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# A Review of the Economic, Social, and Environmental Impacts of China's South–North Water Transfer Project: A Sustainability Perspective

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**Abstract:** China's South–North Water Transfer Project (SNWTP) has the potential to transfer as much as 44.8 $km^3$ $year^{-1}$ of water from the Yangtze River basin to the Yellow River basin. However, the SNWTP has not been assessed from a sustainability perspective. Thus, in this study we evaluated the SNWTP's economic, social, and environmental impacts by reviewing the English literature published in journals that are part of the Web of Science database. We then synthesized this literature using a Triple Bottom Line framework of sustainability assessment. Our study has led to three main findings: (1) whether the SNWTP is economically beneficial depends largely on model assumptions, meaning that economic gains at the regional and national level are uncertain; (2) the SNWTP requires the resettlement of hundreds of thousands of people and challenges existing water management institutions, suggesting possible social concerns beyond the short term; and (3) evidently large environmental costs in water-providing areas and uncertain environmental benefits in water-receiving areas together point to an uncertain environmental future for the geographic regions involved. Thus, the overall sustainability of SNWTP is seriously questionable. Although much work has been done studying individual aspects of SNWTP's sustainability, few studies have utilized the multi-scale, transdisciplinary approaches that such a project demands. To minimize environmental risks, ensure social equity, and sustain economic benefits, we suggest that the project be continuously monitored in all three dimensions, and that integrated sustainability assessments and policy improvements be carried out periodically.

**Keywords:** inter-basin water transfer; Integrated Water Resource Management; North China Plain; South–North Water Transfer Project; water sustainability

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## 1. Introduction

Access to clean water is fundamental to sustainable development. Despite the central role of water, as much as 80% of the human population lives in a state of water insecurity [1]. However, on a global scale water is abundant, suggesting that the problems of water scarcity are partly attributable to spatial and temporal mismatches in water availability and water demand [2]. One solution to these spatial mismatches is to move water from water-rich areas to water-poor areas using inter-basin water transfers.

China is a classic example of the disconnection between water supply and demand. Though the country may have adequate water supplies on a national scale, the vast majority of this water is located in the Yangtze drainage basin which is too mountainous for the large-scale agriculture necessary to feed China's population [3]. In contrast, the North China Plain (NCP), which contains many of China's most productive agricultural centers and large urban areas, faces acute water scarcity when measured on a per capita basis [4,5]. Further, many of the NCP's rivers suffer from poor water quality [6], worsening water scarcity. Exacerbated by the NCP's critical place in China's food supply and economy, this scarcity has long lead the Chinese government to seek alternative measures to alleviate water stress in this region [7,8]. Broadly conceived by Chairman Mao Zedong [9], the South–North Water Transfer Project (SNWTP) represents China's grandest attempt to solve the NCP's water woes through the largest inter-basin water transfer in human history [10].

The SNWTP consists of three routes (Figure 1). The Eastern Route (ER-SNWTP) is an update of the ancient Grand Canal [9], a system of diversions and lakes that historically transported goods from the Yangtze River basin to the Yellow River basin. This route can transfer nearly 9 $km^3$/year of water, and future plans suggest that this could rise to as much as 14.8 $km^3$/year by 2030 [11]. In contrast, the Middle Route (MR-SNWTP), the first stage of which was completed in 2014, is a new construction, reaching from the Danjiangkou Reservoir on the Han River (a tributary to the Yangtze), and crossing Henan and Hebei provinces before reaching its destination in Beijing and Tianjin. In total, the MR-SNWTP can carry up to 9.5 $km^3$/year of water over 1246 km [7]. Similar to the ER-SNWTP, future plans to expand this structure suggest that 13 $km^3$/year of water could eventually be transferred [7]. Finally, the Western Route (WR-SNWTP) calls for a system of canals, which, if constructed, will cross the Qinghai–Tibetan Plateau, transferring 17 $km^3$/year [7] of water from the headwaters of the Yangtze River Basin to the headwaters of the Yellow River Basin.

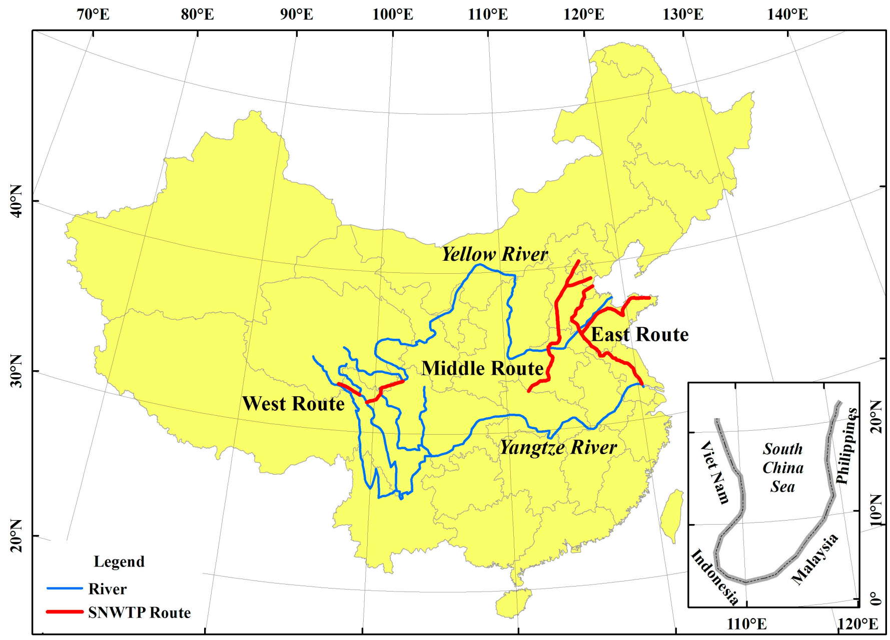


**Figure 1.** A sketch map of the South–North Water Transfer Project (modified from [12]).

Construction of the most recent phase began in 2002 following as much as 50 years of planning [4,13]. Two of three routes, ER-SNWTP and MR-SNWTP, are operational and will together be capable of delivering up to 27.8 $km^3$/year of water to the NCP when future construction is complete [7,11]. The construction of the WR-SNWTP, on the other hand, has been indefinitely delayed [14]. Despite the scale of this massive hydrological project, it has not been holistically assessed from a sustainability perspective. Rather, in place of such a holistic assessment, fragmented literature exists in which individual disciplinary groups have each examined the SNWTP separately while failing to integrate their findings with those from other disciplines. Here we carry out such an integrative analysis, reviewing each paper concerning the SNWTP published in Web of Science journals from up to July 2017, regardless of discipline, and synthesizing the existing knowledge of the SNWTP using a Triple Bottom Line framework [15,16].

## 2. Materials and Methods

To generate the body of literature on the SNWTP, we entered the search term "South North Water Transfer Project" into Clarivate Analytics' Web of Science (https://www.webofknowledge.com/) for the years 1900–2017 on 24 July 2017. To these, we added nine immediately relevant works published outside the journals in the Web of Science database: Liu [3], Liu and Zeng [17], Berkoff [4], Nickum [9], He et al. [7], Freeman [8], Crow [18], Barnett et al. [10], and Crow-Miller and Webber [19]. Papers were first assessed by reading their titles and abstracts. When titles and abstracts were not found to be sufficient, the complete paper was read. When full PDFs were not available in Arizona State University's library, our study was limited to abstracts available through the Web of Science. Papers that were only tangentially related to the SNWTP were eliminated from our review.

This search returned 203 results from Web of Science journals and 9 results from outside sources. Of these 212 results 59 were judged to be off topic or only tangentially related to the SNWTP. Further, papers focusing on specific technical aspects of the SNWTP, such as ice formation [20], soil stabilization [21], or geological stress at planned construction sites [22], were identified in our search, but are beyond the purview of this paper.

The content of this review was then synthesized using a Triple Bottom Line framework. The Triple Bottom Line framework assesses the overall sustainability of a project by simultaneously considering the three dimensions, or pillars, of sustainability: economy, society, and environment [15,16]. This framework is relatively simple, flexible, and has been used frequently in the sustainability literature [16]. To assess the impact of the SNWTP on each pillar, we describe the major conclusions from the existing literature for each pillar and further comment when disagreement appears. While such an approach treats the environmental, economic, and social dimensions separately, it also emphasizes inter-dimension connections [16], which are an important component of sustainability assessments [23].

## 3. Results

### 3.1. Economic Impacts

A central question in the construction of the SNWTP is whether its enormous cost is economically justified. A variety of perspectives, from specific to broad, have been used to answer this question. Some, such as Hu et al. [24], discussed the economic impacts of the SNWTP as it applied to a single issue, in this case land subsidence. Others took a more comprehensive sustainability approach, either by estimating environmental costs and benefits (e.g., [25]) or by assessing ecosystem services of different kinds (e.g., [26]). These studies all broadly agree, as expected, that the SNWTP will transfer ecosystem services from the water-providing areas to the water-receiving areas.

Cost estimates for building the project differed radically [14], ranging at least from 20 billion to 81 billion USD for the ER- and MR-SNWTP alone [27]. Webber et al. [14] noted that these estimates generally only covered construction costs. Beyond these disagreements in project costs, whether the project is economically justified has also been debated. Lin et al. [25] used a water footprint approach to compare and monetize the water footprints in water-providing and water-receiving areas both before and after the project. Their analysis, which assumed that water consumption in more water scarce areas has a larger environmental impact than water consumption in areas of lower water scarcity, found that the ER-SNWTP and MR-SNWTP together (WR-SNWTP not addressed) would provide significant net environmental gains that, when monetized, could justify the cost of the SNWTP. Berkoff [4] performed a detailed analysis of two economic models: one from the World Bank, which found the project to be economically beneficial, and the other from the World Wildlife Fund, which did not. While there are a substantial number of differences between the two models, one significant difference was the value of the transferred water, with the World Bank estimating higher water values across most sectors than the World Wildlife Fund [4]. Another significant difference was in the area of water-use efficiency. According to Berkoff [4], the World Bank model assumes that increasing efficiency for the largest water user (irrigation) has negative economic returns, whereas the World Wildlife Fund report argues that significant potential for increased water-use efficiency remains, suggesting that within-basin water management is a key component in evaluating the economic viability of the SNWTP. This was echoed in more recent analysis by Fang et al. [28], who found that the SNWTP's cost effectiveness was at least partially dependent on within-basin water allocation. Crow-Miller [29], however, pointed out that leaders within the central government see the SNWTP as economic-growth enabling, which implicitly endorses the view that water scarcity is limiting growth on the NCP.

However, based on a scenario analysis of the SNWTP project, Berokoff [4] argued that such perspectives were too simplistic. He found that economic growth could be maintained without the SNWTP, but implementing growth-enabling polices in the absence of additional water supplies would likely undermine social institutions and result in additional environmental degradation [4]. On the other hand, the SNWTP would reduce water scarcity on the NCP, but the primary consequence of this reduced scarcity would be to preserve low value agriculture [4]. Berkoff [4] concluded that no case has been made in English that there are enough direct economic benefits to justify the cost of the program. More recently, Moore [30] pointed out that the project's economic viability remains controversial. With two of the three routes operational, such speculative, assumption-laden economic models are becoming quickly outdated. The relative costs and benefits of the SNWTP can be directly measured from now on, and these direct measurements should provide important data for comparing and validating long-term economic models. Until such work is done, our understanding of the SNWTP's economic impacts will remain largely theoretical.

### 3.2. Social Impacts

Our understanding of how the SNWTP will impact society in water-receiving and water-providing areas has been limited to three primary fields of study: disease (specifically schistosomiasis) transmission, water management, and the impact of the SNWTP on governance at a variety of spatial scales and organizational levels.

Early reviews (e.g., [9,13]) suggested that the SNWTP could increase the transmission of schistosomiasis-carrying freshwater snails from the south of China, where schistosomiasis is a serious concern, to the north of China, where schistosomiasis is relatively rare. These concerns were fleshed out in two experiments [31,32], which showed that, unless there is a radical change in climate, the risk of freshwater snails moving northward is manageable if snail control measures are implemented. However, there has been relatively little research in disease transmission in general, and these findings should be viewed as tentative until more comprehensive studies are done on the topic.

Research concerning how the water from the SNWTP will or should impact Chinese society has broken into two perspectives. The first of these is technical, modeling project management structures to compare various water management strategies (e.g., [33,34]). The second set of papers focused on the SNWTP's impact on governance systems. Though there was some discussion of governance in early papers (e.g., [3]), this literature has swollen in recent years to include Crow-Miller and Webber [19], Webber et al. [14], Rogers et al. [27], Pohlener [35], Crow [18], Crow-Miller [29], and Moore [30]. These papers are rarely quantitative and rely heavily on the author's interpretation of documents and ongoing events. While it is difficult to make generalizations across such a broad set of papers from intellectually diverse authors, the central point of most governance papers can perhaps be best described by synthesizing the common threads expressed by Crow [18], Crow-Miller [29], Rogers et al. [27], Webber et al. [14], and Crow-Miller and Webber [19]. These papers discuss the

SNWTP in political terms, generally finding that the SNWTP has been justified frequently by representing water scarcity in the north as a naturally occurring, national (rather than regional) concern with an obvious engineering solution.

As pointed out by Pohlener [35], Rogers et al. [27], and Webber et al. [14], the administrative structures charged with managing the project are complex. SNWTP water provisions and allocations are initially proposed by river basin commissions and local governments in water-providing and water-receiving areas, respectively [27]. These proposals are evaluated and implemented by the central government, where several governmental agencies and state-owned corporations control different aspects of the SNWTP [27]. However, it remains unclear to what extent local governments can impact final decision making [27]. Furthermore, inter-governmental agreements in which local governments in water-receiving areas compensate local governments in water-providing areas have become increasingly important [27,35]. Similar cooperative relationships exist between the central and various local governments [30,35], and there is some evidence that the central government has used the SNWTP to exert power over local governments under the auspices of protecting water quality [14,19]. This web of interconnected and interdependent institutions may lead to a management structure that is opaque and still changing [14].

The SNWTP will most likely have substantial impacts on local communities, but these impacts are poorly studied. More than 300,000 inhabitants, both immediately around Danjiangkou Reservoir and elsewhere [8,14], either were or will be relocated due to project construction. Though there is much discussion of how the loss of water on the Han River, caused by the MR-SNWTP, will disrupt the environment (see Section 3.3), little is known about how these losses will impact the livelihoods of downstream populations. Webber et al. [14] observed that local development policies were altered in many communities in water-providing areas, including resettlements, restricted development, and reduced use of pesticides. Yet, Berkoff [4] asserted that the SNWTP could reduce rural abandonment in the NCP by alleviating water scarcity.

The SNWTP therefore raises several social concerns occurring across a variety of scales. Locally, building the SNWTP will require the displacement of hundreds of thousands of people [8,14]. Institutionally, building the SNWTP will change existing water management structures [14]. However, had the SNWTP not been built, poor farmers in more isolated locations across the NCP would have likely lost access to the water necessary for farming, altering this traditionally agrarian region [4]. The central government has depicted this tradeoff as beneficial to the national good despite local impacts [19], electing to build the project while centralizing control over a massive water resource [14], altering local governance structures [14,19], and possibly empowering new growth [29]. The long-term social impacts of this choice are yet to unfold.

### 3.3. Environmental Impacts

The promise of environmental restoration in the NCP was a critical factor in the decision to build the SNWTP [5]. Therefore, one of the primary questions surrounding SNWTP construction concerns the relationships between environmental costs and benefits across regional (e.g., water-providing areas vs. water-receiving areas) and national scales. This literature is far more complete than the social and economic literature discussed above.

It is clear that the SNWTP will cause increased environmental problems in water-providing areas [3,9,11,13]. Some of these problems are centered around whether water-providing areas can support the quantity of water to be transferred. Zhang [13] pointed out that water withdrawals due to the MR-SNWTP represent 35% of flow at the point source. Gu et al. [36] found that, in order to reduce the risks of water deficits in the MR-SNWTP source areas, an additional water transfer project should be built, moving at least 100 $m^3/s$ to the Han River from the Yangtze River.

Water quality and water quantity are often linked. As such, an entire branch of study has focused on the relationship between SNWTP withdrawals and water quality in water-providing areas, specifically Yangtze Estuary salinization and Han River degradation. Early reviews noted that decreased flow in the Yangtze Basin could worsen the already existing problem of estuary salinization (e.g., [3,9]). These findings were confirmed by Chen et al. [11] who found that the ER-SNWTP alone could increase estuary salinization between January and February, as well as Webber et al. [37] who carried out a broader analysis of Yangtze Estuary salinization. A similar pattern connects the water losses caused by MR-SNWTP to riparian health along the Han River, from which the MR-SNWTP originates [13,38].

Less clear than the environmental costs in water-providing areas are the potential environmental benefits in water-receiving areas. One possibility is that, although the negative impacts on the water-providing areas will be large, the potential environmental benefits in the water-scarce north will be larger [3,25]. However, a critical assumption of this type of analysis is that the water being transferred will be of high enough quality to be useable. Several studies on both the MR-SNWTP and ER-SNWTP have identified significant pollution loads (e.g., [39–45]), and Freeman [8] noted that some local populations refused to accept polluted water if they had to pay for treatment.

Assuming that these quality problems can be resolved, the ability of the SNWTP to address specific environmental objectives is still controversial. For example, the literature has largely focused on restoring groundwater levels across the NCP as a primary environmental goal of the SNWTP. However, the extent to which the SNWTP's water will be successful in restoring groundwater is unclear. At the basin and landscape scales, Ye et al. [46] and Shu et al. [47] suggested that the SNWTP would not be sufficient to halt groundwater declines. In contrast, Zhang [13] suggested that the MR-SNWTP could increase the risk of secondary salinization (soil salinization caused by over-irrigation). Berkoff [4] pointed out that irrigation has historically been the "user of last resort" during times of scarcity in the NCP, capable of absorbing all available surplus water. Yang et al. [48] found that the SNWTP's water was not sufficient to meet local demands in the Hebei Plain. As it is not possible to earmark all of the transferred water both to direct use and to environmental protection, these goals are at least partially exclusive.

Last, the environmental impacts of the SNWTP will not be limited to the water itself, but will also be felt in the development pathways this additional water makes possible. Berkoff [4] claimed that the SNWTP would preserve agricultural potential across the NCP. Chen and Xie [49] went on to show that the use of the MR-SNWTP's water could have a small effect on regional climates. Another possible risk of increased agriculture in the NCP is secondary salinization. This topic received some attention in early years (e.g., [9,13,17]), but has received little attention since. However, the interactions between the SNWTP and future development pathways are poorly described by the literature (we will discuss this topic further in Section 4.2).

Therefore, while the environmental costs of the SNWTP in water-providing areas are relatively well known, the environmental benefits in water-receiving areas are unclear, with a number of uncertainties. As pointed out by many sources (e.g., [3,11,13]), the amount of water withdrawn by the SNWTP will cause significant negative impacts on the Han River and in the Yangtze Delta. Furthermore, by highlighting poor water quality and the possibility of secondary salinization, the literature questions the usefulness of the transferred water in water-receiving areas. Lin et al. [25] suggested that environmental costs to the water-providing areas could be offset by the benefits of restoration in the water-receiving areas. Such analyses were based on the central assumption that the environmental impacts of water consumption are defined by the water use to availability ratio. This makes some sense, as consuming the last drop of water in a stream certainly has a larger environmental impact than consuming the first drop of water in stream. However, evening the distribution of water across broad geographic regions of different climatic zones cannot be environmentally sustainable over the long term, as such large-scale projects may fundamentally alter the hydrology and ecology of water-providing and water-receiving regions. Furthermore, such technological and engineering approaches are detached from the proximal drivers of environmental degradation. Specific to the SNWTP, Berkoff [4] pointed out that irrigation capacity has historically far outweighed the amount of water available during dry periods, suggesting that any "new" water introduced into the system would most likely be absorbed by irrigation, not environmental restoration. While it is possible that strong government intervention or high pricing could designate this water specifically for environmental restoration, such a policy would undermine the economic goals of the project (e.g., [29]) and could create significant social strife in the NCP [4]. In sum, an environmental sustainability assessment of the SNWTP should be centered more on the costs in water providing areas, which are known and serious, than benefits in the water-receiving areas, which are elusive and path dependent.

## 4. What Knowledge Gaps Remain?

### 4.1. Limitations of Our Literature Review

It is important to note that our literature review only covered English language sources published in Web of Science journals. The Chinese language literature and SNWTP planning documents, which fell outside our review, surely contain a wealth of useful information. Further, it is possible that we failed to identify important papers that were published outside the Web of Science or beyond the scope of our search terms. That considered, our literature review identified two key knowledge gaps remaining in the study of the SNWTP, discussed below.

### 4.2. Path Dependencies and Future Conditions

Projecting the economic, social, and environmental impacts of the SNWTP is fraught with uncertainty. While the majority of sources in the literature admirably answer their specific research questions in relation to current conditions, few recognize that the SNWTP is a project that will be judged not only by today's conditions, but also on future water needs of a growing population facing a changing climate. It is possible that this approach could be appropriate in a stagnant landscape, but the NCP is anything but stagnant. The NCP has been rapidly changing, and will continue to do so. Therefore, when extrapolating the impacts of the SNWTP into the future, rapid population growth and urbanization must be taken into account. To take specific examples, the impacts of the SNWTP on groundwater levels will be determined by future water demand, not today's demand; the pollution load of water leaving source-providing areas will be determined by the future land-use/cover, not today's; and how much water the Han River needs to sustain flows will depend partly on how many downstream farmers come to utilize it. In addition, while the adequacy of the SNWTP is dependent on future conditions, the states of these future conditions (e.g., agricultural water demands, regional land-use/cover, relative population sizes in the north and south, etc.) are also dependent on how the SNWTP's water is managed in the near term. The existing literature has provided the building blocks necessary to deconstruct these circular causalities and path dependencies. Future work should build on and integrate these results to project the SNWTP's impacts through space and time.

Specifically, projecting the interaction between the SNWTP and environmental restoration in the NCP is highly uncertain. To truly curb water-related environmental problems in the NCP, it is likely that policies which focus on environmental protection rather than water stress alleviation will be necessary. Regardless of whether this is the correct path or not, the political feasibility of using the SNWTP's water for environmental restoration remains an open question. On one hand, as Yang and Zehender [5] pointed out, the promise of environmental restoration in the north was a critical factor in the decision to build the SNWTP, and centralized control of the SNWTP's water could make this process easier. However, if one takes the view of Crow-Miller [29], that a primary goal of the SNWTP is to provide the resources necessary for sustained growth, the use of SNWTP water for environmental restoration seems implausible.

Experience with the Central Arizona Project in the United States has shown that few are willing to pay for the more expensive, transferred water while cheaper water is available, leaving governments little choice but to use the water for environmental improvement (in the case of the Central Arizona Project, groundwater restoration, see [50]). Now that both the ER-SNWTP and MR-SNWTP are operational, a careful accounting of how the SNWTP's water is being utilized in reality presents an excellent opportunity for study.

*4.3. Scale Effects and Water Sustainability*

The costs and benefits of the SNWTP occur across both spatial and temporal scales. Locally, water-providing areas will bear the ecological and social cost for this project and see none of the ecological or social benefits. The Han River will experience declines in discharge [13], while the communities who rely on it will continue to grow and demand more water. Yangtze Estuary salinization will grow worse, especially during dry months and years, further increasing the environmental concerns in this already critical region [11,37]. Although the contention that, on balance, the socio-ecological costs in water-providing areas will be outweighed by the benefits in water-receiving areas on a national scale (e.g., [25]) seems plausible, these aggregate effects are likely of little consolation to those who will be negatively impacted by the implementation of this program. Further research is needed to contextualize the environmental costs relative to the benefits across organizational scales, especially from an environmental justice perspective.

More broadly, this review elucidates the challenge of transitioning from a paradigm of traditional water resource management to water sustainability. From its inception, the field of water resource management has been haunted by a lack of time-dynamic and spatially-explicit approaches [51], which are necessary to truly assess projects like the SNWTP. For example, the most fundamental measure of water scarcity—the Falkenmark Index [52]—simply measures water scarcity as water flow per person per year, disregarding the fact that both water supplies and populations are dynamic. While this is not a problem for assessing the water scarcity of a given region in a snapshot of time, translating the paradigms of water scarcity to water sustainability relies on a recognition that both the supply and use of water will change. Therefore, the lack of spatiotemporal considerations in the existing SNWTP literature should not be seen as a specific failing of the SNWTP's planners, but rather another contextual example of how the assumption of stationarity fundamentally limits our ability to assess water resources in the long term.

## 5. Conclusions

To date, with two of the three routes operational, the SNWTP can move up to 18.5 $km^3$ of water/year [7,11]. Even without the WR-SNWTP this figure is expected to rise to 27.8 $km^3$/year in the near future [7,11], making the SNWTP one of the grandest attempts by humans to alter their environment at regional and super-regional scales. However, despite decades of study, surprisingly large uncertainties of the project's economic, social, and environmental impacts remain. Despite these uncertainties, some general conclusions emerge from our literature review and synthesis: projected economic gains vary widely, with no guaranteed economic success at the national level; socially, the project will create challenges at local and regional scales, depending on the central government's policies; and environmental costs in the water-providing area will be large, while benefits in the water-receiving areas will be path-dependent. Together, these results paint a picture of a huge project that is unlikely to be sustainable over the long term without periodic comprehensive sustainability assessments and responsive management.

Regardless of these uncertainties the SNWTP has been built. It is therefore time for research questions to shift from whether the project should exist to how the project can be managed sustainably. Such work will require integrating knowledge across disciplines and through time, which is precisely the type of work we found lacking in the literature. The SNWTP, and water sustainability in general, highlight the importance of multiscale, interdisciplinary, approaches in sustainability science. Populations, social structures, and resource availabilities change in space and time, creating moving targets for policy makers attempting to plan on decadal time scales. However, these moving targets are also the very criteria that determine the relative success or failure of a project. There is no single 'correct' scale to design and implement sustainable management strategies [16]. The interplay between regional (e.g., water-providing vs. water-receiving) and national scales in this review suggests that economic, social, and environmental dimensions all must be considered simultaneously on multiple spatial scales in order to properly evaluate and ensure the sustainability of the SNWTP. Toward this end, hierarchical, time-dynamic approaches based on landscape sustainability science [16] may be necessary for research, monitoring, and management programs. Only through continuous monitoring and periodic sustainability assessment, followed by proper and timely policy actions, can the project's environmental risks be minimized, its social equity be ensured, and its economic benefits be sustained.

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