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POWER OF THE RIVER: INTRODUCING THE GLOBAL DAM TRACKER (GDAT)

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Executive Summary

Dams are a major source of electricity globally, with hydropower generating 16 percent of the world's total electricity and 71 percent of all renewable electricity in 2016. Many developing countries possess great untapped hydropower potential. Sub-Saharan Africa, for example, is estimated to have tapped less than 8 percent of its hydropower potential. Proponents of dams praise them as a source of low-carbon electricity, estimated to reduce annual emissions by about 2.8 billion tons of carbon dioxide equivalent. Dams also provide wide-ranging benefits in terms of flood control, irrigation, navigation, and job creation. But harnessing the power of the river comes with concentrated costs, from fragmenting the river system and destroying natural habitat to triggering ecological hazards and displacing millions of people. As the world is undergoing an energy system transformation toward renewable sources to combat climate change and meet emission reduction targets outlined in the Paris Agreement, understanding the costs and benefits of dam construction has important policy implications.

In this project, the authors compiled a global geospatial database of dams, the GDAT, to enable rigorous research on the costs and benefits of dam construction. The project was motivated by the absence of a comprehensive, reliable, real-time, easy-to-use database on global dam construction. Such data could allow policymakers to make informed decisions on the use of hydroelectric power in the future, based on systematic evaluations of the costs and benefits of hydroelectric dams along the dimensions of energy access, climate change mitigation, water supply, ecological preservation, and population displacement.

Below is a summary of findings:

- Globally, the authors identify 36,222 dams that are spatially concentrated along major river basins in Asia, North America, South America, and Europe.

- Compared to two widely used datasets, AQUASTAT and Global Reservoir and Dam (GRanD), GDAT has not only 144 percent and 419 percent more dam observations, respectively, but also more comprehensive attribute information, such as completion year, geographic location, main purpose, and reservoir and generation capacity.
- Dams are used for a variety of purposes, with considerable heterogeneity across continents. Worldwide, dams are mainly used for irrigation and hydroelectricity, representing 34 percent and 25 percent of the data, respectively.
- There are notable differences in the distribution of dam completion year across continents. While most developed countries in North America, Europe, and Oceania have witnessed a decline in dam construction since the 1970s, developing countries in Africa, Asia, and South America are experiencing a continued increase in the number of dams currently planned or under construction.

GDAT makes three important contributions:

- First, to the best of the authors' knowledge, no prior effort has been made to consolidate official records with existing datasets such as AQUASTAT, GRanD, and World Resources Institute (WRI). By collecting and compiling primary data from administrative sources and secondary data from existing databases, the authors have offerred the most comprehensive geo-referenced data on worldwide dam construction to date.
- Second, through extensive cross-checking and manual validation, the authors fill in important data gaps on key attributes and correct erroneous observations in previous datasets.
- Third, existing datasets are often static and not frequently updated. Efforts are underway to develop a framework for making the data collection and compilation process easily reproducible, so that it can be updated on a reasonable time interval to facilitate intertemporal analysis. Upon publication of academic research papers, the authors are planning to release the entire dataset and documentations to the public, free of charge.

Introduction

Dams are a major source of electricity globally, with hydropower generating 16 percent of the world's total electricity and 71 percent of all renewable electricity in 2016 (World Energy Council 2016). Many developing countries possess great untapped hydropower potential. Sub-Saharan Africa, for example, is estimated to have tapped less than 8 percent of its hydropower potential. Proponents of dams praise them as a source of low-carbon electricity, estimated to reduce annual emissions by about 2.8 billion tons of carbon dioxide equivalent (CO_2e). Dams also provide wide-ranging benefits in terms of flood control, irrigation, navigation, and job creation. But harnessing the power of the river comes with concentrated costs, from fragmenting the river system and destroying natural habitat to triggering ecological hazards and displacing at least 40 million people globally (World Commission on Dams 2000).

In this project, the authors compiled a global geospatial database of dams, the GDAT, to enable rigorous research on the costs and benefits of dam construction and provide a reliable data source for policy evaluation. The project was motivated by the absence of a comprehensive, reliable, real-time, easy-to-use database on global dam construction. Such data could allow policymakers to make informed decisions on the use of hydroelectric power in the future, based on systematic evaluations of the costs and benefits of hydroelectric dams along dimensions of energy access, climate change mitigation, water supply, ecological preservation, and population displacement.

In this briefing paper for the Columbia University Center on Global Energy Policy (CGEP), the authors will introduce GDAT by first showing its spatial and temporal coverage and then highlighting its improvement over existing datasets. During the CGEP funding period, the team focused on collecting data from Asia, South America, and Africa—three continents that have lower data transparency but are of high importance in terms of projected future dam construction.

Globally, the authors identified 36,222 dams that are spatially concentrated along major river basins in Asia, North America, South America, and Europe. Compared to two widely used datasets, AQUASTAT and GRanD, GDAT has not only 144 percent and 419 percent more dam observations, respectively, but also more comprehensive attribute information, such as completion year, geographic location, main purpose, and reservoir and generation capacity. Dams are used for a wide variety of purposes, with considerable heterogeneity across continents. Worldwide, dams are mainly used for irrigation and hydroelectricity, representing 34 percent and 25 percent of the data, respectively. In South America, Africa, and Asia, irrigation is the most common main purpose, whereas in North America, Europe, and Oceania, it is flood control, hydroelectricity, and water storage, respectively. There are notable differences in the distribution of dam completion year across continents. While most developed countries in North America, Europe, and Oceania are witnessing a decline in dam construction since the 1970s, developing countries in Africa, Asia, and South America are experiencing a continued increase in the number of dams currently planned or under construction.

The construction of dams, especially megadams and those that are transboundary, has wide-ranging social, environmental, and geopolitical implications. For instance, upstream dams have contributed to the drying up of wetlands in the Sahel region in Western Africa, which could have devastating consequences for a region already resource constrained and poverty ridden (Salkida 2012). Such environmental change can have potentially major adverse consequences, including the disappearance of fisheries and water sources. The resulting loss of livelihoods displaced populations and encouraged many to seek harmful alternatives, such as joining terrorist organizations like Boko Haram or immigrating to Europe via dangerous human-smuggling networks (Pearce 2017). Similarly, upstream dams in Turkey and Iran have reduced the water flow of major rivers to neighboring downstream countries, such as Iraq and Syria, and have raised geopolitical concerns in an already conflict-prone region. In addition to altering the ecological landscape by diverting water away from downstream locations, dams also pose a threat to fisheries and disrupt the livelihood of communities by forcing people to move out of their homes to make way for the rising water level in the reservoir.

GDAT makes several important contributions. First, to the best of the authors' knowledge, no prior effort has been made to consolidate official records with existing datasets such as AQUASTAT, GRanD, and WRI. By collecting and compiling primary data from administrative sources and secondary data from existing databases, the authors have constructed the most comprehensive geo-referenced data on worldwide dam construction. Sections III and IV present a global overview of GDAT and then discuss each region and its relevant current policies in detail. Second, through extensive cross-checking and manual validation, the authors fill in important data gaps on key attributes and correct erroneous observations in previous datasets. Section V demonstrates the improvements in data quality by comparing the coverage of key attributes, including location, completion year, and installed capacity, between the authors' database and other existing datasets. Third, existing datasets are often static and not frequently updated. Efforts are underway to develop a framework for making the data collection and compilation process easily reproducible, so that it can be updated on a reasonable time interval to facilitate intertemporal analysis. Upon publication of academic research papers, the authors are planning to release the entire dataset and documentations to the public, free of charge.

Gaps in Existing Data

The need for worldwide data on dam construction and characteristics to inform policy is clear. Existing data on dams is sparse, scattered, and difficult to use. Some countries, such as India, have national dam registries, but they are poorly documented and difficult to access. The Columbia University Center for International Earth Science Information Network (CIESIN) database on dams only contains information on a small number of very large dams, has limited information on the timing of construction, and is out of date (2011). The Data Basin website contains information on dams under construction, but the dataset is also out of date (2009) and lacks geospatial detail. By consolidating these existing data sources and collecting new primary data, the authors endeavored to create the most comprehensive global dataset on dams with high spatial and temporal resolution to inform policy through rigorous research and to connect the public through outreach, education, and communication.

For domestic policymakers, international organizations, domestic advocacy groups, and nongovernmental organizations (NGOs), the lack of an up-to-date global database with fine geospatial detail is a severe hindrance. Much of policymaking is done through comparison. States adopt policies to catch up with, or avoid the pitfalls of, policies adopted in other states. Journalists and NGOs rely upon data to monitor and report on abuses and mismanagement. Domestic advocacy groups need to know about planned dam projects to influence the policy system. The database is critical in all of these sectors.

From an academic perspective, compared with the knowledge about the flow, development, and spread of fossil fuel projects, the baseline data available on hydropower is lacking. This is especially unfortunate as the world is currently experiencing a global boom in dam construction (Zarfl et al. 2015, 161–170). Yet, against the backdrop of this boom is a notable gap in the knowledge on how to quantify the environmental, socioeconomic, and geopolitical impacts of dams. Most studies have looked either at particular dam projects (Tilt, Braun, and He 2009) or at major dam projects within a particular country (Fearnside 2014, 2016; Wang et al. 2013). These studies tend to be too context specific to be useful for broader program evaluation purposes. In addition, information is scarce on the impacts of smaller dams, which have been increasing in popularity globally, and studies that cover dams in multiple countries are rare. The lack of rigorous and comprehensive studies to date is in part due to limited data availability on a global scale. Thus, the authors' dataset would cover a critical niche in the academic literature and allow a dramatic expansion of the comparative literature on dams worldwide.

Existing information on dams and their impacts is often contained in official records scattered across a number of websites (when it is digitally published at all) and geographic information system maps of water-flow patterns. Consolidating this information is quite labor intensive and requires a range of skill sets. In this project, the authors created a comprehensive dataset that surpasses the scope of existing widely used global datasets. In particular, the authors collected extensive primary data from governments and NGOs, examined institutional backgrounds to validate records on the design features of dams, geo-referenced the locations of dams and their corresponding reservoirs, and compiled a globally consistent database with detailed temporal information on when the dams were proposed, built, or completed.

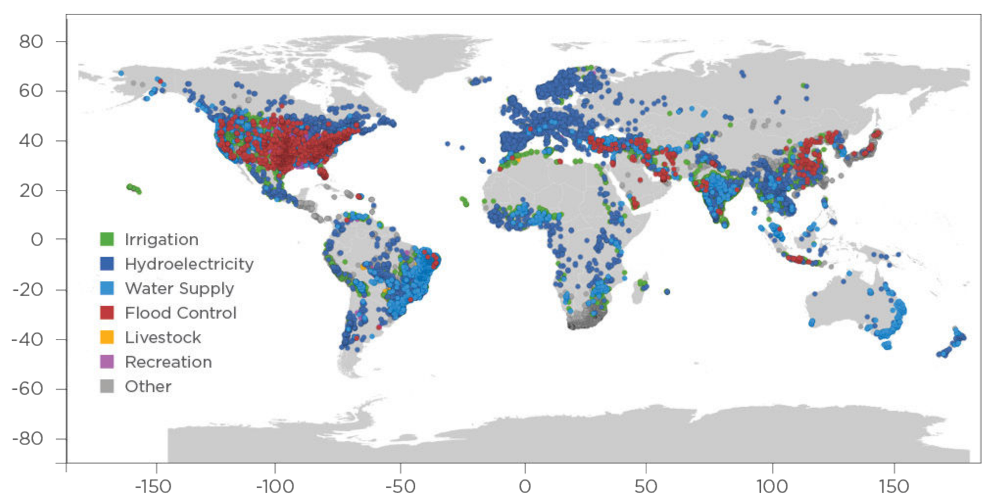
Global Overview

Globally, 36,222 dams were identified that are spatially concentrated along major river basins in Asia, North America, South America, and Europe (figure 1 in appendix C). Asia has the highest number of dams completed to date with 10,138 dams, or 28 percent of worldwide dam construction. North America and South America also have significant hydropower presence, representing 26 percent and 21 percent of the global dam count, respectively, as shown in figure 1. In terms of installed capacity, Asia and South America account for 50 percent and 20 percent of the global total installed capacity, respectively, while Europe and North America account for 18 percent and 9 percent, respectively.

There are notable differences in the distribution of the year when dams were completed across continents. While most developed countries in North America, Europe, and Oceania have been witnessing a decline in dam construction since the 1970s, developing countries in Africa, Asia, and South America have been experiencing a continued increase in dam construction. Most notably, the Yangtze basin in China, the Ganges-Brahmaputra basin in South Asia, and the Amazon basin in South America have a large number of dams currently planned or under construction (Zarfl et al. 2015, 161–170).

Location

Figure 1: World dams by location



Year of Completion

Figure 2: Distribution of dam completion year by continent

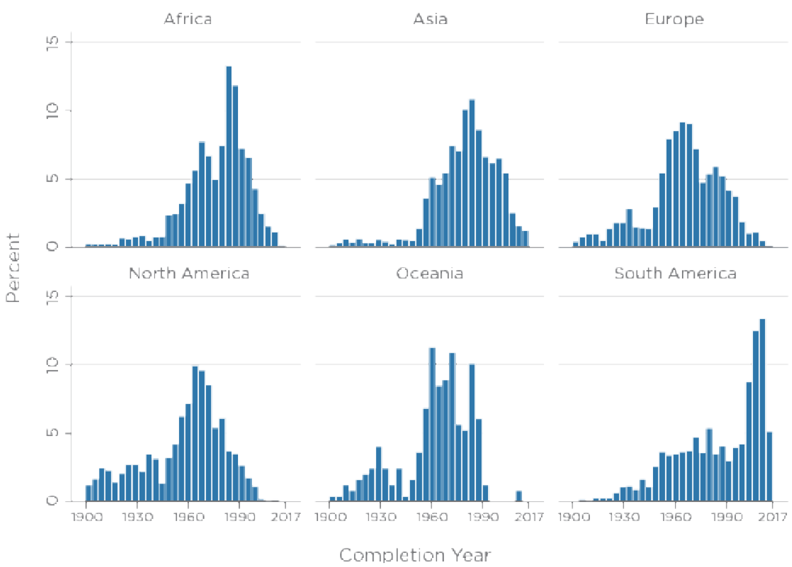
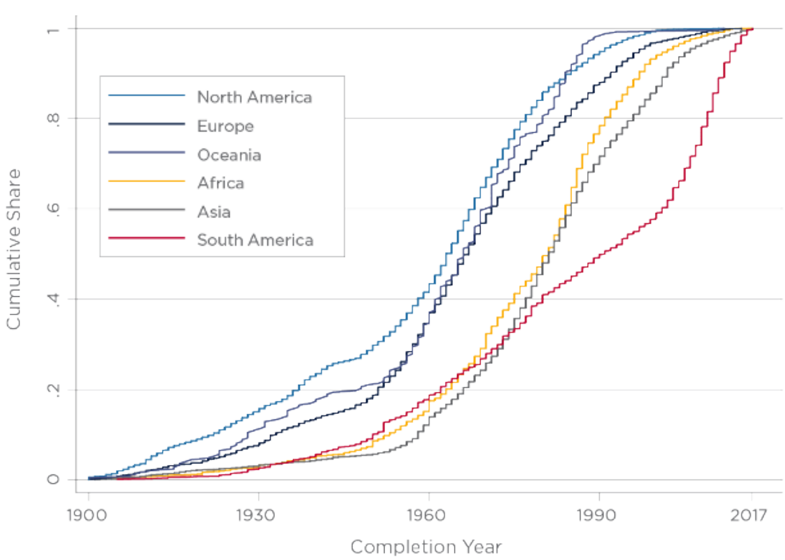
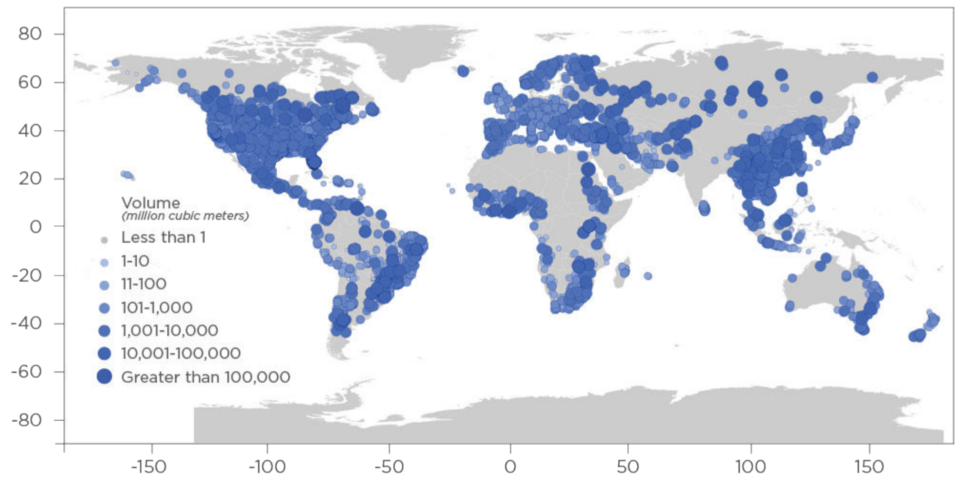


Figure 3: Cumulative distribution of dam completion year by continent



Reservoir Capacity

Figure 4: World dams by reservoir capacity



Purpose

The most common main purposes included in GDAT are irrigation and hydroelectricity, representing 34 percent and 25 percent of the data, respectively (figure 5). The "other" purpose includes unspecified, as well as navigation, pollution control, water storage, flow regulation, and water storage, which each represent less than 0.1 percent of the data. The 29 percent of dams with main purpose classified as "other" were predominantly identified from primary sources with limited-to-no information on the dam usage.

In South America, Africa, and Asia, irrigation is the most common main purpose of dams (figure 6). The most common main purposes in North America, Europe, and Oceania are flood control, hydroelectricity, and water storage, respectively. The number of dams shown under each main purpose reflects the available primary and secondary sources used in the data collection. For example, Europe's high percentage of dams used for hydroelectricity in the data is due to the fact that all of the data was collected from the WRI's Global Power Plant Database. Additional sources will need to be consulted in order to provide a more complete representation of the main purposes of dam construction by region, particularly for North America, Europe, and Oceania.

Figure 5: Distribution of main purpose of dams

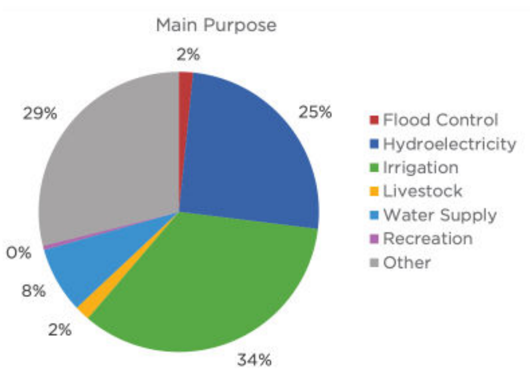
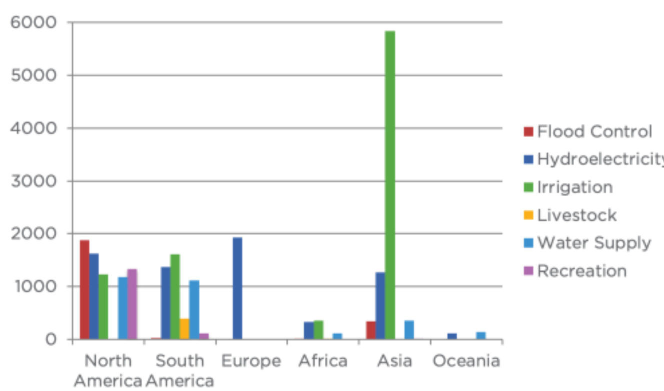


Figure 6: Percentage of main purpose of dam construction, shown by region

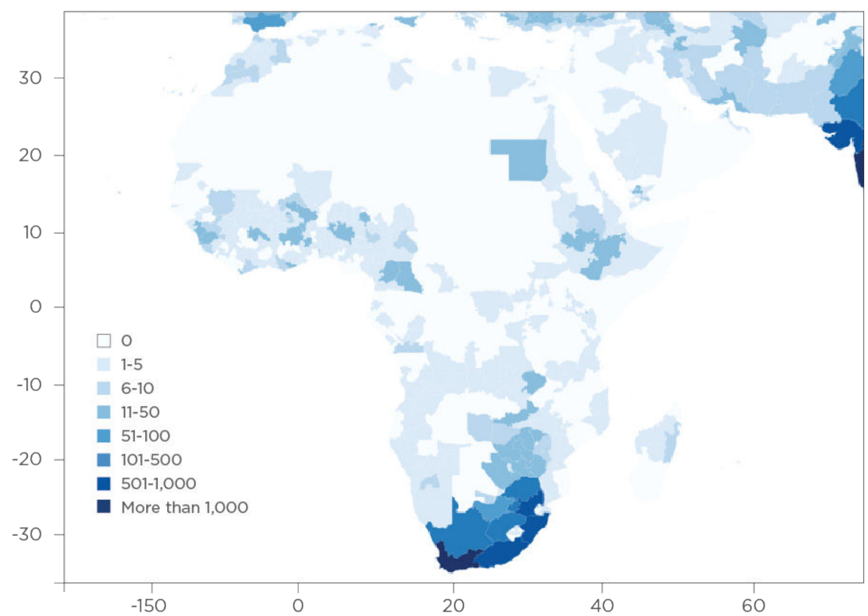


Region Highlights

The research conducted for GDAT over the CGEP funding period (Fall 2017–Spring 2018) focused primarily on data collection for Africa, Asia, and South America. Data are compiled from a number of existing international databases, government sources, and NPOs, as well as using the Google Earth location program. While more comprehensive than prior international datasets, more data-collection and data-compilation work is necessary for certain countries, due to the scarcity of published or available data. Data for countries in Europe, North America, and Oceania are mainly obtained from existing international databases, but because these continents were not the focus of the project, there is a need for further sorting, data collection, and verification to refine the datasets for these continents to improve their coverage and accuracy.

Africa

Figure 7: African regions based on count of geolocated dams

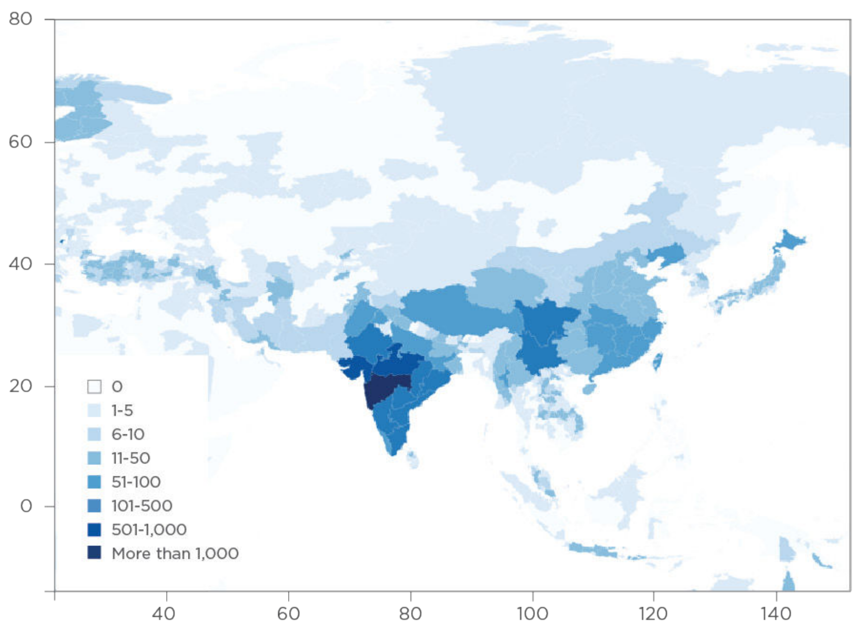


The vast majority of dams in Africa are concentrated in Sub-Saharan Western Africa (Niger river basin), Southern Africa, the Nile river basin, and Morocco. South Africa alone has published information for over 4,000 dams. Among the largest dams in Africa are the Aswân High Dam in Egypt, whose reservoir (Lake Nasser) can hold roughly 132 km3 of water, and the Akosombo Dam in Ghana, with a reservoir that is capable of holding 148 km3 of water and which covers more than 3 percent of Ghana's land area. In addition to the dams on the continent itself, small dams are also present on the small island nations of Cape Verde and Mauritius. Most dams in Africa are hydroelectricity, irrigation, or water supply dams.

The large number of dams shown in South Africa is mainly due to the availability of published data from the South African government. For much of the rest of the continent, the predominant databases used were AQUASTAT and GRanD. Other than South Africa, the rest of the continent has a relatively small number and low density of dams compared to the rest of the world based on available data. Nevertheless, many large hydropower projects are currently being planned, including nearly 150 planned projects that are being tracked by International Rivers. Many large dams are funded by China, which, according to International Rivers, committed more than $3 billion to dam construction in Africa between 2001 and 2007 (Hathaway 2010). Policy drivers such as China's Belt and Road Initiative have been channeling more funds from China to large infrastructure projects in Africa, such as the Kafue Gorge Lower dam in Zambia, the Gilgel Gibe III Dam in Ethiopia, and a $5.8 billion hydropower project in Nigeria that involves four dams (Mongalvy et al. 2018).

Asia

Figure 8: Asian regions based on count of geolocated dams



Based on collected data, most dams in Asia are concentrated in India and Eastern China; India alone has over 4,000 dams, while China has more than 1,000. Japan, Turkey, Iran, and Southeast Asia each have more than 500 dams.

Information about dams in India was collected from the India Water Resources Information System (WRIS), a database that is maintained and funded by various government departments in India involved in space research and water resources. However, reservoir volume data are not provided by the WRIS, and, hence, are not currently available in GDAT for dams in India.

The largest concentrations of dams in India can be found in the central-western part of the country. Most dams are small-scale irrigation dams, but there are also significant numbers of hydroelectric and water-supply dams scattered throughout the central-western parts of the country. The northern and northwestern parts of the country (Rajasthan, Delhi, Uttar Pradesh, Bihar), where the elevation is flatter and lower than the central and southern parts, have a significantly lower density of dams. There are very few dams in the Indo-Gangetic Plain in the northeastern part of the country, as well as in the Thar Desert in Rajasthan.

Dams in the GDAT database for China were compiled from a number of nongovernmental sources: AQUASTAT, GRanD, International Rivers, and the Consultative Group for International Agricultural Research (CGIAR). While the Ministry of Water Resources of the People's Republic of China maintains a database on dams in China, it is not released to the public. Hence, even though the GDAT database has compiled more than 1,000 dams in China, the number is expected to be higher, given that many small-scale dams might be missing from the database. Most dams in China are located in Sichuan and Yunnan, two provinces with high elevation and a number of fast-flowing rivers. Southern China and the Yangtze basin have more dams than Northern China, and dams are mostly concentrated in mountainous areas—there are no dams in the North China Plain. The country has a large number of flood control dams relative to surrounding countries and regions.

There is an especially high density of dams on the watersheds of the upper Yangtze, upper Mekong, and upper Salween rivers, which collectively form the Three Parallel Rivers biosphere reserve. Many of these dams are planned, under construction, or canceled. Being cross-border rivers, dams on the Yangtze, Mekong, and Salween rivers are extensively tracked by international organizations because of the geopolitical implications of dam construction, which partly explains the larger number of dams shown in these areas. Fears of Southeast Asian countries encroaching upon China's upstream dam-building activities have prevailed, despite regional organizations' best efforts, due to an unequal power dynamic (Wong 2016). Further proposals to construct large hydropower dams on China's southwestern rivers have caused concern among downstream neighbors, such as India, toward megadam proposals on the Yarlung Tsangpo in Tibet (Tang 2013).

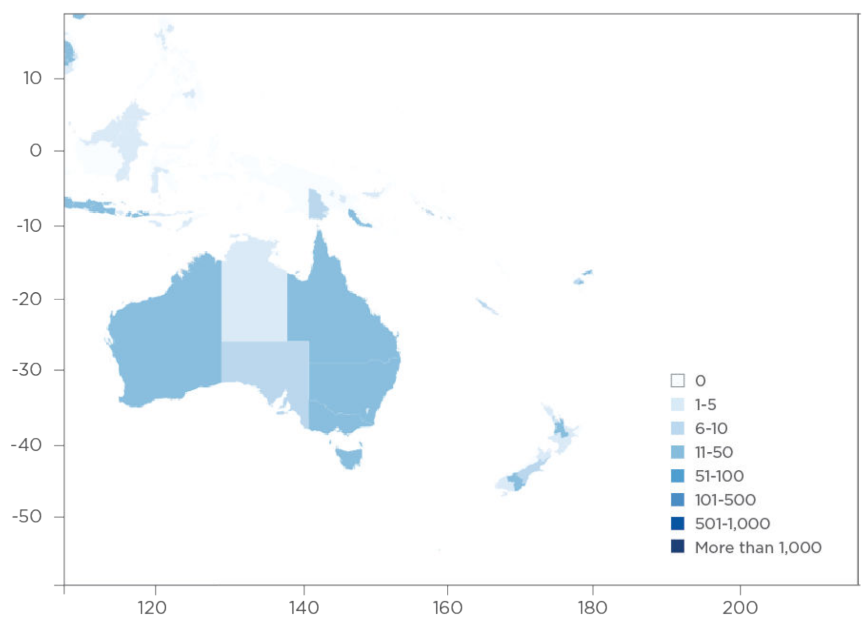
For Southeast Asia, three main data sources contributed to the GDAT database: AQUASTAT, GRanD, and CGIAR. The CGIAR database focuses on the major river basins of continental Southeast Asia (Mekong, Red, Salween, Irrawaddy) and contains information for more than 800 dams in them, which span China, Thailand, Vietnam, Laos, Cambodia, and Myanmar. There is also a high concentration of dams on peninsular Malaysia and on the island of Java, Indonesia.

Data for dams in the Middle East were mainly compiled from AQUASTAT and GRanD, except for Turkey and Iran, which are collected from government websites. The Turkish General Directorate of State Hydraulic Works publishes information for more than 600 dams, and the Iran Water Resources Management Company publishes information for more than 1,000. Neither database, however, is geolocated, hence, the geographic coordinates for these two countries are still in the process of being finalized in the GDAT database. Turkey and Iran have the highest numbers and concentrations of dams in the Middle East, especially because of aggressive dam-construction policies implemented by both countries. The highest density of dams in Iran is found in the northwestern part of the country around Lake Urmia, an endorheic lake that has shrunken significantly due to dam construction.

Because of the upstream location of Turkey and Iran on the Tigris and Euphrates river basins, respectively, dam construction in both countries has raised geopolitical concerns by neighboring downstream countries such as Iraq and Syria. Turkey, which has constructed dams on the Tigris and Euphrates basins as early as the 1950s, has proposed more large-dam projects that are expected to significantly reduce the flow of major rivers into Syria and Iraq. The country has also engaged in water politics against its downstream neighbors on issues such as Kurdish insurgency (Jongerden). As in Africa, the damming of rivers has caused wetlands and previously fertile agricultural lands to dry up, displacing populations and causing some people to seek other livelihoods in terrorist organizations such as ISIS (Levkowitz 2018).

Oceania

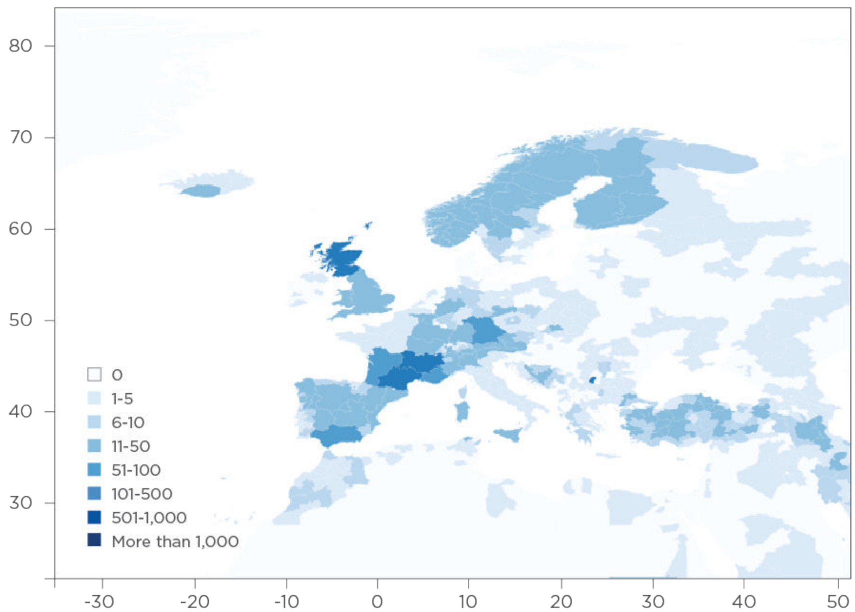
Figure 9: Oceania regions based on count of geolocated dams



Data for Oceania are mostly collected from AQUASTAT and GRanD, except data for Australia, which are collected from the Register of Large Dams maintained by the Australian National Committee on Large Dams. There are more than 500 dams in Australia and roughly 70 in New Zealand. Dams in Australia are mostly concentrated on the coastal regions of the continent and on Tasmania, while dams in New Zealand are relatively evenly distributed between North and South Island. A few Pacific island countries (Fiji, Samoa) and Papua New Guinea also contain a small number of dams. Dams in Oceania are used mostly for hydroelectricity and water supply and are no bigger than a few thousand cubic meters in reservoir capacity.

Europe

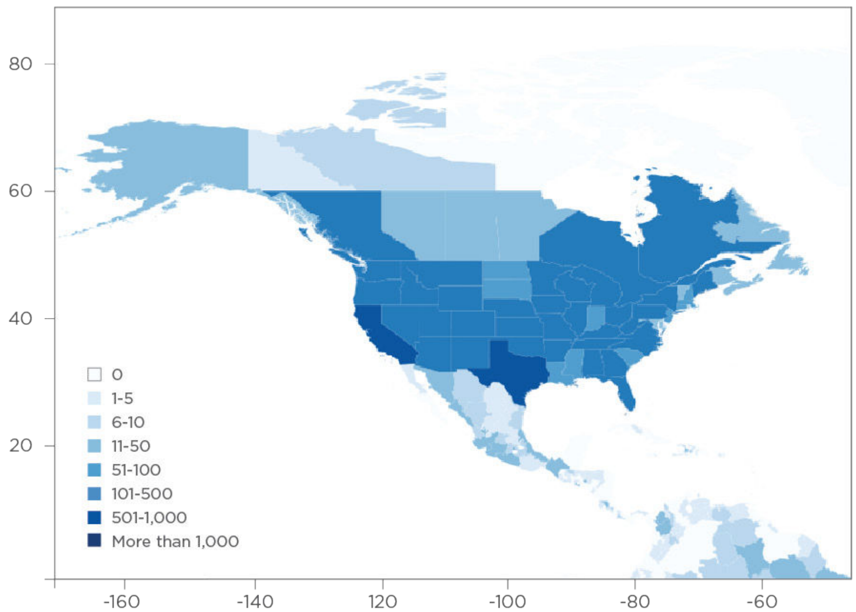
Figure 10: European regions based on count of geolocated dams



The GDAT database for Europe contains information from AQUASTAT, GRanD, and the WRI database on power plants, as well as reports for more than 3,000 dams in Europe. The greatest concentration of dams can be found in southern France, Scotland, southern Norway, the Iberian Peninsula, and the Alpine regions of Central Europe. On average, dams in Western Europe tend to be smaller in reservoir capacity than those in Eastern Europe and Russia, even though they are more numerous. While the rate of dam construction was high in the past two centuries, it has significantly slowed in the present day.

North America

Figure 11: North American regions based on count of geolocated dams



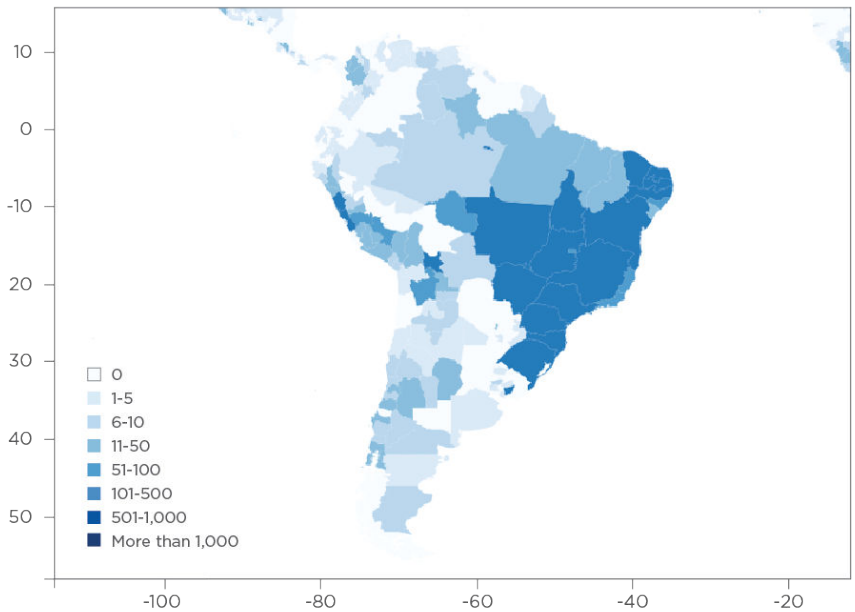
The United States and Canada have some of the highest numbers of dams in the world. The US Geological Survey (USGS) alone lists more than 8,000 dams and dikes, and the GDAT database lists more than 600 dams for Canada, most of which are concentrated in Ontario, Quebec, and British Columbia. Canada boasts some of the largest hydroelectric dams in the world and is among the world's largest hydropower generators.

In the United States, California and Texas stand out as having the highest number of dams, while most states have more than 100. Although there are many large dams in the United States, the vast majority are small. The USGS data also contain information for dams, dikes, and small-river hydroelectric plants that do not necessarily involve dams. Hence, more sorting and data compilation is necessary for the United States to produce a more accurate database.

Dam construction in the United States has taken place since the early nineteenth century to improve navigation on major rivers and provide electricity. During that time, the American public treated water as a commodity that needed to be "improved" through channeling and establishing waterworks. The utilitarian mind-set toward water resources persisted throughout the Progressive Era under then president Theodore Roosevelt, who believed that natural resources needed to be used efficiently to provide the greatest good for the greatest number of people (Billington, Jackson, and Melosi 2005). In subsequent decades, the United States constructed large numbers of dams to power its industrial economy. Many dams in the United States are now old and have reached or exceeded their design life, leading to a need for dam removal (Ho et al. 2017).

South America

Figure 12: South American regions based on count of geolocated dams



In South America, Brazil has over 5,200 dams (if dikes were included, Brazil would have the largest recorded number of dams and dikes). A majority of dams in Brazil are located along the east coast around the population centers of São Paulo, Rio de Janeiro, and Belo Horizonte. Most dams in Brazil are used for hydroelectricity and water supply. Brazil depends on hydroelectricity for over 75 percent of its electric power supply, and a recent boom in the small hydropower sector has put the country on track toward an energy surplus (Harris 2017).

However, Brazil's hydropower construction boom in the Amazon basin has resulted in the destruction and inundation of large areas of rainforest. For example, the Belo Monte Dam, the world's fourth largest hydroelectric project, flooded 260 square miles of forested lowlands and displaced more than 20,000 indigenous people. In response to intense local and international resistance from environmentalists and indigenous groups, the Brazilian government recently announced a major shift away from its policy of building megadams in the Amazon basin (Watts, 2018).

Although the construction of large megadams may be ramping down, Brazil is still experiencing a rapid expansion of small hydroelectric plants. Massive investments by the private sector after 1995 were stimulated by economic incentives and new regulations within the energy market, resulting in hundreds of new small dams. A recent study by researchers at the University of Washington estimates that 1,007 small hydroelectric plants are currently operating in Brazil (Couto and Olden 2018). An additional 35 are under construction, and 156 are approved and awaiting final licensing. Their research reports that 33 small hydropower plants have been constructed per year on average from 2001 to 2016, a growth rate 14 times as fast as that witnessed in the 1990s.

Dams in Brazil were compiled from four sources: AQUASTAT, GRanD, Dams in Amazonia, and the Brazilian National Dam Safety Information System (SNISB). The SNISB for 2016, the most recent version available, includes almost 23,000 dams. However, for the purpose of this study, the authors excluded all dams and reservoirs used exclusively for tailings and hazardous waste storage. The SNISB also only includes structures with a height greater than or equal to 15 meters and total reservoir capacity greater than 3 hm3. As a result, the GDAT database is likely missing a considerable number of small dams that are not monitored by the SNISB.

Other Andean countries (Bolivia, Chile) also have significant numbers of dams, more than 600 of which are located in the Peruvian Andes and used mostly for irrigation and hydroelectricity. In other parts of the Andes, most dams are used for hydroelectricity, water supply, irrigation, and recreation. The Guri Dam in Venezuela, a hydroelectric dam with a reservoir volume of 135 km3, ranks among the largest dams in South America and in the world. According to AQUASTAT, Uruguay is home to the second largest number of dams in South America, following Brazil. However, after spot searching individual listings, the authors were only able to find location data for 4 of the 878 dams and reservoirs included. Additional research will be needed to confirm the validity and physical location of these structures.

Comparison with Existing Datasets

Spatial and Temporal Coverage

The GDAT database surpasses the two other existing global dam databases in not only total dam count, but also in data on completion year, location, and generation capacity (figure 13). Specifically, GDAT is larger than the GRanD and AQUASTAT databases by 419 percent and 144 percent, respectively. The WRI's Global Power Plant Database is excluded from this comparison, because it focuses on power plant data and, hence, contains mostly hydroelectric dams. For a visual comparison of geospatial coverage between the databases, please see appendix A.

GDAT contains more dams in all six geographical regions of the world (figure 14). The most significant improvement in total dam count can be seen in North America, South America, Africa, and Asia, where multiple new primary sources were consulted in the process of data collection. For a detailed breakdown of more regional attributes from each source, please refer to appendix B.

Figure 13: Number of dams with information on location, installed capacity, year of completion for AQUASTAT, GRanD, and GDAT

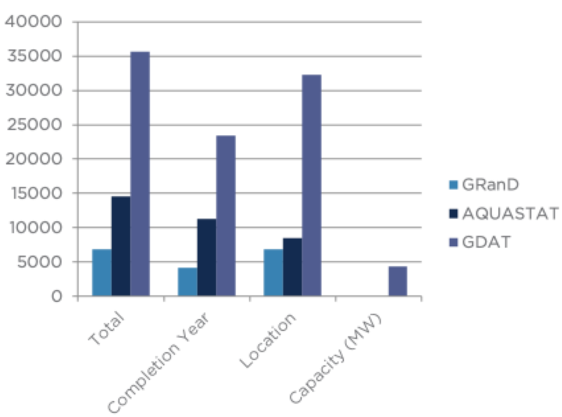
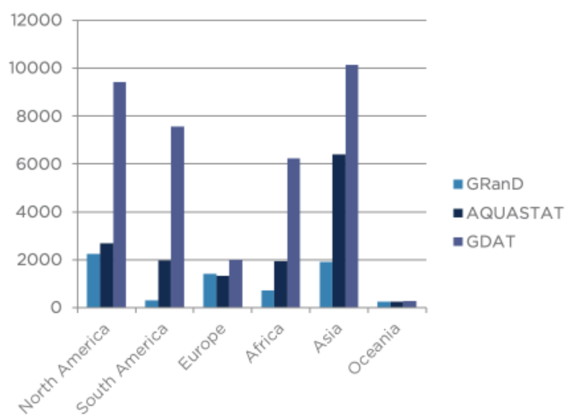
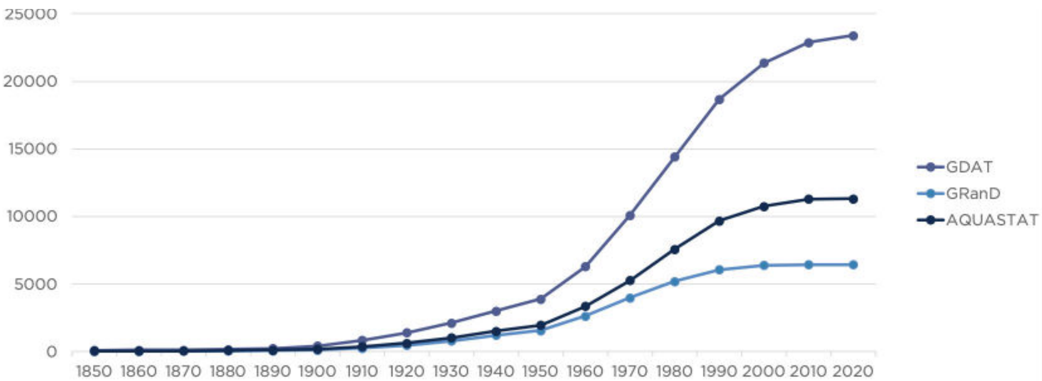


Figure 14: Total number of dams by region for AQUASTAT, GRanD, and GDAT



A time series of dam construction also shows the increased volume of dams included in the GDAT database as compared to the GRanD and AQUASTAT databases (figure 15). The GRanD and AQUASTAT databases include dams constructed up to 2010 and 2013, respectively, and AQUASTAT also contains approximately 250 proposed or incomplete listings. All three sources demonstrate a significant acceleration in dam construction from 1970 to 2000, followed by a slight deceleration over the past decade. Global investments in hydropower peaked in the second half of the twentieth century, partly in response to a growing desire to diversify energy sources, shift away from thermoelectric facilities, and avoid greater dependency on fossil fuels (Couto and Olden 2018).

Figure 15: Time series of number of dams constructed from AQUASTAT, GRanD, and GDAT



Conclusion

In this paper, the authors introduced a global geospatial database of dams, the GDAT, to enable rigorous research on the costs and benefits of dam construction. The project was motivated by the absence of a comprehensive, reliable, real-time, easy-to-use database on global dam construction. Such data could allow policymakers to make informed decisions on the use of hydroelectric power in the future, based on systematic evaluations of the costs and benefits of hydroelectric dams along the dimensions of energy access, climate change mitigation, water supply, ecological preservation, and population displacement.

Globally, the authors identified 36,222 dams that are spatially concentrated along major river basins in Asia, North America, South America, and Europe. GDAT makes considerable improvements compared to existing databases by not only filling in important data gaps on key attributes, but also correcting erroneous observations through extensive cross-checking and manual validation. In addition to consolidating existing databases (AQUASTAT, GRanD, and WRI), the authors collected and compiled primary data from administrative sources to construct the most comprehensive geo-referenced data on worldwide dam construction to date. Effort is underway to develop a framework for making the data collection and compilation process easily reproducible, so that it can be updated on a reasonable time interval to facilitate inter-temporal analysis. Upon publication of academic research papers, the authors are planning to release the entire dataset and documentations to the public free of charge in the future.

Notes

1. Billington, D. P., D. C. Jackson, and M. V. Melosi. 2005. "The History of Large Federal Dams: Planning, Design, and Construction in the Era of Big Dams." *United States Bureau of Reclamation*.

2. Couto, Thiago B. A., and Julian D. Olden. 2018. "Global Proliferation of Small Hydropower Plants - Science and Policy." *Frontiers in Ecology and the Environment* 16 (2): 91–100.

3. Fearnside, P. M. 2014. "Impacts of Brazil's Madeira River Dams: Unlearned Lessons for Hydroelectric Development in Amazonia." *Environmental Science & Policy*, 38: 164–172. https://doi.org/10.1016/j.envsci.2013.11.004

4. Fearnside, P. M. 2016. "Environmental and Social Impacts of Hydroelectric Dams in Brazilian Amazonia: Implications for the Aluminum Industry." *World Development*, 77: 48–65. https://doi.org/10.1016/j.worlddev.2015.08.015

5. Hathaway, T. 2010. "What Is Driving Dams in Africa?" *International Rivers*. https://www.internationalrivers.org/resources/what-is-driving-dams-in-africa-1695

6. Harris, Michael. 2017. "Small Hydro Booming in Brazil as Country Nears Energy Surplus." https://www.hydroworld.com/articles/2017/09/small-hydro-booming-in-brazil-as-country-nears-energy-surplus.html.

7. Ho, M., U. Lall, M. Allaire, N. Devineni, H. Kwon, I. Pal, D. Raff, and D. Wegner. 2017. "The Future Role of Dams in the United States of America." *Columbia Water Center*. https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2016WR019905

8. Jongerden, J. (n.d.). "Dams and Politics in Turkey: Utilizing Water, Developing Conflict." *Middle East Policy Council*. https://mepc.org/dams-and-politics-turkey-utilizing-water-developing-conflict

9. Levkowitz, J. 2018. "Iraq Wilting: How Creeping Drought Could Cause the Next Crisis." *Middle East Institute*. http://www.mei.edu/content/article/iraq-wilting-how-creeping-drought-could-cause-next-crisis

10. McCully, P. (n.d.). "Dam Decommissioning." *International Rivers*. https://www.internationalrivers.org/dam-decommissioning

11. Mongalvy, S., D. M. Doya, and A. Sguazzin. 2018. "Nigeria to Start Building $5.8 Billion Power Plant in 2018." *Bloomberg*. https://www.bloomberg.com/news/articles/2018-01-30/nigeria-to-start-building-5-8-billion-hydro-power-plant-in-2018

12. Pearce, F. 2017. "How Big Water Projects Helped Trigger Africa's Migrant Crisis." *Yale School of Forestry and Environmental Studies*. https://e360.yale.edu/features/how-africas-big-water-projects-helped-trigger-the-migrant-crisis

13. Salkida, A. 2012. "Africa's Vanishing Lake Chad." *Africa Renewal Online. United Nations*.

https://www.un.org/africarenewal/magazine/april-2012/africa's-vanishing-lake-chad

14. Tang, J. 2013. "China Gives Green-Light to New Era of Mega Dams." *Berkeley Energy and Resources Collaborative*. http://berc.berkeley.edu/china-gives-green-light-to-new-era-of-mega-dams/

15. Tilt, B., Y. Braun, and D. He. 2009. "Social Impacts of Large Dam Projects: A Comparison of International Case Studies and Implications for Best Practice." *Journal of Environmental Management*, 90 (Supp. 3): S249–S257. https://doi.org/10.1016/j.jenvman.2008.07.030

16. Wang, P., J. P. Lassoie, S. Dong, and S. J. Morreale. 2013. "A Framework for Social Impact Analysis of Large Dams: A Case Study of Cascading Dams on the Upper-Mekong River, China." *Journal of Environmental Management*, 117: 131–140. https://doi.org/10.1016/j.jenvman.2012.12.045

17. Watts, Jonathan. 2018. "Brazil Raises Hopes of a Retreat from New Mega-Dam Construction." *The Guardian*. http://www.theguardian.com/environment/2018/jan/04/brazil-raises-hopes-of-a-retreat-from-new-mega-dam-construction.

18. Wong, C. 2016. "China and the Mekong: The Floodgates of Power." *The Diplomat*. https://thediplomat.com/2016/05/china-and-the-mekong-the-floodgates-of-power/

19. World Commission on Dams. 2000. *Dams and Development: A New Framework for Decision-making: the Report of the World Commission on Dams*. Earthscan.

20. World Energy Council. 2016. *World Energy Resources Hydropower*. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Hydropower_2016.pdf

21. Zarfl, C., A. E. Lumsdon, J. Berlekamp, L. Tydecks, and K. Tockner. 2015. "A Global Boom in Hydropower Dam Construction." *Aquatic Sciences*, 77(no. 1): 161–170. https://doi.org/10.1007/s00027-014-0377-0

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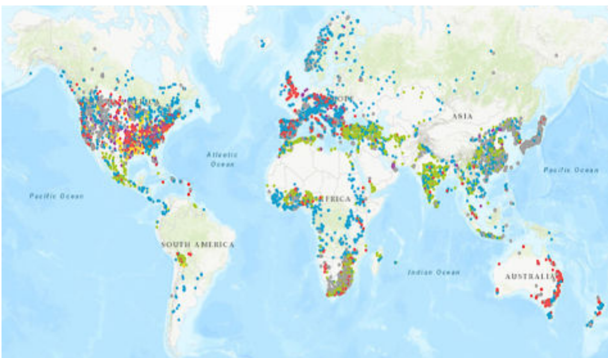
The project benefited from helpful discussions with Ryan Kennedy and S. P. Harish. Vincent Xinyi Gu, Joanie Coker, and Sid Shah provided excellent research assistance. The authors would like to thank Matthew Robinson for his editorial assistance. Funding from the Center on Global Energy Policy is gratefully acknowledged.

Supplemental Appendix

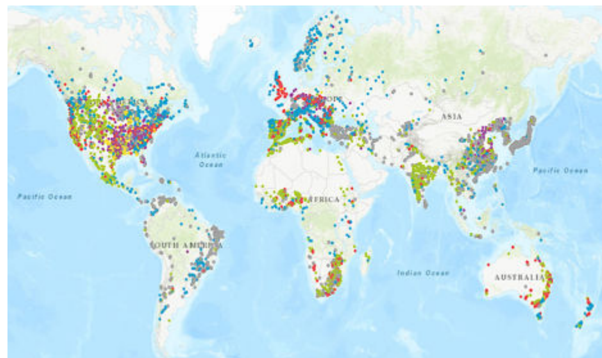
Appendix A

World Maps of Dams from AQUASTAT, GRanD, WRI, and GDAT Showing Main Purpose of Dam Construction: Hydroelectricity (Blue), Irrigation (Green), Water Supply (Red), Flood Control (Purple), Recreation (Yellow), and Other (Gray)

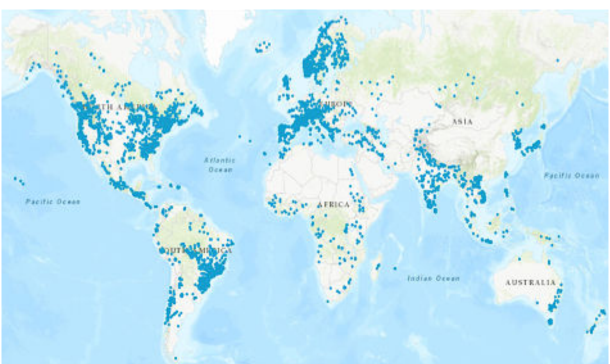
Figure 1: (Left to Right) AQUASTAT, GRanD, World Resources Institute, GDAT



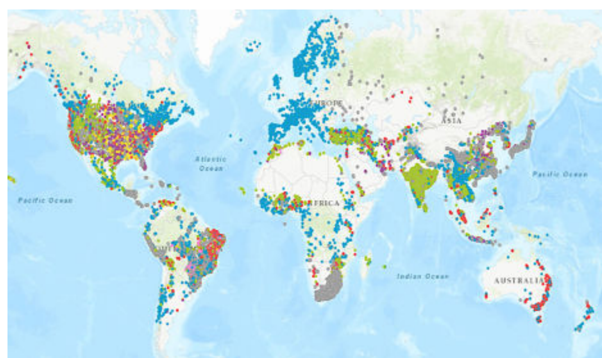
AQUASTAT



GRanD



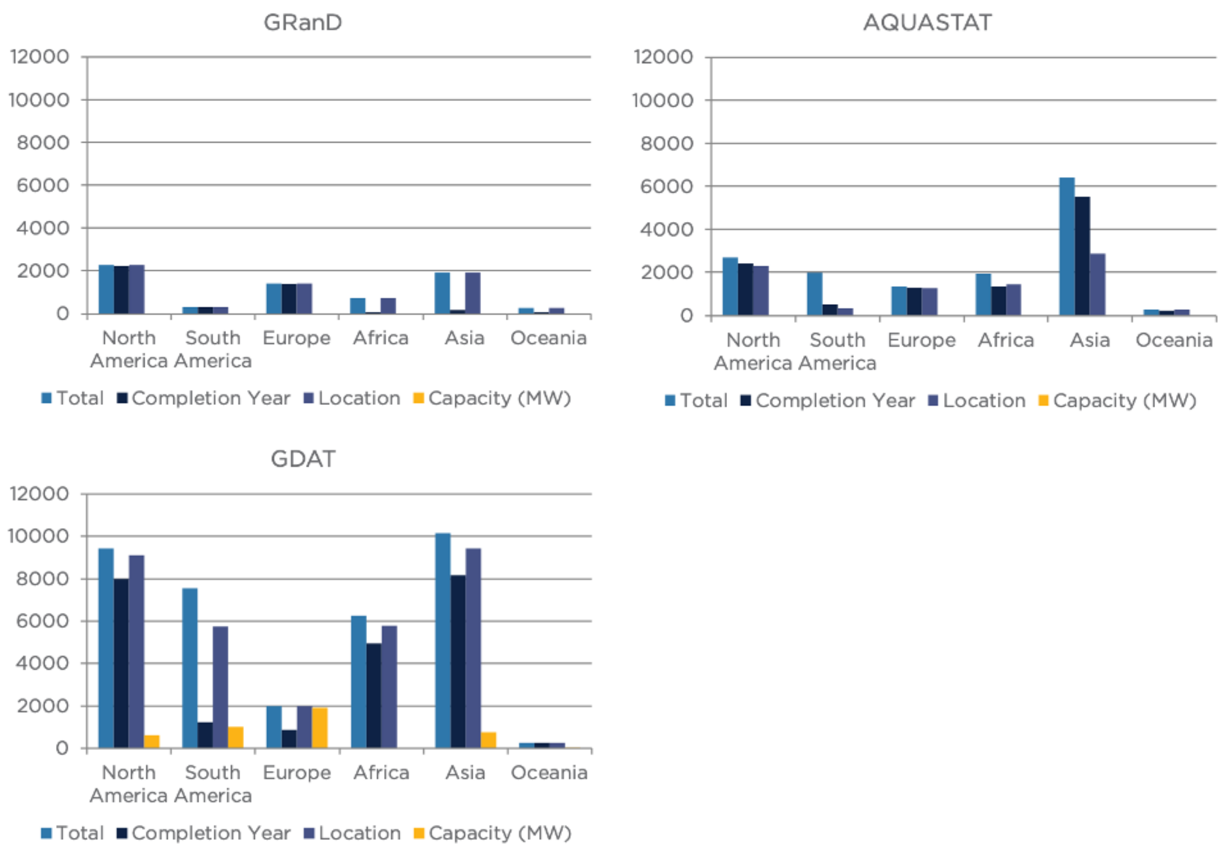
World Resources Institute



GDAT

Appendix B

Number of Dams by Region, with Information on Location, Installed Capacity, and Year of Completion for AQUASTAT, GRanD, and GDAT Databases



Appendix C

World and Regional Maps of Dams by Purpose and Reservoir Capacity

Figure 1: World dams by purpose

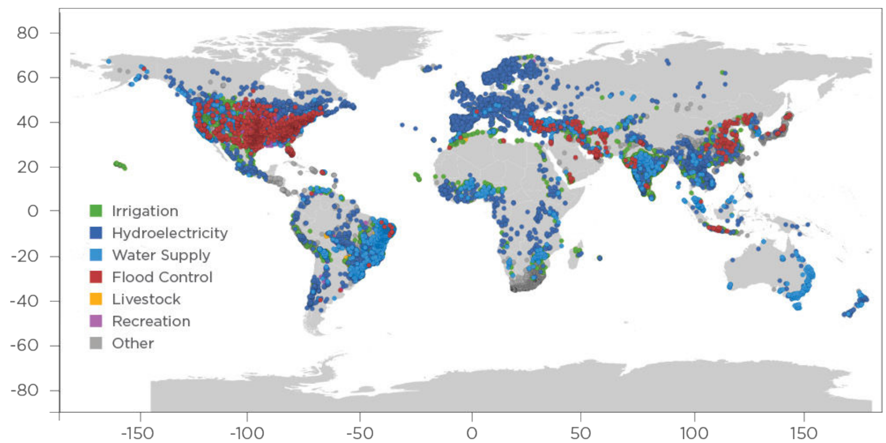


Figure 2: World dams by reservoir capacity

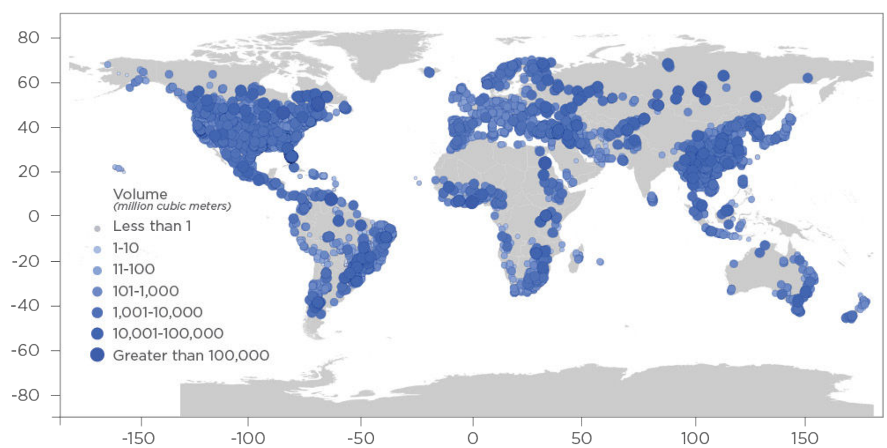


Figure 3: Dams of Africa by purpose

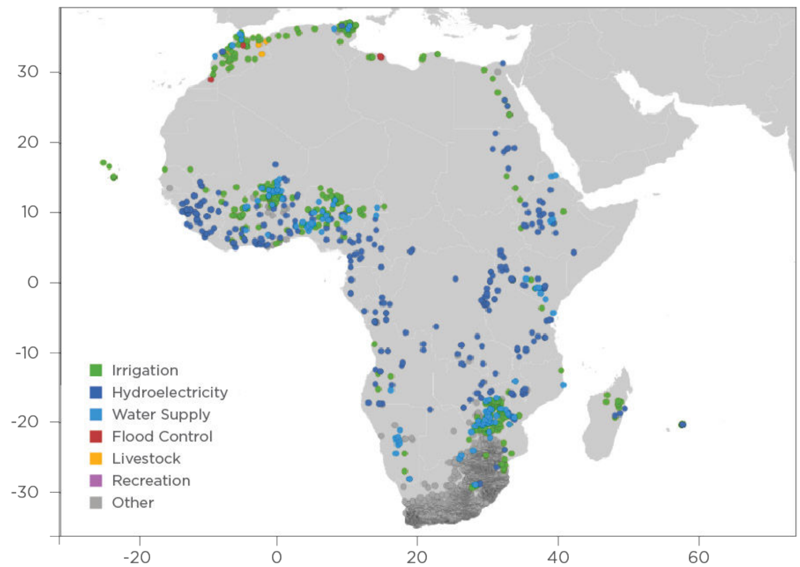


Figure 4: Dams of Africa by reservoir capacity

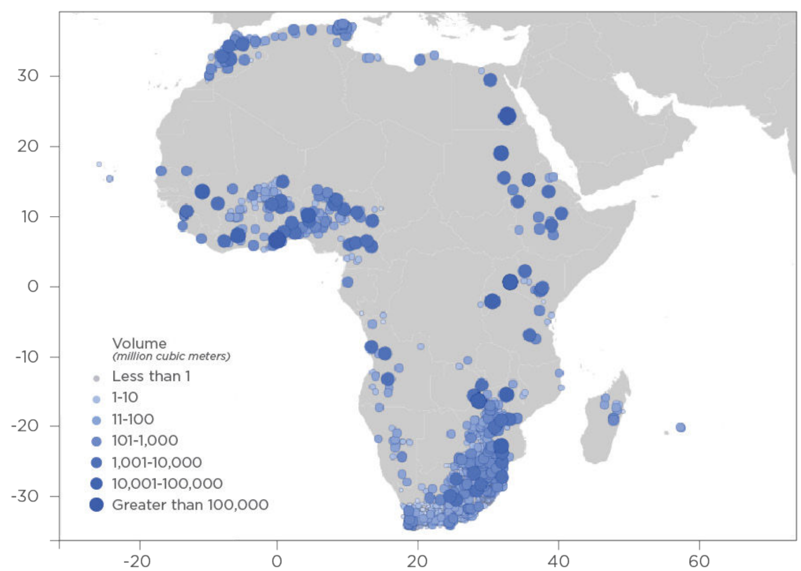


Figure 5: Dams of Asia by purpose

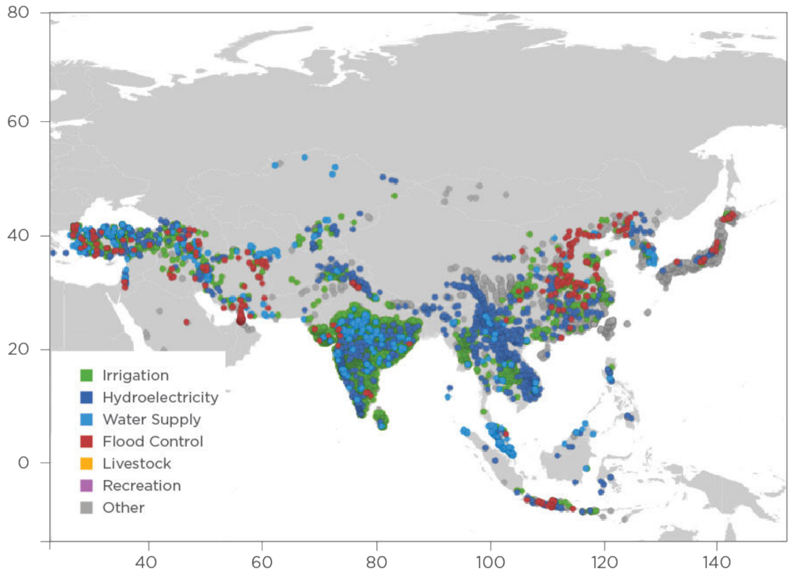


Figure 6: Dams of Asia by reservoir capacity

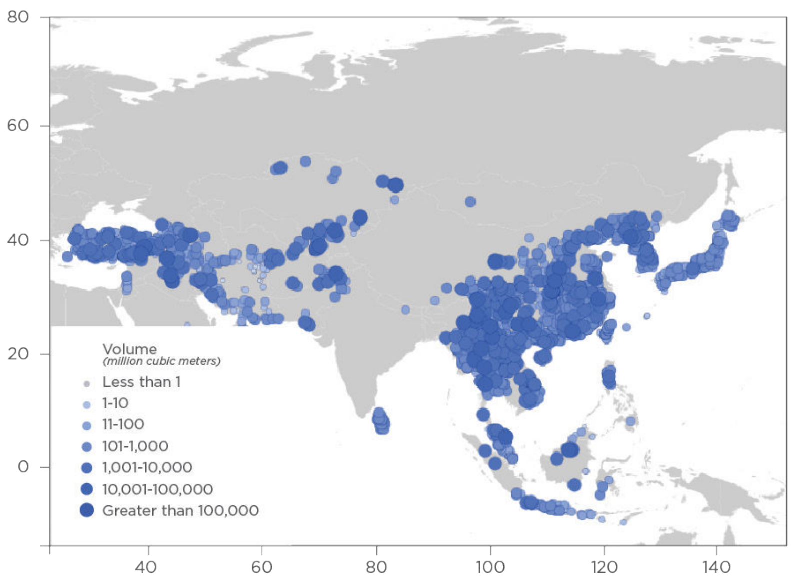


Figure 7: Dams of Oceania by purpose

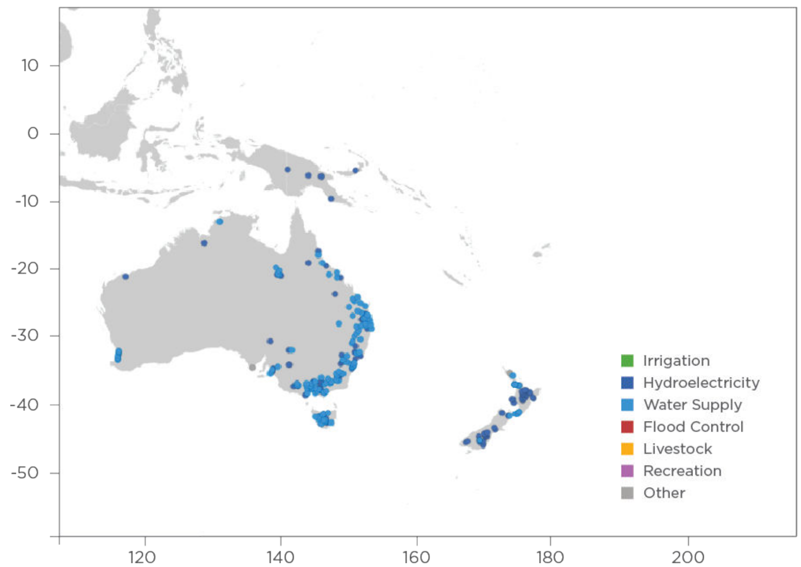


Figure 8: Dams of Oceania by reservoir capacity

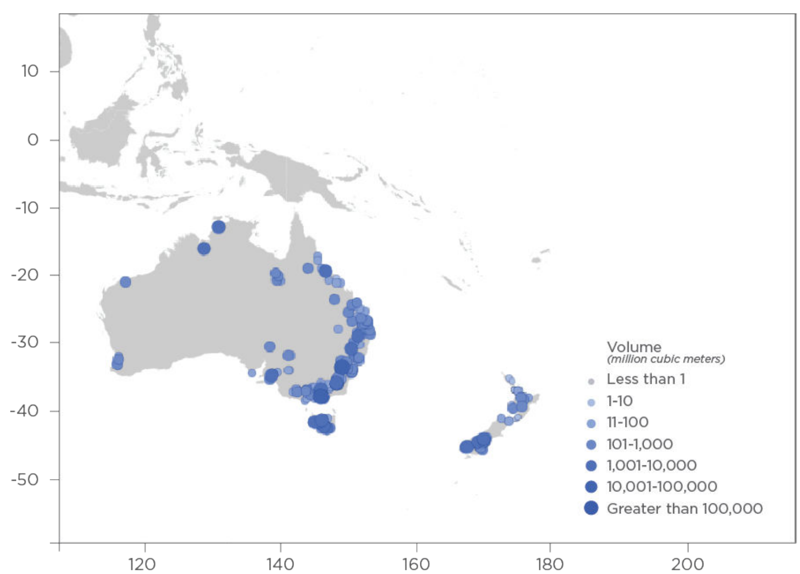


Figure 9: Dams of Europe by purpose

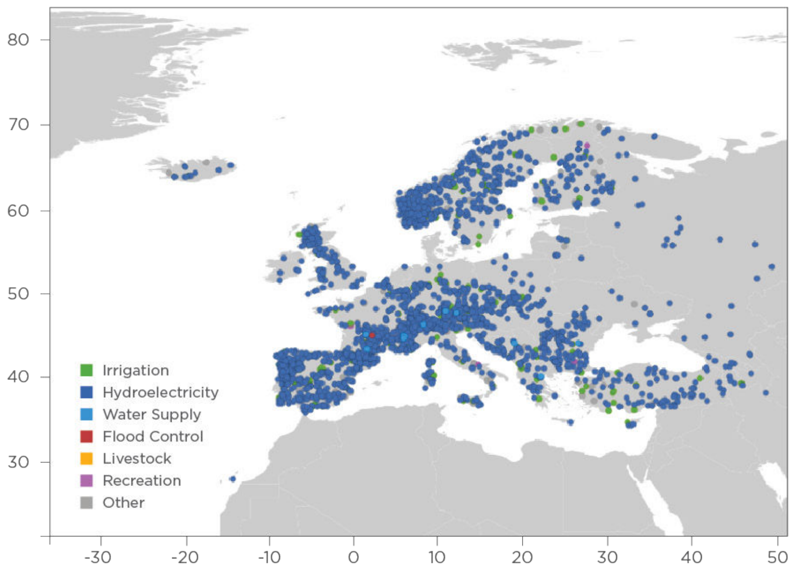


Figure 10: Dams of Europe by reservoir capacity

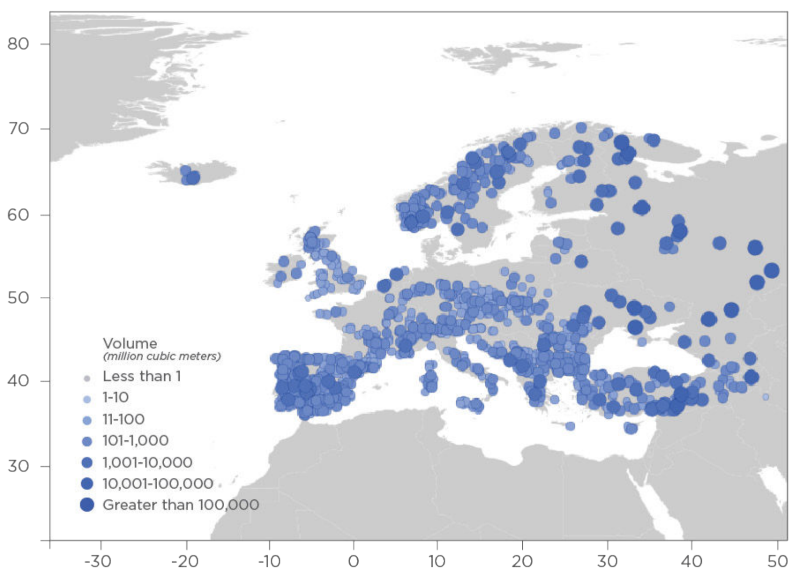


Figure 11: Dams of North America by purpose

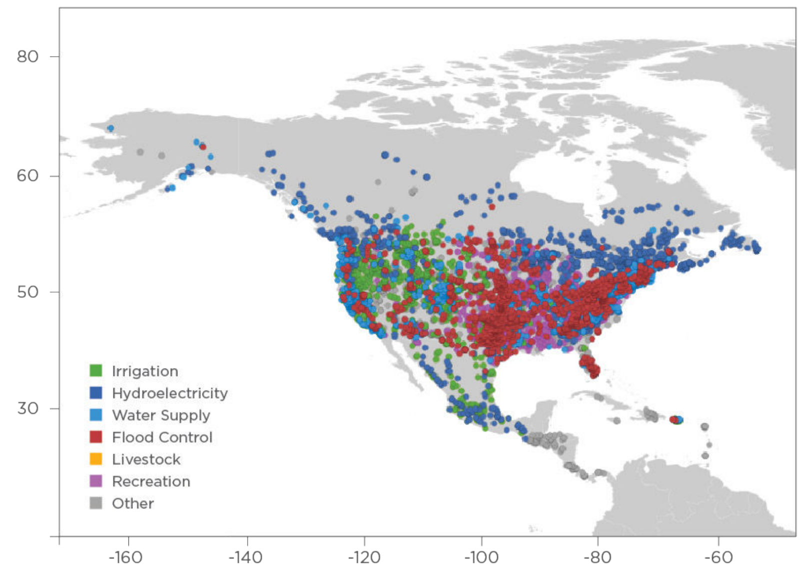


Figure 12: Dams of North America by reservoir capacity

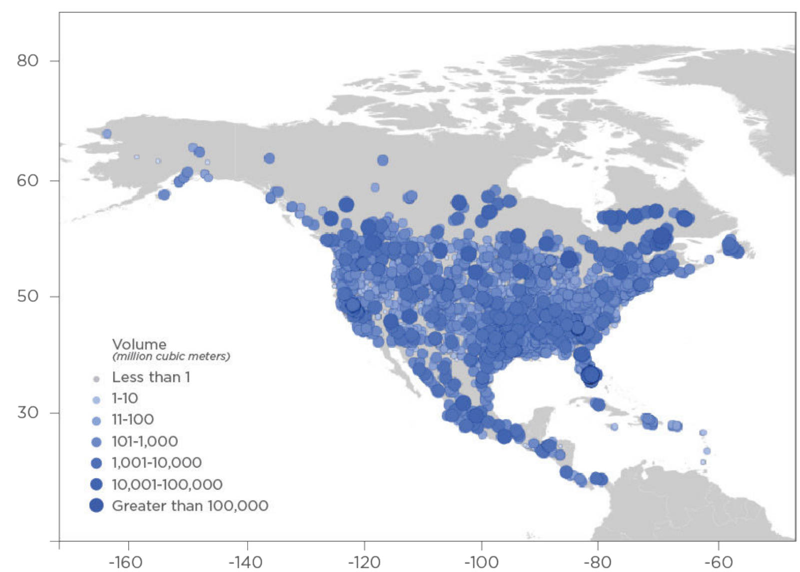


Figure 13: Dams of South America by purpose

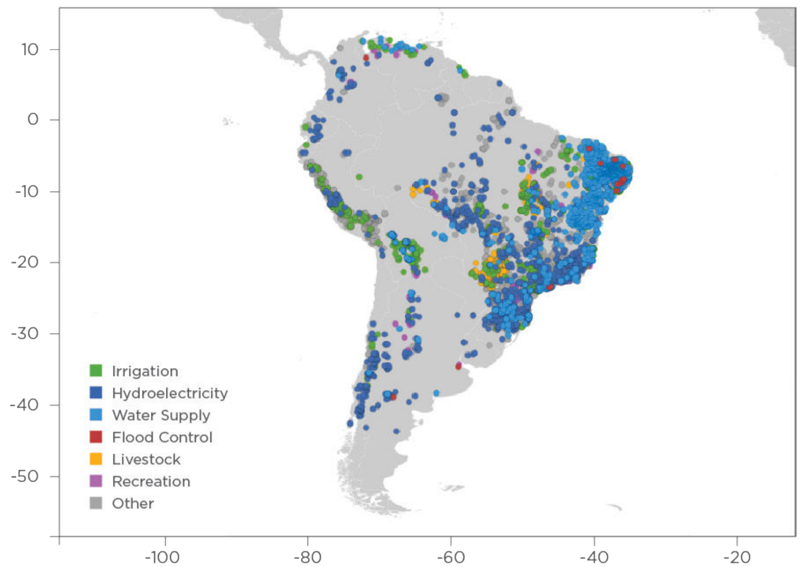
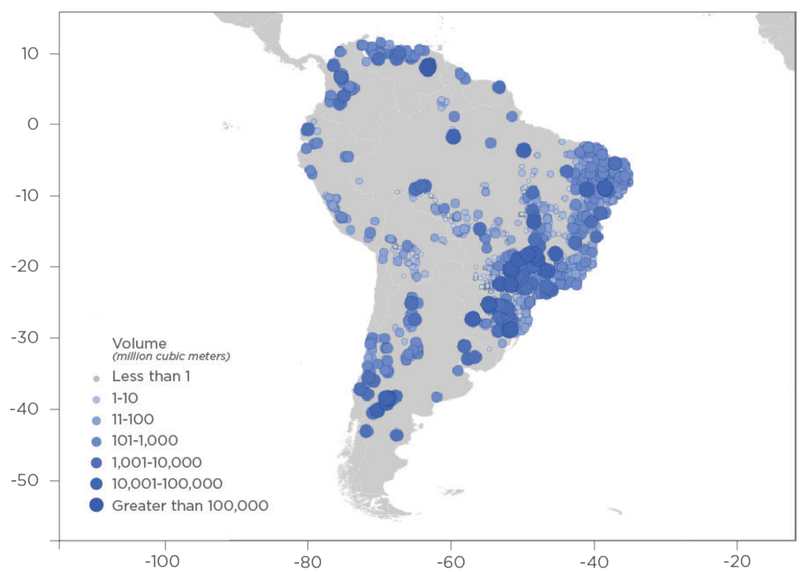


Figure 14: Dams of South America by reservoir capacity



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