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Title:
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Date:
2015-11-01

Citation:
Webber, M., Barnet, J., Chen, Z., Finlayson, B., Wang, M., Chen, D., Chen, J., Li, M., Wei, T., Wu, S. & Xu, H. (2015). Constructing Water Shortages on a Huge River: The Case of Shanghai. Geographical Research, 53 (4), pp.406-418. https://doi.org/10.1111/1745-5871.12132.

Geographical Research

CONSTRUCTING WATER SHORTAGES ON A HUGE RIVER: THE CASE OF SHANGHAI

Journal:	*Geographical Research*
Manuscript ID:	Draft
Wiley - Manuscript type:	Original Article
Keywords:	Yangtze River, Salinity, Pollution, Shanghai, Urban water, Management, Inter-basin transfers
Abstract:	Shanghai is located on the world's third largest river (by volume). Yet it faces the risk of shortages of drinking water. Many decisions and environmental characteristics have contributed to this threat. First, Shanghai has become dependent on water brought into the municipality by rivers. Second, it has become increasingly reliant on water from the Changjiang (Yangzi River), principally in order to control the levels of pollution in the water that enters its treatment plants. Third, for reasons associated with inter-provincial administrative arrangements, the city's water intakes are located within the municipality, within the estuary zone and subject to tidal intrusions of salt water. Fourth, at high tide and when the Changjiang's discharge is low, salt intrudes far into the estuary, beyond the current water intakes. If sea levels rise, these intrusions will become more pronounced. Fifth, large-scale central government infrastructure projects (such as dams and the South-North Transfer) are altering the hydrological characteristics of the river. Such projects raise the probability of salt water intrusions into the water intake zone. The Shanghai and central governments have thus made a series of decisions that, taken together, have led the municipality to rely on a source of drinking water that is increasingly unreliable and subject to the risk of shortages due to salt water intrusions. Why these decisions have been made – independently – is an important problem for those who would understand the provision of water for cities and the practical efficacy of Chinese governance systems.

CONSTRUCTING WATER SHORTAGES ON A HUGE RIVER: THE CASE OF SHANGHAI

1 INTRODUCTION

Shanghai is a subtropical city (Cfa in Köppen's classification: Peel *et al.* 2007). Its mean annual precipitation is approximately 1100 mm (Shanghai Water Authority 2010a) and within its boundaries are large lakes and rivers (Shanghai Water Authority 2010b). It is located on the Changjiang (Yangzi River), the mean annual discharge of which was more than 70 times Shanghai's total water use in 2010 (Shanghai Water Authority 2010c).

FIGURE 1 ABOUT HERE

Yet the municipality apparently faces shortages of drinking water. In spring 2004, the supply of fresh water to Shanghai hit a 'record low' (*People's Daily* 5 March 2004); the Shanghai Water Affairs Bureau predicted that in summer 2005 there could be a shortage of 1.5 10^6 m^3 / d (Shao 2004). By 2009 the municipality identified itself as suffering from a 'pollution-induced water scarcity' (Shanghai Water Authority 2009). It is estimated that by 2020 Shanghai will face a fresh water shortage of about 7.5 per cent of consumption (Hu 2003). Despite the abundance of water, there are problems in supplying freshwater to the municipality's residents and industries.

Many cities face water shortages: in 2000, about 150 million people lived in cities where annual water availability was less than 100 L per person per day; another 886 million lived in cities where for at least one month per year, water availability was less than 100 L per person per day (McDonald *et al.* 2011). Perhaps a third of the world's total population have to contend with polluted water (Howard and Bartram 2003). The distributional issues that underpin these numbers, their relations to poverty, and their impacts on human well being are summarised by the United Nations Development Program's *Human Development Report* for 2006 (UNDP 2006). Yet Shanghai is located where there is plenty of flowing water, much of which can be treated to drinking standards (Tan 2011), and has an average GDP per capita of nearly USD 20 000: it is not a third world city located in a region of high water stress. Focussing on the supply of residential water, therefore, in this paper we ask how wealthy Shanghai, located adjacent to abundant supplies of freshwater, now faces the risk of water shortages.

Is this a matter of demand caused by population growth and economic development, the kind of explanation identified as scarcity (Falkenmark 1990; Goel 2006; Pereira *et al.* 2009)? Such physical or absolute water shortages, an inadequate quantity relative to demand, affect Beijing and Tianjin. In general, such a neo-Malthusian argument ascribes the problem of water shortage to excessive demands from agriculture, industry or consumers, summarised as too much growth of GDP and too many people (Osborn 1948). In its simple form, this is a problem of quantitative insufficiency; but insufficiency of potable water may also induced by pollution from agricultural or industrial sources, a particularly acute problem in China (Economy 2004).

Has the risk been produced by the privatisation or commodification of water, which afflict the management of water supplies elsewhere (Bakker 2000; Johnston 2003; Swyngedouw 2005)? This political ecological approach recognises the constraints imposed on social choices by the environment, but argues that social controls over water 's allocation are more fundamental to shortage than absolute scarcity. The provision of water is a form of social relation, dominated by issues of power and economy, by the contrast between water as a human right and water as a commodity. As a commodity, the supply of water is subject to market rules: greater scarcity means higher prices. So commodity water is made scarce in various ways, including “planning models, allocation politics, policy choices, market forces and local power, social and gender dynamics" (Mehta 2010: 2).

Bakker (2010) observes that both private and public forms of provision of water to urban residents are subject to failure. The problem, she argues, concerns the particular policies chosen by governments – the actions undertaken by central and municipal governments about water sources, dams and interbasin transfers – institutional failures (Nickson and Vargas 2002; Kaika 2003; Wegerich 2005). In turn, these policy choices reflect characteristics of society: short term decision making (Lake 2005), a preference for modern engineering over traditional forms of water management (McCormack 2001), or decisions about who is and who is not regarded as a citizen of the state (Bakker 2010). Likewise, proponents of integrated water basin management point to the failure of central governments to align the regionalisation of decision making authority with the dictates of the natural environment (Song *et al.* 2010).

Different cities face water shortages for different reasons. In some, like Beijing, shortage is absolute: the city's demand exceeds the locally available resource. Elsewhere, privatisation of water supply produced shortages: in Jakarta, for example, the pipe network is neither maintained adequately nor extended to the poorer residents of a city (Kooy and Bakker 2008a, 2008b). The story of the supply of residential water in Shanghai, therefore, cannot identify the general causes of water shortage. Instead, it reveals how in one of the world's largest cities, a series of decisions taken independently by the municipal and central governments interact with the conditions of the physical environment to produce the risk of water shortage: institutional failure. These institutional failures, however, originate in the nature and efficacy of Chinese systems of environmental governance, rather than in short termism, the engineering mentality and citizenship. Hierarchy, central-local relations and scale – the political economy of the Chinese state – are the drivers of water shortages in Shanghai.

We begin with the facts of supply, quality and price in Shanghai, demoonstrating that the problems are not caused by absolute shortages or commodification. Instead, governance failures began with the decision to rely on the Changjiang for fresh water, for hydrogeological and pollution-related reasons (the third section). The municipality chose to place water intakes within its own jurisdiction, rather than in other provinces (section four); but this exposes the water intakes to salt intrusions when tides are high and flows low (fifth section). Finally (section six), large-scale central government infrastructure projects alter the hydrological characteristics of the river. The conclusion draws this argument together and reflects what these decisions reveal about the political economy of Chinese environmental governance.

Our methods are those of hydrology and political economy. We draw upon data about the flow regime of the Changjiang (Finlayson *et al.* 2013), pollution loads within the rivers that feed into Shanghai (Xu *et al.* 2013), water abstractions from the Changjiang basin (Chen *et al.* 2013) and freshwater-seawater interactions in the Changjiang estuary (Li *et al.* 2014), to understand how those characteristics interact with government decisions to produce the problems we see today. We also draw on documentary and secondary sources to identify the decisions that governments have made about water supply.

2 SHANGHAI'S WATER

There is virtually no recycling of water for residential use (Shanghai Municipal Government 2010b), 2010b), though over 80 per cent of industrial water is reported to be recycled (Shanghai Water Authority 2010d). As in most Chinese cities, capital intensive ‘big pipe’ solutions dominate at the expense of local and more distributed options (Cosier and Shen 2009). Local hydrogeological conditions determine that Shanghai no longer uses significant quantities of groundwater because it caused ground subsidence. Average subsidence rates of 40 mm / year occurred in central Shanghai between 1920 and the mid-1960s due to heavy extraction of underground water (Wei *et al.*, 2010). However, reduced pumping and increased groundwater recharge (~ 0.002- 0.010 10^9 m^3 / year) have cut the subsidence rate to ca. 2 mm / year since the mid-1960s. Likewise the 2.75 – 3.5 10^9 m^3 / year of local runoff are not used to supply residents.

Therefore, Shanghai relies on surface water brought into the municipality, from Taihu (Lake Tai) and the Changjiang. Finlayson *et al*. (2013) estimate that in years of normal rainfall runoff into Taihu is ~ 9 10^9 m^3 / year, while the Changjiang has a mean annual discharge at Datong of 870 – 930 10^9 m^3 (Wohl 2008: 31, Zhao *et al.* 2009) (Datong, 500 km upstream of Shanghai, is the lowest permanent hydrometric station with long discharge records on the main stream of the Changjiang). Despite rapid population and economic growth, there has been only a slight decrease in the mean annual discharge of the Changjiang (0.017 10^9 m^3 per year) since 1950 (Yang *et al* 2005).

Shanghai's population and gross domestic product (GDP) have been growing rapidly. After the beginning of reform, population grew at about one per cent annually, but by 1998 that had increased to over two per cent and, since 2004, over three per cent. Shanghai's population is estimated as 23.5 million in 2011 (Shanghai Statistical Bureau 2012). Likewise, real GDP was growing at rates of 6 – 8 per cent per year in the 1980s, but that accelerated to over 10 per cent from 1994, before decelerating to 7 – 8 per cent a year since 2007 (Shanghai Statistical Bureau, various years). Comparable long-period data for water supply are not available, but from 2000 through 2010 total water consumption in Shanghai grew at 1.54 per cent per year (Shanghai Water Authority, various years). In 2010, consumption was 12.63 10^9 m^3, of which about 59 per cent was used to cool power stations (though 80 per cent of that is returned to source after use) , ~14 per cent for agriculture, ~10 per cent by households, ~9 per cent for public open spaces, and ~8 per cent by industry (other than power stations). Most of the water for residential and urban public space is processed through water treatment plants, as is about half of the ‘other industrial’ water. Other water is sourced directly by users. The sum of non-power station use and the 20 per cent of power station water that is not returned is 6.67 10^9 m^3 per year, less than 0.75 per cent of the mean annual flow of the Changjiang. Physical supply of water remains abundant, despite rapid growth in population and GDP (and, therefore, demand).

In 2009, there were 118 water treatment plants in Shanghai and a network of pipes delivering treated water to all parts of the municipality except a few rural areas. Despite a patchwork system, piped water was extended to virtually all city residents in China by the 1980s (Boland 2007) and there is little differentiation of localities in public service provision according to socio-economic status (Wu 2005). Thus, all residents of Shanghai have access to drinking water near or very near their homes, and virtually all have access to piped water, though the suburban water plants and some pipes are old (Hou 1999).

Shanghai does, though, have a pollution problem. All of Shanghai's sources of water are heavily polluted. Some parts of Taihu are seriously polluted and subject to eutrophication (Qin *et al.* 2010). Water continues to be extracted from Taihu via the Huangpujiang, but the water intake has been relocated (Zhang, 1997). The Huangpujiang water in Shanghai is generally of Grade IV of the Chinese national standard ('for general industrial water supply and recreational waters in which there is not direct human contact with the water': World Bank 2006); pollution loads are unlikely to be reduced in the foreseeable future (Chen *et al.*, 2002). The Changjiang is less polluted than the Huangpujiang (Grades II or III, both 'suitable for centralized drinking water supply': World Bank

2006). Even so, the Changjiang estuary is overloaded with nutrients (Meng 2008), associated with industrialisation, agricultural intensification and inadequate treatment of domestic wastes (Xu *et al.* 2013).

The Chinese Ministry of Health promulgated new standards for drinking water in 2006 (China, Ministry of Health 2007). The Shanghai government has regulated the use of source areas within its jurisdiction for drinking water (Shanghai Municipal Government 2011) and is shifting water intakes increasingly to the Changjiang. The Municipality is also imposing increasingly stringent standards on the outputs of its treatment plants (Shanghai Water Supply Trade Association nd). Despite these innovations, water treatment technology in Shanghai lags behind that of many cities, and fails to remove such contaminants as microcystins, perfluorinated compounds and harmful mutagens (Jia 2003, Mak *et al.*, 2009, Shen *et al.*, 2003 Tao *et al.*, 1999), a problem compounded by aging and substandard pipes.

Shanghai's residents also face a problem of price. In 2012 residential water cost 1.63 RMB / m^3, plus a 1.3 RMB / m^3 drainage charge, which represents less than 0.5 per cent of the disposable income of a person who consumes 150 L / d and earns the city-wide average disposable income. Delivered public water is still relatively cheap in Shanghai. Large containers of purified water cost approximately 1.0 – 1.3 RMB / L and companies advertise water filtration systems at 0.25 RMB / L (http://www.purelivingchina.com). These prices are 444 or 85 times (respectively) the price of tap water. Table 1 indicates what these prices mean for residents. Households in the lowest income group consuming 150 L / person / day of tap water and 2 L / person / day of purified water for drinking (and, ideally, cooking) would spend over 16.5 per cent of their disposable income on water. water. Even middle income households that consumed water like this would spend 8.5 per cent of their disposable income on water. The use of purified water for drinking, much less cooking, is highly income constrained in Shanghai. Price expresses the problem of water quality.

TABLE 1 ABOUT HERE

Despite rapid growth in population, economic activity and demand, then, Shanghai does not face a shortage of drinking water: this is not a problem of absolute scarcity. Nor, have Shanghai's water problems been caused by privatisation, for the system remains in state hands (one treatment plant is a joint venture between Veolia and a state water processing company). There is, however, a scarcity of clean drinking water; the costs of purified water are such that the poorer residents in the city must be largely excluded from using it. Improved treatment and a better pipe distribution system could offset this problem. Nevertheless, there is a looming shortage, that arises neither from an inadequate amount of water flowing down the Changjiang, nor its polluted state, and it is this problem that is the focus of the remainder of this paper. That shortage originates in decisions taken at various levels and locations of government within China and in the manner in which those decisions interact with the characteristics of the physical environment.

3 DEPENDING ON THE CHANGJIANG

Until recently Shanghai sourced over 80 per cent of its water from Taihu via the Huangpujiang (Figure 1). The remainder came from the Changjiang, local surface water sources within the municipality (also heavily polluted) and groundwater. Water continues to be extracted from the Huangpujiang (Zhang, 1997), but the supply of water from Taihu via the Huangpujiang is insufficient to meet Shanghai's rapidly growing needs (Chen 2011, Tan 2011). Since three provinces use water from Taihu, the Taihu Basin Administration Bureau, directly under the control of the State Council, was established in 1984 to manage water diversion, irrigation, pollution, water pumping from the Changjiang, climate hazards and flood mitigation. Control of pollution in Taihu and the extraction of its water are thus largely beyond the control of the Shanghai municipality.

Given these problems – lack of control over Taihu, pollution in Taihu and the Huangpujiang and the need for more water than Taihu can provide – the Shanghai municipal government decided to draw water from the lower Changjiang estuary. Alternatives, such as greater storage of rainwater within the municipality, recycling of wastewater, harvesting storm water, education and demand management, have been ignored, or not pursued with much vigour (Liu 2007, Cheng *et al.* 2009, Cheng and Hu 2011).

The Shanghai Municipal Government's Twelfth Five Year Plan describes these plans (finance.eastday.com 2010). The pumping station and storage facility at Chenghang (Figure 3) was opened in 1996 (Hallmark Environmental Technologies, nd); it can store about eight days' supply. A larger intake and storage pond on the Changjiang estuary at Qingcaosha on Changxing Island was completed in 2012 and the consequential pipe network is complete. When Qingcaosha is fully operational it will store 68 days of water supply; 70 per cent of the supply to Shanghai’s domestic water treatment plants can then be sourced from the Changjiang (Shanghai Municipal Government 2010a). Figure 2 locates the water supply system.

FIGURE 2 ABOUT HERE

Thus, Shanghai has become dependent on the Changjiang for its drinking water. The Changjiang, with abundant water, is cleaner than the Huangpujiang or Taihu – for much of the year, national class II standard (Tan 2011). This does not mean that it is clean. The nutrient load in the Changjiang brings with it the threat of eutrophication in the reservoir, especially during the summer

(Chen 2011). In addition, industrial pollution in neighbouring provinces is a significant risk: upstream of Shanghai, there are 400, 000 chemical plants, five major iron and steel plants and seven major refineries. From Nanjing to Shanghai, eight chemical industrial zones spread along the banks of the Changjiang (Liu 2011).

This decision to rely on the Changjiang was largely prompted by the pollution loads of the Huangpujiang and Taihu. In the absence of recycling or storage of local water for residential uses, the first social cause of Shanghai's water problem is therefore China's pollution control regime, which is incapable of controlling the agricultural, industrial and household wastes that are discharged with little prior treatment (Railton 1998, Beyer 2006, Cosier and Shen 2009). The regime is embedded deep within the political structure of the country, reflecting the priority that is given to economic growth at the expense of most other things, including the environment, a structure of governance in which local jurisdictions have a high degree of autonomy and little bureaucratic incentive to control environmental pollution if that comes at the expense of growth and jobs (Lan *et al.* 2011, Wang *et al.* 2007) and the division of responsibility for water quality monitoring and control between the Ministries of Water Resources, Environmental Protection and such other ministries as construction and agriculture (Lee 2006; Yang *et al.* 2009). While the 2008 amendments to the Law on Prevention and Control of Water Pollution (1984) require local jurisdictions to care for the environments within their borders and raise the incentive for them to do so, these are too weak and too late for the Huangpujiang and Taihu.

4 LOCATING INTAKE PIPES

Shanghai municipality draws water from the Changjiang through water intakes that are located within its boundaries, and that are therefore within the estuary zone (Figures 1 and 2). The decisions to build a storage within the estuary at Qingcaosha were vigorously disputed in the 1990s. There were 15 years of studies (Liu 2011) and arguments about water quality, water quantity, salt intrusion, navigation, local ecology and cost (Wang *et al.* 2011). There were several important constraints. First, water in the middle of the river is generally cleaner than that near the banks. Secondly, there are few undeveloped stretches of bank along which a storage could be built (Jiang 2011). Thirdly, water upstream of Shanghai is less affected by salt intrusions than downstream (Wang *et al.* 2011).

It was apparently not possible to locate intake pipes or storages much further upstream, within the neighbouring province of Jiangsu, for example – for several reasons. One is cost: the further upstream the intakes are located, the longer the intake pipes and the further the water has to be pumped to treatment plants in Shanghai. On the other hand, taking water from Jiangsu would have removed the necessity of building storages in the Changjiang to supply water when salt water intrudes into the estuary. The most important considerations appear to have been political and administrative. To build intake and transmission pipes within Jiangsu would need approval of the Jiangsu provincial government and probably compensation. Furthermore, the Changjiang, like China's other big rivers, is administered by a Water Resources Commission (WRC) that is directly under the authority of the Ministry of Water Resources. The Changjiang WRC holds the rights to the water of the Changjiang; it is planning to distribute those rights to the provinces along the river, but only at points where the river is within the province and only on payment of an appropriate fee (Tang and Zhu 2011). To overturn this principle of water allocation would have required delicate negotiations with Jiangsu province, the Changjiang WRC and, probably, the Ministry of Water Resources – with no guarantee of success. Even after the WRC's plan is implemented, the negotiations would remain delicate and precedent-making.

In other words, Shanghai was encouraged to locate intake pipes in the stretch of the Changjiang that lies within the municipality – in the estuary. Although there were debates about where within the municipality to build storages (Wang *et al.* 2011), these came after the crucial decision – to locate the intakes within the municipality. And that decision was driven by the Chinese system of administering multi-province river basins (Webber *et al.* 2008). The water in rivers belongs to the state, whose agent is the Ministry of Water Resources; the Ministry created the Changjiang WRC to manage the river's water. The WRC administers the use of water by allocating use rights to provinces. The WRC, as a central government agent, does not interfere with the detailed administration of the water that has been allocated to a province. The Changjiang WRC cannot allocate to Shanghai rights to use water that is within Jiangsu province, even though the WRC is the agent of the central state that owns the water. The top-down, formal separation of provincial powers and rights from those of the central government has been periodically revised since the 1949 revolution, and since 2002 includes provisions for integrated river basin management (Shen 2004), but the basin management authority (the Changjiang WRC) still cannot interfere with a province's lawful administration of 'its' water. The provinces, at equal hierarchical level within the government bureaucratic ranking (and equal to ministries), have to negotiate among themselves on arrangements such as placing Shanghai's water intake pipes within Jiangsu; since provinces jealously guard their own rights and powers, and fear relying on others, such negotiations would be unlikely to succeed (World Bank 2002, Wang and Ongley 2004, Cosier and Shen 2009).

5 DISCHARGE AND SALT WATER INTRUSIONS

The Changjiang has low inter-annual variability of discharge (McMahon *et al.* 1992). More important though is the fact that the Changjiang's discharge is highly seasonal (Figure 3). On average, discharge in January and February is less than 12 000 m^3 / s and from December through

March is consistently less than 16 000 m^3 / s. In dry years, discharges in December through March are less than 12 500 m^3 / s (Wang *et al*. 2008). In the wet season, June – August, average discharges exceed 40 000 m^3 / s.

FIGURE 3 ABOUT HERE

But when the discharge of the Changjiang is low, salt water intrudes up the estuary. (More precisely, salt water regularly intrudes to the south of Changxing Island; the problem for water supply involves the less regular intrusions on the north side of the island, where Qingcaosha is located.) A saltwater intrusion is defined as occurring when the chlorinity in water reaches 100 mg/L, but water is not potable when chlorinity reaches 250 mg/L (An *et al.* 2009). The key factors controlling salinity intrusion are the discharge of the Changjiang and the external tidal level (An *et al.* 2009, Li 2014). In the wet season, saltwater intrusion hardly occurs. On the other hand, saltwater intrusion is often serious during the dry season, December – March. In April – May and October – November, saltwater intrusion occurs at low probabilities except in dry years (Huang and Wang 2007).

Serious intrusions occurred near Chenhang Reservoir in 1978-79, 2001-02 and 2006-07, when the maximum average monthly discharges in January and February were 7 103 m^3 / s, 10 165 m^3 / s and 11 777 m^3 / s, respectively, suggesting that the critical discharge into the estuary is at least 11 777 m^3 / s. Gu and Yue (2004) suggested a monthly mean Datong discharge of 11 000 m^3 / s was critical and Wang et al. (2008) identified 13 000 m^3 / s. Data in Li (2014) demonstrate that mean salinity levels near Qingcaosha are a negative exponential function of discharge at Datong seven days earlier; at discharges less than 11 500 m^3 / s, mean salinity exceeds 250 mg/L. If sea levels rise in the future, because of global warming, salt water will intrude at even higher discharges: the mean long-term sea level in the Changjiang estuary is rising at an average rate of 2.7 mm / year (Zhang et al., 2011).

Because of such salt water intrusions, the municipal government had to build a water storage, once it decided to use water from the Changjiang and to locate intakes within Shanghai municipality. The capacity of the storage, roughly two months supply, is intended to exceed the anticipated lengths of periods of salt water intrusion.

6 INFRASTRUCTURE PROJECTS

The discharge of the Changjiang is affected by glacier degradation (though meltwater comprises only 0.13 per cent of the runoff of the Changjiang basin: Xie *et al.*, 2004), an increase in winter and summer precipitation which offsets decreases in spring and autumn precipitation (Jiang *et al.*, 2005, 2008, Qin *et al.*, 2005) and changes in land cover (the catchment scale effects of which are unclear: Finlayson *et al.* 2013). More important than any of these, though, are dams and water diversion projects, which are altering the hydrological characteristics of the river.

In the Changjiang basin, there are 46 000 reservoirs with total storage capacity in 2007 of 230.0 10^9 m^3, about 25 per cent of the annual flow, and more are planned (Li *et al.*, 2007). However, the Three Gorges Dam has generated the most concern. The seasonal distribution of discharge changed after the Three Gorges Dam was completed. From January to May (the low flow season), discharge increased by about 2000 m^3 / s, but discharge decreased by 5000 m^3 / s from October to December (Lu *et al*., 2009). However, the dam has no net impact on the total annual flow (Lu *et al.*, 2011).

Three major diversions, western, central and eastern, are now planned or constructed to deliver water out of the Changjiang to northern China. The western scheme would transfer water from the upper Changjiang and the Lancang River into the upper reaches of the Yellow River but no construction date has been set. Liu and Zheng (2002) estimate the amount of water that could be transferred by this route at 22.1 - 500 10^9 m^3 / year, though other estimates are only 4 10^9 m^3 / year (http://www.water-technology.net/projects/south_north/). The central route transfers water from the Danjiangkou reservoir on the Han River into northern China, at a rate of up to 14.5 10^9 m^3 / year (Baidu 2012). The eastern route is also nearly constructed, with a design capacity of 18.9 10^9 m^3 / year (Wang *et al.*, 2006), rising to 25.2 10^9 m^3 / year by 2030 (Chen *et al.* 2013).

Water diversions in the lower Changjiang basin (below Datong gauging station) for irrigation, domestic and industrial water use and other needs have increased greatly, and this trend is likely to continue. Most of this water remains in the basin (for example, is used in Nanjing, or is diverted to Taihu) and has little effect on the discharge into the estuary. However, other planned diversions out of the basin include: (i) Changjiang-Huaihe Water Diversion Project in Anhui Province, which will annually transfer about 2.0 10^9 m^3, or 3.5 10^9 m^3 in dry years (Ji 2010); and (2) the Water Diversion Project in Taizhou (Jiangsu), which has a total capacity of 1.9 10^9 m^3. These smaller inter-basin transfers will also reduce discharge of the Changjiang (Chen *et al.* 2013).

Finally, sea level is rising along the coast of Shanghai. Li *et al.* (2014) identify the rate of sea level rise (net of land subsidence) as equivalent to a reduction in discharge of 506 m^3 / s by 2040.

The net effect of these new constructions on discharge (and therefore on the probability of salt water intrusion into the estuary) can only be approximately determined, because the operation of the Three Gorges Dam and of the eastern and central routes of the South North water transfer project are in their infancy and their rules are not yet clear in practice. Furthermore, there may be political calls to modify the operating rules – for example, from Shanghai municipality – once the implications of the transfers and discharges become clear. Nevertheless, Table 2 illustrates the potential effects of the various interbasin transfers and sea level rise on discharge at the estuary.

TABLE 2 ABOUT HERE

When discharge is normal, before the diversions and interbasin transfers, average discharge at the estuary is close to the predicted discharge for saline intrusions of 250 mg/L in January and February. The diversions and transfers reduce flows in those months below the critical value; but they do not cause other months' discharges to fall below the critical value; December flows are close to the critical discharge. In a normal year, therefore, diversions and discharges intensify but do not extend the period of risks to Shanghai's water supply. In a dry year, however, discharge in December, January and February is below the critical discharge for salt water intrusions of 250 mg/L. The diversions and transfers will force discharges in these months even further below the critical value and extend the period of below-critical flows into March. In normal years, the transfers and diversions will intensify the low flows in January and February but not extend them into March; but in relatively dry years, the low flows of December – February are intensified and perhaps extend into March. Under these conditions, the storage at Qingcaosha is insufficient to meet Shanghai's present demand for water.

7 CONCLUSION

Water is supplied to Shanghai under conditions that reflect a variety of physical difficulties – the highly seasonal flow of the principal water source (the Changjiang) and the flat terrain of the estuary. Yet these physical conditions are important because other, social conditions led the municipal government to rely on the Changjiang rather than other sources of supply, constrained the government to locate storages and intake pipes within the municipality rather than where salt is not an issue, and threaten to make the problem of salt water intrusions even more difficult to overcome. In the face of these conditions, the Shanghai and central governments have thus made a series of decisions that, taken together, led the municipality to rely mainly on a source of drinking water that is increasingly unreliable (even if its annual discharge is huge and its annual variability small). Why these decisions have been made – and with little apparent reference to each other – is an important topic for those who study the provision of water for cities and the practical efficacy of Chinese governance systems.

The decisions reflect the Chinese environmental governance systems. Environmental governance in China is subordinate to the dictates of growth (Naughton 2007). This growth has, since 1993 at least, been enabled through a series of reforms consistent with neoliberal economic theory (Harvey 2003), in which the market has become the principal means of regulating the economy and allocating goods and services. At the same time, the state remains in control of key sectors, of which water is one. In China that control is hierarchical – implemented through a vertical hierarchy that begins at the State Council and runs down through ministries to bureaus at provincial, prefectural/municipal, county, township and even village levels.

Even though China is a unitary state and administration is formally hierarchical, the governance of water remains deeply problematic, as Shanghai's water management decisions indicate. These problems include:

- lack of legal basis for addressing water use, water pollution control and ecological conservation in an integrated fashion at the river basin level (Turner and Otsuka 2006);

- lack of clear assignment of policy responsibilities among government ministries and agencies (Yang and Griffiths 2010);
- lack of effective cross-sectoral and trans-jurisdictional coordination (Yang *et al.* 2009);
- inability of basin commissions to coordinate across jurisdictions, so they cannot override the interests of jurisdictions such as provinces and municipalities (Shen 2004; Song *et al.* 2010; Zhou 2006);
- low level of stakeholder and public participation in river basin management (Yang and Griffiths 2010).

All these deficiencies are at play in creating the pollution problems that led Shanghai to decide to draw water from the Changjiang rather than the Huangpujiang, to locate intake pipes in a location subject to tidal intrusions, and finally to see those intrusions exacerbated by large-scale water withdrawals from the Changjiang.

Superimposed on these administrative deficiencies is a penchant for large technological solutions that are easier to implement than sets of micro-scale adjustments. Such solutions are also symbols of modernisation, development, and state power (Dwivedi 2002, Escobar 2003, Fisher 1995, Hussain 2008). They create employment, and channel public monies into enterprises in which individuals in governments may have pecuniary interests (Webber 2012). They are preferred for cultural reasons too: the Chinese state has a long history of bureaucrats-as-experts (in particular engineers, who dominate the upper echelons of the Chinese Communist Party as well as the river basin commissions). Whatever the underlying attitudes, tendencies to build dams, pipelines and other large infrastructure projects are deeply embedded within the structures of decision making within China (Needham 1986, Elvin 1993). In the case of Shanghai at least, such preferences and managerial styles may create rather than solve urban water problems.

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DC.

Table 1 Costs of water as a proportion of disposable income

	Lowest quintile	Low-middle	Middle quintile	Upper-middle	Highest quintile	Average
Persons / household	3.06	2.92	2.87	2.87	2.76	2.9
Disposable income / person / year (RMB)	17206	24824	31414	40771	70067	36230
Proportion employed	46.1	49.7	54	57.1	65.9	54.5
Household income [RMB]	24272	36026	48685	66814	127441	57262
Tap water 150 L / person / day plus purified drinking water, as percentage disposable income						
0 L purified water containers / day (%)	2.85	1.89	1.47	1.13	0.63	1.28
0.1 L purified water containers / day (%)	3.54	2.34	1.82	1.40	0.78	1.59
1 L purified water containers / day (%)	9.72	6.43	4.99	3.85	2.15	4.38
2 L purified containers / day (%)	16.59	10.97	8.52	6.57	3.67	7.47

Sources: demographic and income data from Shanghai Statistical Bureau (2012); data are for 2011. Price data are from Nongfu Spring, Watson's Water and Nestle Water as at 13 April 2013.

Notes: Household incomes are calculated from given data on disposable income per capita for each quintile group and the proportion of that group employed; they therefore miscount transfer payments and property incomes. The US reference standard for drinking water is 3.7 L / day for males and 2.7 L / day for females (http://iom.edu/Reports/2004/Dietary-Reference-Intakes-Water-Potassium-Sodium-Chloride-and-Sulfate.aspx).

Table 2 Potential effects of interbasin transfers on average monthly discharges of the Changjiang, October – April of wet and dry years (m^3 / s)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Normal year (2005-2006)							
Discharge at Datong	31374	23833	14152	*11384*	11692	21126	24327
Discharge at Estuary	30790	23555	14162	*11356*	11692	21459	24199
South-North water transfer	29403	22168	12775	***9969***	*10305*	20072	22812
Anhui normal diversion	29340	22105	12712	***9906***	*10242*	20009	22749
Taizhou diversion	28740	21505	12112	***9306***	***9642***	19409	22149
Sea level rise	28234	20999	11606	***8800***	***9136***	18903	21643
Dry year (2003-2004)							
Discharge at Datong	32148	15780	*11473*	*10306*	***9291***	13956	18437
Discharge at Estuary	31114	15326	*11265*	***10008***	***8717***	13435	18047
South-North water transfer	29727	13939	***9878***	***8621***	***7330***	12048	16660
Anhui dry year diversion	29616	13828	***9767***	***8510***	***7219***	11937	16549
Taizhou diversion	29016	13228	***9167***	***7910***	***6619***	*11337*	15949
Sea level rise	28510	12722	***8661***	***7404***	***6113***	*10831*	15443

Sources: as identified in text.

Notes: figures in italics are for months and conditions that lead to average monthly discharges less than the critical value for salt water intrusion of 250 mg/L (11 500 m^3 / s). Figures in bold italics are for discharges less than 10 170 m^3 / s, for which the mean predicted salinity exceeds 500 mg/L. Data for the effects of sea level rise are projections for 2040.

FIGURE CAPTIONS

Figure 1 Sketch map of the lower Changjiang downstream

Source: Base map from Zhang *et al.* (2011).

Figure 2 Locations of sources, intake points, treatment plants and pipe network in Shanghai municipality, 2011

Source: http://www.shanghaiwater.gov.cn/web/bmxx/ysgh.jsp, accessed 20 February 2012

Figure 3 Average monthly discharge of the Changjiang at Datong (1951-1984)

Source: Yearbook of Changjiang Water Resources Commission.

Note: + indicates mean monthly flow; - indicate maximum and minimum flows recorded in each month. Month 1 is January.

Figure 1 Sketch map of the lower Changjiang
Source: Base map from Zhang et al. (2011).
83x61mm (72 x 72 DPI)

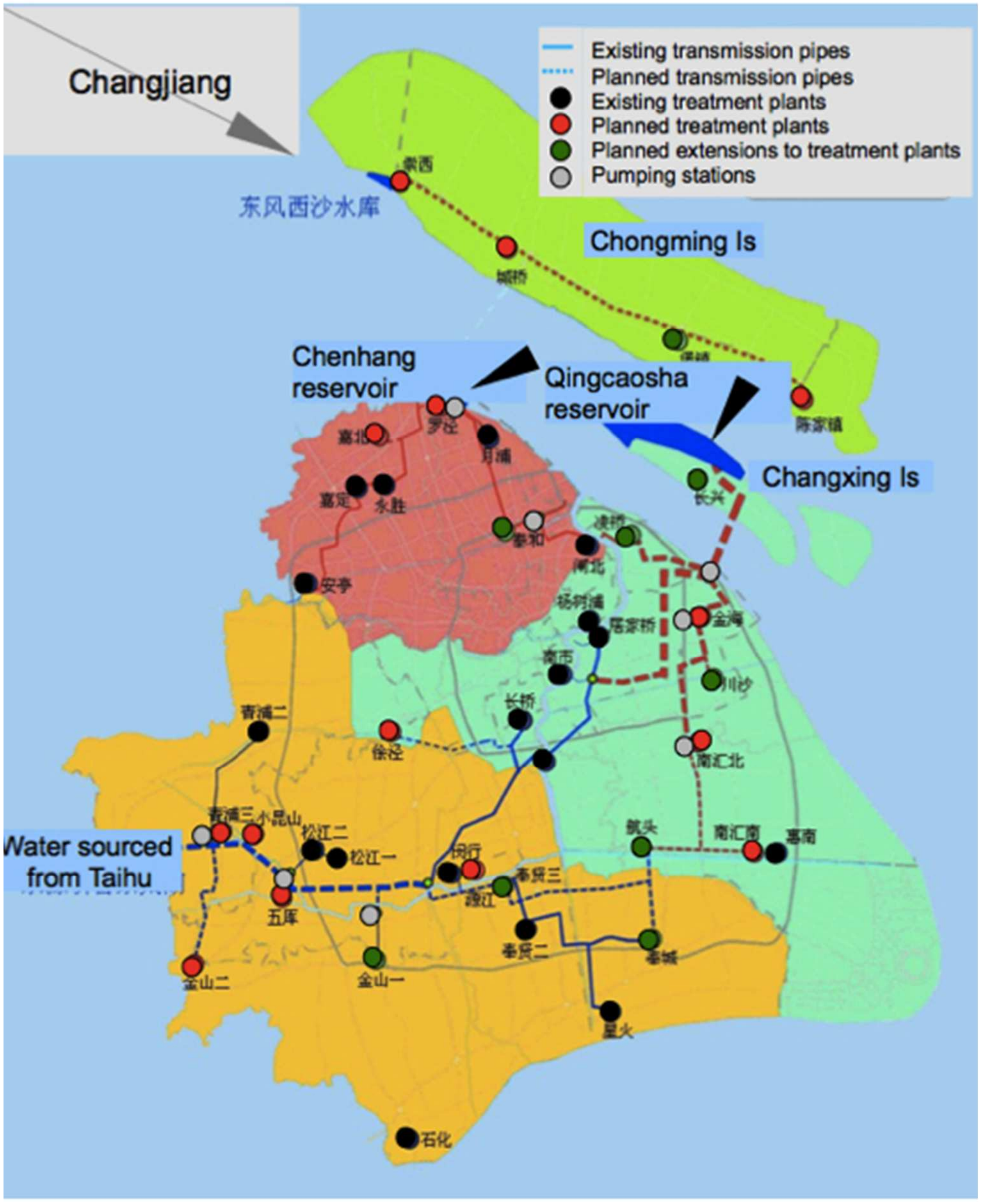

Figure 2 Locations of sources, intake points, treatment plants and pipe network in Shanghai municipality, 2011
Source: modified from http://www.shanghaiwater.gov.cn/web/bmxx/ysgh.jsp, accessed 20 February 2012

184x226mm (72 x 72 DPI)

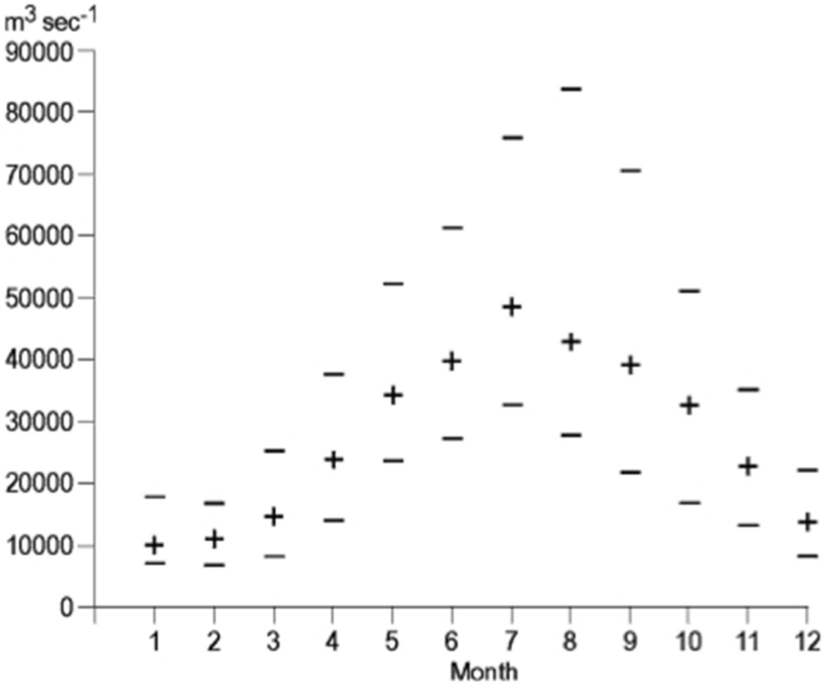

Figure 3 Average monthly discharge of the Changjiang at Datong (1951-1984)
Source: Yearbook of Changjiang Water Resources Commission.
Note: + indicates mean monthly flow; - indicate maximum and minimum flows recorded in each month.
Month 1 is January.
152x127mm (72 x 72 DPI)