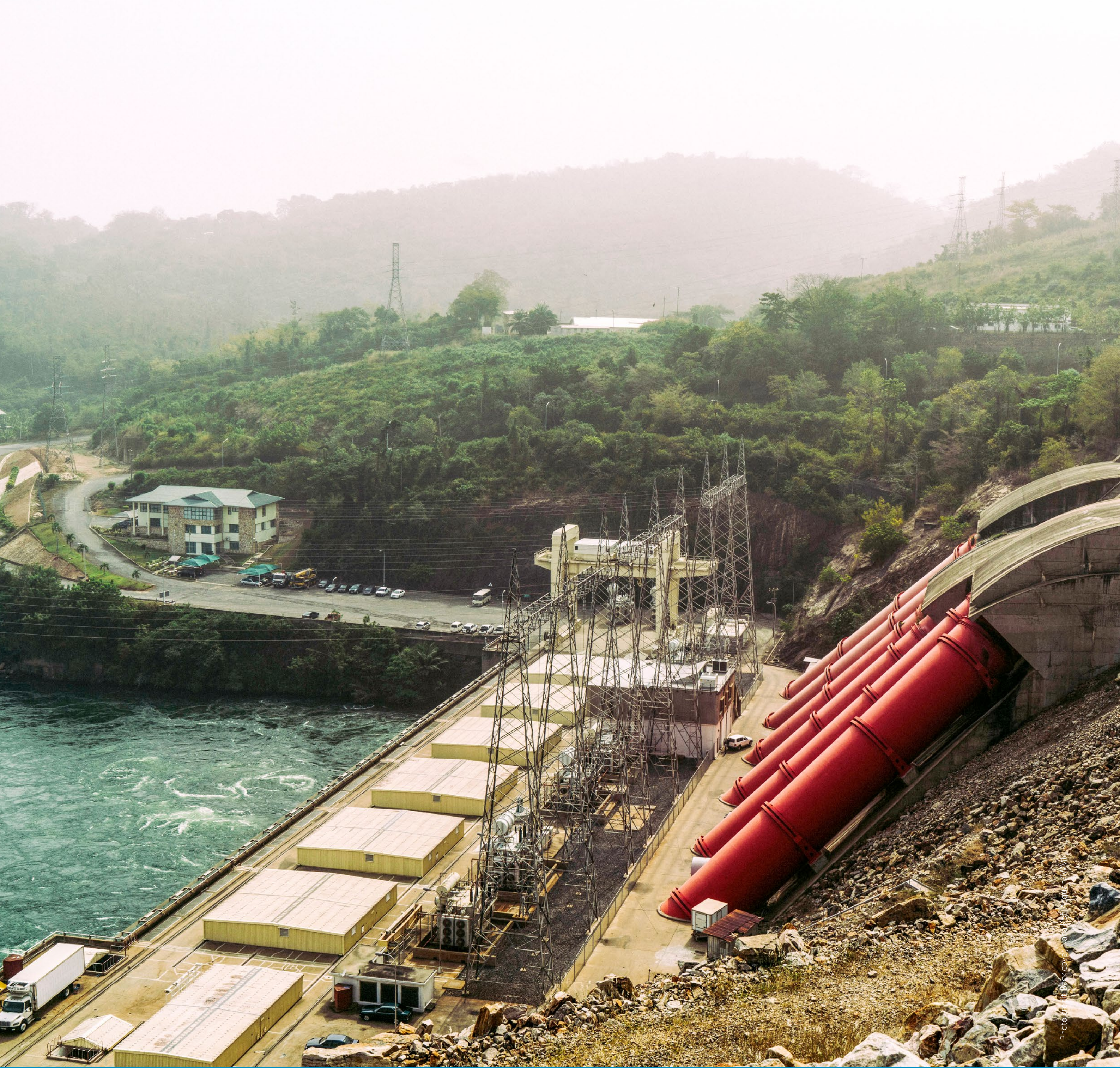

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