Fishing boats on the Sesan River in Cambodia. The river's fishery has seen dramatic losses as a result of dam construction. Photo: International Rivers

Understanding the Climate Risks to Rivers and Communities

The impacts of climate change on freshwater ecosystems will be complex and difficult to predict. These impacts will lead to changes in the quantity, quality, and timing of river flows. Some of these changes are already having major effects on freshwater ecosystems around the world, including:[6]

- Shifts from snow to rainfall, and changes in the timing of snowpack melting
- Alteration of surface runoff and groundwater recharge patterns
- Shifts in the timing of floods and freshwater pulses, and more frequent and intense floods

- Increased evaporation, especially from shallow water bodies and reservoirs
- Saltwater intrusion in coastal and delta areas from rising sea levels
- More intense runoff events, which can lead to increased sediment and pollution loads
- Increased extremes in water temperatures
- More intense and/or frequent droughts

For a comprehensive table of expected and existing impacts, see *Appendix 2: Climate Change Impacts on Rivers and Species*.

River flows are becoming more unpredictable, and "extreme" events such as floods and droughts more common. These changes can have cascading effects on forests, fisheries, a river's shape and delta, and widespread impacts on local economies and communities. Dams can worsen some of these impacts: bigger floods threaten the safety of dams, and their operation during large floods can put people at risk from sudden dam releases. Longer droughts can greatly reduce hydropower and water supply. Salt-water intrusion due to dams withholding sediments downstream, combined with sea level rise, could harm water quality. Increasingly heavy rain and floods can wash pollutants into water sources, or damage water supply systems. A specific basin's vulnerability will depend on the scale and types of water infrastructure in that basin, the scale of deforestation, and other development in the basin.

There is no agreed-upon way to design, manage, and operate dams in a changing climate. Today, most dams have been designed according to the assumption that climate and hydrological patterns are "stationary" (in other words, reliable and predictable based on past events and characteristics).[7] However, this assumption fails under the current climate change scenario. Continuing to depend upon this assumption can leave dams highly vulnerable to even small shifts in climate regime. If a climate change or climate risk assessment were conducted so that a dam design took into account multiple potential futures, the dam would likely need much greater capacities to safely pass high floods, and projections of power generation for hydropower projects would have to allow for the probability of new extremes of drought. These factors could increase its costs and reduce its benefits, potentially making alternatives to the project more attractive.

This chapter offers a summary of some key risks to rivers, riverine communities, and dams in a warming world. A climate risk assessment for any river project should consider each of these major impacts.

PRECIPITATION AND TEMPERATURE

The effects of climate change on rivers are already becoming apparent as major changes in river discharge now affect watersheds around the world. Increasing temperatures will mean that globally, more precipitation will fall as rain rather than snow (though the amount will vary geographically and temporally). Areas that have substantially higher rainfall or that will have more intense storms will experience more flooding, especially in areas with fewer riparian wetlands and forests along rivers, both of which act to capture floodwater and release it more slowly. Regions that are expected to experience less precipitation will have more severe and longer droughts.

Higher precipitation can also lead to a deterioration of water quality, leading to significant impacts on food security and increasing the vulnerability of poor rural farmers, especially in the arid and semi-arid tropics and in Asian and African mega-deltas.[8] Heavy downpours can increase the amount of runoff into rivers and lakes, washing sediment, nutrients, pollutants, trash, animal waste, and other materials into water supplies, making them unusable, unsafe, or in need of water treatment. More intense dry periods can also alter the concentration of nutrients and pollutants, turning freshwater systems into toxic soups (such as in the Murray-Darling Basin in Australia, which has been experiencing a decade-long drought).

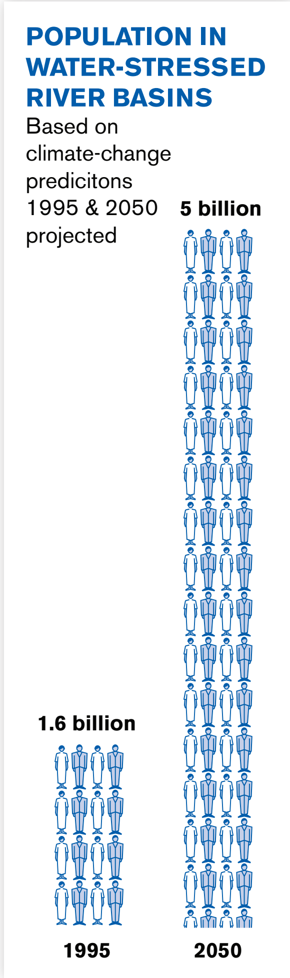
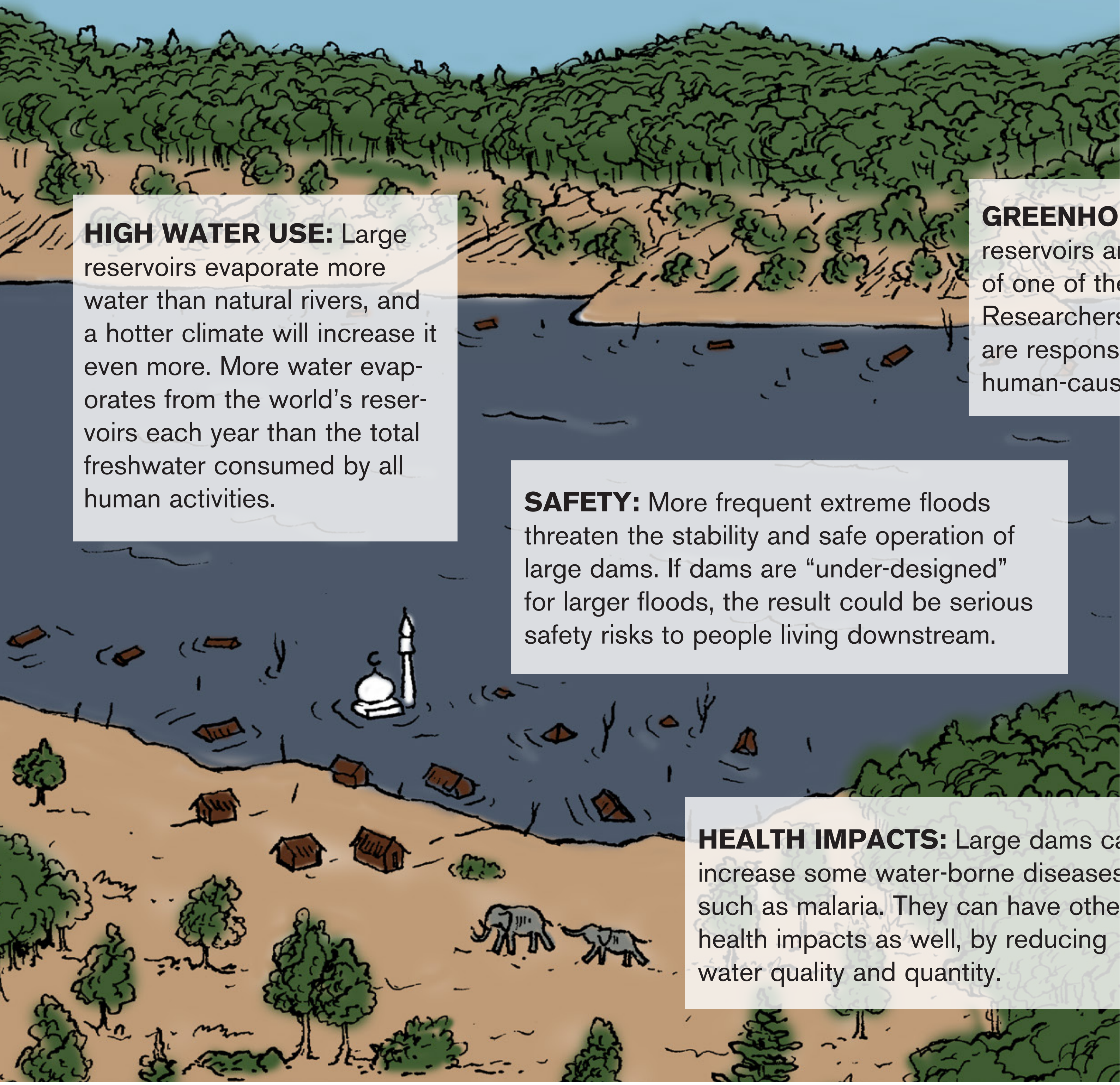


Figure 1: Population in water-stressed river basins, based on climate change predictions. Source: Black, M. and King, J. The Atlas of Water: Mapping the World's Most Critical Resource, 2009.

Changes in water temperatures are more difficult to predict. In some areas, water temperatures have been rising, while in places where there is greater snowmelt or higher levels of precipitation, water temperatures may be decreasing.[9] Increases in water temperature will affect riverine fisheries. If river water warms 3-4° Celsius (C) in the next 25 years, the organisms living in them may not be able to adapt fast enough to cope. At first, there may be fewer offspring or fewer young surviving. Over time, populations of some species will decline, while those species able to withstand warmer water (often non-native species) will increase. If deforestation or damming has occurred in a watershed, temperature increases above historic levels will be far greater and ecologically more harmful.[10] During past periods of climate change, many species responded to shifts in water conditions by moving to nearby basins. However, given the scale of alteration humans have had on rivers globally, these shifts are less likely to succeed.

Dams and Climate Change

Dams are very vulnerable to climate change. In addition, they can worsen som
negative impacts of climate change, which can reduce the ability of river ecos
and communities to adapt.



HIGH WATER USE: Large reservoirs evaporate more water than natural rivers, and a hotter climate will increase it even more. More water evaporates from the world's reservoirs each year than the total freshwater consumed by all human activities.

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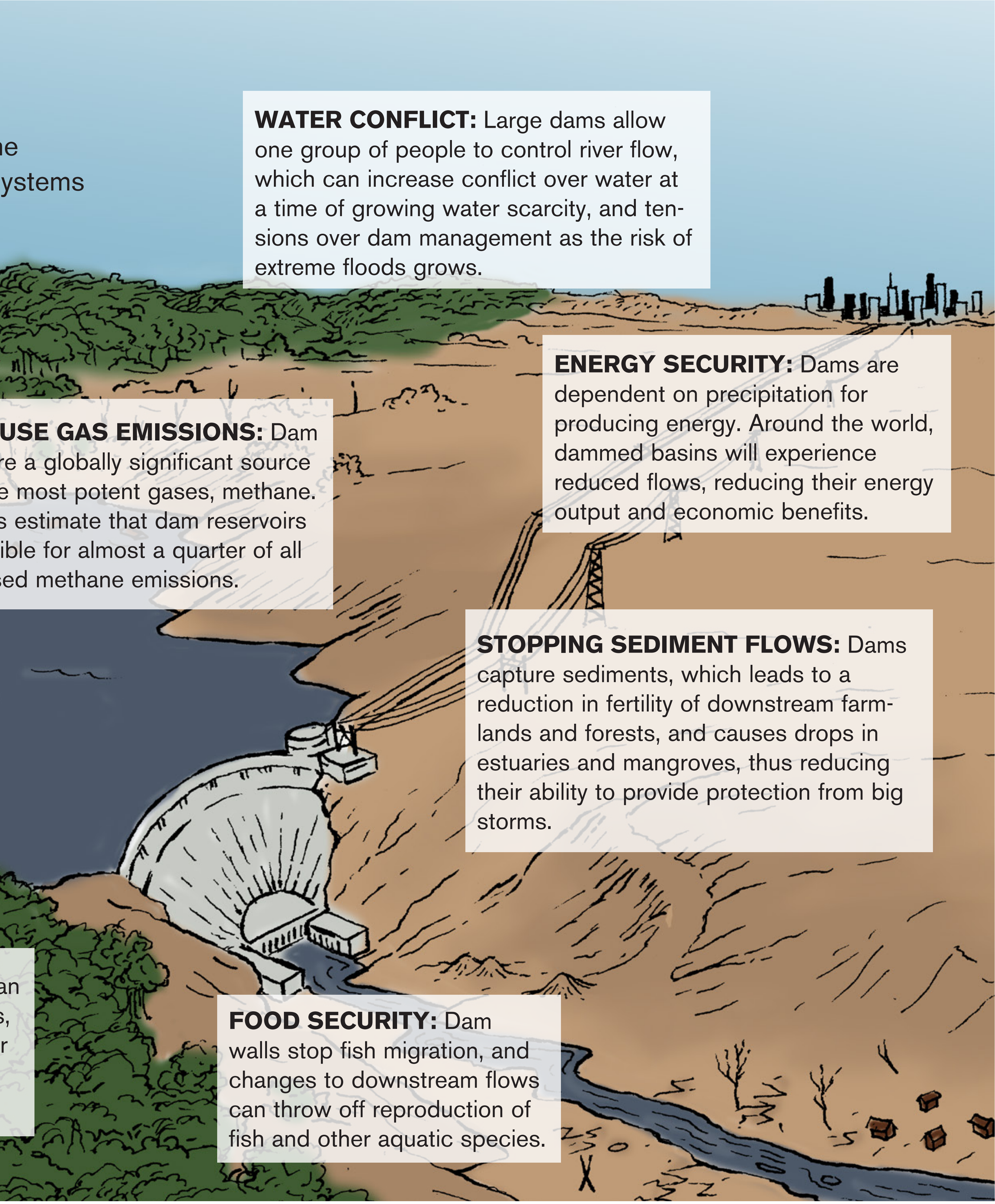
SAFETY: More frequent extreme floods threaten the stability and safe operation of large dams. If dams are "under-designed" for larger floods, the result could be serious safety risks to people living downstream.

HEALTH IMPACTS: Large dams ca
increase some water-borne diseases
such as malaria. They can have othe
health impacts as well, by reducing
water quality and quantity.


ne
ystems
WATER CONFLICT: Large dams allow one group of people to control river flow, which can increase conflict over water at a time of growing water scarcity, and tensions over dam management as the risk of extreme floods grows.
ENERGY SECURITY: Dams are dependent on precipitation for producing energy. Around the world, dammed basins will experience reduced flows, reducing their energy output and economic benefits.
USE GAS EMISSIONS: Dam
re a globally significant source
e most potent gases, methane.
s estimate that dam reservoirs
ible for almost a quarter of all
sed methane emissions.
STOPPING SEDIMENT FLOWS: Dams capture sediments, which leads to a reduction in fertility of downstream farmlands and forests, and causes drops in estuaries and mangroves, thus reducing their ability to provide protection from big storms.
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FOOD SECURITY: Dam walls stop fish migration, and changes to downstream flows can throw off reproduction of fish and other aquatic species.

Regions that depend on melt water from major mountain ranges contain one-sixth of the world's population.

Snowmelt Runoff

Water volume stored in glaciers and snowpack is declining, resulting in decreases in seasonal flows in affected areas. Shrinking glaciers will cause long-term declines in glacial runoff and alpine stream flow during the melting season. This will reduce the hydropower output during the melt season, especially for many Andean and Himalayan countries, as well as the amount of water available for household use, irrigation, and groundwater recharge.

Snowpack, which unlike glaciers accrues and is lost on an annual basis, is very sensitive to temperature and is a major contributor to runoff in alpine regions. Change in the seasonality of runoff due to climate change is becoming more widespread. For instance, in most mountainous regions, snowfall has decreased while rain has increased, leading to lower snowpack accumulation in winter, along with faster spring melting. Runoff is likely to increase at higher latitudes and in some wet tropics, including East and Southeast Asia, and decrease over much of the mid-latitudes and dry tropics, including many areas that are currently water stressed. The combined reduction in runoff and river flow as a result of lower precipitation will negatively affect the production of electricity from hydropower dams.

By 2080, 20% of people will live in areas with increased flood risk.

In addition, the effect of more-rapid snowmelt on potential flooding is a major risk factor for millions of people around the world. Rapid snowmelt can also trigger landslides and debris flows. In combination with specific weather conditions, such as excessive rainfall on melting snow, it may even be a major cause of floods. In Switzerland, snowmelt forecasting is being used as a flood-warning tool to predict snowmelt runoff and potential flooding.[11]

FLOODS AND GLOFS

Climate change has led to a rise in extreme weather events, including higher-intensity hurricanes and heavier rainfall in many parts of the globe. Coupled with rising sea levels, intensifying storms can increase coastal flood damages.

In addition to being deadly for inhabitants in their path, floods can cause a variety of problems, including contaminated drinking water, pollution spills, increased populations of disease-carrying insects and rodents, and disruption of community life and local economies. Floods can also damage critical infrastructure like sewer systems, triggering sewage overflows that can spread into local waters.

More frequent extreme floods also threaten the stability and safe operation of large dams. Dams are designed using historic hydrological variables, such as average annual flow, annual variability of flow, and seasonal distribution of flow. As temperatures warm, however, historic data is increasingly unreliable for dam design. If dams are "under-designed" for larger floods, the result could be serious safety risks to those living downstream of large dams.

The flood risks of large dams are made worse by increasing sedimentation. Larger sediment loads carried by increasingly extreme rainfall can block dam spillways and take up room in the reservoir that could otherwise hold floodwaters.

Many hydropower projects are justified on the basis of providing flood control in addition to energy generation. However, allowing for flood storage means the reservoir must be drawn down to provide flood capture space usually at the same time that water is needed to supply energy. Another problem is that most existing and proposed dams are not designed to handle extreme floods, which are becoming more common in our warming world. This can result in costlier damages than before the dam was built, as more people move into the floodplain and assume it is safer now that a dam exists; when the dam cannot contain the new, larger floods, it can lead to devastation in the now-populated areas.

Floods caused by dam failures and poor management of dams during extreme weather events are already a serious problem in many regions, and are expected to increase. Flood damages have soared in recent decades, despite hundreds of billions of dollars spent on flood control structures. For example, Cameroon is experiencing increasing flooding, which has caused dams to overtop, thus worsening natural flood impacts. In 2012, flood releases from Lagdo Dam resulted in many deaths and huge displacement in downstream Nigeria. Dams are becoming harder to manage as climate change makes rainfall more unpredictable, yet new dams are going to be built that have not been planned with this risk in mind.

GLACIAL LAKE OUTBURST FLOODS

The sudden bursting of glacial lakes, known as glacial lake outburst floods (GLOFs), poses serious risks of flash flooding to downstream communities and ecosystems in some mountainous countries, and for the safety of dams built in these regions. As glaciers melt under a warming planet, they can form large lakes behind temporary dams of ice and rock. When these natural dams collapse, millions of cubic meters of water can be released in massive flash floods.

The Himalayan region – which is experiencing climate change faster than any other region in the world – is currently experiencing a dam boom that could put millions of people at risk from catastrophic floods and dam breaks. The Dig Tsho GLOF in Nepal in 1985 was one of the most devastating in recent history. The bursting of this glacial lake near Mount

India's Himalayan Floods a Manmade Disaster

By Himanshu Thakkar, Director of the South Asia Network on Dams, Rivers and People, Delhi, India

The Northern Indian Himalayan state of Uttarakhand experienced widespread flash floods and landslides in June 2013. At least 1,000 people were confirmed dead, thousands more remain missing, 147 bridges were washed away, and more than 10 hydropower projects damaged or destroyed. One rough estimate put damages at US$50 billion.

Because it is young mountain system, Uttarakhand is inherently vulnerable to natural disasters such as cloudbursts, landslides, flash floods, glacial lake outbursts and earthquakes. Climate change is increasing the frequency of such disasters.

At the root of these floods was a wonton disregard for the "carrying capacity" of this fragile area's natural systems. The human-induced assault included unregulated, unsafe and unplanned infrastructure development along local rivers, including the development of a large number of hydropower projects built in the fragile zone without proper checks and balances.

In the first decade of the new millennium alone, more than 15,000 hectares of forestland have been legally diverted in the state for various projects. More than 1,600 hectares of riverbed mining were given legal sanction in the same period. During this time tourism increased by up to 380%. Uttarakhand has at least 51 existing hydropower projects of various sizes, another 47 under construction and 238 planned. As a post-disaster report from the National Institute of Disaster Management confirmed, all these activities have significant environmental and social impacts that hugely increased the disaster potential of the area.

As Uttarakhand now turns toward rebuilding and rehabilitation, it needs to accept its past mistakes and make urgent amends. Some top priorities should include:

- Initiating cumulative impact assessments and carrying capacity studies in all river basins.
- Putting a stop to hydropower projects that are planned and under construction.

Severe flash floods swept through the Northern Indian state of Uttarakhand in 2013, destroying several hydropower projects including the Vishnuprayag Dam. Photo: Matu Jansangthan

- Demarcating the path of all rivers, declaring no construction zones around them and preparing time-bound plans for the relocation of buildings at risk.
- Ensuring an active disaster-management department that has a key role in decision-making about all new developments.
- Putting in place credible environmental governance and compliance systems along with robust systems for warning, forecasting, monitoring and information dissemination.
- Assessing the vulnerability of infrastructure and people in the changing climate.

This disaster can be taken as a rather costly and tragic wake-up call for Uttarakhand and all Himalayan states and countries. If it is not heeded, what we have seen may turn out to be just a "movie trailer" for the full feature film that is yet to come.

For a full version of this article, see: www.internationalrivers.org/node/8037

Everest caused a huge flood wave that travelled down the valley, killing five people and destroying one hydropower station, damaged many acres of cultivated land, and took out 14 bridges.

In January 2009, the government of Bhutan identified more than 2,600 glacial lakes in the country, of which 25 are considered to be at high risk of bursting, according to Yeshi Dorji of Bhutan's Department of Geology and Mines. While Bhutan is aware of the risk of GLOFs and is improving its early warning system, it is also constructing one of the largest hydropower dams in the region – the 90-meter-high Tala project on the Wangchu River – and has plans for more large dams.[12] These projects could undermine its program to reduce the risks of GLOFs.

DROUGHTS & HIGHER EVAPOTRANSPIRATION

170 cubic kilometers of water evaporates from the world's reservoirs every year.

Many parts of the world are predicted to have less rain, higher temperatures and higher evaporation rates, as well as more severe and frequent droughts, which will have major impacts on food security and livelihoods. High temperatures will mean greater withdrawals by plants and humans, which will lead to a reduction in stream flow. As freshwater becomes scarcer through natural and human withdrawal and drought, and as the sea level rises, salt water will move farther upstream, negatively affecting soils and agricultural production.

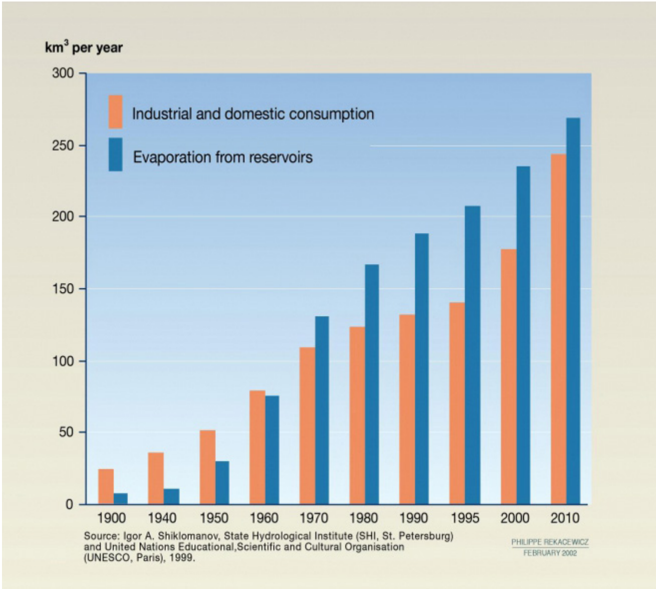

Figure 2: Evaporation from reservoirs compared to amount of water consumed by industry and domestic use. Source: UNESCO, 1999

Changes in evapotranspiration (or the transport of water into the atmosphere from soil, vegetation, and water surfaces) are more difficult to predict. In addition, the amount and/or rate of evaporation from seasonal snowpack and glaciers may be increasing, which means that this water is "lost" to the basin and passes directly to the atmosphere without entering freshwater ecosystems. This will in turn change the amount of runoff.

By 2050, increased water stress will impact land areas twice the size of those areas experiencing increased water availability.

For instance, a 2006 climate study from the University of Cape Town shows that even a small decrease in rainfall in southern Africa could cause a drastic reduction in river flows. The study revealed that a temperature rise of 3-6°C will reduce the water available to southern Africa by as much as half. The authors of the study note that "it will be like erasing large sections of the rivers off the map."[13] Currently, climate activists and practitioners are pushing to keep temperatures below a 2°C rise in recognition of the disastrous existing impacts and potential future consequences of further temperature increases.

Increased evaporation will reduce water storage and electricity generation for all types of dams, but especially those with large, shallow reservoirs. About 170 cubic kilometers of water evaporates from the world's reservoirs every year, more than 7% of the total amount of freshwater consumed by all human activities. To give just one example from a water-stressed country, the annual average of 11.2 cubic kilometers of water evaporated from Egypt's High Aswan Dam reservoir is around 10% of its storage – roughly equal to the total withdrawals of water for residential and commercial use throughout Africa.[14]

HYDROPOWER VULNERABILITY

Hydropower generates almost one-fifth of the world's electricity – though in some nations, nearly all electricity comes from hydropower. Of the world's 50,000 large dams, about 5,000 are strictly for producing hydropower. Brazil, Canada, China, and the United States account for over half of the world's hydropower capacity.

However, climate change means that an over-reliance on hydropower can lead to serious risks to energy security and a nation's economy, since unpredictabil-

Glacial lakes in Bhutan. Photo: NASA

ity in precipitation coupled with extreme weather events will make hydropower an increasingly risky business (see maps, page 19). Energy shortages can impact the delivery of health services, businesses and livelihoods, and education, all of which can in turn decrease a community's resilience to other climate change impacts.

In recent decades, drought has already had a major impact on energy production in many regions where large hydropower dominates. In some places, electricity output was reduced by as much as half. Dozens of developing countries are highly dependent on hydropower, yet it is in these places where the bulk of new large hydro capacity is planned, including Brazil, Ecuador, Ethiopia, China and Southern Africa. For instance, most of the Nile Basin states get more than 70% of their electricity from hydro. The Intergovernmental Panel on Climate Change (IPCC) notes that there has already been "a reduction in run-off of 20% between 1972 and 1987" in the Nile and "significant interruptions in hydropower generation as a result of severe droughts."[15]

These changes illustrate an important concept in hydropower design known as *stationarity,* which is rooted in the idea that future hydrology is predictable and can be based on past hydrological records, and that water-dependent infrastructure projects can be designed to be reliable. Climate change and human alterations to the hydrological cycle have led to the "death of stationarity" and an end to reliable predictions of future flow regimes. This means that in order to effectively adapt to climate change, we will need innovative approaches to water management that are dynamic and can respond with flexibility to all types of events.

A tangle of electrical wires in Raipur, India. India gets about 20-25% of its electricity from hydropower dams. Hydropower production fell by 19% between 2011 and 2012 due to low rainfall, contributing to one of the world's largest blackouts in 2012. Photo: Phil Putnam

Climate Research Reveals Risks in the Zambezi Basin

Currently, 13,000 megawatts of new large-dam hydro is proposed for the Zambezi River in southern Africa, at a time when the river will experience worse droughts and more extreme floods due to climate change. Dams being proposed and built now will be negatively affected, yet energy planning in the basin is not taking serious steps to address these huge hydrological uncertainties. The result could be dams that are uneconomic, disruptive to the energy sector, and possibly even dangerous.

International Rivers commissioned a hydrologist to analyze the hydrological risks to hydropower dams on the Zambezi River because the region's dam-building agencies had not done so, even though they were moving forward with a number of new dams.

The report, A Risky Climate for Southern African Hydro, revealed that the designs for two of the bigger dam projects proposed for the Zambezi – Batoka Gorge and Mphanda Nkuwa – are based on historical hydrological records and have not been evaluated for the risks associated with reduced flows and more extreme flood and drought cycles. Under future climate scenarios, both dams are unlikely to deliver expected services over their lifetimes. Similarly, they have not been designed for more frequent extreme floods. If dams are "under-designed" for larger floods, the result could be serious safety risks to millions of people living in the basin.

Existing dams on the Zambezi have profoundly altered the hydrological conditions important for maintaining downstream livelihoods and biodiversity. The ecological goods and services provided by the Zambezi, which are key to enabling societies to adapt to climate change, are under grave threat. These services are not being properly valued in planning for large dams in the basin.

The report recommends a series of steps to address the coming storm of hydrological changes, including changes to how dams are planned and operated. Its findings are currently being used by civil society groups in the region.

Download the report here:
www.internationalrivers.org/node/7673

Reservoir Emissions Fuel Climate Change

A growing number of scientific studies indicate that reservoirs, especially in the tropics, are a significant source of global greenhouse gas pollution. Brazilian researchers estimated in 2007 that methane from dams is responsible for around 4% of human-caused climate change. In addition, legal and illegal logging at dam sites to clear the area for inundation also removes important carbon sinks.

Where Do the Emissions Come From?
Dam reservoirs emit greenhouse gases, primarily methane (CH_4) and carbon dioxide (CO_2). Measurements have been taken at dozens of reservoirs, and all were shown to emit such gases. Gases are emitted from the surface of the reservoir, at turbines and spillways, and for tens of kilometers downstream. Emissions are highest in hot climates. Hydro plants in the tropics with large reservoirs relative to their generating capacity can have a much greater impact on global warming than fossil fuel plants generating equivalent amounts of electricity (see Figure 3).

The "fuel" for these emissions is rotting organic matter from the vegetation and soils flooded when the reservoir is first filled. The carbon in the plankton and plants that live and die in the reservoir, the detritus washed down from the watershed above, and the seasonal flooding of plants along the reservoir fringes, all ensure that emissions continue for the lifetime of the reservoir. Emission levels vary widely between different reservoirs depending upon the area and type of ecosystems flooded, reservoir depth and shape, the local climate, and the way in which the dam is operated. For instance, China's reservoirs are often deep but sludge-filled, while Brazil's reservoirs are shallow and in a tropical zone. Both cases can lead to high emissions.

Today, global estimates continue to be variable, partly because almost no information is available for the subtropics and especially from Asia where, according to a Toulouse University study, two-thirds of dams are located. Comprehensive studies to analyze a dam's life-cycle emissions are more important now than ever before, partly because millions of dollars in carbon credits are being sought to support hydropower projects.

In Laos, for instance, the construction of reservoirs and related deforestation has led to the country shifting from being a carbon sink to a net emitter of greenhouse gas emissions (GHGs), according to the EU Global Climate Change Alliance. Preliminary research on reservoir emissions at Nam Theun 2 and a 2011 study on the Nam Ngum and Nam Leuk reservoirs showed them to be significant sources of methane, which is 25 times more potent than carbon dioxide over 100 years. While reservoir emissions studies are limited in Southeast Asia, the study of the Nam Leuk reservoir revealed that "GHG emissions are still significant 10 years after impoundment" and that the emissions values were comparable to other tropical reservoirs such as those in Brazil, whose reservoirs have been studied the most.

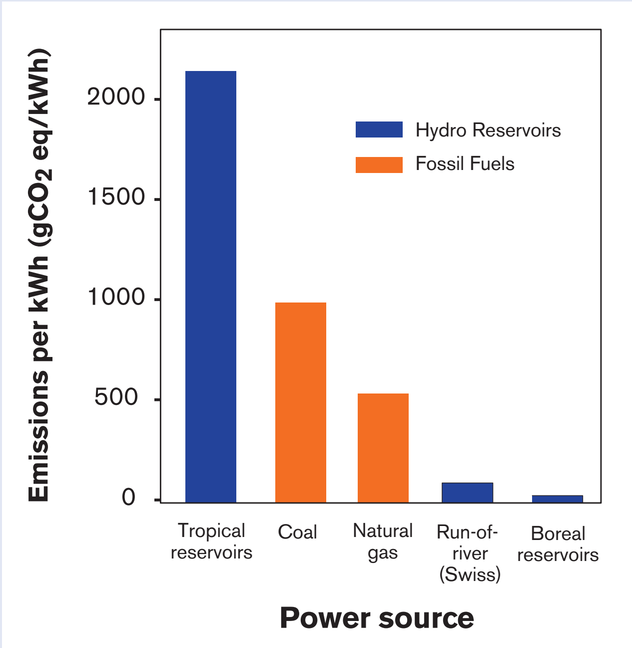

Figure 3: Comparison of emissions per kilowatt-hour for various power sources. The tropical reservoir bar represents the "reservoir net" average emissions from three Brazilian reservoirs. The boreal reservoir bar represents the gross average emissions from five Canadian reservoirs. Run-of-River bar refers to the Wohlensee reservoir in Switzerland. Source: "Dirty Hydro: Dams and Greenhouse Gas Emissions," 2008, International Rivers

All new dam designs nowadays need a thorough GHG emissions assessment. Developers should choose low emissions designs. Dams likely to emit as much GHG as a conventional fossil fuel plant should not be developed. Biomass in the reservoir should be removed before filling. More than 27 European nations and Australia, and many cities and states (for example, Vancouver, Canada) now mandate a charge for GHG emissions. A hydropower project must internalize its reservoir emissions in project design and cost/benefit analysis. The World Bank and other global institutions need to create a global agreement for the "Polluter Pays Principle," or a GHG emissions tax.

For more information, see:
www.internationalrivers.org/node/2374

Maps of Climate Risks & Dams

Around the world, climate change is melting snowpack and glaciers that feed major rivers, contributing to drought-caused hydroelectricity blackouts, and threatening the water supply and river resources of billions of people. Major rivers worldwide have experienced dramatic changes in flow due to dams decreasing their natural ability to adjust to disturbances. For a regularly updated online version of this map, see: www.internationalrivers.org/node/3502

Even the most optimistic climate models for the second half of this century suggest that 30-70% of ***California's*** *Sierra Nevada snowpack will disappear. California's 1,000 dams will face the twin challenges of excessive high flows, which could make them potential hazards to millions living below them; and diminishing flows from increasing drought.*

Climate scientists at Oregon State University project a 56% drop in water stored in peak snowpack in Oregon's ***McKenzie River*** *watershed by mid-century. The water drop will affect hydropower, agriculture, ecosystems and industry. More than 70% of Oregon's population lives in the watershed.*

A study by Queen's University reveals that the ***Winnipeg River Basin*** *could be hit by severe droughts in a climate-changed world. This could set back hydropower generation for Manitoba Hydro, which operates six dams on the river.*

Climate scientists predict 15% less water in the ***Colorado River Basin*** *by mid-century, at the same time the basin is expected to see its population increase by a third or more. The river is already over-allocated among seven US states and Mexico, and a long drought left the two biggest reservoirs at Hoover and Glen Canyon dams only half full, causing tensions among competing users. The Colorado Delta in Mexico is sinking as a result of decreased sediment delivery, which increases risk from storms.*

Costa Rica *gets about 80% of its electricity from hydropower, and 10% of the nation's power comes from one large dam (Angostura). Power shortages have been increasing since the rainy season started to come later and with less rain. The nation intends to build more hydropower plants, but also hopes to diversify the energy sector, including more wind, solar and geothermal.*

Hydropower supported by ***Andean*** *glaciers supplies 81% of Peru's electricity, 73% of Colombia's, 72% of Ecuador's, and 50% of Bolivia's. A recent study predicts significant economic losses from climate-induced glacial retreat.*

Brazil's *hydro-dependent energy sector is at grave risk of climate change, according to the study "The Vulnerability of Energy Systems to Climate Change." The study found that by 2040, Brazil will see significant reductions in hydropower production as a result of a dryer climate, and will need to invest US$503 billion to counter these impacts.*

About 20% of Europe's electricity comes from hydropower. However, the generating potential of hydropower plants is projected to decrease by 6% by the 2070s. Glacial melt from the **Alps** *has been increasing in the past half-century, which means countries like Switzerland that rely on steady glacial runoff for hydropower will see a major strain on electricity production in the long-run if better alternatives are not found.*

Drought lowered hydropower output in **Romania and Bosnia** *in 2012. Production in Bosnia was 42% below target, according to media reports. Bosnia produces about 40% of its energy from hydropower, and normally exports power to neighbors. In recent years, the region has been hit with multiple life-threatening floods.*

West Africa's **Volta River Basin** *is expected to suffer severe declines in water availability in coming years, which could deprive millions of people of food and hydropower, according to a study by the International Water Management Institute. By 2050 current hydropower production could be cut in half, the study found.*

The waters of the **Blue Nile** *are critical to millions of mostly poor people in Egypt, the Sudans, and Ethiopia. Increasing water extraction, damming in Ethiopia and the effects of climate change could significantly reduce water flowing into Egypt, raising tensions over the shared river. Runoff is expected to decrease even if precipitation increases, due to increased evaporation from higher temperatures, affecting both hydropower generation and irrigated agriculture. Experts believe the losses in hydropower alone will cost millions of dollars per year.*

Kenya *has historically been highly dependent on hydropower for its electricity. After withering droughts led to blackouts in 2009-2011, the government began to develop its huge reserves of geothermal energy. Kenya is now Africa's leading user of geothermal, and has begun to exploit wind power as well.*

Tanzania's *hydropower dams have been running on empty in recent years, causing power shortages and blackouts, and bringing unexpected costs for emergency power plants. The East African nation has developed a world-class environmental flows program for the some of its major river basins, as part of a growing focus on climate adaptation.*

Researchers predict that a 3-6°C increase in temperature in the next few years will result in a 30-50% reduction in water availability in **Southern Africa***, a 15-35% reduction in agriculture production across Africa, and 300 million more people at risk of coastal flooding each year. The World Bank says even a 2°C increase could mean that Africa could see permanent reductions in per capita water consumption of 4-5% per year.*

Most glaciers on the ***Tibetan plateau*** *are retreating rapidly, according to a 2012 study based on 30 years of measurements of more than 7,000 glaciers. Seasonal snowpack is in widespread decline with warmer winters (more rain and less snow) and earlier melt dates. Rivers originating in the Tibetan plateau provide water for millions living downstream. China is tapping Tibet's rivers for hydropower and water – controversial plans that are of even greater concern in a time of unpredictable flows.* ***China's*** *three major deltas, the Yellow, the Yangtze, and the Pearl, are all in the world's top 11 highest risk deltas as a result of rising sea levels and a reduction of sediments due to extensive dam building.*

The ***Himalayas'*** *rapidly melting glaciers and reduced snowpack threaten to reduce water flowing into the Indus, Ganges, and Brahmaputra rivers, which support half a billion people. Hundreds of new hydropower dams are proposed in the Himalayas, with little attention being paid to the climate risks. Thankfully, a new three-year study by the International Centre for Integrated Mountain Development (ICIMOD) began in 2013, in order to assess the current state of the Hindu Kush Himalayas, and to make recommendations on how best to safeguard and develop it.*

Pakistan's ***Indus River****, which flows from the Himalayas, is expected to see reduced flows of up to 40% by 2050 due to reduced snowfall and glacial melting. A cycle of heavy monsoons and worse droughts is also predicted, which will adversely affect food security.*

Bangladesh's *location on a low-lying delta with a very high population density makes it one of the countries most at risk of climate change. Dams that hold back water and sediment in the upper reaches of the Ganges-Brahmaputra-Meghna basins increase Bangladesh's risk of waterlogging and flooding. Rising sea levels and increasing risk from large floods have interrupted agriculture and challenged water resources, health, and energy supply, not to mention risking lives and creating legions of climate refugees each year.*

Changes to ***India's monsoon*** *are expected to trigger more extreme storms that will jeopardize the economics and safety of hydropower dams, as well as billions of lives. Sinking deltas from dams that hold back sediment also increase the risk of flooding in the region. Recent analysis reveals that India's large dams are responsible for 19% of the country's total global warming impact,[16] making them the region's largest global warming contributor.*

Vietnam's low-lying ***Mekong Delta*** *is one of the world's most vulnerable to climate change. Rising sea levels, growing water shortages, and increasing saltwater intrusion all threaten the delta's abundant agriculture and fisheries, and a fifth of Vietnam's population. Plans for extensive dam development upstream on the Mekong could block sediment loads that nourish the delta's soils and rebuild land lost to coastal erosion and natural subsidence.*

Australia's *two largest rivers, the Murray and the Darling, have been extensively dammed and dewatered, reducing average flows by nearly three-quarters. The desiccation of the river system has seen extensive loss of floodplain forests and impacts on pastoralists, fisheries and tourism. The river system is increasingly saline, endangering the water supply for over two million people. The Murray-Darling Basin's location is believed to be particularly vulnerable to climate change-induced drying. The Australian government has an AU$14.7 billion Basin Plan to return up to 30% of the previously diverted water to the rivers, but this may not be enough, especially if the climate dries further.*