GLOBAL WATER TRANSFER MEGAPROJECTS: A SOLUTION FOR THE WATER-FOOD-ENERGY NEXUS?

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Abstract (350 words max)

Globally, freshwater is unevenly distributed, both in space and time. Climate change, land use alteration, and increasing human exploitation will further increase the pressure on water as a resource for human welfare and on inland water ecosystems. Water transfer megaprojects (WTMP), i.e. large-scale engineering interventions to divert water within and between catchments, represent an approach in coping with increasing water scarcity. These projects are most commonly associated with large-scale agricultural and energy development schemes, and many of them serve multiple purposes. Despite numerous case studies that focus on the social, economic and environmental impacts of individual projects, a global inventory of existing and planned WTMP is lacking.

We carried out the first comprehensive global inventory of WTMP that are either planned or under construction. We collected key information (e.g. location, distance, volume, costs, purpose) on 33 existing and 76 future (planned or under construction) WTMP. If realized, the future projects will transfer a total volume of 1,923 km^3 per year across a total distance exceeding more than twice the length of Earth’s equator. The largest WTMP planned or under construction are located in North America, Asia and Africa. The predicted total investments in these WTMP will exceed 2.6 trillion US$. Among future projects, 43 will serve purposes of agriculture development, 14 transfer water for hydropower development and 10 combine both purposes.

Our results show that WTMP will create artificial connections between river basins, alter the global hydrological cycle, and change the natural functions and services freshwaters provide for humans and nature. The results also emphasize the need to include these projects in global hydrological models, in strategies related to the water-energy-food nexus, and in developing internationally agreed criteria to assess the ecological, social and economic consequences these projects may cause.

Keywords: (min 5, max 8)
water transfer, megaprojects, hydrological balance, water-food-energy nexus, diversion

1. Introduction

Water is an essential resource for human well-being and the functioning of ecosystems. At the same time, increasing water scarcity is among the biggest challenges humanity is facing (WEF, 2015). By 2030, the world will experience a 40% water deficit under a business-as-usual scenario (2030 WRG, 2009). The global distribution of freshwater is uneven both in space and time (Gupta and van der Zaag, 2008), and becomes further exacerbated through changes in total precipitation, seasonality, interannual variability, and the magnitude and frequency of extreme meteorological events (Schewe et al., 2014; Rockström et al., 2014). Water quality is deteriorating, too, due to industrial, agricultural and municipal pollution, further constraining water resources for humans and nature alike (UNESCO-WWAP, 2017).

While the availability of freshwater remains relatively constant, the demand is growing. This increasing demand is tightly linked to providing food and energy security to growing human populations (UNESCO-WWAP, 2014; UNSD, 2016). Water and energy are necessary for all stages of food production, from irrigation to processing. Currently, agricultural activities account for 70% of the total global freshwater withdrawal and for 30% of the global energy consumption (FAO, 2011). Energy is used for water extraction, treatment and distribution for agricultural and domestic purposes. At the same time, water is required for power generation, cooling and the production of biofuels. Hence, the so-called “water-food-energy nexus” was identified by the World Economic Forum as a key development challenge for the increasing human population (WEF, 2011). By 2050, the human population is projected to reach 9.8 billion (UN, 2017), with 66% living in urban areas (UN, 2014). In addition, the food demand will increase by 50% (FAO, IFAD, UNICEF, WFP and WHO, 2017), the energy demand by up to 61% (WEC, 2013), and the water demand by 55% (UNESCO-WWAP, 2014). Therefore, ensuring sufficient water resources, in the required quality, and sustainable energy and food supply chains are considered essential for sustaining human wellbeing.

High water demand increases the risk that water of the required amount and quality will not be available at the time and place it is needed (Gupta and van der Zaag, 2008). This calls for large-scale engineering solutions to store, redistribute and treat water resources. Such megaprojects are often high-risk projects because they require major financial investments, demand long time frames from planning to completion, and may have major socio-economic and environmental ramifications (Flyvbjerg, 2014; Sternberg, 2016). In the water sector, megaprojects include transfer projects, large dams, desalination plants, treatment plants, and ecosystem restoration schemes (Sternberg, 2016; Tockner et al., 2016). Megaprojects are often initiated as an expression of national and political power and expected to trigger economic and social development (Sternberg, 2016). Concurrently, the social, economic and environmental consequences receive much less attention in the decision-making process (WWF, 2007; Sternberg, 2016; Zhuang, 2016).

Water transfer megaprojects (WTMP) may play an important role in sustaining the water-food-energy nexus, as they can provide water for irrigation, domestic supply, energy production, navigation, and industrial development (Sternberg, 2016). In general, water transfer is defined as “the transfer of water from one geographically distinct river basin to another, or from one river reach to another”; hereafter called “donor” and “recipient” system, respectively (Davies et al., 1992; Gupta and van der Zaag, 2008). According to the International Commission on Irrigation and Dams (ICID, 2005), water transfer accounted for 540 km^3 a^{-1} or 14% of the global water withdrawals in the beginning of this century. Global water withdrawal through transfer schemes is expected to increase by 25% until 2025 (Gupta and van der Zaag, 2008), primarily through an expansion of water transfer schemes. In the USA, for example, the number of interbasin water transfers (primarily ordinary transfer projects) has increased by an order-of-magnitude, from 256 in 1985/1986 to 2,161 in 2017 (Dickson and Dzombak, 2017).

Since 1991, a continuous increase in publications on various environmental, societal and economic consequences of interbasin water transfers can be observed (Zhang et al., 2015; WWF, 2007; Zhuang, 2016 and examples therein). On the one hand, water transfer schemes can reduce the pressure on groundwater resources (Poland, 1981), improve water quality (Hu et al., 2008; Rivera-Monroy et al., 2013), and support ecosystem restoration measurements (Snedden et al., 2007; Dadaser-Celik et al., 2009). On the other hand, they may waste water resources due to evaporative losses and a poor state of infrastructure (Davies et al. 1992), cause salinization due to reduced water flow (Zhuang et al., 2016), increase nutrient concentrations due to inputs from nutrient-rich basins (Fornarelli and Antenucci, 2011; Jin et al., 2013), facilitate the spreading of pollutants and invasive species (Murphy and Rzeszutko, 1977; O'Keeffe and DeMoor, 1988; Snaddon and Davies, 1998; Clarkson, 2004), and alter and decrease biodiversity (Grant et al., 2012; Lin et al., 2017). From the societal point of view, large-scale water transfer schemes may cause conflicts among human societies living in the donating and receiving basins. Due to increased water supply residents in receiving basins may benefit from boosted agriculture and industry development, while environmental deterioration in water donating basins may lead to reduction in income and force local communities to change the traditional place of leaving (Sternberg, 2016; Yu et al., 2018). Inappropriate planning of water transfer schemes can also lead to major economic failures, for example when high construction costs lead to increased water prices that exceed the paying ability of target groups (Sternberg, 2016).

Comprehensive data and information on the global extent of future WTMP are lacking so far (Tockner et al., 2016). Design, construction, and commencement of megaprojects require time, money and technical skills (Flyvbjerg, 2014). WTMP that are currently in the planning or construction stages may require decades until completion. However, knowing their distribution and key characteristics will help coping with the challenges humans and freshwater ecosystems are facing, and support appropriate strategies for managing water resources and ecosystem processes (Shumilova, 2018).

The aim of this study was to collate data and information about WTMP that are currently planned or under construction globally, and to be completed by about 2050.

The key research questions are:

(1) What is the global distribution of WTMP planned or under construction?
(2) How much water will be transferred across which distances?
(3) What are the estimated costs of future WTMP?
(4) Which purposes will future WTMP fulfill, particularly in meeting the water-food-energy nexus?

In addition, we collected information on the distribution and key characteristics of existing WTMP, in order to put existing and future WTMP into context. Finally, we discuss the consequences WTMP may cause in affecting humans and nature alike.

2. Methods

2. 1. Definition of water transfer megaprojects

Water transfer projects include any type of infrastructure that transfers water from one river catchment to another, from one river reach to another, or from any freshwater body (rivers, lakes, groundwater sources) to a place where it will be utilized by humans (Davies et al., 1992;

Gupta and van der Zaag, 2008). **Megaprojects** are generally defined based on actual construction costs, with a threshold of about one billion US$ per project (Flyvbjerg, 2014). We extended that definition for **water transfer megaprojects** to include projects that meet one of the following criteria: construction costs amount to one billion US$ or more, distance of transfer is 190 km or more, or volume of water transferred exceeds 0.23 km^3 a^{-1} (Shumilova, 2018). To set these criteria we first selected a sample of 15 WTMP planned or under construction with the estimated construction cost of 1±0.5 billion US$. Then, we calculated the median water transfer distance and volume of these projects (Table S1). These criteria were used to identify existing megaprojects, too.

2.2. Data collection sources and criteria

We collected data and information on all megaprojects based on peer-reviewed publications, official web-sites of water transfer projects, environmental impact assessments, reports of non-governmental organizations, and information available in online newspapers. Data and information were collected between January and December 2017. We searched for the English terms “water transfer”, “water diversion”, “water megaproject”, and “water redistribution schemes”, using various search engines (www.webofscience.com; www.googlescholar.com; www.google.com). In order to improve the data quality, we used multiple sources for each project for cross-validation (the full list of information sources for projects planned and under construction is provided in the Supplementary Material).

For each project, we compiled the following data and information: geographic location of the project (continent, country), project status (planned, under construction), donor and recipient system, total water transfer distance, total water transfer volume (i.e. maximum annual capacity), estimated construction cost (future WTMP), and main purpose(s) of the project. In case information sources provided different values on water transfer distance, volume and cost, we used the largest values found in the literature. We visualized the location of each project using QGIS software (version 2.12). Identification of the location and course of the planned WTMP was based on available project plans, terrain topography, or depicted as the shortest connection between donating and receiving water body in case no other information was available.

3. Results

3. 1. Geographic distribution of existing and future WTMP

A total of 33 existing WTMP were identified, with 17 projects located in North America and 10 in Asia (Fig. 1, Table S2). A total of 76 WTMP are either under construction (34) or in the planning phase (42) (Fig. 2; Table S3). The majority of future WTMP will be located in North America (34 projects) and Asia (17) (Fig. 2; Table 1). In Europe, only three WTMP are expected, of which two are under construction.

3.2. Water volume and distance of existing and future WTMP

For existing WTMP, the water transfer volume ranged from 0.06 to 51 km^3 a^{-1} (median: 2.4 km^3 a^{-1}), with a combined water transfer volume of 203 km^3 a^{-1} (Table S2). The “James Bay Project” (Canada; 51 km^3 a^{-1}) and the “Goldfields Water Supply Scheme” (Australia; 33 km^3 a^{-1}) transfer the largest volumes. For future WTMP, the estimated water volume transferred will range from 0.05 to 317 km^3 a^{-1} (median: 2.2 km^3 a^{-1}), with a combined water transfer volume of 1,923 km^3 a^{-1} (Table 1). The planned “North American Water and Power Alliance” (NAWAPA) megaproject is estimated to transfer 193 km^3 a^{-1} across the entire continent, and the “Great Recycling and Northern Development (GRAND) Canal of North America” will transfer 317 km^3 a^{-1}.

The water transfer distance of existing WTMP ranged from 0.4 to 2,820 km (median: 367 km) with a combined length of 12,913 km (Table 1). The longest distance of water transfer amounts to 2,820 km for the “Great Manmade River” (Libya) and the California State Water Project (USA; 1,128 km). The calculated water transfer distance of future WTMP will range from 3.2 km to 14,900 km (median: 482 km) (Table S3). The combined length of all megaprojects planned (51,720 km) or under construction (26,420 km) will amount to 88,140 km. Thereof, the “National River Linking Project” (India), which is under construction, will stretch a total length of 14,900 km, and the planned “NAWAPA” megaproject (North America) will cover 10,620 km.

3.3. Estimated costs of future WTMP

The construction costs of future WTMP range from 0.095 to 1,500 billion US$ per project (median: 4.25 billion US$) (Table 1). The construction of all 76 WTMP will require a combined investment of around 2.7 trillion US$. On its own, the construction of “NAWAPA” is estimated to cost 1.5 trillion US$. Regarding the projected costs per km of water transfer, the most expensive projects currently in the planning phase are the “California Water Fix and Eco Restore” project (USA; 479 million US$ per km), the “Mid-Barataria Sediment Diversion” project (USA; 375 million US$ per km), and the Acheloos River diversion project (Greece; 339 million US$ per km). Regarding the costs of transfer in relation to the water volume transferred, i.e. per millions of m^3 a^{-1}, the calculated prices are the highest for the channel connecting Lake Baikal (Russia) with the Chinese city Lanzhou (325 million US$ per million m^3 a^{-1}), the pipeline connecting the underground aquifer in eastern Nevada with Las Vegas (USA; 97 million US$ per million m^3 a^{-1}), and the Kimberley-Perth canal (Australia; 73 million US$ per million m^3 a^{-1}), all of which are in the planning phase.

3.4. Purposes of WTMP

Among the existing WTMP, twelve projects provide water for irrigation, seven for hydropower generation, four for both purposes, and one project serves ecosystem restoration (Table S2). Among future projects, 43 projects will transfer water for agriculture development, 14 for hydropower generation, and ten for both purposes (Fig. 3). Furthermore, six future WTMP will meet the needs of the mining industry, four will support ecosystem restoration, and three projects will serve as navigation canals.

4. Discussion

4.1. Global scale inventory on WTMP

In this paper, we present the most comprehensive global synthesis on future WTMP, which are expected to be completed by around 2050, as well as on the key characteristics of each of these projects. The inventory shows that all WTMP will become a global phenomenon. They are planned across all continents and in countries that are both developed and developing.

Building massive water transfer infrastructures people are creating “artificial rivers” on Earth. The 76 future WTMP will transfer a calculated total volume of 1,923 km^3, along a combined distance exceeding twice the length of Earth’s equator. For comparison: the mean annual flow at the mouth of the Rhine River, one of the longest (total length: 1,250 km) and economically most important rivers in Europe, amounts to 72 km^3 a^{-1} (Uehlinger et al., 2009). While the median water transfer distance per individual project will be around one third of the Rhine River length, 17 projects will exceed the length of river Rhine. In respect to flow, about 30 new Rhine Rivers are in the planning or construction phase globally. The scale of these interventions allows considering them as transformations in the global water cycle. The total volume of transferred water will account for up to 48 % of the total global water withdrawal (based on the present total withdrawal rate of around 4,000 km^3 $year^{-1}$ (FAO, 2010)), and to about 5 % of the total global continental discharge to oceans (Table 2). Indeed, we may expect an even greater increase because our analysis includes megaprojects only. For example, in the USA we identified 8 existing megaprojects, while a recent inventory of the total number of inter-basin transfer projects in the country includes 2,161 projects (Dickson and Dzombak, 2017; Table S2).

One of the characteristic of future WTMP revealed by our inventory is that a significant number of projects (15 in total) is transboundary and will transfer water across longer distances compared to existing projects. The median water transfer distance of future WTMP will exceed the values of existing projects by more than 100 km, although the median water transfer volume of existing and future WTMP is very similar (2.4 versus 2.2 km^3 a^{-1}, respectively). Among the 76 future projects, 23 will transfer water further than 1,000 km, compared to two out of 33 existing projects. This highlights the need to consider WTMP as integral parts of the global hydrosystem network, and to consider transferred water volumes in global hydrological models.

Currently we are lacking solid data on existing and future WTMP for individual countries. There is no dedicated agency responsible for maintaining a database on water transfer projects, not even in countries where water transfer already is an important component of water supply, such as in the United States and China (Dickson and Dzombak, 2017; Yu et al., 2018). Furthermore, we lack internationally agreed standards to evaluate water transfer project performance and impacts on people and ecosystems, as it is available for large dams (Roman, 2017; World Commission on Dams, 2000; HSAP, 2010).

Although our dataset contains the most comprehensive information that we were able to collect, the quality and completeness of information should be treated with caution. For example, there is heterogeneity in information on projects’ characteristics. Also, only English search terms were applied for data acquisition, which potentially may lead to an incomplete representation of existing and future projects in certain regions, in particular in Asia and Latin America.

Several of the future projects included in the inventory are so-called “zombie-projects” (Gleick et al., 2014). They were once proposed, declined for some reason, but then brought back to life. For example, the NAWAPA project in North America was first proposed in 1954 and discussed again in 2010s (Nuclear NAWAPA XXI, 2013). Another example is the Sibaral Project (2,500 km of water transfer from Siberian rivers to the Aral Sea), which was proposed during the Soviet Union era and recently discussed among various actors in Central Asia and Russia (Pearce, 2004). Such projects are connected with massive environmental, social, and economic interventions and are often unjustified. Their realization, however, cannot be omitted as extreme droughts, natural disasters, famines can open so-called “windows-of-opportunities” for a definite decision on their construction (Tockner et al., 2016).

Data on expected costs of WTMP show that these projects will require enormous investments, which can be even underestimated. The construction costs of all future WTMP will need more than 2.7 trillion US$, which exceeds the calculated investments for constructing 3,700 large hydropower dams, either planned or under construction (Zarfl et al., 2015). The median costs of a single WTMP (4.5 billion US$) can comprise a significant proportion of the annual GDP of individual countries (for comparison, the annual GDP of Greece is 196 billion US$ (World Economic Outlook Database, 2017)). In China, the estimated expenses on water diversion projects, both completed and planned until 2015, account for around 1% of the country’s GDP in 2014, corresponding to more than 150 billion US$ (average costs per project: 3.5 billion US$; Yu et al., 2018). High costs, however, can lead to financial failures of megaprojects (Sternberg, 2016). For example, the Central Arizona Project (USA), completed in 1992, provided water for farmers with very high irrigation fees, but investments in the project have still not been covered (Sternberg, 2016). Estimated expenses of WTMP increase while projects are under construction. The costs of the Sao Francisco irrigation project (Brazil), currently under construction, have increased from initially 4.5 to more than 10 billion US$, and may further increase until completion – and running costs are not yet included (Roman, 2017). Expenses on water transfer may compete with other societal requirements. For example, 4% of the GDP of Saudi Arabia are dedicated to sustaining water resources, compared to 8% for health and social affairs (Ministry of Finance, Saudi Arabia, 2013).

4.2. WTMP within the context of the water-food-energy nexus

WTMP offer an engineering solution meeting increasing water needs (Gupta and van der Zaag, 2008) and are part of national water management strategies and plans. The development of future WTMP is mainly driven by geographical limitations in water availability (e.g., large water volumes planned to be transferred from water secure areas to arid regions) as well as by existing deficits in water supply, thereby limiting future economic development (e.g., transfer schemes to provide water for mining schemes in Chile and Australia). Future WTMP are also proposed to facilitate the economic linkage of regions (e.g., navigation canals in South America and Africa). Some projects aim to provide water supply for particular cities (e.g., water transfer from the aquifer in East Nevada to Las Vegas, water transfer from Lake Baikal to the Chinese city Lanzhou). Currently, 12% of the largest cities in the world (with a population larger than 750,000 people) are dependent on inter-basin water transfer, and the number of cities relying on transferred water is increasing (McDonald et al., 2014). In the next decades, further expansion of urban infrastructure is expected, particularly in developing countries with relatively few financial resources (McDonald et al., 2014). The fastest growing large cities dependent on water transfer are located in China, India, and Mexico (McDonald et al., 2014).

Future WTMP will play a significant role in supporting the water-food-energy nexus. The majority of projects will support the agricultural sector. The Aquatacama Project (Chile), which will transfer around 1.5 km^3 a^{-1} over a distance of 2,500 km from the South to the North, is expected to double the area of agricultural land and food production in the country (Dourojeanni et al., 2013). Very large-scale projects in North America as NAWAPA, PLHINO and PLHIGON will jointly form a single water transfer network, boosting food production in Mexico. The area of irrigated land in Mexico will increase by 75% and grain production will be doubled (Small, 2007). Finally, the South-to-North water transfer project in China provides water for agriculture and domestic use in the densely populated areas in Northern China. A number of projects will also serve multiple purposes including providing water for agriculture, energy supply and domestic purposes. For example, Turkey, a country with the second largest hydropower potential in Europe (following Norway; Yuksel, 2015), demonstrates how water transfer schemes will support both the energy and the agricultural sector. Within the Southeastern Greater Anatolian Project (GAP), for example, 22 dams and 19 hydroelectric power plants (total installed capacity: 7,500 MW) will be constructed along the Tigris and Euphrates Rivers. After completion, the project will produce 27 billion kWh of energy annually and irrigate 1.8 million ha of land, with a total length of irrigation channels of 1,032 km (Yuksel, 2015). In Egypt and Sudan, within the scope of the New Nile Project, a 2,500 km long canal will be built to provide water for agriculture and to generate 18 gigawatt of electricity (Ahram, 2014).

However, WTMP can cause undesirable social-economic consequences, particularly when projects with underestimated costs and overestimated benefits are approved (Flyvbjerg, 2007). Water usage can be unsustainable when water is transferred to promote agriculture in water-poor areas. For example, this is the case for the Central Arizona Project (USA), which supports water-intensive cotton growth in the semiarid Phoenix region. Another example of poor-grounded water transfer is the Great Manmade River Project (Libya), which transfers groundwater from the Sahara to the Mediterranean coast, facilitating the migration of people to the desert, further increasing the pressure on scarce water resources (Sternberg, 2016). In addition, many of the future WTMP are transboundary and are planned in countries that are less stable politically and economically. This may lead to international disputes in water issues (Tockner et al., 2016).

4.3. Impacts on freshwater ecosystems

Although environmental impacts of individual inter-basin transfer projects have been analyzed in multiple studies (Zhuang et al., 2016), the impact of megaprojects in general is difficult to predict due to their large scale.

With the help of WTMP humans will redistribute large volumes of water between distantly located catchments and thus change the hydrological balance. Intense water withdrawals can lead to a flow reduction in donating basins. For example, the annual flow of the Yellow River in China was reduced by 10% in 2013, compared to the average flows within the last 60 years due to average withdrawal of 3.3 km^3 a^{-1} (Yu et al., 2018). In many cases, however, extraction of streamflow from the donating basins is not significant. For example, half of the inter-basin transfer schemes that existed in the US in 1973-1982 extracted 0.04%, and 78% of the projects less than 1% of streamflow from the donating basins (Emanuel et al., 2015). Overall, water transfer between wet and dry catchments will lead to a flow homogenization at regional and continental scales, but solid data to underpin this observation are still missing (McDonald et al., 2014).

In some cases, concerns about the environmental consequences of future WTMP have already been raised. For example, the “Acheloos Diversion” project (Greece; under construction) that was named a “Modern Greek Drama” (Tyralis et al., 2017) may cause irreversible damage to highly valuable ecosystems containing internationally protected species (WWF, 2007). The Sao Francisco irrigation project (Brazil) is expected to increase desertification and cause salinization of irrigated soils due to increased evapotranspiration (Stolf et al., 2012). However, by constructing some of the future WTMP ecological losses shall be prevented, for example by implementing the “Transaqua” project the shrinking Lake Chad is intended to be refilled, or by following the “Comprehensive Everglades Restoration Plan” the hydrology of one of the most important wetlands globally shall be stabilized (Ifabiyi 2013; CERP, 2015).

Overall, the effects on freshwater ecosystems need to be estimated individually for each project. In general, the extent of the effects will depend on the physical and biological characteristics of the donating and recipient systems, the type of the connecting structure (pipelines or open canals), the volume of water transferred and the frequency of transfers (Soulsby et al., 1999; Gibbins et al., 2001; Fornarelli and Antenucci, 2011). The current inventory on future WTMP can serve to identify evolving changes and potential impacts on freshwaters by overlapping the WTMP data with further datasets (e.g. with hot-spots of biodiversity, water quality in donating and receiving basins).

5. Conclusions

Within the next decades, we may expect a massive boom in the construction of WTMP. As water scarcity becomes a global phenomenon, WTMP are currently considered to be a solution to meet the increasing water demands in both developed and developing countries. These projects may play a fundamental role in balancing the water-food-energy nexus, thereby sustaining food production, producing hydropower, and supporting industry. Even projects which seem to be unrealizable and unjustified can become implemented under certain economic and political conditions.

The lack of solid data does not allow to fully evaluate environmental, social, and economic potential impacts of such projects so far. The size of these WTMP suggests, however, that their impacts will cover regional and continental scales and will be irreversible. Thus, before implementing these risky engineering solutions, the efficiency of water usage needs to be reconsidered. Measures as using recycled water, improving piping and distribution in existing urban systems, and increasing the efficiency of irrigation for agricultural purposes should come first in addressing the challenges of water shortage.

Overall, the results of the inventory of WTMP emphasize the need to include these projects in global hydrological models and to develop internationally agreed criteria for their multiple assessments. Otherwise, we are facing an engineered water future, which may constrain alternative solutions to cope with an increasingly uneven distribution, both in space and time, of the global water resources. We need to manage our hydrological systems as hybrid systems – as resources for human use as well as highly valuable ecosystems, for the benefit of people and nature alike.

Author Contributions Statement

OS, KT and CZ designed the study. OS, AK and CZ collected information. OS compiled the manuscript and all co-authors contributed to the text.

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Conflict of Interest Statement

Authors declare no conflict of interests.

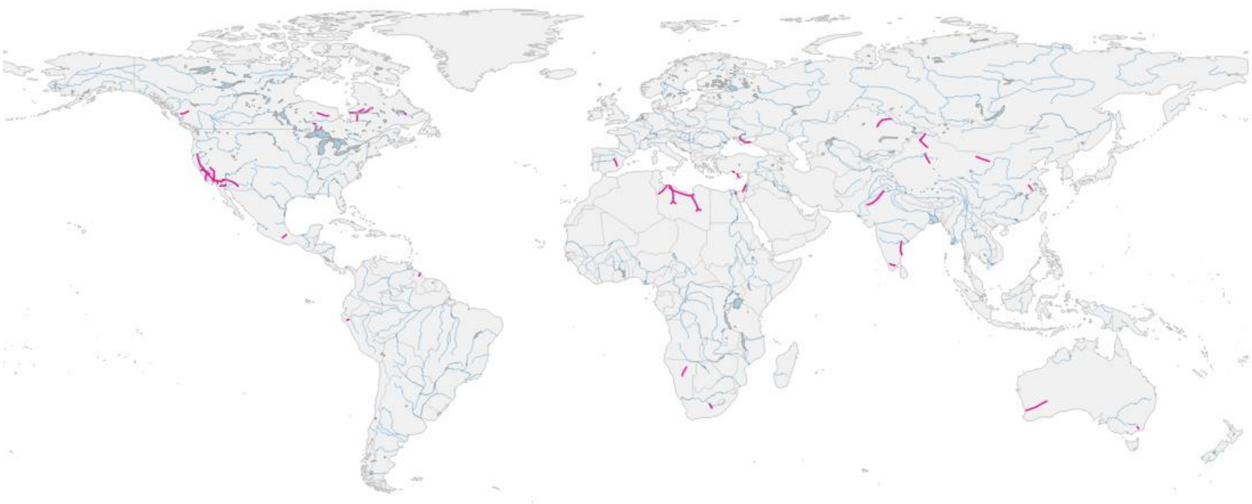

Fig. 1. Global distribution of existing water transfer megaprojects (purple lines) (N=33). Blue lines show major world rivers.

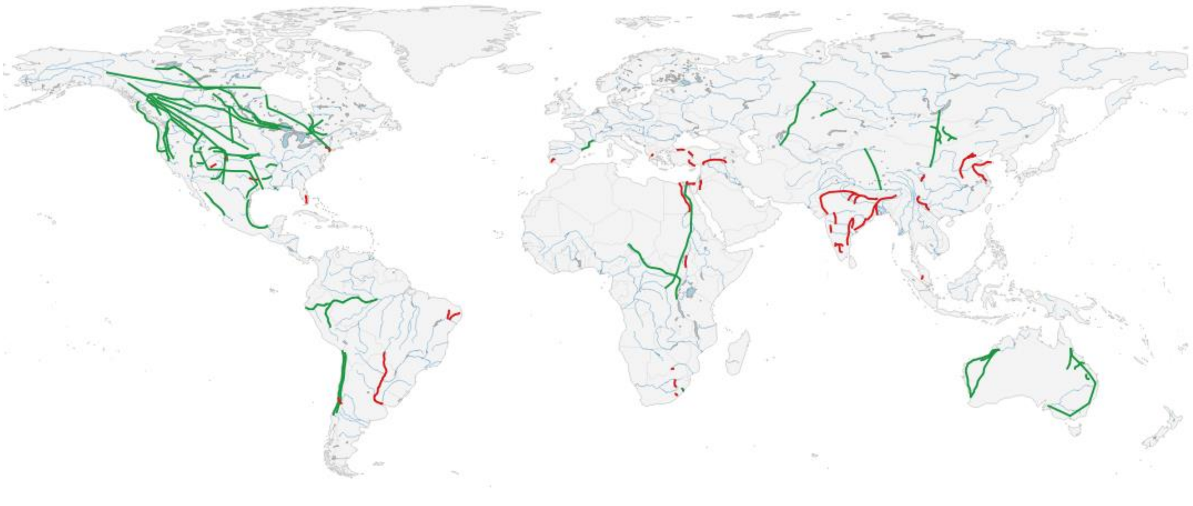

Fig. 2. Global distribution of future water transfer megaprojects that are under construction (red lines) or in the planning phase (green lines) (N_{total}=76). Blue lines show major world rivers.

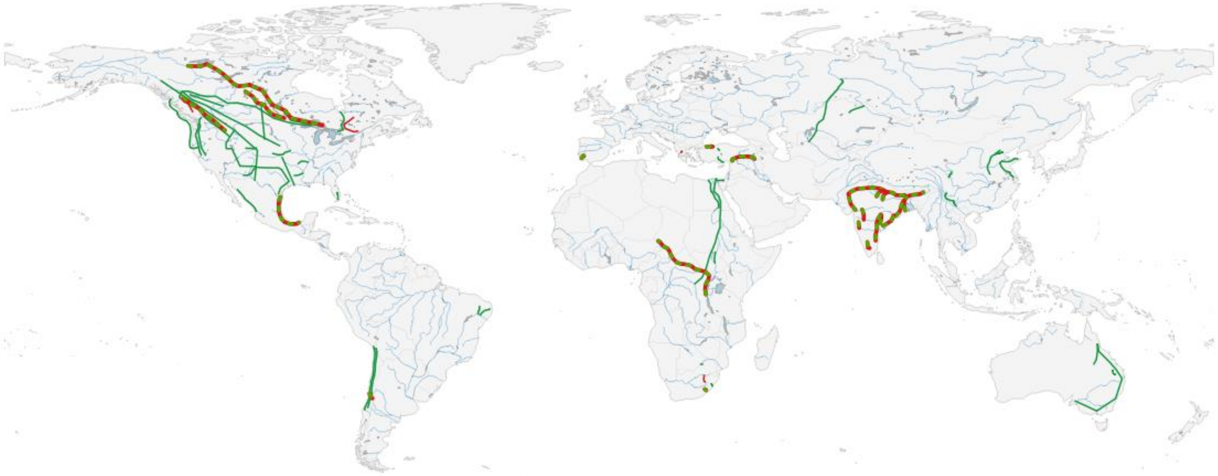

Fig. 3. Distribution of future WTMP according to their purposes: water supply for purposes of agriculture (green lines, N=43), hydropower development (red lines, N=14) or both (red-green stripped lines, N=10). Blue lines show major world rivers.

Table 1. Summary information (per continent) on water transfer megaprojects, either planned or under construction.

Continent	Number of projects	Total water transfer distances[1] (km)	Total water transfer volume[2] (km^3 a^{-1})	Total cost of all projects combined[3] (billion US$)
North America	34	30,240	1346	1,936
Asia	17	28,450	321	522
Africa	9	6,600	233	130
Australia	7	8,720	12.9	72
South America	6	11,780	8.2	36
Europe	3	2,350	1.9	12
Total	**76**	**88,140**	**1,923**	**2,708**

[1] One project in Australia has missing information on distance, 11 in North America; [2] Four projects have missing information on total water transfer volume (3 in North America, 1 in South America, 1 in Asia); [3] 14 projects have missing information on cost (10 in North America, 1 in Asia, 1 in Europe). All missing values were substituted with respective median values.

Table 2. Water volumes transferred in future WTMP versus volumes of continental water withdrawals and total discharge to oceans (per continent).

Continent	**Water volumes transferred through future WTMP (km^3 a^{-1})**	**Continental water withdrawals (km^3 a^{-1})**		**Continental discharge to oceans[3] (km^3 a^{-1})**
		Total in 2000[1]	**Through IBT in 2005[2]**	
North America	1,346	705	300	5,890
Asia	321	2,357	146	13,090
Africa	233	235	11	4,520
Australia	12.9	32	1	1,320
South America	8.2	182	3	11,715
Europe	1.9	463	79	2,770
Sum	**1,923**	**3,974**	**540**	**39,305**

[1] Shiklomanov (2000); [2] ICID (2005); [3] Fekete et al. (2002). Abbreviations: IBT – inter-basin transfer

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